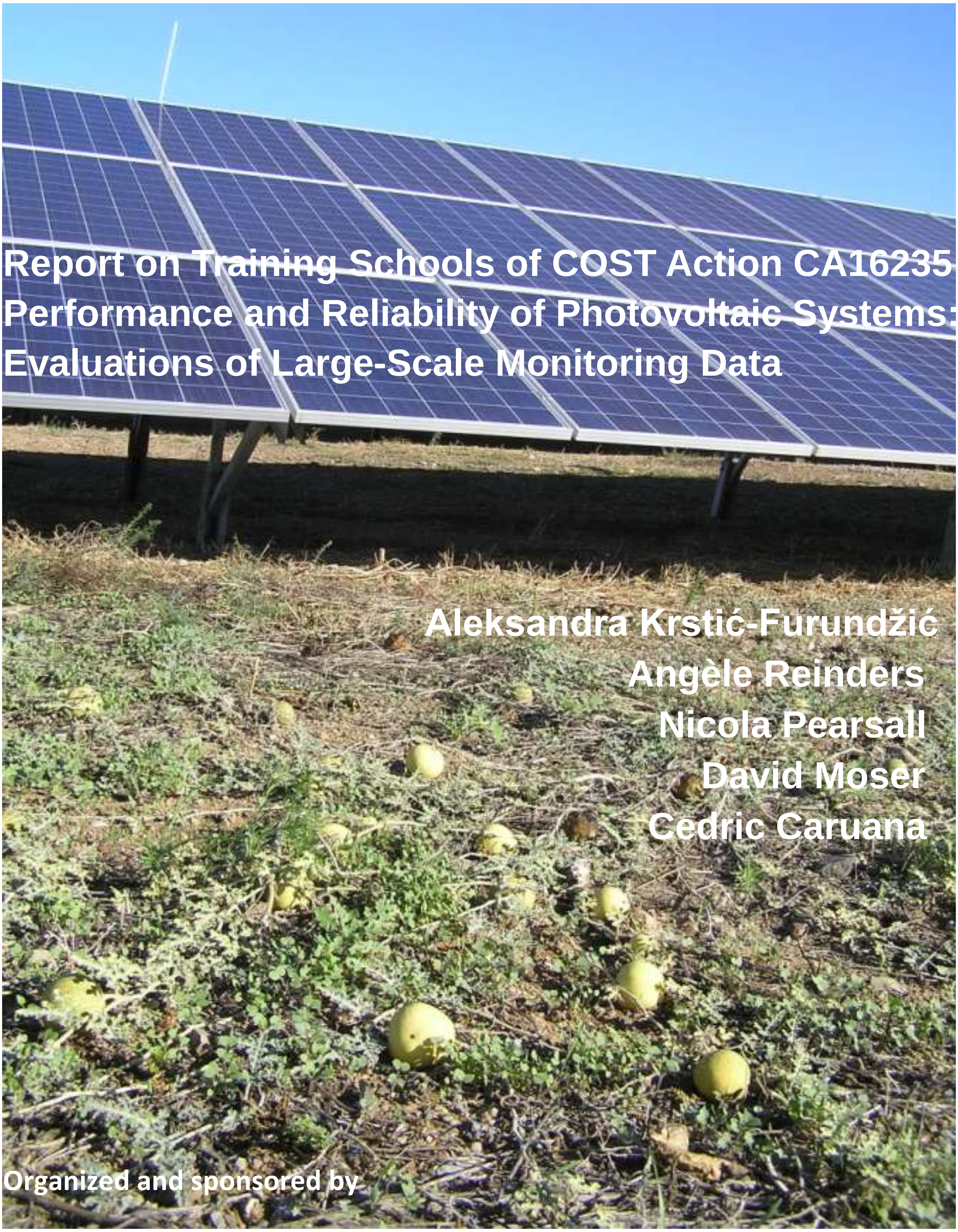
PEARL PV



Report on Training Schools of COST Action CA16235 Performance and Reliability of Photovoltaic Systems: Evaluations of Large-Scale Monitoring Data

Aleksandra Krstić-Furundžić
Angèle Reinders
Nicola Pearsall
David Moser
Cedric Caruana

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COST Action CA16235 –
Performance and Reliability of Photovoltaic Systems:
Evaluations of Large-Scale Monitoring Data
https://www.pearlpv-cost.eu/event/training-school/

Book title

Report on Training Schools of COST Action CA16235 – Performance and Reliability of Photovoltaic Systems: Evaluations of Large-Scale Monitoring Data

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This research in Training Schools and Workshops can be useful for research in the field of photovoltaic systems design, conducted by electrical, mechanical and environmental engineers and architects, as well as for student education.

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Table of Contents

Preface by the Action Chair and Vice-Chair

Before you lies this beautiful report on all four Training Schools which were organized by COST Action PEARL PV in the period from 2018 to 2022. The implementation of the Training Schools was not possible without the efforts of the Training School managers Prof. Dr. Aleksandra Kristić- Furundžić, Dr. Gabriele Eder and Dr. Cedric Caruana, who played a key role in the preparations and organization of the programs. We warmheartedly thank them for their dedication, time and efforts.

The aim of the COST Action CA16235 - PEARL PV is to improve the energy performance and reliability of photovoltaic (PV) solar energy systems in Europe leading to lower costs of electricity produced by PV systems by a higher energy yield, a longer life time eventually beyond the guaranteed 20 years as specified by manufacturers, and a reduction in the perceived risk in investments in PV projects. This objective will be achieved by analyzing data of actual monitored long-term performance, defects and failures in PV systems installed all over Europe to quantitatively determine the absolute influences of components rated performance, key design of systems, installation, operation, maintenance practice, geographic location and weather factors on the performance, performance degradation over time and failure modes of these PV systems. It is very important to ensure the performance of PV systems to achieve long term goals for PV systems in the future single energy market such as: economic viability, securing investments, environmental sustainability and security and predictability of supply.

Research activities and engagement of participants in this Action were organized in 5 working groups: WG 1: PV monitoring, WG 2: Reliability and durability of PV, WG 3: PV simulation, WG 4: PV in the built environment and WG 5: PV in grids. One of the significant activities of COST Action CA 16235 is the organization of training schools that aimed to acquaint trainees theoretically and practically with relevant knowledge and skills that are the subject of working groups. Therefore, the Training Schools were dedicated to the topics of these working groups and the participation of their leaders and members, as well as visiting experts, was implied.

The trainees who participated in the training schools expressed their satisfaction with the concepts, presented theoretical and practical knowledge, joined in excursions and visits to PV plants, and actively contributed to the creation of new research networks. We would like to thank them as well as the wonderful trainers who shared their excellent knowledge with these trainees.

We hope that you will enjoy reading this report as much as we did!

Prof. Dr. Angèle Reinders, Chair of COST Action PEARL PV

Prof. Dr. David Moser, Vice-Chair of COST Action PEARL PV

1. The First PEARL-PV Training School

"Monitoring and Simulation of the Performance and Reliability of Photovoltaics in the Built Environment"

1.1. About the Training School

The first PEARL-PV Training School on the topic "Monitoring and Simulation of the Performance and Reliability of Photovoltaics in the Built Environment" was held at the University of Cyprus in Nicosia, Cyprus, between 23th and 26th October 2018. It was focused on the special requirements and challenges of integrating PV in the built environment and grids with focus on the determination and prediction of performance and reliability. In the 3.5-day training school, which consisted of introductory lectures, practical courses and field trips, participants gained a deep understanding of planning and building integrated photovoltaic systems and learned about key topics from PEARL PV Working Groups such as performance monitoring, reliability and simulation issues.


University of Cypros

Training School trainees (students, researchers, educators and practitioners) participated in multiple introductive expert lectures, interactive seminars, practical courses including team action work, study tours, and much more. Participants gained the opportunity to acquire and transfer knowledge about the challenges and opportunities of photovoltaics integrated into the built environment by learning from experts and experiences from best practice projects.

Training School Managers:
Dr. Gabriele Eder (Gabriele.Eder@ofi.at)
Prof. Dr. Aleksandra Krstić-Furundžić (akrstic@arh.bg.ac.rs ; akrsticfurundzic@gmail.com)
Local organizer: Dr. Marios Theristis

Schedule of Events

Tuesday 23 October 2018

Time	Activity	Lecturer
13:00-14:00	Registration and Opening of the Training School	Angele Reinders / UT and David Moser / EURAC
14:00-15:00	Keynote lecture: The use of PV in the built environment: Potentialities and challenges	Alessandra Scognamiglio / ENEA
15:00-15:30	Architectural aspects of building integrated photovoltaics	Aleksandra Krstic-Furundzic / University of Belgrade
15:30-16:00	**Coffee break**	
16:00-16:30	Trends of innovation for PV products integrated as buildings skin systems	Pierluigi Bonomo / SUPSI
16:30-17:00	Competitiveness of BIPV systems: status, key influencing factors & possible improvements	Philippe Mace / Bequerel institute
17:00-17:30	Experience of the European project PV Sites: Developing different BIPVs for different markets: technological, visual, standardization and regulatory issues	Maider Machado / Tecnalia
17:30-18:00	BIPV: An overview from the industry perspective about the past - present - future.	Dieter Moor / Ertex Solar
19:00-21:00	**Joint social evening event in Nicosia**	

Wednesday 24 October 2018

Time	Activity	Lecturer
9:00–10:00	Keynote lecture: Monitoring of the performance of integrated PV systems	Wilfried van Sark / Utrecht University
10:00-10:30	Round Robin on Monitoring of BIPV of IEA PVPS TASK15	Karl Berger/ AIT
10:30-11:00	Economics and Technology of Agro-Photovoltaics	Christian Braun / Fraunhofer ISE
11:00-11:30	Coffee break	
11:30-12:00	Performance measurements in the Lab	Marios Theristis and George Makrides / Univ. of Cyprus
12:00-12:30	Monitoring via remote labs (Dem4BIPV)	Karl Knöbl / FH-TW & George Makrides / Univ. of Cyprus
12:30-13:00	Performance, reliability and durability of PV systems integrated in the built environment	Gabriele Eder / OFI
13:00-14:00	Lunch break	
14:00-18:00	Lab-tour Practical course: performance measurements in the PV Lab and monitoring in remote lab	Marios Theristis and George Makrides / Univ. of Cyprus Karl Knöbl / FH-TW & Wilfried van Sark / Utrecht University
19:30-...	Social gathering with dinner in a typical tavern: Zanettos Tavern, Trikoupi 65, Nicosia 1015	

Thursday 25 October 2018

Time	Activity	Lecturer
9:00–10:00	Keynote lecture: Simulation and modeling of the performance of PV	Joshua Stein / Sandia
10:00-10:30	Basics for BIPV design and analysis	Nicola Pearsall / Northumbria University
10:30-11:00	Coffee Break	
11:00-11:30	The importance of early design phase simulation, an approach	Marco Lovati / EURAC
11:30-12:00	Advanced concepts for 3D modeling of PV	Angele Reinders / University of Twente
12.00-12:30	Optical PV raytracing simulations for the analysis of BIPV modules in different scenarios (PV-Enerate)	Vasco Medici /SUPSI, PV ENERATE project
12:30-13:00	From product to process innovation in BIPV: perspectives towards a BIM-based approach and tools for BIPV analysis	Erika Saretta / SUPSI
13:00-14:00	Lunch break	
14:00-18:00	Practical course and Workshop: Modeling and simulations Possible training: - Analysis of optimal BIPV scenarios for façade (1h) - Analysis of BIPV building/urban scenarios and PV plant design (PVSites) (1h) - Modelling for a detailed estimation of BIPV modules power output in different scenarios (PV Enerate) (1h)	Nicola Pearsall / Northumbria University Erika Saretta and Vasco Medici / SUPSI (PV ENERATE project) Marco Lovati / EURAC
19:00-21:00	Joint social event in Nicosia	

Friday 26 October 2018

Time	Activity	Lecturer
9:00–11:00	Excursion I Field trip to PV installation	Marios Theristis and George Makrides / Univ. of Cyprus
11:00-13:00	Excursion II	Marios Theristis and George Makrides / Univ. of Cyprus
13:00-14:30	Final gathering with progress reports, feedback and discussions; Closure of the training school and Lunch	Angele Reinders / UT

List of trainees

	Name	Affilation
1	Anna Svensson	SolTech Energy / Sweden
2	Andaloro Annalisa	EURAC / Italy
3	Yuliya Voronko	OFI / Austria
4	Cihan Gercek	Univ. Twente / The Netherlands
5	Stellbogen Dirk	ZSW / Germany
6	Ismail Borazan	Bartin Univerity / Turkey
7	Jennifer Adami	EURAC / Italy
8	Juliana Emanuella Goncalves	KU Leuven / Belgium
9	Kemal Koca	Erciyes University
10	Madalina Barbu	University Politehnica of Bucharest / Romania
11	Marcus B. Schubert	IPV Stuttgart / Germany
12	Sara Mirbagheri Golroodbari	U Utrecht / The Netherlands
13	Nicolas Riedel	TU Denmark / Denmark
14	Odysseas Tsafarakis	U Utrecht / The Netherlands
15	Omer kaspi	Bar Ijan University / Israel
16	Panagiotis Moraitis	U Utrecht / The Netherlands
17	Pascal Kolblin	IPV Stuttgart / Germany
18	Sara Freitas	Universidade de Lisboa / Portugal
19	Amrita Raghoebarsing	U Twente / The Netherlands
20	Peter Ijlich	FH-TW / Austria
21	Christian Braun	Fraunhofer ISE, Germany

1.2. Workshop

Based on a practical course, a workshop was organized on the topic of photovoltaic system design and a rough overview of its efficiency. It was not planned for the trainees to create posters during the workshop.

1.3. Pictures of the Training School 1

2. The Second PEARL-PV Training School

"Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability"

2.1. About the Training School

The PEARL-PV Training School on the topic "Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability" was held at the Malta College of Arts, Science and Technology MCAST in Paola, Malta, between 15th and 18th October 2019. It was focused on reliability topics of PV systems with special attention on degradation effects of PV materials, components and systems. Various failure modes and their detectability were illustrated. Furthermore their impact on the electrical performance and economic viability of PV systems was calculated. In 3.5 days of expert lectures, on-site practical courses and excursions, trainees gained a deeper understanding of the causes of potential ageing-induced electrical performance losses and the way of determining and measuring various failure modes. The attendants learned about key topics of reliability for state-of-the-art crystalline Si-technologies as well as for thin film and emerging technologies from PEARL PV Working Group members and external experts.

The Malta College of Arts, Science and Technology MCAST

Training School trainees (students, researchers, educators and practitioners) participated in multiple introductive expert lectures, interactive seminars, practical courses including team action work, study tours, and much more. Participants gained the opportunity to acquire and transfer knowledge on the reliability of the various photovoltaic technologies, failure mechanisms and detection, by learning from experts and experiences from best practice projects.

Training School Managers:
Dr. Gabriele Eder (Gabriele.Eder@ofi.at)
Prof. Dr. Aleksandra Krstić-Furundžić (akrstic@arh.bg.ac.rs ; akrsticfurundzic@gmail.com)
Dr. Cihan Gercek (c.gercek@utwente.nl)
Local organizer: Dr Eur. Ing. Inġ. Brian Azzopardi

Schedule of Events

Tuesday 15 October 2019

Time	Activity	Lecturer
9.00 - 9.30	Registration Opening of the Training School	Angele Reinders / UTwente
9.30 - 10.45	Keynote and expert lecture: Reliability of Photovoltaic systems (c-Si) and Activities in IEA PVPS Task13 Failure models of c-Si-PV Systems, Modules and Components	Karl Berger / AIT Gabriele Eder / OFI
10.45 - 11.00	Coffeebreak	
11.00 - 12.30	Postersession I: Mutual introduction of all participants	Cihan Gercek Univ. Twente & Gabriele Eder / OFI
12.30 - 13.30	Lunch	
13.30 - 15.15	Expert lectures + Discussions: Degradation mechanisms of PV-cells and polymeric materials	Gernot Oreski/ PCCL Abdülkerim Gök/ Gebze TU
15.15 - 15.30	Coffee break	
15.30 - 17.00	Practical Course: Degradation modeling	Gernot Oreski/ PCCL Abdülkerim Gök/ Gebze TU

Wednesday 16 October 2019

Time	Topic	Lecturers
9.00 - 10.45	Keynote and expert lectures: Measurement of performance degradation, failure detection	Jonathan Leloux / UPM Killian Lobato/Univ.Lisboa Christian Braun/ Fraunhofer
10.45 - 11.00	Coffee Break	
11.00 - 12.30	Bankability/calculations: effect of degradation and lifetime on economic viability	David Moser/ EURAC
12.30 - 13.30	Lunch	
13.30 - 17.00	Excursion to PV-Installation at MCAST + Workshop: Evaluation and interpretation of electrical data I performance degradation, data treatment -> failure identification	Jonathan Leloux / UPM Karl Berger / AIT Abdülkerim Gök / Gebze TU
Evening	Joined Dinner (invited)	Villa Bighi, Kalkara: https://villabighi.com/

Thursday 17 October 2019

Time	Topic	Lecturers
9.00 – 10.15	*Keynote + expert lectures:* Performance degradation of thin film PV	Marcus Rennhofer / AIT
10.15 - 10.45	Coffee break	
10.45 -12.00	Realiability engineering and modeling: root cause analysis and predictive ageing	Jeffrey Kettle/ Bangor Univ.
12.00 - 13.00	Lunch	
13.00 -17:00	Visit to The University of Malta Solar Laboratory + Workshop: Measurement and interpretation of characterization data II Failure detection with EL, TG, UV-F…	 Gabriele Eder / OFI Marcus Rennhofer / AIT Angele Reinders / UTwente Wolfgang Muhleisen / SAL
Evening	Social evening	

Friday 18 October 2019

Time	Topic	Lecturers
9.00 – 10.45	Reliability and challenges of emerging PV / Nanostructured PV Reliability of next generation PV-systems OPV Hybrid organic-inorganic Pb-free perovskite materials for PV applications	Shahzada Ahmad/BC materials Jeffrey Kettle/ Bangor Univ. Anna Ioannou/ EIE
10.45 - 11.00	Coffee break	
11.00 - 12.30	Interactive poster session II	Cihan Gercek / Univ. Twente
12.30 - 13.30	Wrap up & closing / joined lunch	

List of trainees

	Name	Affilation
1	Anna Svensson	SolTech Energy / Sweden
2	Anna Ioannou	National Hellenic Research Foundation / Greece
3	Yassine Raoui	BCMaterials - Basque Center / Spain
4	Yuliya Voronko	OFI / Austria
5	Cihan Gerceg	Univ. Twente / The Netherlands
6	Julian Andreas Ascencio-Vasquez	University of Ljubljana / Slovenia
7	Ismail Borazan	Bartin Univerity / Turkey
8	Muhammad Bilal	University of Agder / Norway
9	Pelin Yilmaz	TNO-Soliance & University of Twente / The Netherlands
10	Christian Braun	Fraunhofer ISE / Germany
11	Elisabeth Klimm	Fraunhofer ISE / Germany
12	Sara Mirbagheri Golroodbari	U Utrecht / The Netherlands
13	Rudy Alexis Guejia Burbano	University of Salermo / Italy
14	Li Baojie	Universite Paris Saclary / France
15	Amrita Raghoebarsing	U Twente / The Netherlands
16	Lukas Konrad Koester	EURAC / Italy
17	Subhash Chandra	Trinity College Dublin / Ireland
18	Wolfgang Muhleisen	SAL / Austria
19	Altin Maraj	Politech. Univ. Tirana / Albania
20	Ebrar Oezkalay	SUPSI / Switzerland
21	Panagopoulou Panagiota	National Hellenic Research Foundation / Greece
22	Reza Aghaei	Eindhoven University of Technology / Netherlands

2.2. Current Research of participants

Poster session-I was dedicated to getting acquainted with the research orientations of all trainees among themselves. Each trainee prepared a concise presentation of his/her current research, for doctoral or master thesis, highlighting the topic, problem and results. Presentations were the basis for developing scientific discussions between participants. This session was practical networking of researchers on a particular topic. It was interactive and also a team building activity. Posters are shown in Appendix 1.

2.3. Workshop

The theme of the Workshop and Session II was a presentation of practical knowledge acquired during lectures and excursions. Students worked in 4 groups on specific topics and each group prepared a poster with case studies related to a selected topic that was discussed in lectures and during fieldwork. The poster presentation follows, presenting the results of the Workshop.

P ARL PV

2nd TRAINING SCHOOL

Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Faults and Degradation in PV

Panagiota Panagopoulou, Anna Ioannou, Muhammad Bilal, Ismail Borazan, Altin Maraj

Field Evaluation at MCAST

We inspected a multi- Si PV module with reference number: 1010086506286 (Fig. 1). With observation with the naked eye we were able to detect rusted cells, snail tracks and blackspots. The backsheet, wires, frame grounding and junction box were in great condition. The gridlines/fingers had a dark discoloration (5-25%), the busbars had a light discoloration (5-25%) and diffuse burn marks. The cell interconnect ribbon and the string interconnect had a light discoloration and obvious signs of corrosion.

In general, 20 out of 60 cells had marks/tracks and 2 of them had obvious burn marks (Fig. 2 left)

Figure 1: Most important picture at field evaluation

Night Fluorescence

We used the torch with UV light to evident the cracked cells during the dark.

From this inspection we noticed that our PV panel had plenty of cracks and snail tracks.

The cell which was damaged the most is shown in Fig. 2(right).

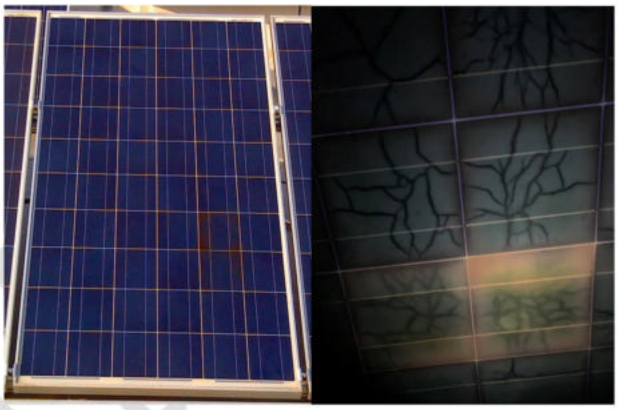

Figure 2: (left) The selected PV panel (right) under night fluorescence

Thermal Image

Through the FLIR camera we were able to obtain a clear view of the thermal field on the PV panel and also on the most damaged cell (Fig.3).

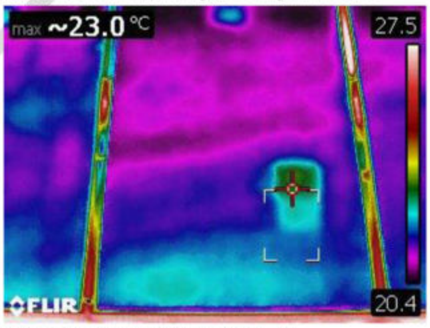

Figure 3: Thermal Image of selected PV panel

Electroluminescence

We applied forward bias voltage to get the electroluminescence image of our PV module (Fig. 4). We observed more cracks than with the naked eye. The image was taken by a regular camera without the IR filter.

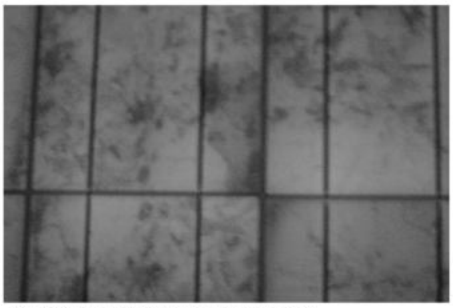

Figure 4: Electroluminescence of the selected PV

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2nd TRAINING SCHOOL

Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Degradation of PV Module

Anna Svensson, Sara Golroodbari, Lukas Koester, Ebrar Ozkalay, Reza Aghae

Introduction

Training school at Malta 2019, visit of MCAST rooftop installation. Analysation of PV module.
Module: NESL, polycrystalline silicon, 60 cells, 220 Wp.

Research Aims

Checking the physical condition and failure identification.

Research Problems, Questions

Problem: Many failures not visible for naked eye. Different techniques necessary to identify.

Questions: Which failures influence the power output

Research Methodology

Identifying with different methods including:

(i) visible inspection,

(ii) Infrared thermology,

(iii) Measuring voltage and current

(iv) UV fluorescence.

Research Results / planned or achieved

Visible inspection: corrosion of silicon (contacts and back sheet not affected), visible as dark brown colouring. Total corrosion less then 5% of the cell.. Front and back sheet are intact.

Infrared Image: never arrived.

Measurements: V=33.6 V I=3.3 A

UV fluorescence: track between brown spots visible, probably cell crack

Disseminations / References

PV PEARL Training school 2019 talks

Supervisor (Title, Name and Surname, Affiliation)

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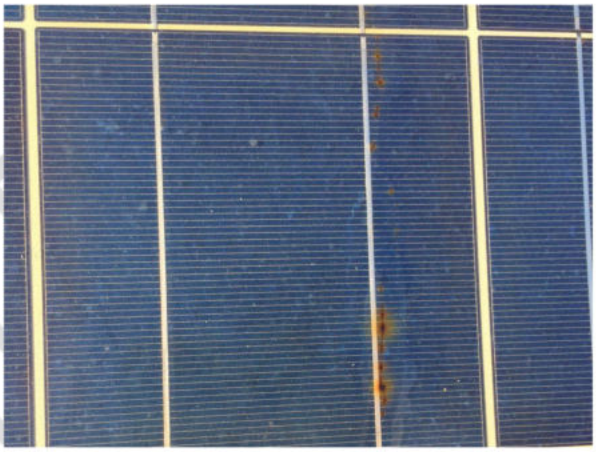

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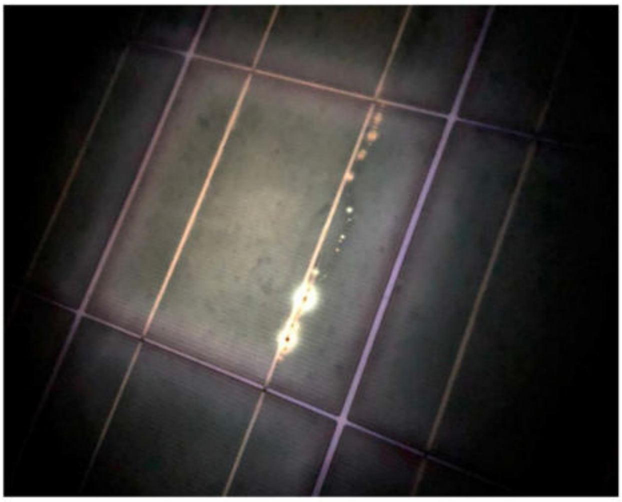

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PEARL PV 2nd TRAINING SCHOOL

Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Visual and Spectroscopy Investigation for damages in Solar Panel

Subhash Chandra , Yassine Raoui , LI Baojie, Rudy A. Guejia

Introduction.

Solar energy solves the problem of production from fossil fuel based .The efficiency of solar PV cells and models can reduce due to outdoors conditions. Besides different methods of detection will discus.

Figure 1: PV module front face with specification

Research Aims

(i) To identify the damage and degradation in the solar panel using visual and spectroscopy techniques

Research Problems,

Effect of shading on PV module .

Figure 2: PV module Detection of damage through visual inspection

Research Methodology

Visualization Spectroscopy Techniques

Research Results

Damage on PV cell due to shading , Oxygen trapping due to damage

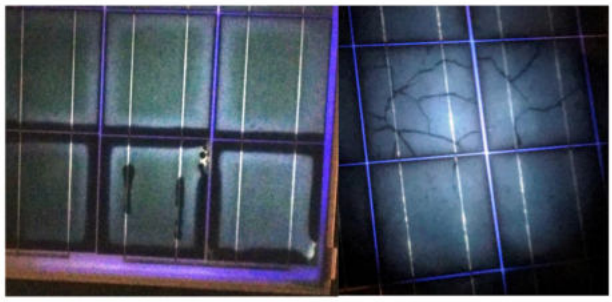

Figure 3: UV images of PV module(UV fluorescence images)

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PEARL PV 2nd TRAINING SCHOOL

Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Group4ever
PV Module Inspection and Evaluation

Elisabeth, Yuliya, Alex, Wolfgang, Pelin, Jurrian

Introduction

We inspected MCAST PV roof farms. 3 Modules. The modules are commercial SolarTech c-Si modules connected in series (11) and grounded for safety reasons. Here are the results of the last module.

The Days G(horizontal) = 273.6 kWh/m² G(POA)=356 kWh/m²; measures Data of the module: 33.4 W and 2.8 V

Module Data	
Solar Module Type	SolarTech DJ -220P
Nominal Peak Power	220W
V_{oc}	35.9V
I_{SC}	8.40A
V_{MPP}	29.4V
I_{MPP}	7.48A

Methodology

- Visual inspection
- UVF – for encapsulation and cracks
- EL – inspection for cracks
- LIT cameras – for inspection of hotspots
- Completion of inspection sheet

Visual Inspection

List filled out acc. to visual inspection sheet (Task XIII)

- Inverter SunnyBoy SB5KW: OK
- Multi SI
- Degradation:
  - BS – horizontal Cracks
  - Wires / Connectors: OK
  - J-Box: OK
  - Frame Grounding: OK
  - Frame Edge Seal: OK
  - Glass Cover: Light soiling @ whole surface and medium at lower edge
  - Metalization: OK
  - Cell (6 inch, spacing 2.5 cm / 1 cm / 0.3 cm):
    - 75-100 % discoloration on edges
    - Burn marks (hot spots)

UV-F / EL / TG

List filled out acc. to visual inspection sheet (Task XIII) – Fig. 1-3

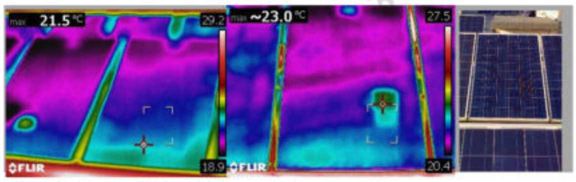

Figure 1: Gewneral PV Module Thermografie Imageing by Brian

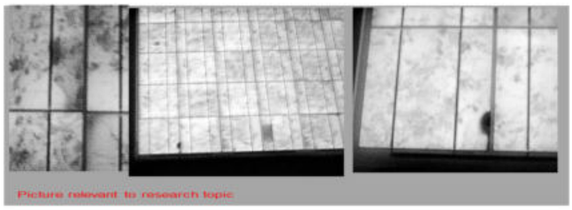

Figure 2: EL Imaging. Left: µ-Crack (not our Module); Middle + Right: our Module with HOT-SPOT

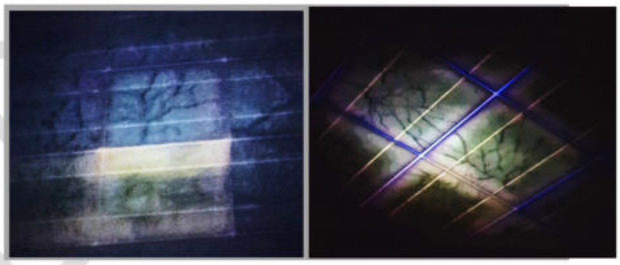

Figure 3: UV-Flurosecence imageing of cracked cells

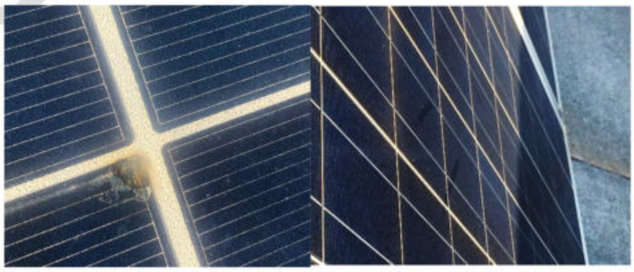

Figure 4: Hots spot (Left); Soiling (right)

Figure 5: Back-sheet Cracking

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2.4. Pictures of the Training School 2

3. The Third PEARL-PV Training School

"Simulation tools and models for the analysis of PV system performance"

3.1. About the Training School

The PEARL-PV Training School on the topic "Simulation tools and models for the analysis of PV system performance" was held at the Transilvania University of Braşov, in Braşov, Romania, between 6th and 9th July 2021. The event was implemented in a hybrid format due to the rules, restrictions and conditions caused by the Covid-19 pandemic on a global scale. It was focused on simulation tools and models that can be used to investigate the design of photovoltaic systems, predict their output and assess their performance in operation. In 3.5 days of expert lectures, modelling exercises and excursions, trainees acquired an understanding of modelling approaches for PV system analysis, including system optimisation, performance prediction and fault and loss identification. The participants learned about modelling principles and current software developments from PEARL PV Working Group members and external experts.


The Transilvania University of Braşov (left) and Institute RDI High Tech Products for Sustainable Development (right)

Training School trainees (students, researchers, educators and practitioners) participated in expert lectures, interactive seminars and modelling exercises, including team action work and study tours. Learning from experts and the experiences of others engaged in best practice projects, participants were enabled to acquire knowledge about modelling photovoltaic systems that they can transfer to students and colleagues in their institutes and faculties.

Training School Managers:
Prof. Dr. Aleksandra Krstić-Furundžić (akrstic@arh.bg.ac.rs ; akrsticfurundzic@gmail.com)
Dr. Cedric Caruana (cedric.caruana@um.edu.mt)

Chair of PV Simulation WG: Prof. Dr. Nicola Pearsall (nicola.pearsall@northumbria.ac.uk)

Local organizer: PhD. Eng. Bogdan-Gabriel Burduhos

Schedule of Events

Tuesday 6 July 2021 – Day 1: Modelling Principles

Time	Activity	Lecturer
09:30-10:00	Registration and Opening of the Training School	Nicola Pearsall, University of Northumbria / Bogdan Burduhos, Transilvania University of Brasov
10:00–11:15	Participants introduction – training school participants introduce themselves and their research activities	Chair: Aleksandra Krstic-Furundzic, Univ.Belgrade
11:15-11:45	*Coffee break*	
11:45-12:30	The role of modelling in assessing and monitoring PV system performance	Nicola Pearsall, University of Northumbria
12:30-13:30	*Lunch*	
13:30-14:15	Introduction to energy harvesting and simulation of PV systems	Joao Serra, University of Lisbon
14: 15 -15:15	Modelling of PV modules and systems	Steve Ransome, Consultant
15:15-15:45	*Coffee break*	
15:45-17:00	Simulation of system performance	Facilitated discussion
17:00-18:00	The PVLIB approach to modelling and analysis	Josh Stein, Sandia National Laboratory (USA)

Wednesday 7 July 2021 – Day 2: Investigating Performance

Time	Activity	Lecturer
09:30-10:30	Irradiance modelling using LightTools, a ray tracing technique	Xitong Zhu, Eindhoven University of Technology
10:30-11:15	Reliability modelling	Jeff Kettle, Glasgow University
11:15-11:45	*Coffee break*	
11:45-12:30	Encoder-decoder image segmentation models for EL images of thin-film modules	Evgenii Sovetkin, FZ-Jülich
12:30-13:30	*Lunch break*	
13:30–14:15	Modelling of degradation	Facilitated discussion
14:15-15:00	Fault detection for PV systems using machine learning techniques	Mohammedreza Aghei, Eindhoven University of Technology
15:00-15:30	*Coffee break*	
15:30-17:00	Field performance and fault detection	Facilitated discussion

Thursday 8 July 2021 – Day 3: Modelling System Concepts

Time	Activity	Lecturer
09:45-10:30	Energy loss modelling	Angele Reinders, University of Twente
10:30-11:15	Modelling of floating PV systems	Sara Golroodbari, University of Utrecht
11:15-11:30	*Coffee Break*	
11:30-13:00	Simulation of the bifacial energy gain for photovoltaic plants using the Graphics Processing Unit (GPU) 1) Introduction to the theoretical concepts 2) Practical simulation exercises using the Lusim tool	Jonathan Leloux, Lucisun Jesus Robledo Bueno, Lucisun
13:00-14:00	*Lunch Break*	
14:00-14:15	Introduction to modelling group challenge	Joao Serra, University of Lisbon
14:15-15:30	Group modelling exercise	
15:30-16:00	*Coffee Break*	
16:00-17:00	Group modelling exercise (continued)	
17:00-17:30	Preparation of group presentations for wrap-up session tomorrow	

Friday 9 July 2021 – Extending modelling to non-technical aspects

Time	Activity	Lecturer
9:30–10:15	Economic aspects of PV system modelling	David Moser, EURAC
10:15-11:00	Environmental impact assessment for PV modules and systems – using environmental models	Nicola Pearsall, University of Northumbria
11:00-11:30	Coffee break	
11:30-12:45	Interactive poster session and reports on modelling challenge	Aleksandra Krstic-Furundzic, Univ.Belgrade / Joao Serra, University of Lisbon
12:45-13:30	Wrap-up and closure of the training school/ joined lunch for on-site participants	Aleksandra Krstic-Furundzic, Univ.Belgrade

List of trainees

	Name	Affilation
1	Altin Maraj	Polytechnic University of Tirana / Albania
2	Amrita Raghoebarsing	University of Twente / The Netherlands
3	Ankit Verma	Dublin City University / Ireland
4	Ana Foles	UEVORA / Portugal
5	Afonso Cavaco	University of Evora / Portugal
6	Alexandru Patrolea	Transilvania University of Brasov / Romania
7	Atsu Divine Kafui	Szent Istvan University / Hungary
8	Fatme Hakka	AIT Austrian Institute of Technology GmbH / Austria
9	Joao Gabriel Bessa	Universidad de Jaen / Spain
10	Jose Domingo Santos Rodriguez	TECNALIA / Spain
11	Li Baojie	Universite Paris-Saclay / France
12	Mari B. Øgaard	University of Oslo / IFE / Norway
13	Mihai Petre Oproiu	Transilvania University of Brasov / Romania
14	Moira Torres	SIRTA, Laboratorie de Meteorologie Dynamique / France
15	Nina Ditoiu	Technical University of Cluj-Napoca / Romania
16	Younjung Choi	University of Twente / The Netherlands

3.2. Current research of participants

Poster session-I – Participants introduction aimed at the participants of the training school to present themselves and their research activities in order to get to know each other. Each participant prepared and explained a poster that was a concise presentation of his/her current research, for a doctoral or master's thesis, highlighting the topic, problem and results. Presentations were the basis for developing scientific discussions between participants. This session was practical networking of researchers on a particular topic. It was interactive and also a team building activity relevant to creating teams for the Workshop. Posters are shown in Appendix 2.

3.3. Workshop

The topic of the Workshop was the *Modelling Challenge Specification,* which involved solving specific tasks and presenting the results on posters using practical knowledge acquired during lectures and excursions. Students worked in 2 groups on specific topics and each group prepared a poster with case studies related to a given topic. The presentation of the posters as a result of the Workshop follows.

3rd TRAINING SCHOOL

Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

Workshop

Modelling of Lugano On-Grid 25.5 kWp PV System

Working Group N1

Baojie LI, Moira Torres, Joao Gabriel Bessa, Alexandru Patrolea, Mihai Peter Oproiu

Introduction

Solar photovoltaics (PV) is one of the most promising renewable energy technologies. In recent years, interest in the building integration of PV elements is growing worldwide, where the PV elements actually become an integral part of the building, often serving as the exterior weather skin [1]. A **Building Integrated Photovoltaics (BIPV)** system consists of integrating photovoltaics modules into the building envelope, such as the roof or the facade. In this study, we select a BIPV on a residential and administrative building [2] (shown in Figure 1) in **Lugano, Switzerland**. The building envelope of its seven floors was retrofitted by Zurich Insurance. The design of the BIPV façade aims to maximize the energy production rather than the architectonic design of the building envelope. The modelling on the **energy output** of this BIPV building and the **related challenges** will be addressed.

Figure 1: Lugano On-Grid 25.5 kWp BIPV building

Details of PV system

- The building is located in a residential and administrative region in Lugano, Switzerland.
- The multi-orientated system is composed of 3 arrays installed in the **west, east and south facades** of the building, with a nominal power of 8.5 kW_p each.
- The modules are installed on the building envelope vertically occupying an area of 150 m^2.

System characteristics	
Location	Lugano, Switzerland
Total area	150 m^2
Tilt	90°
Module technology	Mono c-Si
Nominal Power	25.5 kW_p
Power per Facade	8.5 kW_p
Losses	14 %

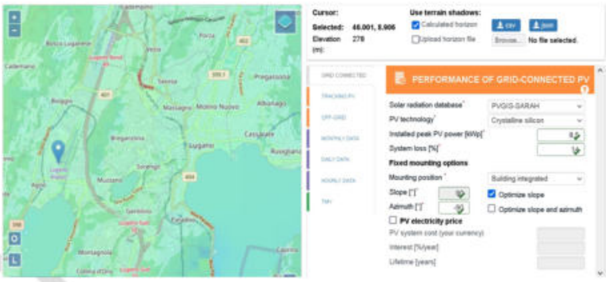

Figure 2: PVGIS setting

Modelling challenges and aims

Challenges:

- Modules integrated with the façade with different orientations (West, East and South);
- Modules installed on a fixed angle (90°);
- Nearby buildings causing shadows.

Aims:

- Model the energy production by each array;
- Model the energy production by each array with an optimum tilt angle.

Modelling approaches

For modelling the system we use **PVGIS** sustained and available in online website version from European Commission. As input dates for modelling, we use next parameters:

- The total rated power of the system of 25,5 kWp which is divided into 3 facades each with 8.5 kW_p per 50 m^2;
- Meteorological data from the place of the system (PVGIS solar radiation database, 12 months 2016);
- 3 different scenarios with changing azimuth angle for each facade and 3 different scenarios with optimized azimuth angle (south, east, west).

The modeling results were downloaded as csv and processed into Phyton and shown in the adjacent figures.

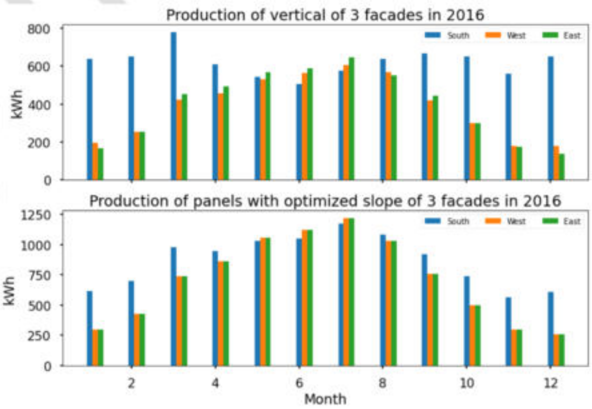

Figure 3: Energy production of panels in the 3 facades

Initial results

The simulated energy output are shown on Figure 3 and 4, from which we can observe the following details:

- Different energy production in different months of a year, based on the PV orientation of the façade
- From the point of view of electricity production, depending on the season, the southern façade can produce more electricity throughout the year comparing to the other facades, except in summer.
- With the optimized tilt angle, the energy production increase through the year constantly for the west and east facades. Instead, the south façade present the most significant improvement during the summer.

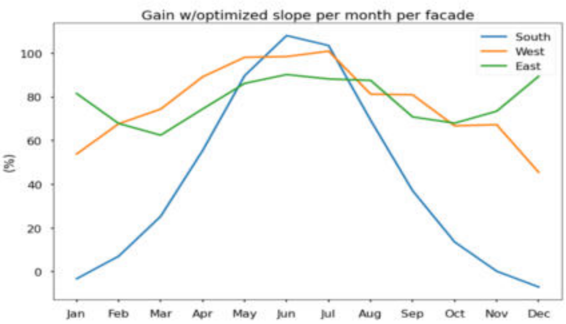

Figure 4: Gain of energy output if using optimized slope

Conclusions

Some conclusion could be drawn from this study:

- The energy output of BIPV building with different facades in Lugano could be modelled through the PVGIS platform.
- The energy output of different facades shows large difference in different period of one year, where the south façade produces larger compared to the others.
- Modelling of the BIPV building is essential to a better optimization of the energy production and management.

References

[1] Yang T, Athienitis A K. A review of research and developments of building-integrated photovoltaic/thermal (BIPV/T) systems[J]. Renewable and Sustainable Energy Reviews, 2016, 66: 886-912.

[2] Building Integrated Photovoltaics: A practical handbook for solar buildings' stakeholders, Status Report 2020, [Online] https://solarchitecture.ch/bipv-status-report-2020/

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PARLPV

3rd TRAINING SCHOOL

Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

Workshop

Simulation of an Agrophotovoltaic System

Fatme Hakka, Divine Atsu, Nina Ditoiu, Jose Santos, Altin Maraj

Working Group No 4

Introduction

Type of the PV system: Agrophotovoltaics (Agro-PV or APV) → Combining crop growth and the production of photovoltaic energy on a site (Source: DOI: 10.4229/EUPVSEC20202020-6DO.14.2)

Application of the Agro-PV: PV system on the roof of a greenhouse (Fig. 1).

Modelling scope: Optimization of the produced energy and crop quantity

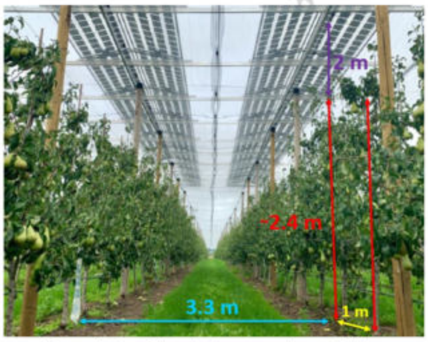


Figure 1: Agro-PV application, a greenhouse in Belgium (Source: Willockx et al, presentation, EUPVSEC 2020)

Details of PV system

Location: Bierbeek, Belgium

Component specifications: Semi-transparent PV modules, utilizing crystalline silicon cells, are placed above the line of trees, with a Ground Cover Ratio of 36%. Modules are 36-cell, 40% transparency and rated at 185 W.

Installation details: The trees are about 2.4 m high, with a planting distance of 1 m between the trees and an inter-row distance of 3.3 m. The modules are placed about 2 m above the trees. For three rows of trees, an array size of 13 kW can be installed (Fig. 1).

Modelling challenges and aims

The aim of the modelling:

-Maximizing energy yield

-Protection of the crops from severe weather conditions

-Providing a heat source for the crop during winter, depending on the crop choice of the landowner

The main challenges for the system:

- Modelling the module temperature considering differences between indoor vs. outdoor temperature and wind speed
- Type of crop (summer vs. winter crops)
- Calculation of albedo in case of bifacial PV modules are considered in order to improve generated energy
- Height of modules (depending on the height of crops), especially if bifacial PV modules are used
- Spectral effect in the reflected light (albedo), especially related to PV plant absorption/reflection
- Module spacing and transparency (Fig. 2)
- Homogeneity of the PV modules (Fig. 3)
- Orientation of the modules: All facing different sides or the same?
- Adaptable tilt angles for summer and winter seasons

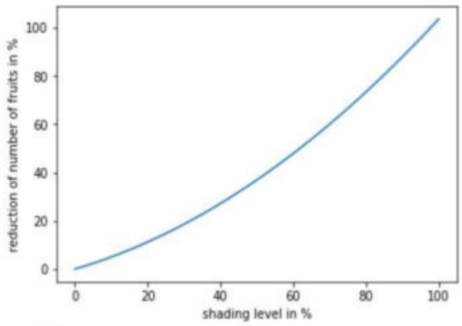


Figure 2: Variation of fruit reduction on different shading levels of the PV system (Source: DOI: 10.4229/EUPVSEC20202020-6DO.14.2)

Modelling approaches

-Ray-tracing will be used for better prediction of albedo and total (not only for incident irradiance on the trees)

-A better thermal model will be used to take into account differences between indoor-outdoor temperature and wind speed (greenhouse effect could lead to lower efficiencies)

-Experimental measurements of Global Horizontal Irradiance, wind speed, indoor-outdoor air temperature are required

-Specifications of the chosen crop: the time interval they grow, the collection time...

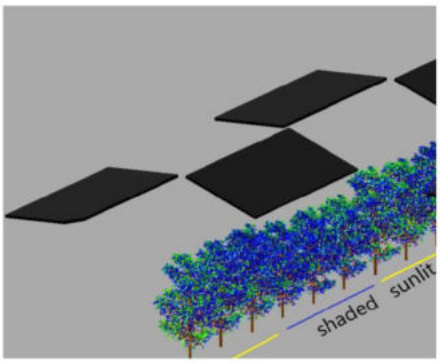


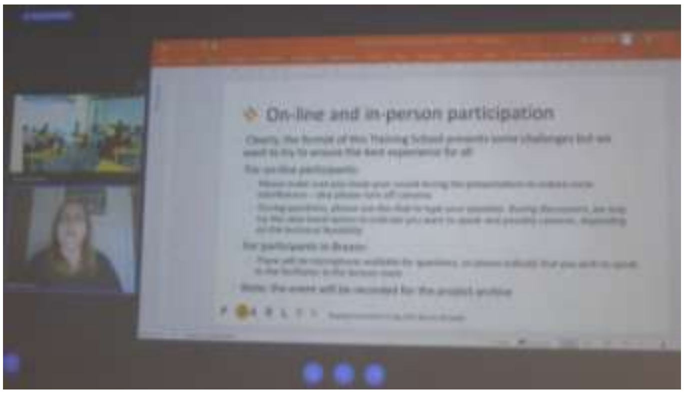
Figure 3: Inhomogeneous PV design causing different growing patterns in the crop (Source: DOI: 10.4229/EUPVSEC20202020-6DO.14.2)

Conclusions

-Agricultural lands can be utilized both for growing crops and electricity production, but a trade off between the produced crop and the electrical energy should be identified clearly to meet the expectations of the landowner.

-Information on the type of the crop is definitely needed in order to optimize the whole system (plants + PV).

3.4. Pictures of the Training School 3



Hybrid format of the Training school - participation in person and online

4. The Fourth PEARL-PV Training School

"Potential of monitoring tools and advanced operation and maintenance practice for security and predictability of PV performance"

4.1. About the Training School

The PEARL-PV Training School on the topic "Potential of monitoring tools and advanced operation and maintenance practice for security and predictability of PV performance" was held at the University of Twente, Enschede, The Netherlands, between 8th and 11th March 2022. The aim was to discuss how the analysis of data on actual long-term monitored performance, defects and failures in photovoltaic (PV) systems allows to quantitatively determine the absolute effects of nominal component characteristics, key system design, installation, operation, maintenance practices on efficiency, reliability and durability of solar PV energy systems as well as their forecasting. The discussion also included the use of various (including future) products which will enable PV system owners (residential and utility-scale) to control the quality of their PV systems. In 3.5 days of expert lectures, exercises and excursions, trainees acquired an understanding of the potential of monitoring tools and advanced operation and maintenance practice for security and predictability of PV performance. The participants learned about monitoring tools, defects and failures in PV systems and maintenance practice from PEARL PV Working Group members and external experts. The event was implemented in a hybrid format due to the rules, restrictions and conditions caused by the Covid-19 pandemic on a global scale.

The University of Twente, Enschede (left) and Horst Building (right)

Training School Managers:
Prof. Dr. Aleksandra Krstić-Furundžić / University of Belgrade (akrstic@arh.bg.ac.rs)
Dr. Cedric Caruana / University of Malta (cedric.caruana@um.edu.mt)

Local organizers: Prof. Dr. Angele Reinders / University of Twente, Prof. Dr. Wilfried Van Sark/ University of Utrecht, Copernicus Institute, Prof. Dr. Jeffrey Kettle / University of Glasgow, Dr. Eli Shirazi / University of Twente, Ms. Saskia Groenendijk / University of Twente.

Schedule of Events

Tuesday 08 March 2022 – Day 1 – Room T1300, Horst Building

Time	Activity	Lecturer
09:30-10:00	Registration and Opening of the Training School	Angèle Reinders / University of Twente Wilfried Van Sark/ Utrecht University, Copernicus Institute Jeffrey Kettle / University of Glasgow Cedric Caruana/ University of Malta Eli Shirazi / University of Twente
10:00–11:30	Participants introduction – training school participants introduce themselves and their research activities / team building	Chair: Cedric Caruana/ University of Malta
11:30-12:00	*Coffee break*	
12:00-13:00	Product development for PV performance control	Angèle Reinders / University of Twente
13:00-14:00	*Lunch break*	
14:00-15:00	Data monitoring & analytics for better PV performance and grid integration	Jonathan Leloux / Polytechnic University of Madrid, Spain
15:00-15:45	Fabrication of Al-BSF cells; assembly of crystalline-silicon-based modules	Jurriaan Schmitz / University of Twente
15:45-16:15	*Coffee break*	
16:15-17:00	PV reliability review	Jurriaan Schmitz / University of Twente

Wednesday 09 March 2022 – Day 2 – Room T1300 Horst Building

Time	Activity	Lecturer
09:30-10:30	PV performance monitoring in a 100% renewable society	Wilfried Van Sark/ Utrecht University, Copernicus Institute
10:30-11:30	Understanding potential-induced degradation (PID) of photovoltaic (PV) modules	Mahmoud Dhimish / University of York, UK
11:30-12:00	*Coffee break*	
12:00-13:00	PV Module forensics and characterization of material degradation in the field	Gernot Orenski / Polymer Competence Center Leoben GmbH (PCCL)
13:00-14:00	*Lunch break*	
14:00–14:45 14:45-15:45	Excursion at University of Twente Campus – visit to PV plants and energy projects	Ray Klumpert / University of Twente, start at Linde Building
15:45-16:15	*Coffee break*	
16:15-17:00	Workshop - explanation of the task Facilitated discussion	Cedric Caruana, Univ. Malta

Thursday 10 March 2022 – Day 3 - Room T1300, Horst Building

Time	Activity	Lecturer
09:30-10:30	Monitoring system for floating solar	Sara Mirbagheri Golroodbari / Utrecht University, Copernicus Institute
10:30-11:30	Photovoltaic and Solar Forecasting	Eli Shirazi / University of Twente
11:30-12:00	*Coffee break*	
12:00-13:00	The role of digitalization in advanced operation and maintenance practices	Atse Louwen / EURAC Research
13:00-14:00	*Lunch break*	
14:00-14:15	Workshop - Group exercise	Cedric Caruana/ University of Malta Eli Shirazi / University of Twente
14:15-15:30	Workshop - Group exercise	Cedric Caruana/ University of Malta Eli Shirazi / University of Twente
15:30-16:00	*Coffee break*	
16:00-17:00	Workshop - Group exercise Preparation of group presentations for wrap-up session on Friday	Cedric Caruana/ University of Malta Eli Shirazi / University of Twente

Friday 11 March 2022 – Day 4 Room W3, Waaier Building

Time	Activity	Lecturer
09:30–10:15	Preparation of group presentations for wrap-up session	Cedric Caruana/ University of Malta Eli Shirazi / University of Twente
10:15-11:00	Preparation of group presentations for wrap-up session	
11:00-11:30	Coffee break	
11:30-12:45	Interactive poster session and reports on task	Cedric Caruana/ University of Malta Angèle Reinders/University of Twente, Wilfried Van Sark/ University of Utrecht, Jeffrey Kettle / University of Glasgow Eli Shirazi / University of Twente
12:45-13:30	Wrap-up and closure of the training school/ joined lunch for on-site participants	Angèle Reinders / University of Twente, Wilfried Van Sark/ University of Utrecht, Jeffrey Kettle / University of Glasgow Cedric Caruana/ University of Malta

List of trainees

	Name	Affilation
1	Ajith Gopi	University Malaysia / Malaysia
2	Altin Maraj	Dept Energy, Polytechnic university of Tirana
3	Alvaro Fernandez Solas	University of Jaen / Spain
4	Aswin Vadavathi	University of Twente, Faculty of EEMCS / The Netherlands
5	Bashayer Alsulami	University of Glasgow / UK
6	Eduardo Sarquis Filho	University of Lisbon / Portugal
7	Elmehdi Mouhib	University of Jaen / Spain
8	Fatih Karipoglu	Izmir Institute of Technology / Turkey
9	Fatih Ozkaynak	Firat University, Faculty of Technology / Turkey
10	Hugo Quest	Ecole Polytechnique Federale de Lausanne / Switzerland
11	Idda Ahmed	University of Bechar / Algeria
12	Ismail Borazan	Bursa Technical Univerity / Turkey
13	Kemal Koca	Cumhuriyet University / Turkey
14	Khadija Barhmi	Utrecht University / The Netherlands
15	Nikolaus Houben	Technische Universitat Wien / Austria
16	Parnian Alikhani	Utrecht University / The Netherlands
17	Radu Opreanu	Polytechnic University of Bucharest / Romania
18	Sandra Gallmetzer	Eurac Research / Italy
19	Sukumaran Sreenath	Solar Research Institute, UITM / Malaysia
20	Thomas De Bruin	Utrecht University / The Netherlands
21	Yasin Altin	Ordu University / Turkey
22	Zaoui Fares	University of Mohamed El Bachir El Ibrahimi / Algeria

4.2. Current Research of participants

Poster session-I – Participants introduction aims for the participants of the training school to present themselves and their research activities in order to get to know each other. Each participant prepared and explained a poster that was a concise presentation of his/her current research for a doctoral or master's thesis, highlighting the topic, problem and results. The session was practical networking. It was interactive and also a team building activity relevant to creating teams for the Workshop. Posters are shown in Appendix 3.

4.3. Workshop

For trainees the tasks during the Workshop were to identify techniques, describe the required data, define the implementation strategy and discuss the potential benefits relating to a combination of at least two themes covered in the Trainers' presentations. Students worked in 5 groups. Each group had to design a representative case study that demonstrates the application of the considered strategy. The presentation of the posters as a result of the Workshop follows.

PEARL PV

4th TRAINING SCHOOL

University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Preliminary study on effect of the environmental factors on the the PV performance under different weather conditions

Aswin Vadavathi[1], Khadija Barhmi[2], Sreenath Sukumaran[3], Yasin Altin[4]
[1]University of Twente, Netherlands,
[2]Copernicus Institute of Sustainable Development, Utrecht University, Netherlands.,
[3]Research Associate, UiTM Solar Research Institute, Shah Alam, Malaysia.,
[4]Department of Chemistry, Ordu University, Turkey.

Introduction

- Solar PV technology is widely considered in countries
- Solar PV performance is highly influenced by system losses
- PV losses arises from environmental factors as well as component selection
- PV losses such as soiling, shading, snow are geographically dependent
- Related themes are Data Monitoring and Analytics & Advanced Operation and Maintenance Practice

Aims and Objectives

- To estimate the solar energy output in different climatic conditions
- To analyse the impact of environmental factors on PV performance
- To compare the PV performance in different climatic conditions

Methodology

- Selection of sites from different climatic zones
- Estimation of system loss for each site manually
- Prediction of PV energy output using PV software
- Comparison of technical performance with location specific loss values

Case Study

- 5kWp rooftop solar PV system is considered
- Consist of 12 numbers of 400 Watts Mono Crystalline PV modules
- PVWatts software & Excel platform was utilized for the analysis

Conclusions

- Estimated the loss parameters and the PV performance in different climatic conditions.
- Solar PV seems to be a feasible alternative for solar in places of high snow and large latitude.
- External environment loses such as show can affect the PV performance to a significant extent
- Varied environmental factors in different locations showed affect on PV performance.
- Observed that the loss due to dust and snow have a significant influence in PV performance compared to other losses considered.
- Detailed study utilizing real data to study the impact of environmental parameters on PV performance

References

- User Manual Solargis pvPlanner 2016 www. solargis.com
- Øgaard, M. B., Riise, H. N., Haug, H., Sartori, S., & Selj, J. H. (2020). Photovoltaic system monitoring for high latitude locations. Solar Energy, 207, 1045-1054.
- Livera, A., Theristis, M., Makrides, G., Sutterlueti, J., Ransome, S., & Georghiou, G. E. (2019, September). Performance analysis of mechanistic and machine learning models for photovoltaic energy yield prediction. In Proceedings of the 36th European Photovoltaic Solar Energy Conference and Exhibition, Marseille, France (pp. 9-13).
- https://upload.wikimedia.org/wikipedia/commons/f/f6/Global_Solar_Atlas_1.0.png
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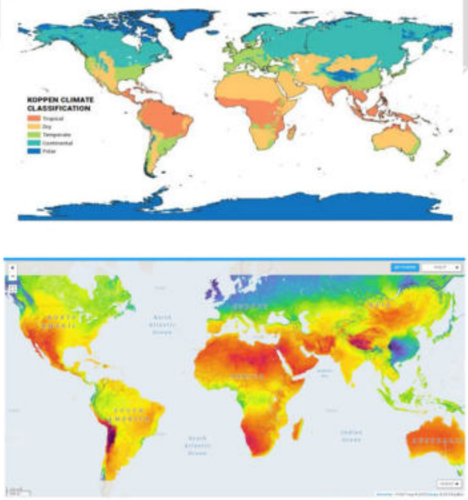

Figure 1: Map showing the climatic condition map & solar irradiation

Losses	Default Loss (%)	Location Specific Loss (%)			
Climatic Zones		Tropical & Urban	Dry & rural	Temperate & Urban	Continental & rural with snow season
Location	-	Singapore	Al Ajban, UAE	Amsterdam, Netherlands	Jammu, India
Tilt angle (degree)	-	10°	24°	52°	34°
Soiling	2	2	5	2	2
Shading	3	5	1	5	1
Snow	0	0	0	0	10
Mismatch	2	2	2	2	2
Wiring	2	2	2	2	2
Connections	0.5	0.5	0.5	0.5	0.5
Light Induced Degradation	1.5	1.5	1.5	1.5	1.5
Nameplate rating	1	1	1	1	1
Age	0	0	0	0	0
Availability	3	3	3	3	3
Total	14	17	16	17	23

Figure 2: Assumed loss parameters for the selected locations in different climatic zones .

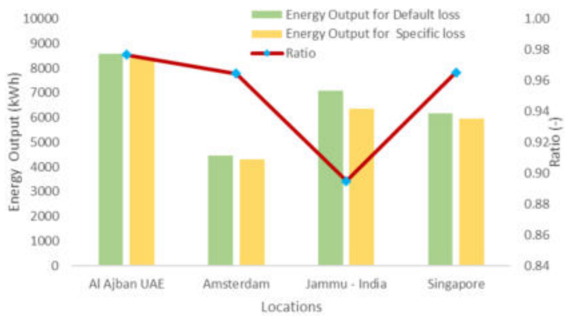

Figure 3: Effect of environmental factors on annual PV energy yield

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University of Twente, The Netherlands, March 2022
Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Application of the decision support system for soiling issues on a real case study in Spain

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Thomas de Bruin

Introduction

Soiling is an issue that impacts PV systems worldwide and soiling losses should be quantified accurately (see Figure 1) in order to plan optimal cleaning schedules. Decisions on cleaning frequency depends on a wide variety of factors, such as the electricity price or the cleaning cost. The decision support system calculates the economic impact of soiling by applying the CPN Methodology to a PV plant located in Spain and suggests the best cleaning solution of the modules (see Figure 3).

Aims and Objectives

This study develops a decision support system that investigates repair and downtime costs for a case study of a large-scale (4.4 MWp) solar plant in the South-East of Spain (see Figure 2). Two time periods are investigated, one in summer (July) and one in winter (January). The aim is to analyze soiling issues for large-scale PV plants and their economic impact in order to decide the best time for cleaning.

Methodology

The decision support system (see Figure 3) is based on the Cost Priority Number (CPN) methodology which calculates the economic impact of soiling considering the downtime costs due to energy loss and the fixing costs due to cleaning and labor.

$$CPN\ [euro/kW_p/year] = Cost_{down} + Cost_{fix}$$

Case Study

For a PV plant in the southeast of Spain with 4400 kWp of installed capacity, half of the 22.000 modules are affected by soiling with an estimated performance loss of 10%. Due to the large scale of the plant, robotic cleaning with a cost of 0.2 €/kWp is applied and the cleaning time takes eight hours.

Results (see Figure 4) show that soiling effects in July are more severe when compared to January due to higher irradiance and consequently energy yields. Therefore, for this specific case study the PV plant system operators should decide to clean the panels if the periodic maintenance is scheduled after 16 days since the fault detection for July and 26 days for January.

Conclusions

In this work, the relevance of considering energy losses due to soiling is demonstrated:

- An in-depth analysis that addresses the economic impact of soiling in a large PV plant has been conducted.
- The cost of cleaning has been calculated by considering both the downtime of the plant and the own cleaning cost.
- Future studies should consider the exponential effect of soiling and rain forecasts which have not been taken into account in this research.

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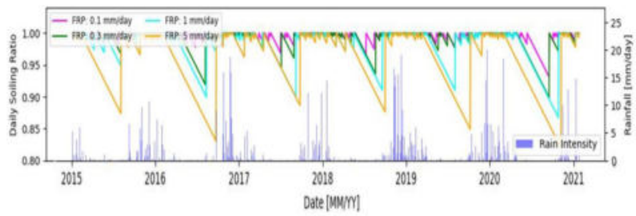

Figure 1: Soiling profile of an array of solar panels in the South-East of Spain from 2015 until 2022.

Figure 2: Left: Aerial photograph of the PV plant. It has a nominal capacity of 4.4 MWp. Right: Location of the plant within Spain. The plant is located in the southeast of Spain. The average annual horizontal solar irradiance is higher than 1800 kWh/m².

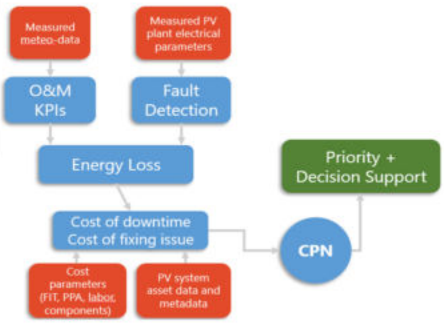

Figure 3: Cost priority number decision support system flow chart showing the required input parameters and results.

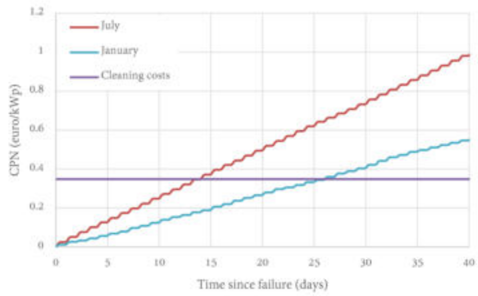

Figure 4: Cost priority number as a function of time for soiling losses in July and January. The cost of cleaning are represented by the green line.

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Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Should the faults drives us to lose forecasting accuracy?

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Parnian Alikhani, PhD student - Utrecht University

Introduction

- The growth of renewables in the energy market, especially solar, comes with the challenge of unpredictability of the generated power. Therefore, improvements in forecast accuracy play an important role in reducing the operating cost of PV systems [1].
- Nowadays there are methods to forecast the behaviour of PVs based on historical data, sky images, satellite data, etc. This project aim to improve the accuracy of forecasting by updating the digital twin model with the information gathered from field inspections.
- The typical data obtained from the inspections will refer to faulty grounding, broken panels, disengaged cables etc. Thus, the approach we propose use techniques from advanced operation and maintenance and photovoltaic forecasting in order to facilitate the exchange of information between different levels of the PV operations.

Aims and Objectives

- Improve the accuracy of forecasting enough to avoid/reduce curtailments and reduce operational costs.
- Create a digital twin modelling capable of handling specific information about failures.
- Define the preprocessing needed to extract the relevant information from the inspections (thermography, measurements, visual inspections).
- Facilitate the development of PV forecasting by transferring information between different entities of the PV operation chain.

Methodology

1. Collect the documentation from the PV plant design, inspections (visual, electrical, thermography, etc.) and maintenance interventions. Identify the relevant information for the performance simulation.
2. Evaluate the PV modelling techniques suitable for handling heterogeneous components. For example [2].
3. Create a digital twin adding the components' faults identified in the field inspections.
4. Forecast the energy generation using the developed digital twin with and without the inspection information. Compare the accuracy with the current energy forecasting method.

Case Study

The proposed idea should be developed based on a real data from a working PV system **"[ABD] Bolzano CdTe PV Plant"** with such characteristics:

- More than 2 years of operation: **Established in 2010 / test field(+11 years data)**
- Documented field inspections and maintenance actions
- High accuracy and resolution monitoring data: **Equipped with high quality sensors and meters**
- Minimum installed capacity of 500 kWp: **Overall nominal power of 724 kWp**
- Complete design documentation (datasheets, electrical and physical layouts)
- Technology diversity: **Multi-technology modules/ four mounting systems**

Expected outcomes:

- Create a forecasting tool with fault inspection integration
- More accurate forecasting model implemented on different installed PV technologies
- New insights and possibilities for future studies, due to better PV monetization and forecasting

Conclusions

Evaluate the potential benefits for PV forecasting through using a digital twin with faults information.

The potential impacts are:

- Economical: Possibilities for grid services & day-ahead market
- Technical: Power plant control & grid compliance
- Environmental: Encouraging renewable energy generation by increasing the forecasting accuracy and so allowing the increase of PV penetration in the energy matrix.

Proposal application:

Implement on any commercial PV plants with available required information which are participating in market.

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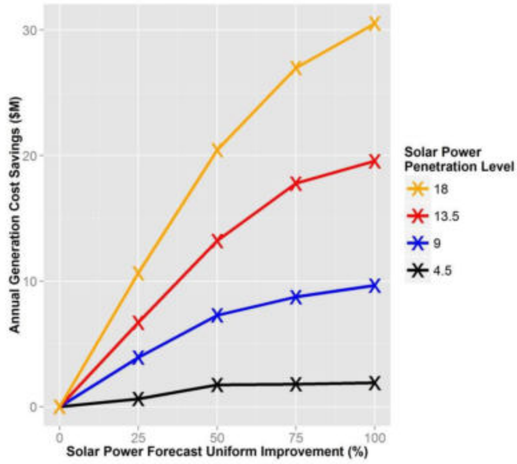

Figure 1: Estimated reduction of annual operational electricity generation costs according to improvements in forecasting accuracy [1].

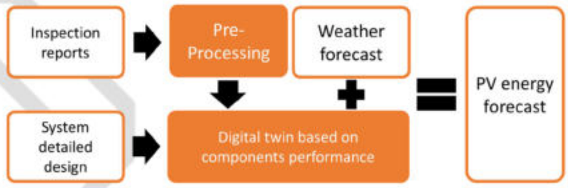

Figure 2: Proposed data processing to forecast energy generation considering the inspection reports information.

Figure 3: Case study - Bolzano PV Plant [3]

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University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Advanced monitoring and analysis for PV performance optimisation under snow conditions

Bashayer Alsulami (University of Glasgow, UK), Fatih Ozkaynak (Firat University, Turkey), Hugo Quest (3S Solar Plus & EPFL, Switzerland), Nikolas Houben (TU Wien, Austria)

Introduction

PV systems paradoxically work best at high irradiance and cold conditions, and an increasing amount of systems are being installed in cold climate regions. However, snow coverage can be an issue for such systems, as seen in **Figure 1**. This project proposal aims at creating an advanced monitoring and analysis tool to optimise the performance of PV systems under snow conditions.

The project will cover the following key aspects:

- Security – ensuring privacy and security through encryption of monitoring data.
- Monitoring & analysis – automatic fault detection based on PV yield predictions.
- Reliability – contribution towards the understanding of PV system long-term performance.
- Design – proposal of innovative solutions to avoid losses due to snowfall.

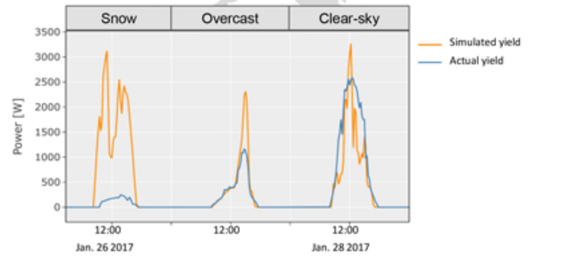


Figure 1: Example daily production profiles with snow, overcast and clear-sky conditions. Snow coverage of the PV modules after heavy snowfall results in poor performance.

Aims and Objectives

1. Create a data analysis pipeline for PV monitoring with secure data encryption
2. Detect snow-related faults in PV systems using physical modelling and SVM yield predictions
3. Quantifying the yield and economic loss and propose innovative solutions based on the analysis

Methodology

Figure 2 shows a flowchart of the proposed methodology. The main steps are as follows:

1 Data security & encryption

- **Selection of entropy source**: chaotic component to shuffle the data (PV output data in this case).
- **Generation of substitution box**: create transform table that replaces the data with encrypted data .
- **Data encryption**: generation of encrypted data based on the substitution box.

2 SVM yield prediction

- **Data gathering and scrubbing**: data pre-processing (e.g. treating missing values) .
- **Data Exploration**: look for patterns, correlations, and trends in the cleaned and uniform data.
- **Data modelling and interpretation**: build a Support Vector Machine (SVM) yield prediction model based on 16 attributes.

Fault detection & diagnosis

- **Physical model of PV yield**: compute simulated PV output based on the single-diode model .
- **Threshold determination**: determine statistical thresholds to determine faults.
- **Fault detection & clustering**: identify and categorise faults.

3 Yield loss quantification & Economic evaluation

- **Compute yield loss**: determine the yield loss by comparing actual and predicted yield.
- **Determine market price**: find the market price of electricity for the considered time steps.
- **Evaluate monetary losses**: compute economic losses.

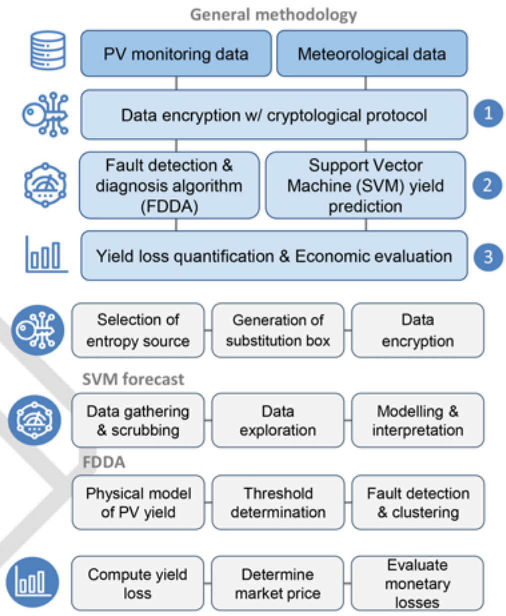
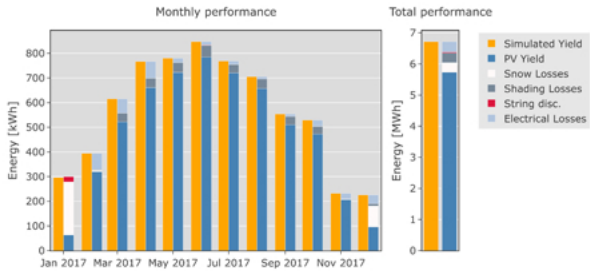
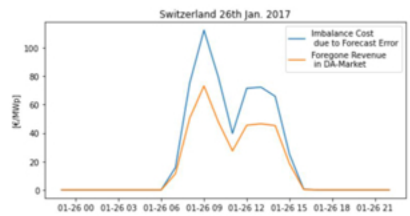


Figure 2: Methodological flowchart for the PV performance analysis - general analysis and detailed steps for each sub-part.

Case Study

- A cryptographic component was created using the Substation Voltages in [1], using the PV system data as the chaotic entropy source [2], yielding a successful and effective encryption.
- **Figure 3** shows the analysis of a building-integrated PV system in central Switzerland in 2017.
- By comparing the simulated and actual yield, and with the fault detection and diagnosis algorithm, snow-related losses are identified and quantified.
- For the studied year, 300 kWh were lost due to snow covering the PV modules, with economic losses of 925 euros/MWp.
- With the addition of accurate predicted yields from the SVM model, taking into account weather-related variables, system owners can then avoid these losses through innovative solutions such as:
  - Melting the snow by passing a reverse current in the event of detected snow coverage.
  - Automated notifications to owners in order to monitor their consumption based on the expected lower PV yields.





- Foregone Revenue due to snow:: 366€ /MWp
- Imbalance Cost due to wrong forecast: 558€ / MWp

Total : 925€ / MWp

Figure 3: Case study results for a BIPV system - monthly and yearly system actual and predicted yields with snow loss quantification. Daily example of the economic loss evaluation.

Conclusions

- Data from PV systems can successfully be used as an alternative entropy source to ensure the security of data for owners and installers. This innovative solution enables the use of the data itself to for encryption, in line with General Data Protection Regulation (GDPR).
- The combination of physical modelling and yield predictions give insights in the yield and economic losses from snow coverage.
- This methodology could easily be expanded to other fault conditions in PV systems.

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4th TRAINING SCHOOL

University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Mitigating Soiling in Bifacial PV Systems

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Ajith Gopi PhD Research Scholar University Malaysia Pahang
Zaoui Fares Assistant lecturer University of Mohamed El Bachir El Ibrahimi Algeria
Altin Maraj PhD Polytechnic University of Tirana - Albania

Introduction

- The main idea of this poster is to separately investigate the soiling deposits on the rear and front side of the bifacial PV modules.
- Soiling is currently one of the major issues for decreasing power production of PV plants in the world. In order to prevent significant power losses , optimal cleaning frequencies should be considered.
- The monitoring and analyse of the soiling rate can be helpful to lower the cost of cleaning operation and increase the bifacial power plant yield.

Figure 1:Bifacial photovoltaic power plant

Aims and Objectives

The objectives of this this study::

- Detect soiling deposits on front and rear side separately
- Processing the images to estimate the soiling rate
- Define a cleaning methodology on the rear and front side separately.

Methodology

- The device will be composed of two low-power digital microscopes, with glass slide glued to the front of the microscopes.
- One microscope will face the ground to measure the rear soiling and the other will face the sun side to collect the front soiling deposits.
- The tilt and orientation will be the same as the bifacial power plant we are investigating.
- A Raspberry pi computer can be used for the image processing with a python code for that.
- A percentage of soiling will be fixed to emit a signal for a cleaning operation on one or both sides of the PV plant modules.

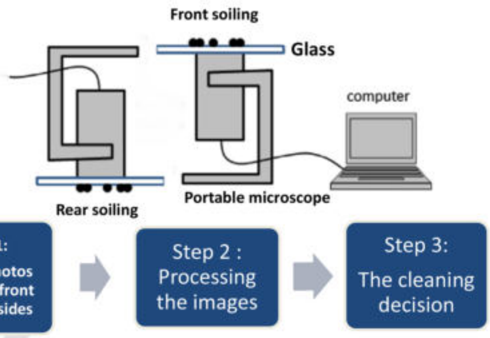

Figure 2: (up) bifacial outdoor soiling microscopes ,(down) The cleaning decision steps

Case Study

- The soling experimental set up is incorporated as part of the Bifacial PV Plant with a dedicated Bifacial PV.
- The soling images will be continuously monitored and processed through Raspberry Pi Computer. A threshold level is pre-programmed in the computer to fix the interval of soling.
- The results can be modelled to get insights on Bifacial PV Module Soiling. The modeling provide inputs to the soiling characteristics in different weather seasons.
- The influence of weather parameters like wind speed , rain, relative humidity on soiling can be studied by correlating the weather parameters into the model
- A study in Santiago Chile proved that the measured soiling rate on front and rear side are different, the front is 9 times higher.
- Another experimental study in Mumbai proved that the soiling deposit depend of the orientation and tilt of the bifacial module.
- Another study of optimization of the bifacial plants cleaning in Chile, reveals that separate cleaning strategy has higher balance values.

Figure 3: (left) a front soiling microscope (right) photo taken with the microscope

Conclusions

- This device concept can be a very good solution to investigate separately the soiling on the rear and front side of the bifacial modules.
- A combination of atmospheric parameters measures (wind speed, humidity...) with the outdoor bifacial microscope can be used to model their effect.
- And it help monitoring teams in the power plants to optimize the cleaning processes.

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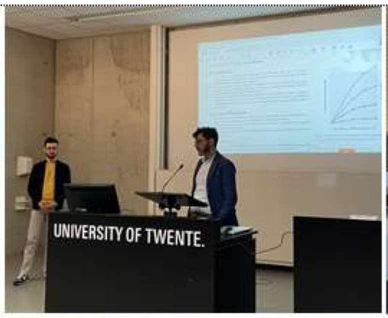
4.4. Pictures of the Training School 4

Workshop poster presentations

Excursion – visit to PV plants



APPENDIX 1- Posters representing Current Research of Training School 2 participants

Posters representing the current research of trainees who participated in the Training School II held in October 2019 at the Malta College of Arts, Science and Technology MCAST, in Paola, Malta.

P A R L P V

2nd TRAINING SCHOOL

Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Modelling and experimental validation of the long-term averaged solar radiation on a tilted south-east facing surface under the Mediterranean climate conditions

Altin Maraj, Polytechnic University of Tirana, "Mother Teresa" Square, No. 4, Tirana, Albania, e-mail: amaraj@fim.edu.al

Introduction

The estimation of monthly average daily total radiation on a tilted surface with various orientations is very helpful to properly design and evaluate different types of solar energy systems.

Also, these values are very important to design photovoltaic panels, structures of buildings, etc.

Research Aims

The present work is an analysis of solar radiation data generated from the (K-T method).
Through this method are generated:

(i) values of the ratio, and

(ii) values of the total radiation on the tilted surface.

Research Problems

Tilted surfaces with different orientations are not so widespread as those facing the south direction. There are plenty of applications where the knowledge regarding the available solar radiation is appreciable.

Also, the validation of the obtained results is very important for the application of a method, or a model.

Research Methodology

The (K-T method) was employed to obtain the monthly averaged values of daily total radiation on the tilted surface.

Validation of the estimated values was performed by leaning on recorded experimental data obtained every minute during a multi-year period.

For this purpose, several statistical test methods (the percentage error, MPE, MBE, RMSE, coefficient of determination) were employed.

Research Results

Recorded data obtained from the controller of a SWHS for a period of 3-years were employed. The conclusions for the selected region are as follows:

a) The monthly average clearness index ranged between $\bar{K}_T = (0.430 - 0.601)$.

b) The monthly fraction of solar radiation that is diffuse fluctuated between $\frac{\bar{H}_d}{\bar{H}} = (0.337 - 0.480)$.

c) The ratio ranged between $\bar{R} = (0.853'1 - 1.745'3)$.

d) The estimated value of the monthly average daily total radiation on a tilted surface ranged between $\bar{H}_{T-c} = (2.698 - 5.910)\ \mathrm{kWh/(m^2 \cdot day)}$

e) From the comparison between the estimated and the measured values, it is noticed that $\varepsilon_{min} = -14.226\ \%$, $\varepsilon_{max} = 7.401\ \%$, $MBE = 0.065\ \mathrm{kWh/(m^2 \cdot day)}$, $MPE = -2.269\ \%$, $RMSE = 0.217\ \mathrm{kWh/(m^2 \cdot day)}$, and $R^2 = 0.964$.

Preferably to refer to Fig. .

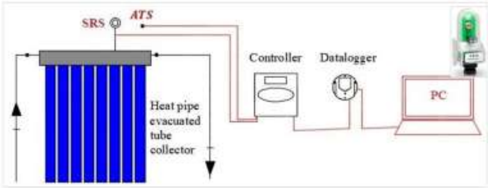


Figure 1: Input parameters and the utilised sensors (Maraj et al., 2019).

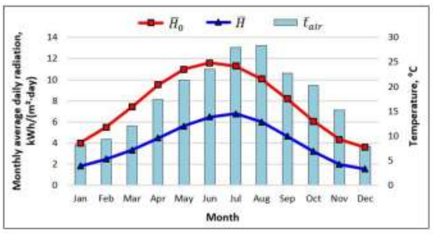


Figure 2: Monthly average daily radiation for $\bar{H}_0$, $\bar{H}$, and the ambient air temperature (Maraj et al., 2019).

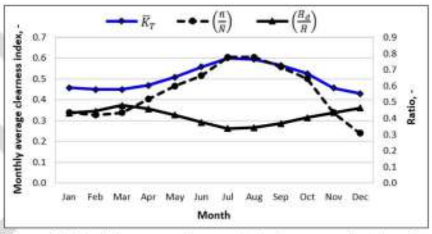


Figure 3: Monthly average clearness index, the average fraction of possible sunshine hours, and the monthly fraction of solar radiation that is diffuse (Maraj et al., 2019).

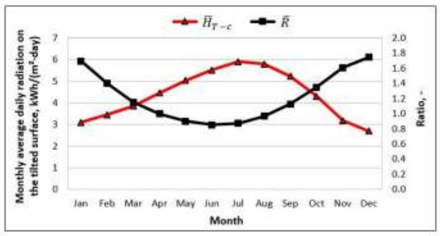


Figure 4: Values of monthly averaged daily radiation on the tilted surface and the ratio (Maraj et. al., 2019).

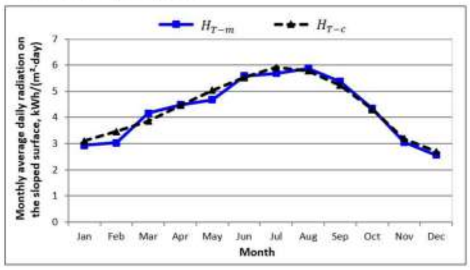


Figure 5: Comparison between the measured and the estimated values (Maraj et. al., 2019).

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Performance analysis and other aspects of photovoltaic (PV) systems in tropical region

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UNIVERSITY OF TWENTE.

Introduction

PhD candidate at the University of Twente (UT), besides

Renewable energy systems researcher and lecturer at the Anton de Kom University of Suriname (ADEKUS).

The PhD research is being on:

- **Tropical region, especially Suriname**
- **User study, cost, performance of PV systems and future energy transition using PV**


Figure 1: Map of Suriname (source: CELOS) and South America

Research Aims

(i) To assess the **perception of the end users** regarding the implementation of PV systems in Suriname,
(ii) To determine and to investigate the **cost and performance of PV** systems under **tropical climate** conditions,
(iii) To assess the **future energy transition** using PV systems in Suriname.

Research Questions

1. What is the public perception regarding the implementation of PV systems in Suriname?
2. What is the performance of grid-connected PV systems in countries with tropical climate conditions?
3. How does the performance of PV systems in the tropical region differs from other regions, taking into account the various performance indicators?
4. Which role can PV play in the future energy transition of Suriname?

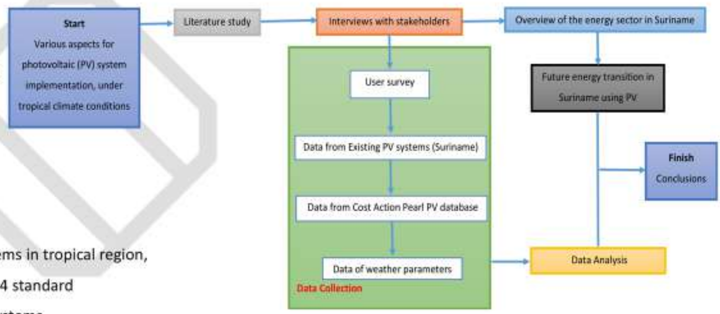

Figure 2: Research methodology

Research Methodology

1. Literature study
2. Interviews with stakeholders
3. User survey
4. Data gathering: weather station data, PV systems data in Suriname & data from database Cost Action
5. Data analysis:
   Performance analysis of grid-connected PV systems in tropical region, using the performance indicators in the IEC61724 standard
6. Future energy transition in Suriname using PV systems

Research Results

- Average **irradiance** is approx. **5** kWh/m²/day and average **final yield** (Y_f) is approx. **3.7** kWh/kW/day [1].
- To achieve the **2027 RE target** with **only PV systems**, additional 110 MWp of installed PV capacity will be required [3].
- To meet the **electricity demand of 2027** with **only PV systems**, additional 2.2 TWh PV electricity will be required [3].
- **Citizens perception** regarding **implementation of PV** in Suriname (user survey) [4]:
  - 75% were aware of electricity generation with PV systems and related benefits
  - 65% are not willing to install PV systems at their homes due to high investment costs and low electricity tariffs
  - Only, 26% of the respondents are willing to install a PV system at their homes
  - Knowledge dissemination about PV systems and subsidies, incentives and rebates remain important in enhancing PV installations in Suriname.

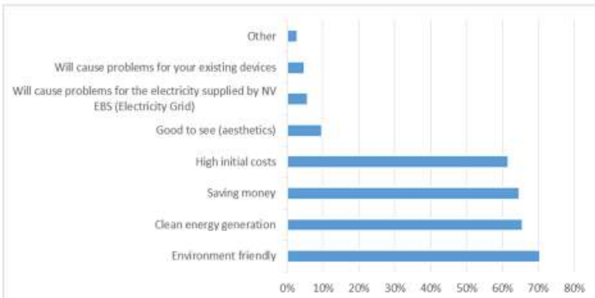

Figure 3: Awareness regarding PV systems in Suriname [4]

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Figure 4: Daily average solar radiation, Reference and Final yield in Suriname [1]

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PEARL PV

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2nd TRAINING SCHOOL

Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Design of Sustainable Energy Systems

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UNIVERSITY OF TWENTE. TU/e UNSW

Introduction

To support the energy transition, sustainable energy technologies should be optimally integrated in products, buildings and local infrastructures. On this poster shown how, in this context, design-driven research is executed by data analysis, simulation, prototyping and testing of conceptual and existing PV systems, smart energy products, smart grids, luminescent solar concentrators and PV powered mobility.

Research Aims

(i) enhancing the performance of sustainable energy technologies,

(ii) understanding the transdisciplinary aspects of energy systems,

(iii) designing improved energy systems, products, buildings and vehicles with integrated sustainable energy systems.

These aims/objectives will be achieved by design-driven research.

Research Questions

How do sustainable energy systems with a large share of PV perform?

How do they interact with each other and with the grid?

How do they perform in the context of an application?

How can they be improved based on outdoor performance in various climates?

What are the experiences with regards financial, societal and user aspects? See Figure 2.

How can we translate these experiences to future designs which reliably perform, can meet the demands of various stakeholders and fit in markets.

Research Methodology

The research methodology is called design-driven research:

- Monitoring: indoor testing, long term outdoor monitoring, surveyance user tests.
- Data analysis: determining indicators, regression, artificial intelligence, nowcasting.
- Simulation: energy flows, real time (digital twin), CAD, 3D, virtual reality, ray tracing.
- (Re)design: conceptualization, embodiment design, prototyping, pilots with realized designs.

Research Results

Ongoing: COST Action PEARL PV, LSC PV project and PV in Mobility project.

Ongoing: set-up of a data server for sharing of data and simulation tools in the context of PEARL PV, see Figure 3.

Ongoing design projects in the field of PV for charging of EVs and other sustainable energy technologies.

Planned: artificial intelligence for understanding, nowcasting, pricing and management of (PV) energy systems with user interaction.

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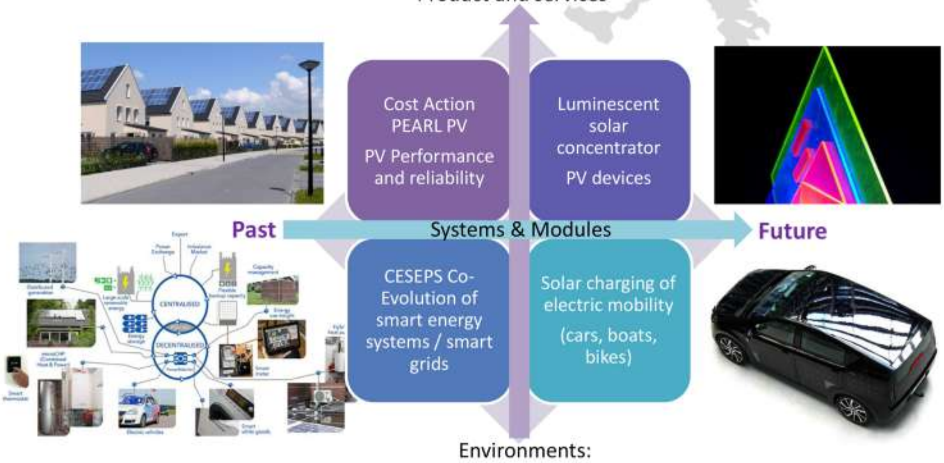

Figure 1: Projects in the Design of Sustainable Energy Systems program which give insights in the past performance of energy systems which can be used for the design of future systems, products, buildings and vehicles.

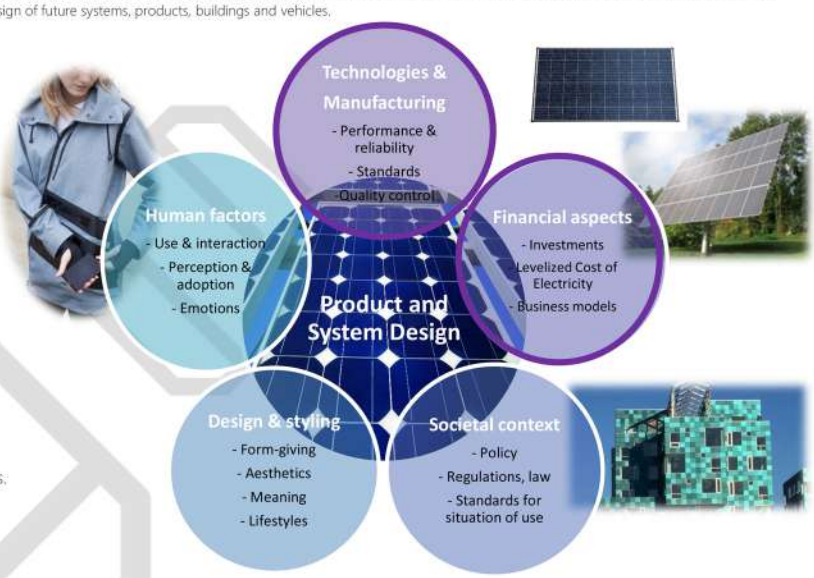

Figure 2: The five aspects of design-driven research in the context of PV applications

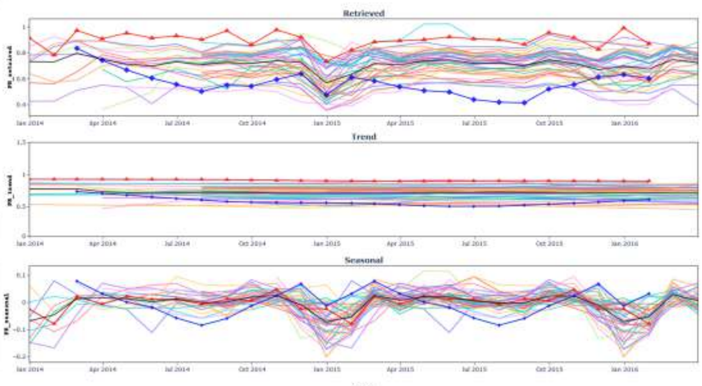

Figure 3: Results of data analysis of the performance of >60 PV systems in the Netherlands (Romero-Ruhss, 2019)

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Synthesis & Study of new hybrid organic-inorganic Perovskites for PV applications

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HYDROSOL

Introduction

An emerging class of materials is the organic-inorganic hybrid perovskites. They have the general Formula AxMXy (A is an amine, M is a metal and X a halide anion). They present excellent optoelectronic properties such as a high and balanced carrier mobility, long carrier diffusion length, large light absorption coefficient in the UV–vis range nonlinear optical effects and efficient luminescence. Within a decade, halide perovskite solar cells showed power conversion efficiency up to 22.7%[1]. Most of these perovskites are based on Lead (Pb). Due to Pb's instability under moist and radiation and its high toxicity, researchers focus on replacing Pb with other metals, as seen in **Fig.1**.

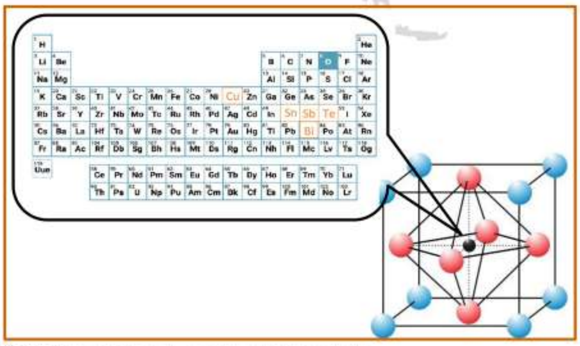

Figure 1: Perovskite's structure and the substitution of metal.

Research Aims

(i) Substitution of Lead ,

(ii) Tailor made hybrid organic-inorganic materials ,

(iii) Optoelectronic devices .

These objectives will be achieved by synthesizing new hybrid organic – inorganic materials with perovskite like structure to gain inside of the impact of the amine in the structure and properties of the as composed materials. Furthermore, by mixing the amines and the halogens we will synthesize materials with the desirable structure and properties and test them as optoelectronic devices.

Research Problems, Questions, Hypotheses

Possible substitution of Lead? → Trigger commercialization

How the amine affects the properties and the structure? → Tailor made materials

Properties of the new compounds? → Optoelectronic devices

What is the ideal experimental procedure? → Low cost synthesis

Research Methodology

The research methodology includes the mixing under reflux of the metal oxides (except for $(BiO)_2CO_3$) and the amines in the right ratio. As solvents we used HCl, HBr and HI and all the amines were synthesized in our laboratory. It took many trial and error attempts in order to find the right ratios and a lot of recrystallizations. We used different amines in order to study the impact of the amine in the structure and properties of the final compound. After the solution took room temperature, we cool it at 0°C for 24h or even 1-3 days until crystal were formed. Then se solution was filtrated and the precipitate was cooled again to afford more product. The crystals were left under vacuum for 8h to remove any traces of the solvents. The experimental procedure is briefly shown in **Fig 2.**

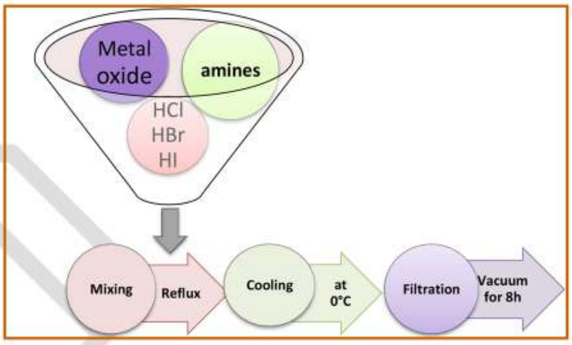

Figure 2: Experimental Procedure

Research Results / planned or achieved

We achieved the synthesis of perovskite like structure with very promising optoelectronic properties. Since we wanted to substitute Pb with other novel metals, we used Bi, Sb and Cu. We carried out measurements such as NMR, ESI-MS, ICP-MS, XRD, PXRD, FTIR, RAMAN, TGA and in order to measure their optoelectronic properties we performed UV-Vis, Photoconductivity and Fluorescence. In the future, the plan is to fabricate a solar cell and test it as a prospect light harvesting material.

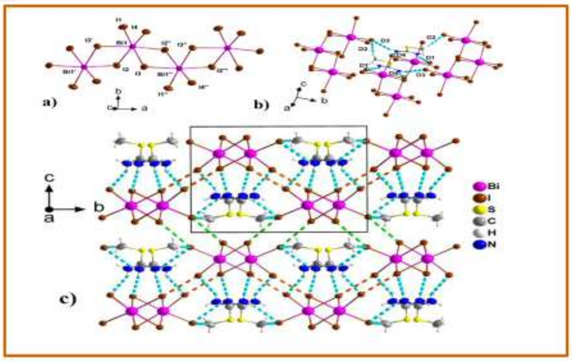

Figure 3: Crystallographic representation of $[CH_3SC(NH_2)_2]BiI_4$

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Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

BIPV & BAPV solutions

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SolTech Energy

Introduction

I'm an intrapreneur within BIPV & BAPV (Building Integrated PhotoVoltaics & Building Attached PhotoVoltaics) at SolTech Energy. I believe that this is the future and wish to see all new buildings and renovations – for skyscrapers as well as family homes – built with materials that can produce their own power. I've developed and develop BIPV such as BAPV solutions from ideas to final products in Sweden as well in China. I'm also working on different way to spread awareness of BIPV & BAPV solutions nationally through speaking at solar conferences such as real state conferences and different tech and innovation conferences.

Research Aims

(i) Increase awareness of BIPV & BAPV solutions nationally.

(ii) Integrate solar into roofs and on all roof sides, even north.

(iii)Integrate solar into facades

These aims/objectives will be achieved by SolTech Energy Sweden.

Research Problems, Questions, Hypotheses

- Only 0,4% of the energy mix in Sweden today is solar energy. If one of four houses installed solar power on their roof would Sweden increase the energy mix with 10% from solar energy. One obstacle to install solar power in Sweden is because Swedes found solar panels ugly. How do we increase the awareness of aesthetic BIPV solutions nationally, focusing on BIPV and BAPV solutions.
- Perhaps buildings will look different in the future, more optimized for solar solutions but today we have roofs in all directions. In Figure 1, they had to replace the entire sheet metal roof because it was worned out. So instead of replace with a new sheet metal roof we put BIPV solar tiles (SolTech ShingEl) on all four roof sides even north and we are looking forward to the output result end of this year.

Research Methodology

1. (Creating awareness) – attend as speaker in different conferences, tech and innovation panels.
2. (Develop new solutions – from sketches to mass production, see Figure 2) Market research - Quality of demands - Idea generation – sketches – concept validation with QFD (Quality Function Deployment) – IP-rights (apply for patent) - Construction drawings – Finding Suppliers – negotiating prices and volumes such as delivery times – CE-marking and validation according to standards - Set up production.
3. (A collaboration with one of our partners ASP, Advanced Solar Power in Hangzhou, semi-transparent solar panels in different colors) – Ide generation – Testing – Validation – CE-marking.

Research Results / planned or achieved

We have developed BIPV and BAPV solutions that are on the market. For example Soltech ShingEl (solar roof tile) see Figure 1, SolTech RooF (larger solar roof tile) and Soltech Facades (solar facades, see Figure 3)

We are looking forward to the result with SolTech ShingEl (solar tile) on four sides of the roof with an optimizing solution that can handle the different voltage of the four roof sides. The solar technique used in SolTech ShingEl is CdTe and each panels have 1 bypass diode. The roof being tested is in Figure 1.

Disseminations / References

References of buildings with our developed BIPV and BAPV products.

1. SolTech ShingEl reference – Office building, Vasakronan in Uppsala, Sweden, See Figure 1.
2. SolTech ShingEl reference – Multiple resident building in Stockholm, Sweden
3. SolTech Façade BAPV reference – Multistory Car Park in Vallastaden, Linköping, Sweden, see Figure 3.
4. SolTech RooF reference – Private Villa in Täby, Stockholm, Sweden
5. Speaker at Gather Tech festival 2019 https://www.gatherfestival.com/speakers-2019/anna-svensson

More info and pictures of the above reference can be found at SolTech Energys webpage: https://www.soltechenergy.com/en/

Figure 1: Creating awareness of BIPV solutions – photo: Tove Risberg – through speaking at different solar conferences, real state conferences such as several other arenas within tech and innovation. Picture to the right: Product: BIPV solution Soltech ShingEl, Photo: SolTech Energy

Figure 2: Developing process of Soltech ShingEl (solar tile) from sketches, making 3D drawings, creating prototypes, validation according to standards to negotiating suppliers, negotiating prices, making construction drawings, decide tolerances, set up production.

Figure 3: Semi-transparent BAPV in different colors on a parking house in Linköping in Sweden. Product is called Soltech Façade Semi-transparent. Photo: SolTech Energy.

Stefan Ölander (CEO, Stefan Ölander, SolTech Energy Sweden)

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Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Climate Data and PV Degradation

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solartrain

Introduction

The installed capacity of photovoltaic technologies worldwide is growing exponentially. This expansion is bringing clean energy production to all climate zones worldwide, but the uncertainty in the operation and reliability of PV systems and materials under different climatic stresses is still under investigation.

In this work, we cover different aspects of lifetime assessment of PV module technologies regarding data analytics, climate modelling and electrical modelling associated with challenges to cover large geographical regions. We aim to develop a new climate classification scheme and extend the understanding of PV performance and aging in different climate zones.

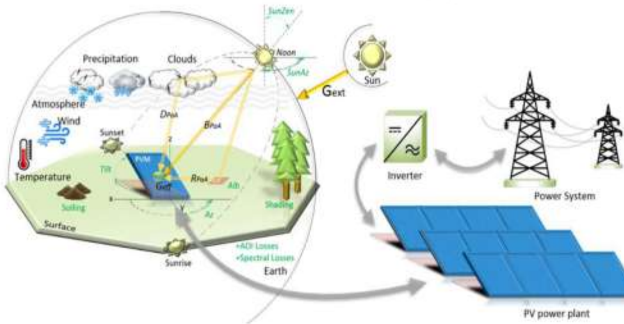

Figure 1: Scheme of main climate variables for the performance and degradation modelling of PV systems (source: [1])

Research Aims

(i) Estimate the climate degradation factors using free access climate data sources for PV applications.

(ii) Develop a scheme to identify the most relevant climate zones for PV performance and degradation.

(iii) Model the energy yield and degradation rate of PV modules under different climate conditions.

Research Problems, Questions, Hypotheses

The global deployment of PV systems is bringing uncertainty in terms of performance and reliability when the local climate conditions present large deviations from the STC or NOC under which the modules are tested and certified. The understanding of the climatic stresses and further identification of critical climate zones regarding the long-term operation of PV systems can be achieved by processing global climate datasets and modelling the relevant PV indicators, such as, energy yield and degradation rate. Also this approach facilitate the understanding and experience of stakeholders investing in PV systems in remote areas.

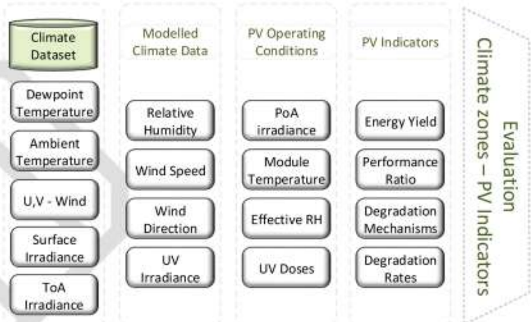

Figure 2: Flowchart for processing global climate data and evaluation of PV degradation rates in terms of climate zones..

Research Methodology

The extraction of appropriate climate data needs to be addressed. Then, using real performance data from PV modules and PV systems, the modelling of energy yield and degradation rates is carried out. Finally, the evaluation of PV indicators in view of the Köppen-Geiger-Photovoltaic climate classification is presented. A flowchart to summarize the methodology is shown in Figure 2.

Research Results / planned or achieved

The Köppen-Geiger-Photovoltaic climate classification has been published, and the evaluation and mapping of the main climate variables for the modelling of energy yield and performance ratio have been carried out (see Figure 3). Further work includes the creation of PV degradation maps in terms of different degradation mechanisms [2,3], together with the identification of critical areas for certain PV modules and PV materials.

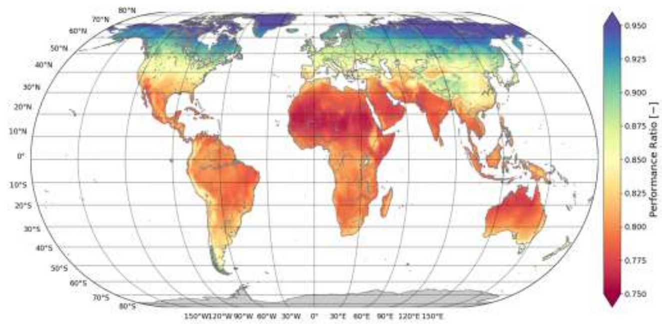

Figure 3: Worldwide PV Performance Ratio for mc-Si PV modules. (Source: [1])

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Supervisor Prof. Dr. Marko Topič, LPVO - University of Ljubljana, Slovenia

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Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

PV Systems in Smart Grids

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UNIVERSITY OF TWENTE.

Introduction

Member of Working Group 5: PV in Grids, my research consists of PV performance and their efficient integration using big data originating from the smart meters of residential smart grid pilots. I evaluated PV power generation and technologies employed for solar energy integration with key performance indicators. Those technologies are namely; smart wet appliances [1,2], smart heat pumps [3], micro-combined-heat-and-power (μCHP) [1]. Via STSM granted by PEARL PV, we were also able to investigate the stability of a PV charging station at the University of Twente [4]. Besides, I am teaching, under the coordination of Prof. Dr. A. Reinders, the course Building Integrated Photovoltaics, based on the output of the PEARL PV Training School in Cyprus last year.

Aims

PV performance analysis using big data originating from existing residential smart grids to quantify :

(i) Increase in self-sufficiency by the mean of other distributed energy resources as μCHP (Figure 1)

(ii) Increase in self-consumption and flexibility by employing demand response with smart appliances (Figure 2)

(iii) Evaluating the effectiveness of PV integration of technologies used with key performance indicators

Solar integration: Technical, Market&Stakeholders

Interdisciplinary analysis from technical, market and stakeholders perspective of PV integration in residential grids :

- Impacts of smart energy products and services (SEPS) for maximizing PV energy use & stabilizing import (Figure 3)
- PV peak feed-in and peak consumption to inform better stakeholders (DSO, TSO...)
- Flexibility created with smart wet appliances, heat pumps and μCHP
- Dynamics of user cooperation with SEPS, permitted and perceived shifting vs. actual data, economic benefits

Materials & Methods

Data processing & analysis using own MatLab© algorithms :

- PV and smart meter consumption data at yearly, monthly, hourly, minutes resolution [1-3] over 217 HH from 3 different Dutch residential smart grid pilot with various PV configurations and systems
- +170 smart appliances data with time of use, wash request, temperature ... logs, transform to quantify their usefulness to match demand-supply and decrease peak consumption [1,2]
- PV simulation to optimize in 3D environments (BIMSolar©) considering TMY irradiation and electricity demand

Results

Research results : The technologies employed as smart washing machines, dishwashers, heat pumps and μCHP [1-3] were providing flexibility (+14% of the total consumption) [1,2], increased self-sufficiency (+20%) [1] and self-consumption of PV (50% of smart wet appliances consumption was PV generated)[2]

Collaboration via PEARL PV: STMS report delivered, a paper published in open access [4].

Education via PEARL PV: BIPV course realized thanks to the training school, the first BIPV lecture in the Netherlands at University of Twente (Master of Sustainable Energy Technologies – 5 ECT)

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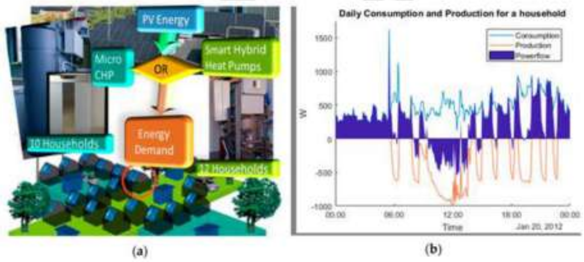

Figure 1: PowerMatching City: (a) scheme of the system, (b) energy consumption (blue line), energy production (red line), and power flow (blue area) for a household with photovoltaic (PV) systems and Micro-combined heat and power (μCHP) jointly producing energy, in the winter of 2012 [1].

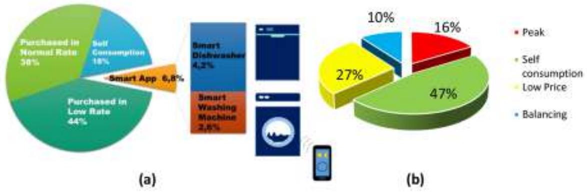

Figure 2: Smart Washing Machine and Dishwasher consumption regarding (a) total consumption and (b) different clusters in PowerMatching City [2]

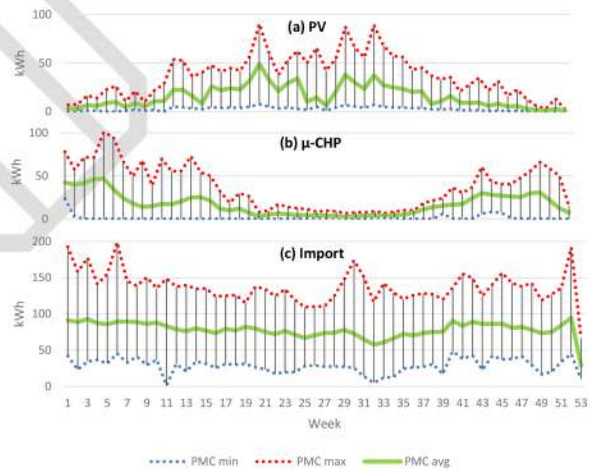

Figure 3: PowerMatching City (PMC) weekly values of (a) PV generation (b) μ-CHP generation and (c) import from the grid in kWh [1].

Table 1 : Summary of the calculated key performance indicators in average values for 287 households for 4 different dataset [3]

Smart meter data	Annual Import (MWh)	Peak Import (kW)	Peak PV (kW)	Annual PV Generation (MWh)	Self-consumption (%)	Self-sufficiency (%)	Import Simultaneity (%)	Feed-in Simultaneity (%)
Zonnedael	3.2	4.8	0.27	0.22	-	-	20.5%	88.8%
R4I	3.1	5.1	2.2	1	50%	20%	23.0%	74.9%
JEM-Meulenspie	4.5	6.2	1.8	0.9	-	-	65.1%	89.5%
PMC	4.3	6.8	0.5	0.86	70%	18%	70.5%	n.a.

Supervisor : Prof. Dr. Angele Reinders, University of Twente & Technical University of Eindhoven

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Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

REBI: Reliability of PV Systems integrated in to the built environment (BIPV)

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SUPSI EPFL

Introduction

Integration of photovoltaic (PV) modules to residential and commercial buildings offer high potential since around 40% of the global energy demand is consumed in the buildings. Hence, the construction sector is one of the main target of European and global policies on mitigating climate change. The application of BIPV in different building types have been spread in recent years with the benefit of decreasing cost per watt, new energy efficiency targets/regulations and increasing efficiency of PV modules [1]. Different kinds of BIPV solutions have been already implemented as pitched roof, cold facade etc. [2] (Figure 1 & 2). There are still some arguments to be solved in order to improve and accelerate the diffusion of the implementation of BIPV solutions. One of the main issues is **the reliability and stability of BIPV** which includes **production of energy for at least 30 years with acceptable degradation rate**, **the rigidity and safety as building material** (e.g. construction requirements such as durability, comfort, fire safety etc.) [3], **the stability of aesthetical aspects** (e.g. resistance to colour fading) and **the safety in use**.

Research Aims

The project aims to have quantitative knowledge on the reliability of BIPV panels for different application types via:

i. Understanding the specific **operating conditions** (more challenging, e.g. limited or no ventilation, possible shadowing etc.) and **additional aging contributions** (compared to field-mounted devices) of BIPV,
ii. Understanding and investigating **known and unknown** (triggered by accelerated tests) failure modes,
iii. Investigation and assessments on **norms and standards** to be able to test BIPV panels as combination of **electrical and building component**.

Research Problems, Questions, Hypotheses

Thermal and electrical behaviour of fully integrated PV modules change significantly compared to conventional field applications [4] which cause power drop, enhanced ageing and degradation and even failure. In addition, the mechanical stability requirements of building components (also for BIPV modules) are more complicated than mechanical stability requirements of field applications of PV. The new BIPV Standard (EN50583:2016) [5] states that the BIPV products should comply with both building requirements (CPR 305/2011/EU) and electro-technical requirements of the IEC standards. On the basis of the mentioned issues, the main research questions are:

i. What are the boundary conditions and theoretical limits of BIPV panels?
ii. What are the known and triggered unknown main failure modes of BIPV applications?
iii. Which procedures should be followed in order to test reliability of BIPV panel/system properly as both electrical and building component?

Research Methodology

To realize the project, 4 Work Packages have been set up. WP1 is about **the investigation on boundary conditions and theoretical limit of different types of BIPV systems** by analysing data from the realized BIPV systems, WP2 is about **designing and monitoring corresponding BIPV prototypes (mock-ups) for outdoor monitoring under real and worst conditions** (Figure 3 shows example of outdoor monitoring setup), WP3 is about **test to failure; indoor environmental chamber with extended cycling (long term exposure, high temperature and humidity conditions)** and **outdoor tests at harsh (artificial heating, shadowing) conditions to trigger new failure modes**, WP4 is about **the development of predictive models of different failure modes and model life-time of BIPV**.

Research Results / planned or achieved

The planned outcomes of the research are:

i. Most common failures and boundary conditions of BIPV panels for each implementation type,
ii. Indoor reliability tests of BIPV products according to norm, IEC standards and suggested tests,
iii. Outdoor monitoring of representative BIPV applications (cold façade, warm façade, roof, ventilated insulated etc.),
iv. Triggered unknown failures from indoor and outdoor extended and harsh accelerated tests (e.g. longer exposure, higher temperature and humidity),
v. Model of most relevant failure modes on BIPV panels.

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Figure 1: Plus Energy Building, Chiasso, CH: Re-cladding of the building envelope with a ventilated façade (cold façade) and balcony fence applications (Source: BFE-SUPSI).

Figure 2: Positive Energy House, Innerberg, CH: Integrated pitched roof application as building envelope (Source: www.luedi-architekten.ch).

Figure 3: Examples of two different BIPV mock-ups from other authors for outdoor monitoring [6,7].

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Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Qualification of Functional Coatings on Glass in Extreme Climatic Conditions – Surface Degradation Effects

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Introduction

Sunny desert regions seem to facilitate the best conditions for the operation of solar energy systems. Unfortunately the environmental stress factors can reduce the economic feasibility significantly. In this respect interactions of mineral dust particles are a major stress factor in this area.

Research Aims

The primary and secondary objectives of the research are

(i) Investigation of effects on functional coatings on solar glass samples after long-term exposure (two years) in the dry, arid climate of the Negev Desert.

(ii) Investigation, if there is a surface roughening from outdoor exposure at the specific arid location.

(iii) Simulation of abrasive effects and comparison with outdoor degradation effects .

These effects will be analysed by high resolution analytics:

- WiTec alpha500: high precision AMF for small, light (< 500 g) samples
- NanosurfFlex: transportable AFM for large, heavy samples, for non-destructive measurement

Research Problems, Questions, Hypotheses

Previous studies [1,2,3] focused on the effects of dust from and in arid region. The chosen location for specific investigation is the Negev Desert. A transmittance loss caused by soiling of about 6 % was found. This effect could be reversed by cleaning. Research questions and hypotheses:

- How can functional surfaces be qualified for their function and reliability.
- What are the best methods for the subsequent characterisation. Will functional coatings (anti-soiling coatings) help to prevent soiling or reduced water consume on long term basis

Research Methodology

The research methodology includes the design of testing methods and sequences. An inorganic porous SiO_2 coating was analyzed for degradation and abrasion effects.

The investigation of surface defects is done by atomic force microscopy (AFM) by evaluation of Root Mean Square (RMS) and average roughness (Ra) detection.

Research Results

Results:

The analyzed porous SiO_2 coating shows severe degradation, but impact craters or traces from sand particle abrasion can not be found.

The parameters (RMS and Ra) of AFM measurement proof degradation, see values of areas with increasing roughness. Area C leads to the interpretation that the coating bulked and opened up.

The microscopic pictures show optical effects, changing reflection and color, indicating delamination of functional coating.

Planned:

1. Comparison of samples with damages and visual impacts on the surface after of long term outdoor exposed at the dry-maritime location of Gran Canaria Island with the roughness of the sand blasted samples; adjustment of sand blasting set-up

2. . As well as further investigation by accelerated ageing testing on the same surfaces to detect the main degradation load for the bulking of the surface

Disseminations / References

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Supervisor

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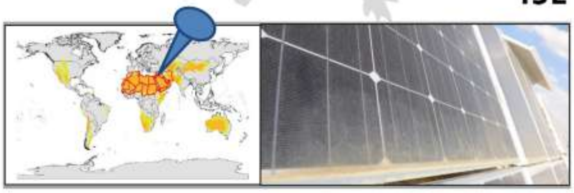
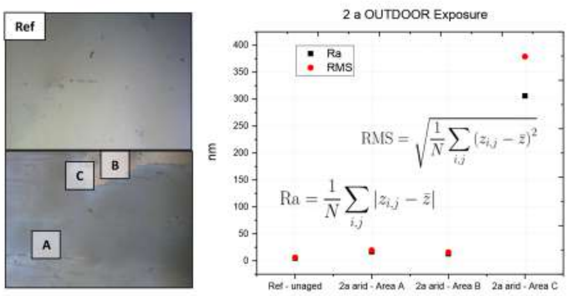


Figure 1: Global desert and steppe (Köppen-Geiger-Climate-Classification); Area of interest MENA: Middle East & North Africa; Location of Exposure Negev Desert dust deposition on PV

Figure 2: Testing of functional surfaces on glass at the Negev Desert; Same sample after 2 years, half side cleaned for characterization

Figure 3: Sand blasting set-up; AFM measurement of sand blasted glass sample; AFM mobile devise on the left side

Figure 4: Hand held of mobile AFM devise



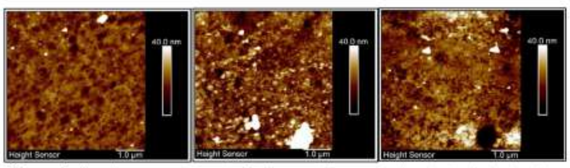


Figure 5: Roughness measurement of a 2 year outdoor exposed coated and structured solar glass;

form left to right: intact, unaged area (Ref); scratched, partly laminating area with light roughening (A); grey flat area after delamination (B); area with increase defects caused by delamination (C)

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Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Photovoltaic Textiles

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Introduction

- **B.Sc. in Textile Engineering, Suleyman Demirel University, Turkey, 2009**
- **M.Sc. in Textile Engineering, Istanbul Technical University, Turkey, 2012**
  MSc thesis title: Development of organic based photovoltaic fiber
- **Ph.D. in Textile Engineering, Istanbul Technical University, Turkey, 2017**
  PhD thesis title: An investigation into polymer-based photovoltaic fiber structures
- **Visiting scholar during PhD in Wake Forest University, Winston-Salem. NC, USA, 2014-2015**
- **Organic/flexible solar cells, fiber shaped solar cells, conductive polymers, conductive textiles, smart textiles, technical textiles, electrospinning/nanofiber production, nanowire synthesis, transparent electrode for solar cells, hybrid solar cells, solution-based coating techniques**

Figure 1: Photovoltaic textiles

Research Aims

(i) Transparent electrode and homogenius conductive thin film studies to apply on textiles ,

(ii) Photovoltaic effect on textiles ,

(iii) Protection of photovoltaic layers from oxygen, moisture, physical impacts etc. .

These aims/objectives will be achieved in future works

Research Problems, Questions, Hypotheses

Point to the identified problems that lead to your research. In this regard, list the research questions and hypotheses.

- Difficulty of producing homogenius conductvity and transparency on cylindrical(fiber)-shaped substrates
- Having transparent electrode on polymer-based fiber structures
- Homogenius thin film production problem
- An assistive layer on rough textile surfaces might help
- Thicker electrode layers might help with conductivity problems
- A protection layer that is flexible and resistant to textile regarding processes

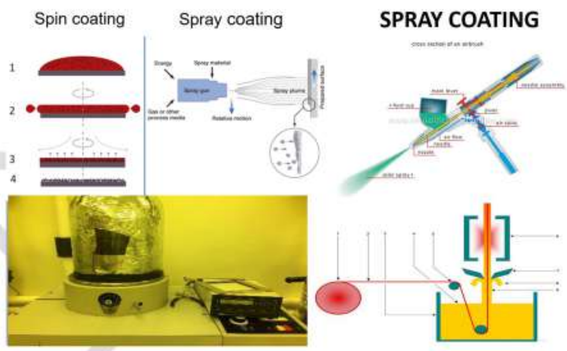

Figure 2: Photovoltaic textiles produced by Borazan et al. 2012-2017

Research Methodology

- Solution-based coating techniques similar to textile processes
- Military and outdoor use are primary using areas
- Energy provide to portable electrical devices
- Wearable electronics

Research Results / planned or achieved

- 4,5% on glass, 2,4% on ITO coated PET, 2,1% on conventional textile fibers were achieved with organic semiconductors.
- Flexible coating materials are studied for encapsulation
- Transparent electrode studies ongoing

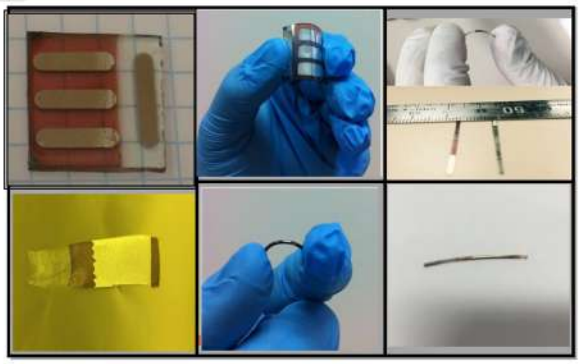

Figure 3: Figure title - Authors are asked to respect the copyrights of sources that have been taken from other authors or organizations (specify sources). Figure size 300dpi..

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Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Research on the translation of PV short-circuit current

Baojie LI

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Introduction

With the rapid development of photovoltaic (PV) power plant, health monitoring has become an important issue for the reliability and durability of PV-systems. Health monitoring relies on the inspection and evaluation of various features of PV-systems, among which, the short-circuit current (Isc) is one important characteristic. The change of Isc over long period could reflect the performance of PV modules and indicate the existence of some PV faults. For example, the diminution of Isc may point out the delamination fault [1]. However, the measured Isc data in real condition at different time is not comparable due to different irradiance and temperature, therefore an accurate translation of Isc to same meteorological condition, e.g., standard test condition (STC, T=25° C, G=1000W/m²) is crucial to conduct the analysis of Isc.

Research Aims

(i) Evaluate the translation performance of Isc when using different translation equations

(ii) Explore the behaviour of the temperature coefficient of Isc (TC_Isc) and the impact on translation

(iii) Assess the degradation of Isc for modules under operation based on the translation method

These objectives will be achieved by indoor and outdoor tests and subsequent analyses.

Test platforms

Four PV platforms with different scales and locations are adopted to carry on the tests with different requirements:

(i) **SIRTA platform**: 5 PV modules with different technologies (under operation since 2014) as in Figure 1, equipped with 1 common plane-of-array irradiance (Gpoa) probe and PT100 temperature sensor attached at the rear of each module, besides, the wind speed, ambient temperature and solar spectrum are also simultaneously recorded.

(ii) **GeePs rooftop platform**: 6 pc-Si PV modules are connected in series at the rooftop, equipped with one common Gpoa probe and PT100 temperature sensor attached at the rear of each module, as in Figure 2.

(iii) **GeePs indoor small-scale platform with control of irradiance**: 4 Xenon lamps are used to control the level of irradiance on one PV panel, equipped with one Gpoa probe and PT100 sensor as shown in Figure 3 (a).

(iv) **GeePs removable small-scale platform**: suitable for test of 1 module, wheels permit quick movement from indoor / shading condition to outdoor full-sunlight condition, as shown in Figure 3 (b).

Research Methodology

Different methodologies are considered to achieve corresponding objectives:

(i) **For comparison of translation equations**: evaluate the following equations [2,3] with field-measured data from SIRTA and GeePs rooftop platforms.

① $I_{SC2} = I_{SC1} G_2 / G_1 + TC_{Isc}(T_2 - T_1)$

② $I_{SC2} = I_{SC1}[1 + TC_{Isc\_rel}(T_2 - T_1)] G_2 / G_1$

③ $I_{SC2} = I_{SC1}[1 + TC_{Isc\_rel}(T_2 - T_1)](G_2 / G_1)^{\alpha}$

where G is the plane-of-array irradiance, T is the module temperature, the subscript 1 or 2 denotes different condition, TC_{Isc} and TC_{Isc_rel} are the absolute and relative temperature coefficient of Isc, respectively; α is the nonlinear correction factor.

(ii) **For understanding the behaviour of TC_Isc**: firstly use the indoor small-scale platform to test one panel with the irradiance level controlled, record Isc during the heating process; then use the outdoor small-scale platform to test the panel in real sunlight condition, make the panel cool down to ambient temperature, and then record Isc during the natural heating process.

Research Results / planned or achieved

The result of preliminary translation test is shown in Figure 4, where all the **measured Isc in 1 day are translated to STC condition** (using equation number 2 and the relative TC_Isc is taken from datasheet) is presented. Generally, all the translated Isc should be of same value in same condition. However, compared to the STC datasheet value, the error becomes larger for low irradiance. A hysteresis phenomenon is also observed, which requires further analysis.

As for the behaviour of TC_Isc, through literature research, this value is reported to **decrease as a function of irradiance** [4], as shown in Figure 5. Our research is planned to validate and analyse this phenomenon so as to realize the translation of Isc with better performance.

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Figure 1: PV modules in SIRTA with 5 different technologies under operation since 2014

Figure 2: 6 pc-Si PV modules in series at GeePs rooftop under operation since Feb. 2019

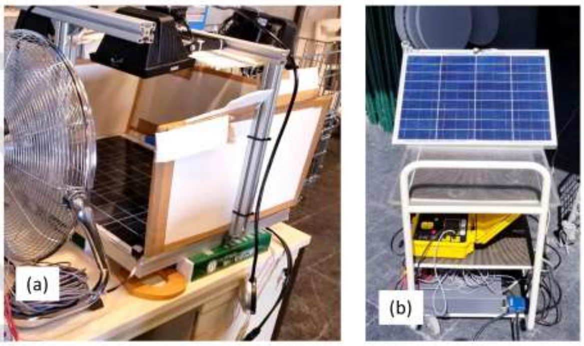

Figure 3: Temporary platforms: (a) indoor platform with control of irradiance, (b) outdoor removable small-scale platform

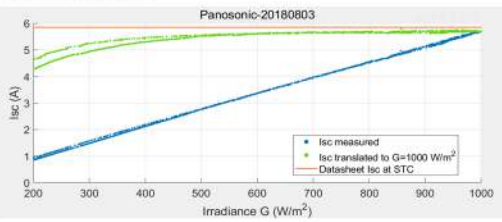

Figure 4: Measured Isc and Isc translated to G=1000 W/m² using Equation 2

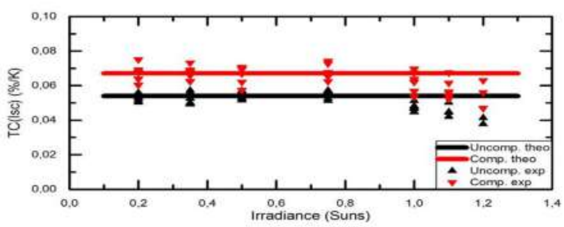

Figure 5: Sensitivity of TC_Isc as function of irradiance for ESS compensated silicon (black) and uncompensated silicon (red). (Triangles represent the experimental results, the lines for theoretical value) [4]

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Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Quantifying PV Module Failures in the Field

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Introduction

Photovoltaic (PV) is one of the main technologies for a sustainable energy supply in the future. To ensure continuous attention PV technology needs to be reliable and profitable.

During its operation time of more than 20 years a PV module is exposed to severe weather conditions with continuous cycles. This leads to an immense stress on all materials and results in the appearance of various degradation modes (DM), which may reduce the output power of a PV system. The resulting degradation can be measured and a performance loss (PL) of the system calculated.

This has been done by Lindig et al. [1] for a PV plant with 26 systems of eight different technologies (total nominal power of 59 kW), installed 2010 in Bolzano/Italy (temperate climate). To calculate the PL, the measured data needs to be filtered, corrected and normalized (cp. Fig. 1).

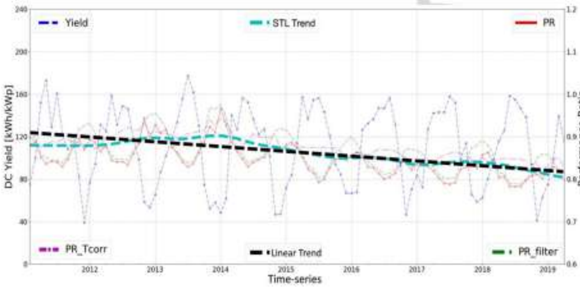

Figure 1: Performance Loss – PL linear trend (black dashed line) achieved by several steps of filtering, correcting and normalizing (other lines) of the measured data. With permission from [4].

Research Aims

This work aims to:

(i) Identify and characterize the underlying DMs and quantify their impact on the PL,

(ii) Give a better understanding of occurrence and propagation of DMs,

(iii) Identify the costs for preventive / corrective measures concerning appearing DMs.

This objectives will be achieved by the combination of several imaging and measuring methods.

Research Problems, Questions, Hypotheses

According to Jordan et al. [2] the most occurring DMs are encapsulant discoloration, hot spots, interconnection discoloration, glass breakage and fractured cells (descending order).

A major difficulty is the evaluation of PV systems. The present PLs are calculated for strings with several modules. To quantify the impact of a DM the impact on module level needs to be considered as well as the impact on string level. Thus, imaging and I-V curve measurements should be done on both levels.

Additionally, a DM will not appear in isolation, but they will mostly occur cumulative. Therefore, a direct quantification of the PL due to a single DM will be challenging. Physical models may provide remedy (Koentges et al. [3]), as well as quantifications of standalone DMs during this work.

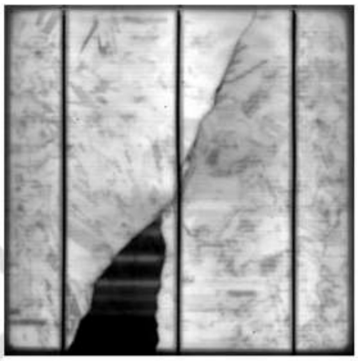

Figure 2: Cell Crack – electroluminescence image of a crystalline-silicon (c-Si) solar cell with cell crack (upper right) and "dead" spot (black area, lower left). With permission from [1].

Research Methodology

Different techniques are used to identify DMs and to estimate their impact: Electroluminescence (EL): provides images containing the inner structure and disruptions like cell cracks (cp. Fig. 2); Photoluminescence (Ph): estimation of minority carrier lifetimes and series resistances; Infrared (IR) imagery: detection of hot spots and rate other DMs. Current-Voltage (I-V) curve measurements allow to examine the impact of the detected DMs. For example, Fig. 3 shows the measured I-V curve of a module with cell mismatch.

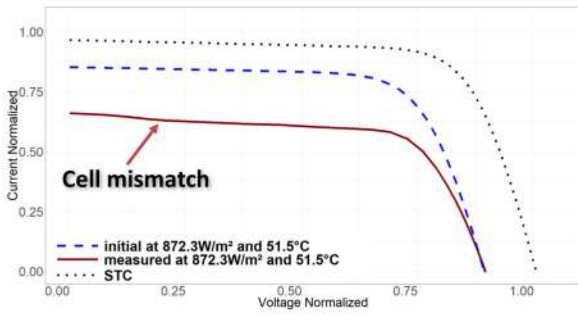

Figure 3: I-V curve – for standard test conditions (STC), initial result at reduced irradiance and result with presence of a cell mismatch. With permission from [1].

Research Results

So far, theoretical revision and familiarization with the measuring techniques (imaging and I-V curve) was the focus of my work. The calculation of the PL for each system, done in 2018, may is renewed periodically. The next step will be the execution of a measurement campaign to collect system data and to detect the most severe DMs.

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Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Developing a scientific database and data sharing mechanism

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Introduction

An effective database management system for storing scientific research data offers many benefits over a flat file system. The foremost advantage is data integrity. The data we collect, clean, validate and store in a database is no longer subject to accidental errors, as a contrast to data stored over multiple files for a system, which is susceptible to errors in the long term. The detection of occurrences of such errors is almost impossible for larger datasets, hence, raising a question of data integrity. The other advantage is the ease with which the data could be shared with fellow researchers, independent of geographical distances. One way of doing that is to design a web portal where external visitors can make a guest account and request specific datasets. This research work aims to implement a model database management system at University of Agder (UiA), which could be used as a case study for other universities and research institutes who wish to follow the same path. The database will provide external access for guest users to solar resource and climate data, and datasets for PV performance and degradation analysis.

Figure 1: PV lab roof top at UiA – (Source: Anne Gerd Imenes)

Research Aims

i. Designing a relational database management system that will host all the available data from different research systems on a server. This will ensure data integrity across all research projects.

ii. Utilize the data for insights into long-term outdoor PV performance and degradation analysis. The data will also be used for advance statistical and machine learning techniques to detect PV degradation and anomalies.

iii. Allow public access to data for research purposes through a web portal.

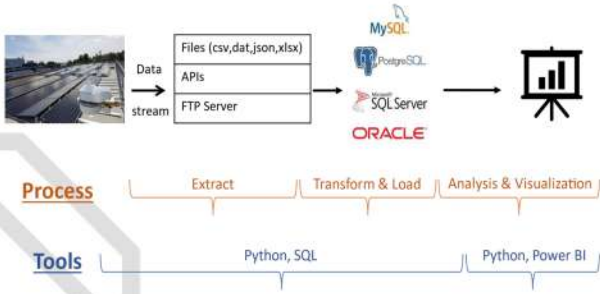

Figure 2: Extract, Validate, Transform and Load data onto databases.

Research Problems

There is a lot of research data accumulating every day from different projects and in different formats. The data comes from outdoor PV plants, meteorological instruments and experimental setups. One of the key challenges is to ensure data integrity in a uniform format that agrees on single timestamp entry. Another challenge is to make sure the data is available over long term usage. Prior to this project, the PV research group at UiA has accumulated a large amount of datasets consisting of various PV technologies spanning over a number of years. The data is kept in various formats such as csv, json, and excel. Moreover, a number of copies were made on different systems. This raises confusion about its integrity. The aim of this project is to cross-verify available datasets and design a relational database management system that will host the data. Later in the project, public access to data will be offered through a web portal. An example of a typical PV project, installed on a rooftop at UiA, is shown in figure 1.

Research Methodology

The main research methodology is shown in figure 2. The data coming from different sources and in different formats will be cleaned, validated and transformed in Python. Once data integrity is ensured, the project aims to design an effective relational database management system that will host all the data and the associated metadata. At UiA, the relational database management system is implemented in Microsoft Azure and Python is used to interact with the database. However, the database design is platform independent and could be implemented through any open source database system such as MySQL, PostgreSQL and Oracle. The stored data is then accessible for addressing any scientific question, and later in the project the data will be freely accessible through a web portal for external users. Access to specific data for external users can be controlled through administration rights. External users can make a guest account on the UiA official website and request relevant dataset for download. The data then be used for any kind of post analysis, such as the one shown in figure 3.

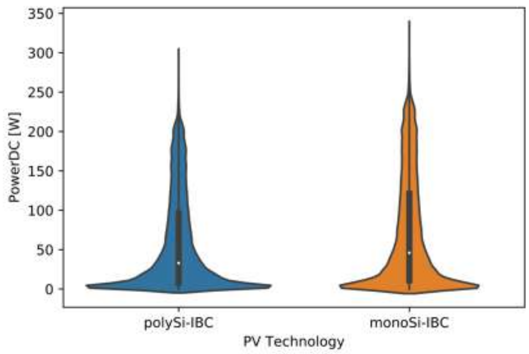

Figure 3: An example of violin plot created directly from database.

Research Results: Achieved and Planned

Achieved

1. Data integrity is ensured.
2. Database Implemented.
3. Long term data availability.

Planned

1. Data validation and filtering.
2. Web portal for public access.
3. Applying ML/Statistical tools for analysis.

Disseminations / References

Two related journal papers are in process.

Supervisor (Prof. Anne Gerd Imenes, University of Agder)

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Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Institute of Historical Research
National Hellenic Research Foundation

Hybrid perovskite/polymer materials: Preparation and Physicochemical Properties

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Introduction

Organic-inorganic hybrid perovskites (Hyb-Per) are an emerging class of solution processable semiconducting materials that combine the favorable properties of the inorganic semiconductor with the flexibility and low-temperature process ability of the organic material[1]. They show excellent optoelectronic properties such as a high and balanced carrier mobility, high photoluminescence quantum yield and large light absorption coefficient in the UV-Vis range. Their use for photovoltaic applications took the photovoltaic community by storm with an improvement of the solar to electric conversion efficiency from 3.8% to 22.7% in just a decade[4] . They have the general Formula AxMXy (A is an amine, M is a metal and X a halide anion), as seen in Fig 1. By choosing the appropriate amine-metal-halogen combination, the optical band gap, as well as their emission and absorption spectra, can be controlled throughout the entire visible range[3]. Most of these perovskites are based on Lead (Pb). Due to Pb's instability under moist and radiation and its high toxicity, researchers focus on ways to increase the stability of Pb perovskites by using polymers as protectives agents.

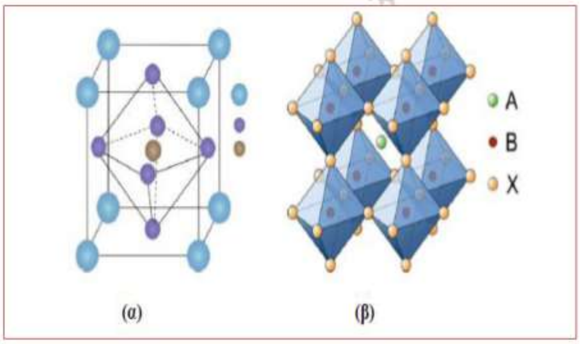

Figure 1: Schematic illustration of classic 3D perovskite in the form of (a) cell, (b) octahedra[2].

Research Aims

(i) Stabilization of organic-inorganic hybrid Lead based perovskites nanoparticles,

(ii) Study of Degradation,

(iii) Optical properties (enhanced fluorescence).

These objectives will be achieved by encapsulating Pb nanoparticles in polymer matrix. By combining different polymers with different Pb nanoparticles we measured their stability through time.

Research Problems, Questions, Hypotheses

Hybrid lead perovskites are the most promising candidates for PV applications. Since Pb is characterized by high toxicity and is not stable under moisture and radiation, we wanted to "protect" the perovskites by encapsulation in a polymer matrix. Hopefully, the polymers don't act as a barrier in the perovskites optoelectronic properties but instead, it helps them to remain stable under moisture and radiation for a longer period of time.

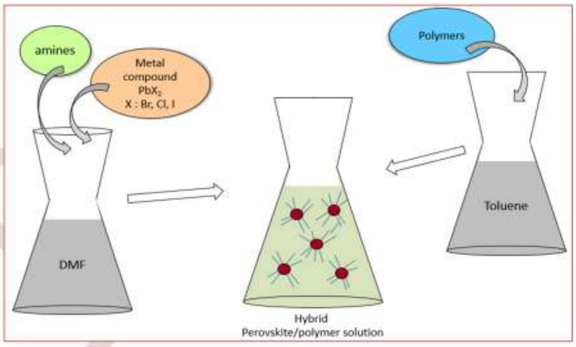

Figure 2: Experimental procedure.

Research Methodology

The research methodology includes the preparation of perovskite nanoparticles by adding a DMF solution of the perovskite at a polymer containing toluene solution under intense steering. The perovskite used are the 3D $CH_3NH_3PbX_3$ the 2D $[H_3N(CH_2)_6NH_3]PbX_4$ and their Q-2D mixtures $(CH_3NH_3)_y[H_3N(CH_2)_6NH_3]PbX_{4+y}$ (X=I, Br, Cl and their mixtures). Different concentrations were made in order to study the colloidal stability of the nanoparticles inside the polymers. Two different polymer solutions were synthesized using PMMA and P(MMA-co-DMAEMA) and as a solvent we used toluene. The experimental procedure is briefly shown in Fig 2.

The optical properties of the final solutions were investigated by UV-Vis and Fluorescence Spectroscopy and Dynamic light scattering for determining the size of the nanoparticles, the degree of polydispersity and the dispersion stability over time for each sample.

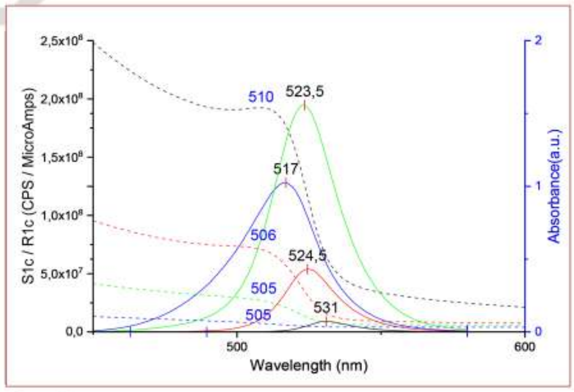

Figure 3: Fluorescence Spectroscopy (solid lines) and UV-Vis (dotted lines) measurements of samples with concentrations 100mM (black), 50mM (red), 25mM (green) and 12,5mM (blue) of $CH_3NH_3PbBr_2$ in 2% PMMA polymer solution in toluene.

Research Results / planned or achieved

By UV-Vis, Fluoresence and DLS analysis we were able to measure the properties and stability of the synthesized perovskite encapsulation. The polymer functions as a protective agent against perovskite precipitation without damaging the optical properties of the perovskites (Fig. 3). The whole system remains intact for at least a short period of time (4 days). In the future, the plan is to fabricate thin-films in order to investigate the optical properties of the samples in the absence of the solvent.

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Dr. George Mousdis, Head of Research
National Hellenic Research Foundation

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Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Potential Induced Degradation (PID) in CIGS Solar Modules

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Introduction

Potential Induced Degradation (PID) is a specific degradation type observed in PV modules, which results from a high voltage difference built up between the solar cells and the grounded module frame in grid-connected PV systems. This potential difference causes high leakage currents to flow between the frame and the solar cells, which drives the ion mobility within the cell. Sodium ions, being the primary suspect among other alkali metals due their availability and high mobility, can accumulate at junctions in different layers of the solar cell and can form local shunts or delamination of layers, eventually leading to catastrophic failure of the PV modules.

Post-mortem analysis on failed PV modules is of crucial importance to understand the degradation mechanisms. A unique method to do this can be mechanically drilling a core out of the module to obtain a minimodule with defects representative of the failed module. In-depth study of these cores can shed light to the origins of the failure mechanisms in order to improve the long term stability of the PV modules.

Research Aims

This research project aims to:

(i) Develop a reliable and reproducible method for coring of the PV modules

(ii) Understand the failure mechanisms in thin-film CIGS solar modules due to the potential induced degradation

These aims will be achieved by a post-mortem analysis on the cores with representative defects using various techniques such as photoluminescence (PL), lock-in thermography (LIT), and secondary ion mass spectroscopy (SIMS).

Research Problems, Questions, Hypotheses

The failure mechanism behind PID is still not fully understood and current technical standard IEC tests are found to be insufficient. In this regard, the following research questions have arisen:

- Voltage-current distributions and corresponding leakage current pathways
- Diffusion behaviour of the alkali metals: To where and how far do Na ions migrate?
- Can PID be reversed by light soaking or applying forward bias?

Research Methodology

- Conduction of PID tests on commercial PV modules known to be prone to PID, in a damp-heat chamber
- Detection of the defects on the failed PV modules by using a mobile EL camera
- Coring of the degraded parts with representative defects by mechanical drilling
- Obtaining a core of CIGS solar cells by removing the cover glass and peeling off the encapsulant
- In-depth analysis of the cores by techniques such as SEM, EL, PL, and ILIT
- Examination of the diffusion behaviour of alkali metals by SIMS

Research Results

- In-house coring of commercial PV module has been successfully executed by mechanical hollow diamond drill.
- In most cases, CIGS layer comes off with the encapsulant layer upon peeling; a more reliable methodology is in progress.
- The core samples have been analysed with SEM, ILIT and PL to detect the local defected areas.
- A comparison analysis will be done between the degraded and non-degraded parts in PID tested PV modules.
- Na profiles among different layers of the CIGS will be obtained by SIMS to study the diffusion behaviour.

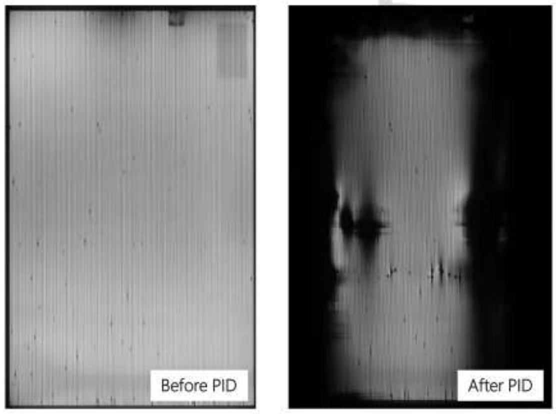

Figure 1: Electroluminescence (EL) images of a commercial PV module taken before and after PID test at an applied voltage of -1000V under damp-heat (85ºC, 85% RH) for 48 hours. (Tests conducted and EL images taken by PI-Berlin)

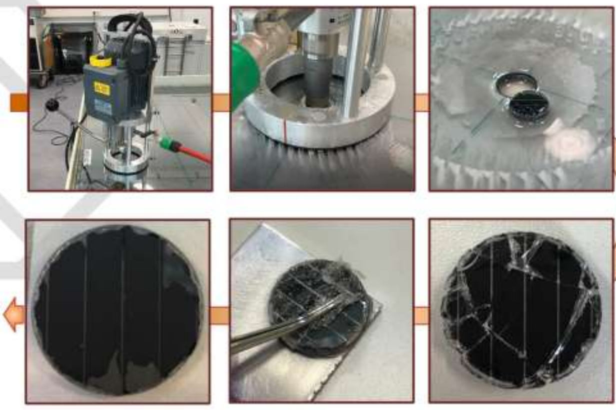

Figure 2: Coring of the PV module – The cores are mechanically drilled from the back side of the PV module with a hollow diamond drill under a water cooling system. The tempered cover glass is then removed, followed by peeling the encapsulant to obtain a core sample of CIGS solar cells.

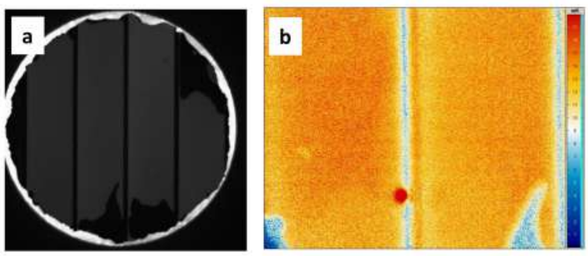

Figure 3: Characterisation of the core samples obtained from a commercial PV module – (a) Photoluminescence and (b) Illuminated Lock-in Thermography images obtained for locating the defected areas

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Acknowledgements

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Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Line-to-Line Faults Detection for Photovoltaic Arrays Based on Machine Learning Techniques

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Introduction

Line-to-Line (L-L) faults are defined as accidental short-circuit two different points in one array. For instance, the points of F1, F2 and F3 annotated in Fig. 1(a). The mismatch percentage demonstrates the intensity of the faults. In Fig. 1(a), F1 refers to a line-to-line fault with one module mismatch or 10% mismatch, while F2 and F3 refer to 20% mismatch and 30% mismatch, respectively. Typically, the L-L faults lead to significant voltage drop and consequently, draws a back-feed current from other strings. OCPD (Overcurrent Protection Devices) is employed to disconnect back-feed current and clear the faults. I-V curves show normal operation and fault conditions (30%mismatch) in Fig. 1(b). The pre fault operating point of the PV array and the string is 'A' and 'C' respectively. Because of presence MPPT diminishes the effect of the Line-Line fault by optimizing the post fault operating point of the PV array to point E in 30% mismatch fault with a significant reduction in power and voltage.

Research Aims

(i) using less data to train algorithms.

(ii) Improving accuracy in fault detection.

(iii) fault classification in low mismatch percentage.

These aims are achieved by feature extraction based on I_V characteristics and using cross validation method in algorithm training phase.

Protection challenges

Fuses may fail to detect the faults under the following situation:

1) Fault event under low radiance level, which lead to draw a low fault current from other strings.

2) Fault event under lower mismatch percentage or with high impedance in the fault path a low cause any back-feed current into the faulted string.

3) Fault event in PV arrays, where MPPT is still working, and the MPPT of DC/DC converter can decrease the fault effect on the PV system by moving operating point to a new maximum power point.

Methodology

Supervised learning is one of the machine learning categories, by which a set of rules are learned from dataset and a learning algorithm is chosen that can apply these rules successfully to new samples. The selection of specific learning algorithm to use is a critical step. An algorithm is selected, it is applied to a dataset, and then it is evaluated before using. The evaluation is mostly based on prediction precision, i.e., the percentage of the right prediction divided by the total number of predictions. (as shown in Fig. 2(a)). In this method has used three algorithms, called Support Vector Machine (SVM), Logistic Regression (LR), and Naive Bayesian (NB).

K-fold cross-validation is the most important technique which is used to calculate the accuracy of a learning algorithm. The k-fold cross validation method is used to evaluate the performance of a classifier. In this method, the dataset is divided into k same-sized subsets. It is repeated k times, such that each time, one of the k subsets is chosen for testing fold and the other k-1 subsets are used for training fold. The error estimation is averaged all k trials to get total capability of the model. As can be seen, every data point gets to be in a testing fold exactly once and gets to be in a training fold k-1 times. (as shown in Fig. 2(b))

Results

In order to evaluate the performance of the proposed method, a PV system with central inverter is simulated in environment of MATLAB/Simulink. Various scenarios of L-L faults have been simulated by making short-circuit between two points in a string. The simulation results prove the fault detection and classification by proposed technique is very accurate at different situations. Especially, when L-L faults occur with mismatch percentage less than 30% under all fault impedances. The results are demonstrated in Fig. 3 and Table 1. Fig. 3 shows accuracy in fault detection for three algorithms. Table 1 illustrates the results of the fault classification with logistic regression algorithm.

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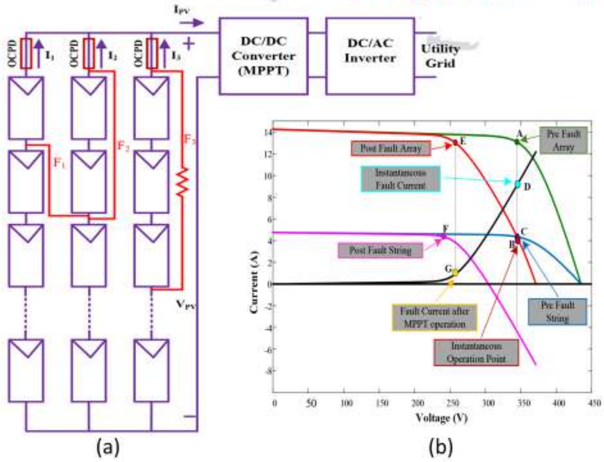

Figure 1: (a) A typical configuration of PV system, its potential faults ,and (b) I-V curve of PV array: Transition from normal to fault event

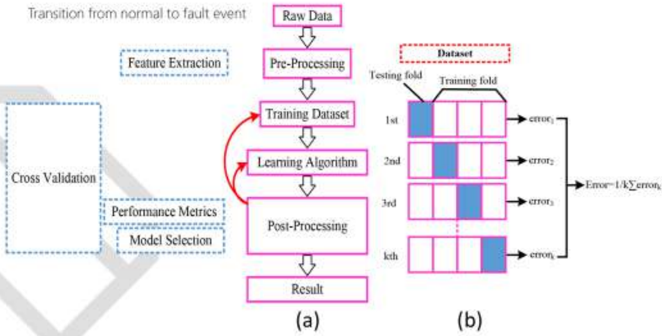

Figure 2: (a) Flowchart for the proposed detection method, and (b) K-Fold cross-validation

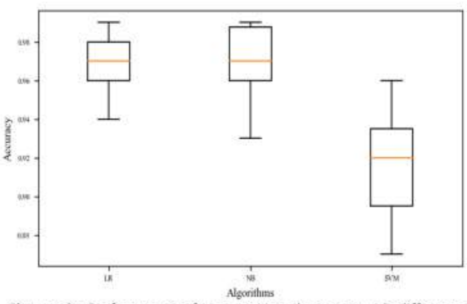

Figure 3: Performance of Line-to Line detection with different classifiers with the cross-validation

Table 1: Line-to-Line fault detection results with Logistic regression (LR) algorithm

Mismatch Percentage (%)	Fault Impedance				Accuracy Average
	0	10	15	25	
10	93.33%	73.33%	73.33%	60%	75%
20	100%	93.33%	80%	73.33%	86.67%
30	100%	100%	93.33%	93.33%	96.67%
40	100%	100%	100%	100%	100%
50	100%	100%	100%	100%	100%

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Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Online diagnosis of Photovoltaic Systems

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Introduction

The subject of the current research is focused on diagnosis tools for fault identification in photovoltaic panels related to mismatch conditions or degradation processes (Fig 1). Classical analysis mainly focused on the series resistance evaluation is combined with new methodologies such as Electrochemical Impedance Spectroscopy (EIS). Main aspects:

- Low cost-implementations.
- Online systems.

Research Aims

Defining and implement an online diagnostic approach for photovoltaic systems by using embedded systems.

Specific objectives:

i. To revise the state of art about modelling, parametric identification, monitoring and diagnostic techniques in PV systems.
ii. To design a software/hardware structure to execute monitoring and diagnosis tasks.
iii. To implement the designed monitoring and diagnostic techniques on a real system.

Research Problems

i. How to relate the degradation and failures factors?
ii. What type of photovoltaic system models are necessary?
iii. How to develop a hardware system and suitable methods for applying online monitoring and diagnostic tasks for photovoltaic systems?

Research Methodology

i. Development of methods for parameters identification by using time or frequency domain measurements. Detection of the degradation phenomena and failures affecting the PV system behavior (Fig. 2).
ii. Implementation of data-based and model-based approaches using embedded systems.

Research Results Planned

i. Identification of suitable methods for representing the behavior of photovoltaic devices in different operating points related to the on-field outdoor conditions.
ii. To implement the right methodologies for identifying the main parameters affected by the degradation processes or failures (Fig. 3).
iii. To design and implement a hardware/software platform for diagnostic tasks using embedded system with appropriated computational resources.

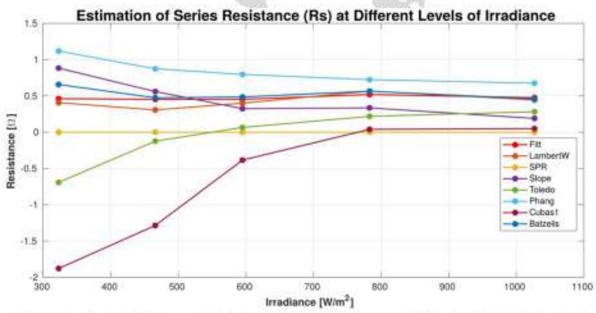

Figure 1: Variation of PV series resistance with respect to the irradiance. Estimation obtained with experimental data by using different analytical methods.

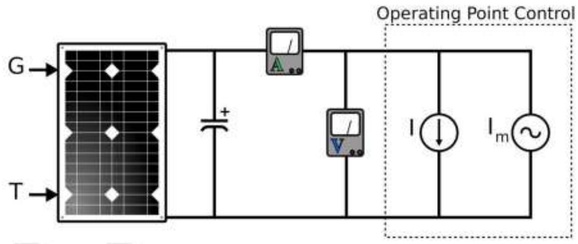

Figure 2: General scheme for measuring the impedance of the photovoltaic source by using the spectroscopy principles.

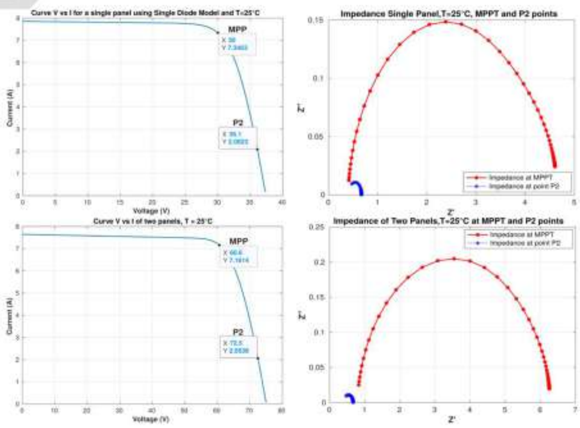

Figure 3: Analysis of the PV impedance on simulated photovoltaic devices operating in different conditions.

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Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

PV performance under different conditions

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Introduction

My Ph.D. research is mainly about the effect of surrounding condition on the PV performance. My research is under process in two different parts as is described in the following:

In first part of my research, I have studied on the smart shade-resilient PV module.

In the second part, I studied about the performance of floating PV system, compared to the same system located on land.

Figure 1: Smart panel under partial shading conditions.

Research Aims

State clearly the primary and secondary objectives of the research

(i) To mitigate the effect of shading on panels,

(ii) To maximize the harvested energy from the PV system ,

(iii) To analyse the effect of environment like water and wind speed of PV performance.

Research Problems, Questions, Hypotheses

The main question is how to harvest more energy from a PV system? Then, we need to consider the environmental conditions like the shading, how we can mitigate the effect of shading from the surrounding obstacles?

Another unpleasant factor is the temperature, and the main question is how to cool down the panels? One way for cooling the panels is to install the system on the water. Then, modelling and designing the system popped up for a research based system.

How we can model a floating PV system on an open sea? How to consider the effect of wave on the system? What is the role of wind and humidity?

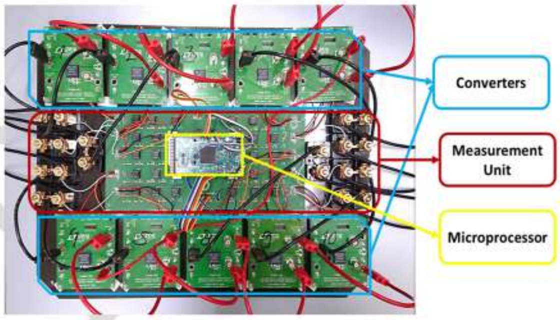

Figure 2: Prototype board

Research Methodology

For the smart panel we modeled, simulated, design and prototyped a panel which mitigates the effect of shading. Figure 2 shows the prototyped circuit which is developed for the smart panels.

For the FPV and LBPV comparison, first we need to have deep understanding about two systems. Figure 3 depicts two systems with the possible environmental effect like animals and the weather elements.

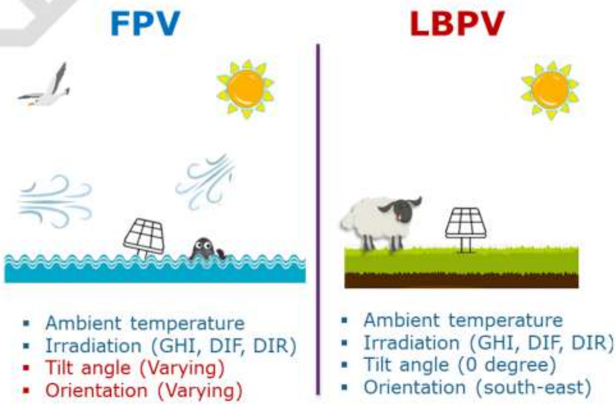

Figure 3: Floating PV system in comparison to the Land-based PV system.

Research Results / planned or achieved

Data of one year is used to simulate the behavior of the smart panel. Also, practical test is done for that panel and analysis of the results published it two different papers.

FPV system is modeled and the simulations shows that the energy yield from FPV is 12,9% higher than the LBPV system. However, by deducting the irradiation difference between two locations it is concluded that the FPV system is almost 4.5% more efficient compared to the LBPV.

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Supervisor (Dr. Wilfried van Sark, Full Professor of Photovoltaics Integration, Copernicus Institute, Utrecht University)

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Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Plasmonic Enhancement and Directionality of Emission for Advanced Luminescent Solar Devices (PEDAL)

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The University of Dublin

Introduction

Buildings play a significant role in the global energy balance. Typically they account for 20-30% of the total primary energy requirement of industrialized countries, 40% in the EU. Applying photovoltaic (PV) panels to buildings is an important application for wider PV deployment and to achieving our 20% Renewable Energy EU target by 2020. The luminescent device; Plasmonic Luminescent Solar Concentrators (PLSC) and Plasmonic Luminescent downshifting layers (PLDS) offered excellent opportunities for BIPV technology not only breakthroughs in solar device efficiencies but also the development of unique building integrated components (Figure 1, for example)

Figure 1: Possible applications for the PLSC and PLDS devices a coloured glazing facades of a building and PLSC devices.

Research Aims

- To capture diffuse and direct solar radiation to produce higher efficiencies with concentration ratios over 3 in a plasmonically enhanced luminescent solar concentrator (PLSC).
- Plasmonically enhanced downshifting(PLDS) thin-films to increase the efficiency of all solar cells types independent of material composition.
- These PLSC and PLDS novel system up-scaled and a building integrated component fabricated, with the ability not only to generate power but with options for demand side management within the building.

Research Problems

- In Europe about 50% of the solar radiation is diffuse. PEDAL project research address issue to concentrate both direct and diffuse solar radiation in a static building component to produce the electrical energy

Research Methodology

- PLSC Research Methodology: The various size and shape of Gold nanopartciles/silver were synthesised for plasmonic coupling with luminescnet material (QDs , Dye)
- Modelling and characterisation: The ray-tracing and Finite-difference time-domain(FDTD) modelling applied to model the plasmonic interaction between luminescnet material and Gold nanopartciles and optmize the PLSC and PLDS devices .
- Design and fabrication of PLSC & PLDS: The modelling and experimentally optimized parameters used to fabricate the PLSC and PLDS devices more detail in Figure 2.

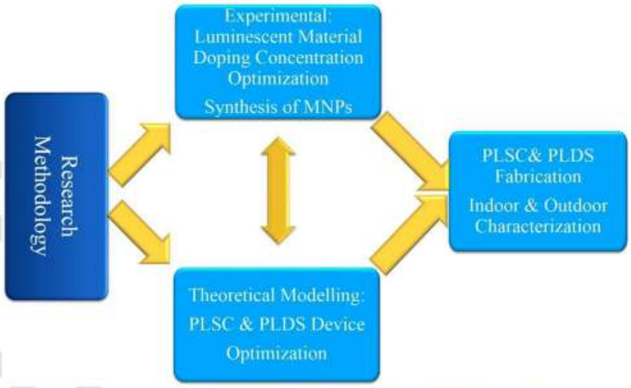

Figure 2: The research methodology for PSLCS and PLDS device fabrication

Research Results

- The plasmonic interaction of metal nanoparticles (MNPs) with fluorophores to improve the optical performance of Plasmonic Luminescent Solar Concentrators (PLSCs). PLSC with dimensions of 45×45×3mm3 containing Lumogen Red305 dye and Au@Ag NCs were fabricated and characterized. A maximum enhancement of 30% in the fluorescence was achieved for PLSC device containing an optimal doping concentration (1.1 ppm) of Au@Ag NCs. Monocrystalline silicon solar cells were attached to one edge of the PLSC waveguides and the power conversion efficiency was found to be 1.2 times higher than the power conversion efficiency of 0 ppm sample(see Figure 3).

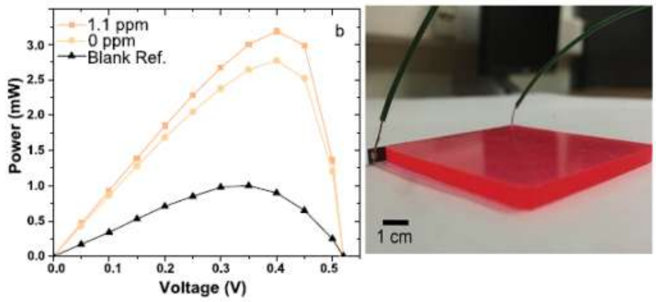

Figure 3:The power curve of the PLSC device and Photograph of a 45×45×3mm3 PLSC devices PLSC containing 1.1 ppm Au@Ag NCs, and 70ppm of red dye doping concentration, respectively (Ref. 3).

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Principle Investigator: Dr Sarah McCormack
Associate Professor in Energy Engineering
School of Engineering, Trinity College Dublin, College Green, Dublin 2

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P ARL PV

P E A R L P V

2nd TRAINING SCHOOL

Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Bifacial PV module design – learnings from field inspection

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Introduction

To design bifacial PV modules, learning steps based on previous field inspections can help making a material set-up decision (Fig. 1). PV plants can fail due to problems in installation, aged materials or system setup. The fast detection of the failure and its root cause is one step forward to save cost and avoid failures in future. A suited design and tested material combinations are an important requirement for reliable products. All over the world, there is a remarkable interest for increasing the yield, shortening the maintenance effort, failures and downtimes.

Figure 1: left: Specimens based on different material combinations; right: 60-cells standard PV modules with two different bifacial cell technologies and a glass-backsheet encapsulation

Research Aims

(i) Development of a novel and innovative bifacial module design for industry based on a glass-foil laminate

(ii) Impact of the failure in the short and long-term perspective that will be seen with inspection techniques

(iii) Taking efficient and inexpensive countermeasures after I) sample testing or II) field inspection

→ These aims/objectives will be achieved by experience and affordable suited equipment

Research Problems, Questions, Hypotheses

- Often new questions have arisen if previous used methods are still best choice?
- Are new material combinations enough tested by accelerated aging tests?
- Is a current accelerated procedure still up to date and meaningful?
- Often more than one inspection technology is needed to be sure of a failure and having enough evidence
- The knowledge found in papers or conferences is very important for the training and to be experienced

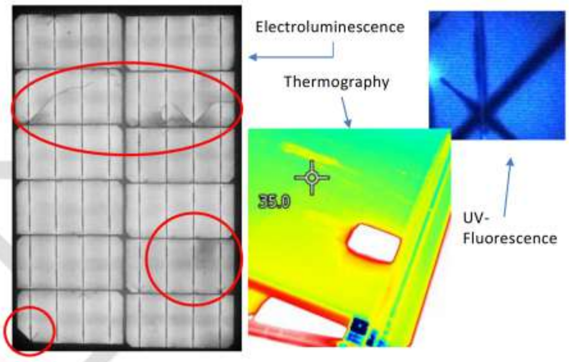

Figure 2: Examples for inspection possibilities after an accelerated aging procedure or after a couple of years after installation in the field. The most promising methods to detect the weaknesses are I-V-characteristic curves, visual inspection, electroluminescence imaging, thermography and UV-fluorescence.

Research Methodology

The standard test equipment includes module climatic chambers, a multimeter, thermal camera, electroluminescence camera, I-V-characteristic curve device, UV-lamp and a power source. With this technical support, a fast assessment after accelerated aging tests or field inspection is possible (see Fig. 2).

Research Results / planned or achieved

- Due to the experience from the field, the knowledge could be used for designing bifacial PV modules
- A previous method comparison was done and in combination with accelerated aging tests (see publication "Scientific and economic comparison of outdoor characterisation methods for photovoltaic power plants")
- The planned next steps are to check novel designed bifacial PV modules (see Fig. 3)

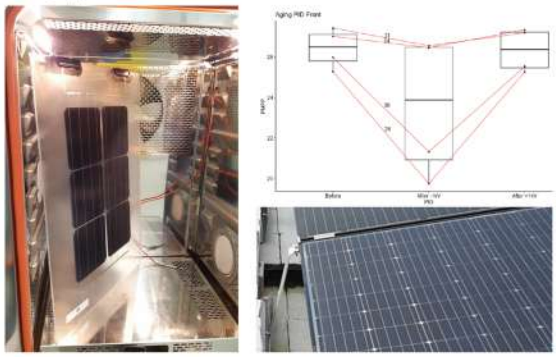

Figure 3: Accelerated aging test in a climatic chamber; indoor and outdoor test setup with bifacial PV modules and a glass-foil design concept

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Acknowledgements

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BIFACE

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P E A R L P V

Improve the performance of inorganic Sn-based Pb free Perovskite solar cells: Synergies between the computational modelling and experimental studies

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BASQUE CENTER FOR MATERIALS, APPLICATIONS & NANOSTRUCTURES ehugroup BCMATERIALS

Introduction

The Pb-based perovskite absorber has become useful for perovskite solar cells (PSCs) due to their amazing optical and electrical properties led to attend the best record efficiency in PSCs[1,3] but the toxicity of Pb metal as an impenetrable barrier for making these new generations of solar cell commercially viable. Sn can replace Pb to former the structure of perovskite material, Sn-based Pb free perovskite are showed high optical absorption coefficient but had poor performance and stability [2,5] (fig2) .In first stage we investigated the issue of poor efficiency by computational modelling such as electro-optical simulation to boot for experimental studies which can allow us to prepare 'non-toxic, abundant low-cost solar cells.

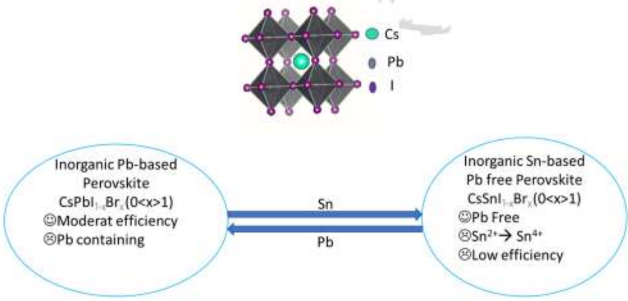

Figure 1: Crystal structure of inorganic Pb-based and Sn-based Perovskite materials

Research Aims

This project will focus on the following points :

(i) Implementing the density functional theory to study the electronic structure of Pb free perovskite materials ,

(ii) Electro-optical simulation of PSCs based on Pb free perovskite materials ,

(iii) Preparation of Pb free perovskite materials and integrate them into PV devices by low cost methods ,

Research Problems, Questions, Hypotheses

- Toxicity of Pb element
- Stability of Sn based Pb-free perovskite sola cells
- Efficiency of Sn based Pb-free perovskite sola cells

Research Methodology

- Computationnel Modeling :DFT [4] ,Electo-optical Simulation (fig3),
- Device Fabrication :Solvent engineering ...

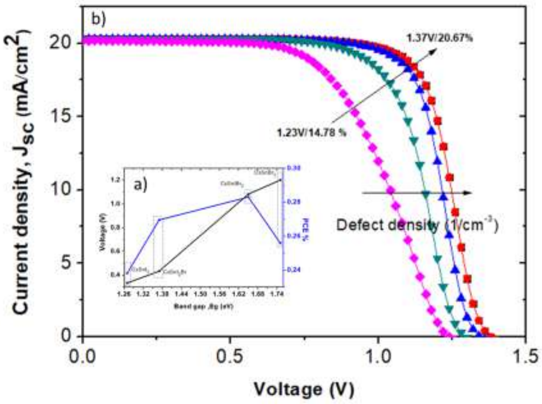

Figure 2: (a) Effect of Br on band gap of $CsSnI_{1-x}Br_x$ and (b) effect of defect density into $CsSnIBr_2$ on the performance of PSCs.

Research Results / planned or achieved

- We started our investigation by Electro-optical simulation which showed interesting finding which we reached an efficiency of 20 % and voltage of 1. 37 V by diffientes optimisations especially the impact of defect density into the perovskite and between its selective layers related to the planar structure with CsSnIBr2 as absorber light (figure 3).
- Density functional theory of Lead-free perovskite materials.
- Device fabrication of perovskite solar cell using Sn-based Pb free perovskite materials.

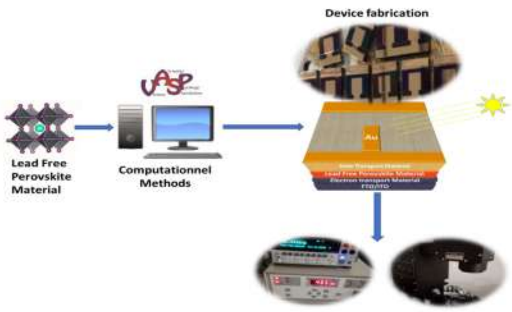

Figure 3: Research and Methodology for low cost solar cell with Sn based Pb-free perovskite materials .

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Co-Supervisor (Prof Shahzada Ahmed ,Dr.Samrana Kazim ,BC-Materials - Leioa –Spain)

P E A R L P V **2nd TRAINING SCHOOL**

Malta, October 2019

Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability

Reliability Testing of PV Materials/ PV Modules

Yuliya Voronko

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Introduction

During the operation of PV-modules of ~25 years lifetime in the field, PV-modules have to withstand extreme environmental influences (Fig.1). Hence the long-term stability of the protective polymeric materials (backsheet, encapsulant) is crucial for the reliability of the active PV component over the whole life cycle. Therefore, (i) polymeric materials are required that fulfill the versatile properties like cost-effective, long-term reliable, etc. and are compatible with each other and (ii) suitable specific artificial aging tests that make it possible to find the right polymer materials & material combinations for different location.

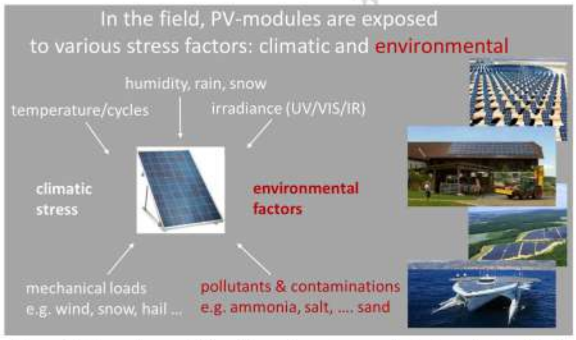

Figure 1: Overview of climatic and environmental stress factor that PV module have to withstand for +25 years

Research Aims

I. Development of artificial aging test procedures (material testing optimized for different climate zones)
II. Development and testing of innovative methods for analyses of PV-Modules
III. Investigation of the degradation/aging behaviour of polymeric materials used in PV Modules

Research Problems & Challenges

→ Up to now, the ultimate barrier to the market approval of novel materials & components is passing of the standardized "Design Qualification and Type Approval" tests according to IEC 61215-2, where the same type of PV-Module is used for all regions

Problems:		**Challenges:**
(i) the principle of one (standard) PV-module for all climatic conditions does not fit anymore	→	(i) Developing of climate-specific tests & understanding of the degradation modes of PV modules & materials
(ii) the artificial aging tests lead to positive results while material failure occurs in the field deployment	→  Backsheet cracks	(ii & iii) →finding of suitable measurement tool set for PV module testing
(iii) accelerated aging tests lead to false negative results, which lead to the exclusion of suitable materials	→  Yellowing after accelerated ageing	→ a detailed analysis of the individual adjacent materials used in PV modules

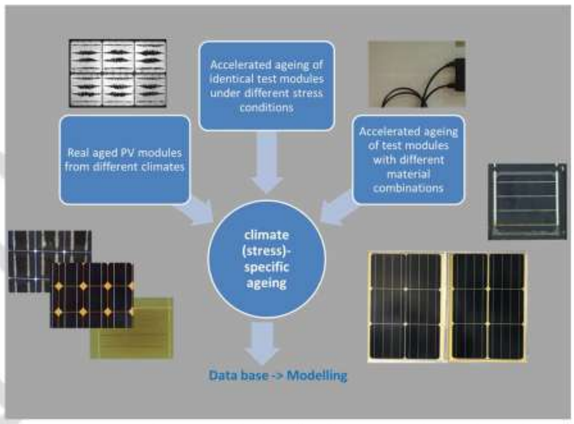

Figure 2: scientific approach for development of specific artificial ageing test procedures

Research Methodology

I. creation of specific artificial ageing tests procedures (See Fig.2)
II. climate-specific ageing of test modules with different materials combinations
III. thorough characterization before, during and after artificial ageing
- detect ageing induced changes on PV-module, component and material level with novel non-destructive & destructive techniques
- compile all characterization data in database
- use these datasets as basis for advanced data treatment and modelling of the ageing/degradation behavior

→ the best material combination selection depending to different climate zones

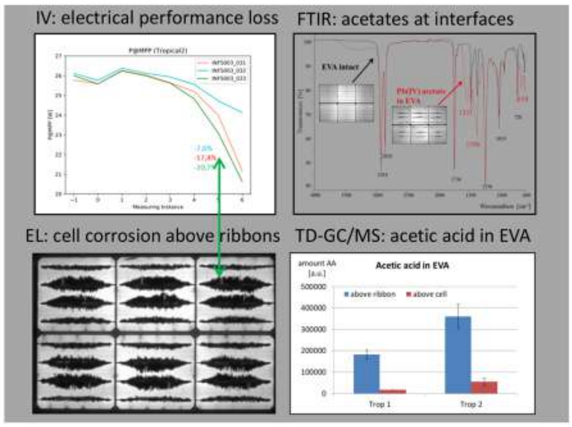

Figure 3: results of the aged test-modules according to the testing for climate zones Tropical (B) – power loss, cell corrion & encapsulant degradation (EVA)

Research Results

✓ Definition of 4 climate profiles (dry and hot - arid, moderate, humid and hot -tropical and high irradiation - alpine) and program with 14 climate-specific test conditions for accelerated aging tests was performed → tool for climate-specific testing of materials

✓ Material analysis for a large number of test modules was performed and data base as basis for the modelling of the ageing/degradation behaviour was designed

✓ Combination of climatic and environmental stress factors such as temperature, humidity, and irradiation for example for climate zone Tropical (Fig.3) led to power decrease, degradation and other material errors in test modules such as:
- Cell corrosion and formation of lead acetate above band
- Encapsulation: hydrolysis and formation of acetic acids
- Backsheet: cracking and PET layer degradation

Supervisor DI Dr. Gabriele C. Eder

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P E A R L P V

Acknowledgment: This work was conducted as part of the Austrian "Energy Research Program" project INFINITY (Project number 850.414). Funded by the Austrian Climate and Energy Fund and the Austrian Research Promotion Agency (FFG), both are gratefully acknowledged.

APPENDIX 2 - Posters representing Current Research of Training School 3 participants

Posters representing the current research of trainees who participated in the Training School III held in July 2021 at the Transilvania University of Braşov, in Braşov, Romania.

P ARLPV **3rd TRAINING SCHOOL**

Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

Research Title

Afonso Cavaco, Renewable Energies Chair, Évora, acavaco@uevora.pt
(the institution where the research is conducted)

UNIVERSITY OF ÉVORA

RENEWABLE ENERGIES CHAIR

Introduction

PhD in Earth and Space Sciences dedicated to the assessment of Direct Normal Irradiation (DNI) in the south of Portugal for solar concentration applications and the development of methodologies to estimate DNI with basis in Global Horizontal Irradiation (GHI) and Diffuse Horizontal Irradiation (DHI).

Currently carrying out research in the field of solar radiation: DNI assessment, site assessment and getting into forecasting systems. On the other hand, starting to help in the development of PV projects within the group.

Research Aims

State clearly the primary and secondary objectives of the research

(i) Solar radiation assessment in the south of Portugal, with focus on DNI (Figure 1),

(ii) Identification of locations for the implementation of solar energy projects

These objectives will be achieved by maintaining the operation of a solar radiation network initiated in 2014.

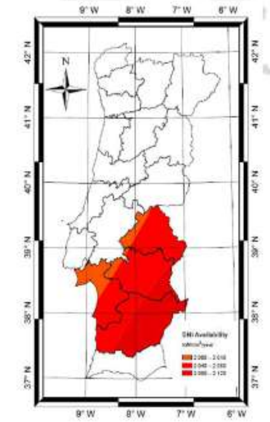

Figure 1: DNI mean annual availability in the south of Portugal

Research Problems, Questions, Hypotheses

In Portugal there was no information about DNI mean annual availability, only GHI and in a few location also DHI. Foreseeing the development of solar concentration systems, mostly Solar Thermal Energy systems.

Besides the assessing the mean annual availability one of the objectives was to develop methodologies that would allow the estimation of DNI mean annual values, with basis on GHI and DHI measurements since it would allow to estimate past mean annual availabilities.

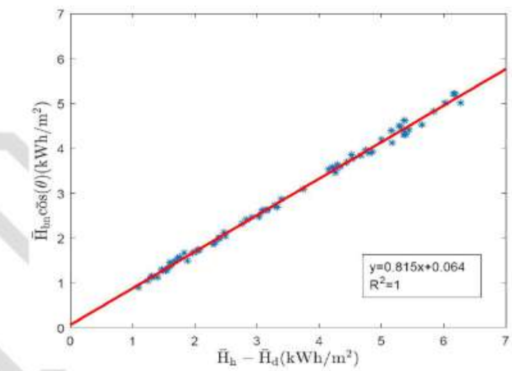

Figure 2: Correlation between the product of monthly mean daily values of DNI and monthly mean cosine of solar zenith angle and the difference between monthly mean values of daily GHI and DHI.

Research Methodology

The research methodology included the implementation of a solar monitoring network in the south of Portugal, processing solar radiation data and study the relationship between the different components of solar radiation as a way to obtain significative past information about DNI availability.

Research Results achieved

The achieved research results were:

(i) Development of a DNI mean annual availability map with basis on the measurements made during the PhD

(ii) Development of correlation to estimate past DNI with basis on DHI and/or GHI measurements (Figure 2)

(iii) Application the correlation to estimate DNI to a long period of GHI data measured by the national meteorological Institute (Figure 3).

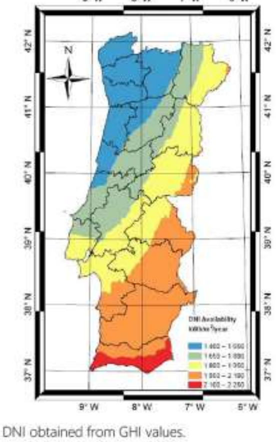

Figure 3: Estimated DNI obtained from GHI values.

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Modelling and simulation of a Floating Photovoltaic Unit of 500 kW_p installed on a hydropower plant reservoir

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Introduction

Utilization of photovoltaic systems on water bodies offers an enormous potential for many countries worldwide. Actually, an interesting application considers their installation on hydropower plant reservoirs. The related term used nowadays is floating photovoltaic systems. One of the main benefits associated to them, is that through their contribution they open a path to the energy transition on a national scale.

Figure 1: Floating unit of 500 kW_p (Stattkraft, 2021).

Research Aims

The obtained results will be valuable to offer their contribution on the future predictability.
The obtained results include:

i. the monthly values of energy injected into grid,
ii. the energy at the output of the array, and
iii. the performance ratio.

Also, the annual energy balance for the modelled unit is shown.

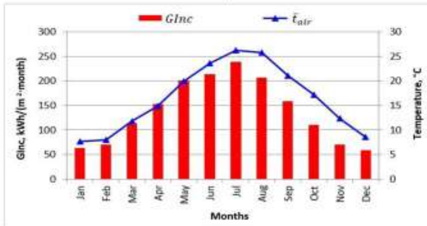

Figure 2: Global incident radiation in PV panel plane and the ambient air temperature (Maraj et al., 2021).

Research Problems

Utilized platforms utilized nowadays are different on size, forms and design. At present, there is very little data related to circular membrane units employed in FPV.

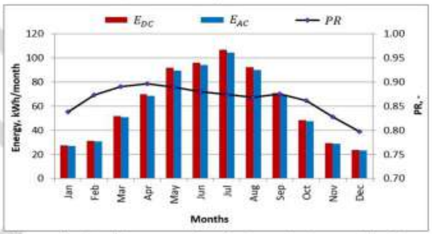

Figure 3: Monthly average values for E_{DC}, the E_{AC}, and the PR (Maraj et al., 2021).

Research Methodology

In the present work the modelling and the simulation of a floating photovoltaic plant is carried out. The modelled unit is newly installed and has a peak power of 500 kW.

The PVSYST tool is utilized for this case study.

Research Results

From the modelled and the simulated Floating Photovoltaic (FPV) unit with an installed peak power of 500 kW, it was noticed that:

a) the annual global incident radiation on PV array was 1654 kWh/m^2.
b) the annual energy at DC part is 739.9 MWh/year.
c) the annual energy at AC part is 723.4 MWh/year.
d) the annual averaged value of PR was 0.872.

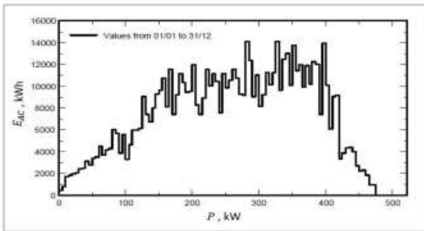

Figure 4: System output power distribution (Maraj et. al., 2021).

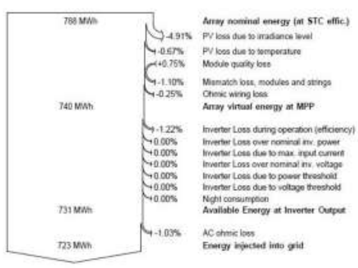

Figure 5: Energy balance for the floating PV unit (Maraj et. al., 2021).

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P E A R L P V

3rd TRAINING SCHOOL

Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

Yield assessment, user adoption and other aspects of PV-systems in the tropical region

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UNIVERSITY OF TWENTE.

Introduction

Ph.D. candidate at the University of Twente, researcher & lecturer at the Electrical Engineering Department of the Anton de Kom University of Suriname. My research focus on modeling of yield assessment, cost and user adoption of grid-connected PV systems in the tropical region, especially Suriname.

- Few publications exist regarding the performance of PV systems in South America and the Caribbean region
- Research regarding PV has been conducted in countries like: Brazil, Chile, Guyana, Bolivia, Colombia, Argentina, Dominican Republic and Puerto Rico.
- Some of the research topics were: rural electrification, performance assessment, power quality analysis, economical assessment and policy

Figure 1: Map of Suriname (source: CELOS) and South America

Research Aims

i. To assess the perception of the end users regarding the implementation of PV systems in Suriname
ii. To determine and to investigate the cost and yield assessment of PV systems under tropical climate conditions
iii. To assess the future energy transition using grid-connected PV systems in Suriname.

Research Methodology

A. Qualitative Research method

1. Overview current electricity sector in Suriname: interviews with stakeholders and literature study.
2. Overview of PV implementation in Europe and other selected countries

B. Quantitative Research method

1. User survey for user adoption analysis
2. Data gathering: weather station data, PV output data in Suriname & from database of PEARL PV
3. Modeling of yield assessment of grid-connected PV systems in tropical region with Python
4. Future energy transition in Suriname: creating different scenarios to investigate the energy transition possibilities, using residential and utility scale grid-connected PV systems

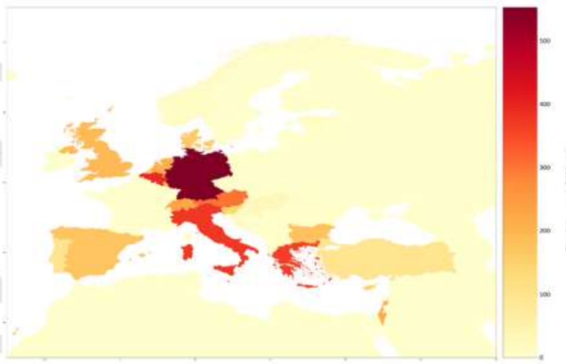

Figure 2: PV production per capita (kWh/capita) in Europe (2018) [5]

Research Results

- Germany has the highest PV production per capita with 552kWh/capita, followed by Belgium, with 391kWh/capita. Central European countries produce quite a lot of PV electricity per capita compared to other countries in Europe (fig. 2).
- Average irradiance is approx. 5 kWh/m^2/day and average final yield (Y_f) is approx. 3.7 kWh/kW/day [1] (fig.4).
- To achieve the 2027 RE target with only PV systems, additional 110 MWp of installed PV capacity will be required [3].
- To meet the electricity demand of 2027 with only PV systems, additional 2.2 TWh PV electricity will be required [3].
- Citizens perception regarding implementation of PV in Suriname (user survey) [4]:
  - 75% were aware of electricity generation with PV systems and related benefits (fig.3)
  - 65% are not willing to install PV systems at their homes due to high investment costs and low electricity tariffs
  - Only 26% of the respondents are willing to install a PV system at their homes
  - Knowledge dissemination about PV systems and subsidies, incentives and rebates remain important in enhancing PV installations

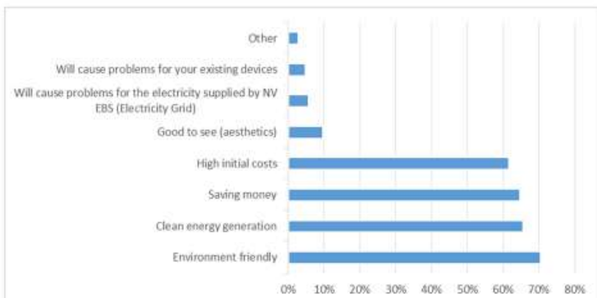

Figure 3: Awareness regarding PV systems in Suriname [4]

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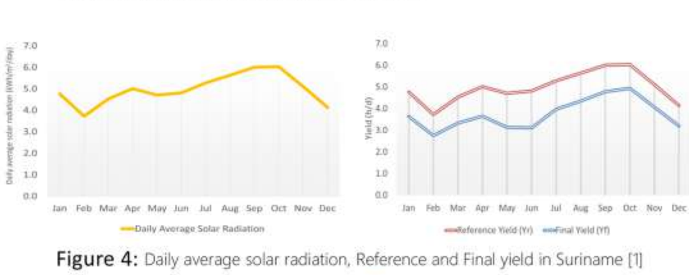

Figure 4: Daily average solar radiation, Reference and Final yield in Suriname [1]

Prof. Angele Reinders
University of Twente and Eindhoven University of Technology (TU/e), The Netherlands

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P E A R L P V

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Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

Integration, control and optimization of the solar photovoltaic+batteries in the buildings sector

UNIVERSITY OF ÉVORA

RENEWABLE ENERGIES CHAIR 10 YEARS

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Introduction

Within the scope of the research topic, the authors intend to study and implement control models which optimize the solar photovoltaic energy use in the building sector, considering energy storage systems. Operating techniques in electrochemical energy storage are investigated, namely in first life and second life lithium-ion batteries, nickel sodium chloride, and vanadium redox flow technology (see Figure 1), of the University of Évora, jointly with the solar photovoltaic systems, to improve performance of the integrated system. Control algorithms are developed using MATLAB programming and electrical battery models and are applied in real-time using LabVIEW software. The algorithms allow the balance of the solar photovoltaic energy generation in conjunction with the operation of the batteries, with and without the interaction with the electrical grid, evaluated through energetic, technical, and economic feasibility perspectives, based on key performance indicators.

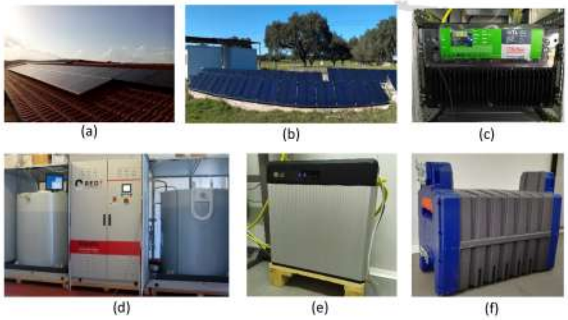

Figure 1: Technologies of the Renewable Energies Chair's microgrids: (a) BAPV of 3.5 kWp polycrystalline and 3.2 kWp monocrystalline technologies; (b) fixed amorphous PV of 3.2 kWp; (c) Sodium-nickel chloride battery of 3kW/ 7.7kWh; (d) Vanadium redox flow battery 5kW/ 60kWh; (e) Lithium-ion battery of 5kW/ 9.8kWh; (f) Second life lithium-ion battery of 3kW/ 3.3kWh.

Research Aims

This research work has implied the help on the answer to the following enunciated research aims:

i. Collection and research-based scientific and technical documentation on the simulation and modelling techniques which allow the optimization of the energy management applied to the buildings' sector;

ii. Real-time monitoring and advanced diagnosis of a microgrid systems performance; Control strategies in energy optimization, from an energy, technical and economic point of view, including variables studying;

iii. Study and identify the technical parameters which are more relevant to the leverage of synergies of the microgrid, considering the energy management strategy in the study and the desired performance indicator improvement.

The research is going to be achieved to the testing and operation of these physical energy systems, based on previous simulation work done.

Research Problems, Questions, Hypotheses

The work has implied the following enunciated research questions:

- With the currently existing technologies and tools, it is technically possible to solve PV obstacles through algorithm control, at a building's scale, using the batteries? How to develop these algorithms? Are they suitable?
- Does the strategies combination control have enough synergies to justify its feasibility? To which variables do the combination impact? To which situations should the strategy be applied? Does the adding of parameters improve any of the studied performance indicators? Is it only beneficially?
- Does the variable use to assess a single system fit the assessment of a hybrid battery+PV system? Which are the more useful variables? To what extent these variables influence the investment?
- How to manage a hybrid battery system? How the hybrid command power affects the combination?
- Which technical parameters are more important to leverage the synergies among different batteries?

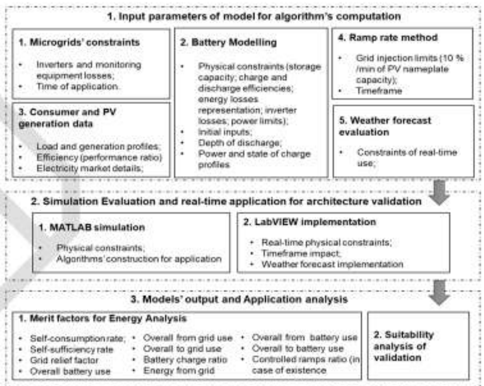

Figure 2: General Modelling architecture layout underlying present work methodology. Here, with a self-consumption algorithm combined with a ramp-rate method for power ramp control.

Research Methodology

The research methodology includes the use of the MATLAB programming to model the batteries technologies, to compose and evaluate the control algorithms, the PV data treatment, and the load profile treatment, to evaluate and improve the desired parameters. The LabVIEW software is used to conduct the real-time implementation of the data acquisition and power command control with the inverters, batteries and data precision monitoring. An example of this general methodology was developed and can be visualized in Figure 2, as an example of its functioning.

Research Results / planned or achieved

- The research methodology Integration of the batteries within the solar PV microgrids;
- Characterization tests of the batteries, in real operating characteristics of the microgrid integration;
- Electrical modelling of the battery's technologies;
- Development of energy management strategies simulation program and real-time implementation controls;
- Technic and economic viability of application of the technologies in the Portuguese buildings sector, consider various algorithm's approaches;
- Hybridization control of the lithium-ion battery (LIB) with the vanadium redox flow battery (VRFB) with two PV systems (simulation example in Figure 3);
- Fault detection, discussion of limitations and future possible perspectives for the PV+battery market and research field.

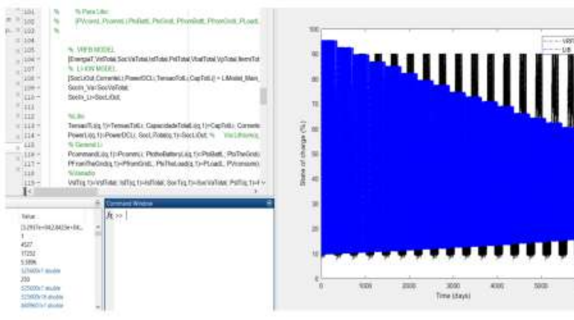

Figure 3: MATLAB programming example of the hybridization control of the LIB and the VRFB within self-consumption strategy, to evaluate the batteries' state of charge response over a PV and load consumption profiles, considering LIB aging and degradation of NMC technology, within a timeframe of 16 years. In this case, a study to improve an economic parameter was being tested.

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Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

SolarMap

Urban rooftop solar prospecting in Dublin, Ireland

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Insight SFI RESEARCH CENTRE FOR DATA ANALYTICS

Introduction

In line with UN and EU policies, the Irish Government's recent Climate Action Plan 2019 has set a national target to generate 70% of electricity from renewable energy sources by 2030. Solar irradiation levels in Ireland are equivalent to north European countries (i.e., Germany) [1]. However, as of 2019, Ireland has the second lowest installed PV capacity in the EU (36 MW) [2]. According to the Sustainable Energy Authority of Ireland "Energy in Ireland 2020" report, 36.5% of electricity demand was met by renewable energy sources in 2019. Wind energy contributes 32%; however, solar energy only contributes 0.07% to total electricity usage.

Ireland's National Energy and Climate Plan 2021-2030 has a set target of 1.5 GW of grid-scale solar PV capacity by 2030. There are 192 industrial and commercial estates in Ireland with a footprint of ~150,000,000 m^2 (estimated from CORINE 2018). Rooftop PV systems can contribute to significant renewable electricity generation and decarbonisation targets through many installations on the large surface areas available on industrial and commercial building roofs. Photovoltaic technology is rapidly becoming cost-competitive for electricity generation compared with other forms of energy generation [3]. The deployment of solar PV in Ireland can increase energy security, contribute to renewable energy targets, and support economic growth.

SolarMap identifies suitable building rooftop in industrial and commercial estates for PV installation in Ireland. Here we present preliminary results from a solar prospecting study in 20 such area of interests (AOIs) in Dublin, Ireland.

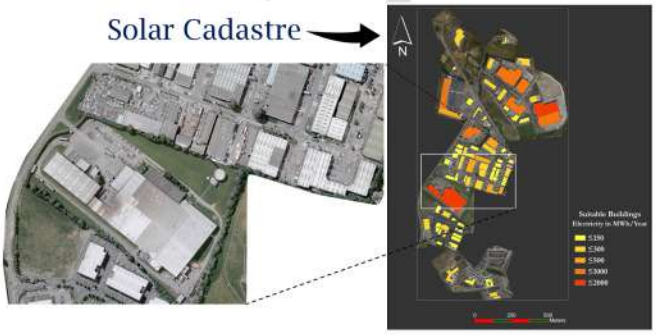

Figure 1: This figure shows solar cadastre in one of the SolarMap's area of interests (AOIs) in Ashbourne. The legend shows the annual PV electricity generation potential.

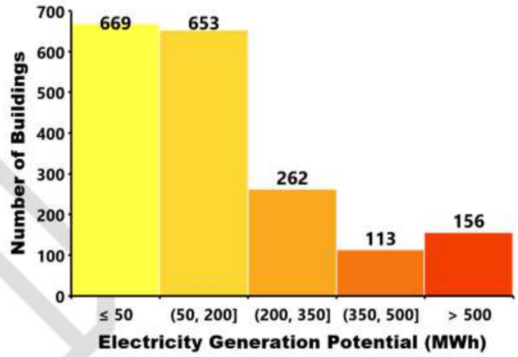

Figure 2: PV electricity generation potential in 20 AOIs in Dublin.

Research Aim

SolarMap aims to identify commercial rooftops suitable for solar photovoltaic (PV) installation in urban environment in Ireland using GIS and Remote Sensing.

Research Problems and Question

PV penetration has been slow in Ireland due to a lack of solar energy policy provision (e.g., feed-in-tariff payment for excess solar PV electricity fed into the grid), investment, and solar prospecting research. Previous studies in Ireland do not consider the impact of rooftop structures or shadow effect on solar irradiation [4-5]. Shading blocks significant amounts of solar irradiation, thus inhibiting optimum PV electricity output.

Can GIS based solar irradiation modelling help us overcome this challenge?

SolarMap tackles this problem using high-resolution topographic and meteorological data to model solar irradiation at a rooftop scale. In addition, high-resolution aerial images are used to estimate suitable areas for PV installation.

Research Methodology

Annual solar irradiation was modelled using 25 cm Dense Surface Models and Met Eireann meteorological data using solar analyst tool in ArcGIS Pro. High-resolution 12.5 cm aerial image and building footprint data combined with solar radiation models were utilised to filter rooftop areas unsuitable for PV installation. Solar Cadastres (Figure 1) containing electricity generation (Figure 2) and decarbonisation potential (Figure 3)were produced for 20 AOIs.

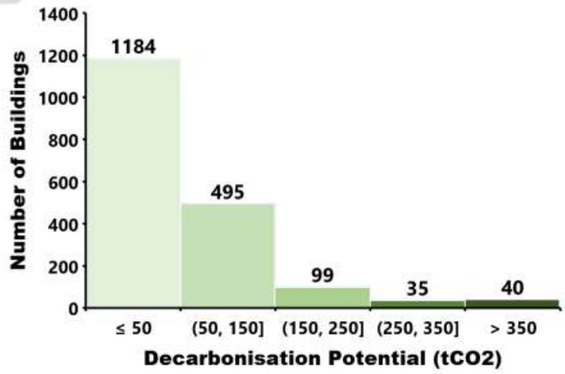

Figure 3: Decarbonisation Potential in 20 AOIs in Dublin due to PV installation.

Research Results

Our solar irradiation models revealed that the maximum annual solar irradiation in Dublin is 1000-1050 kWh/m^2. We found that 1,853 commercial building rooftops in 20 AOIs results in an annual electricity generation potential of 367 GWh (Figure 1) and carbon emission reduction potential of 122,469 tCO2 (Figure 2). The usable rooftop area available for PV installation is 84.85% of total rooftop area or 3,262,386 m^2.

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Trinity College Dublin Coláiste na Tríonóide, Baile Átha Cliath The University of Dublin

DCU Ollscoil Chathair Bhaile Átha Cliath Dublin City University

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Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

Performance and power quality evaluation of grid-connected solar photovoltaic systems

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Introduction

Solar PV has experienced unprecedented growth in the last decade as a result of the favourable policy initiatives by different countries and subregional unions, improvement in technology and reduction in cost, among others. However, the bulk of the increase was in the area of grid-connected systems. Consequently, the typical unidirectional power flow of the electrical distribution system has been altered, introducing numerous power quality issues into the power distribution network. The impact is dependent on the structure and the robustness of the grid.

Research Aims

- Determine the performance output of microinverters under constant indoor conditions and outdoor real operation condition.
- Assess the performance output of different grid-connected string inverters under varying ambient conditions and determine their compliance with specified grid-connection standards in the Hungarian low voltage power network.
- Determine the correlation between the harmonic current and the system harmonic voltage for the different inverter systems.

Research Methodology

This study investigates the power quality output of different sizes and types of grid-connected solar PV systems by studying the inverter output at the point of common coupling under various operating conditions whiles applying microinverters and string inverters (see Figure 1). The power quality output of microinverters is comprehensively analysed and characterized, considering their compliance with the local grid standards and requirements in the low voltage network. Comparisons are made for the appropriateness of the various types of inverters for the low voltage power network. The correlation of the different system harmonic voltage and the generated harmonic current has been evaluated.

Research Results

It has been observed that the current total harmonic distortion profiles of microinverters under indoor studies with constant irradiation produced profiles with zero slopes, while the profiles for the outdoor study recorded varying positive integer slopes for all the scenarios as shown in Figure 2.

The correlation between the generated harmonic current and the system harmonic voltage of grid-connected PV systems with microinverters and string inverters for varying data points and operating conditions were investigated. It was established that the generated harmonic current of the 5th harmonic order for both microinverter systems and string inverter systems correlate positively with the system harmonic voltage of the studied systems irrespective of system type or operating condition in the low voltage grid system, as shown in Figure 3.

A linear model for the relationship between the harmonic current and the harmonic voltage for the 5th harmonic order of microinverter systems and string inverter systems employed in the low voltage grid system was obtained as shown in Eqn. 1. The standard deviation was 0.0011.

$$I_H = 0.03979 + 0.0064\,V_H, \quad (1)$$

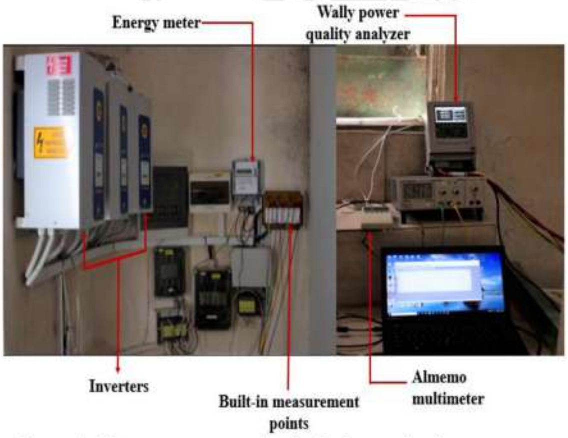

Figure 1: Measurement setup for the 3-phase string inverter system

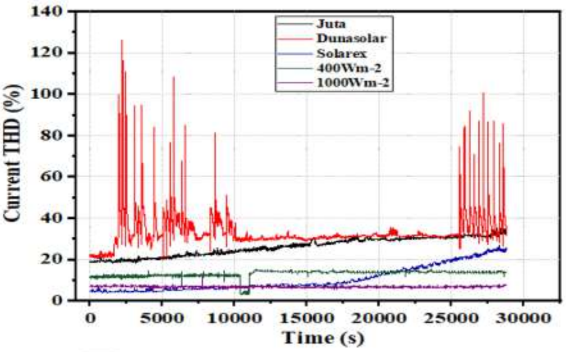

Figure 2: Current THD of microinverters for indoor and outdoor studies

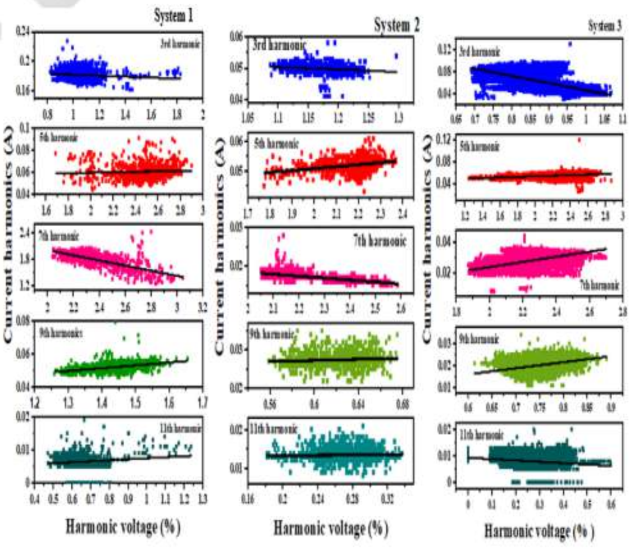

Figure 3: Plots of harmonic current against system harmonic voltage for the 3-phase grid-connected system (System 1, 2, and 3)

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Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

Tradition after the fourth industrial revolution: The solar architecture of the photovoltaic technology on vernacular homes from Transylvania's villages, Romania

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

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Introduction

Photovoltaic technology in vernacular architecture, as a regenerative action of changing the roof finishing with PV solar roof tiles in traditional architecture from Transylvania, Romania, as a cultural heritage preservation action of space started with an undeveloped but may be desirable intervention: The same regenerative action applied as a model on the iconic architecture of the Romanian villages, the church. The study was done for the church from Cojocna [1], a restoration work-in-progress but without PV tiles, with wooden shingles that changed a metallic roof. The village's iconic building could be un input on excellent assimilation by the local community of a technological intervention sometimes hard to be accepted by more conservatory people.

Figure 1: Render images of PV tiles grey color church roof versus existing photos taken in January 2013 from similar positions, published in 1. Diţoiu Nina-Cristina, Mihaela Ioana Maria Agachi, Mugur Balan, , "Newness touches conventional history: the research of the photovoltaic technology on a wooden church heritage building", p.4., figure 3)

Research Aims

The regenerative action of using PV solar roof tiles on vernacular architecture in a rural area with a forceful identity or just a cultural heritage of the geographic area, humanistic approach versus technological approach could be an issue. The proper answer is to mediate them in order to achieve the best option. The secondary aims of my research are to define the input dates for the technical calculus that generate a technical answer. The primary goal is to generate the optimum answer, starting from the humanistic and technical as an easy replicable holistic approach.

Research Problems, Questions, Hypotheses

The goal is to mediate the humanistic approach of cultural heritage and the technical approach of technological intervention and the hypotheses can be defined as:

- the use of the technology in order to reduce energetical poverty **versus** sustaining the tradition of preservation after ICOMOS's nowadays specified charters, the conditions of including the PV technologies probably follows to be indicated in a new ICOMOS's charter;
- the denying the opportunity of PV technology and the appropriation to a cultural landscape with many historical values **versus** adopting the PV technology without worrying about the cultural impact as a climate change adequate action.

Figure 2: Photos taken in January 2021, Rusor, Hunedoara county, Romania / cad drawings after published documents by Stoica Georgeta and Petrescu Paul in "Dicţionar de artă populara", Ed. Enciclopedică, 1997.

Research Methodology

Study case Rusor, Hunedoara county, Romania - to evaluate the opportunity of regenerative action to the scale of locality and the cultural heritage impact:

• first evaluate the opportunity of regenerative action to a documented vernacular residential architecture specific to the cultural local environment that can be easily replicated;

• calculate in the preliminary design stage the energy production versus evaluated energy consumption;

• introduce results as input dates in a humanistic analysis.

Research Results / planned or achieved

In the case study from Rusor, Hunedoara county, the energy produced covers the estimated consumption evaluated both in the preliminary design stage with dedicated software (Pvsyst, https://www.pvsyst.com /Polysun, https://www.velasolaris.com). Similar studies were done in different localities from Transylvania, Romania.

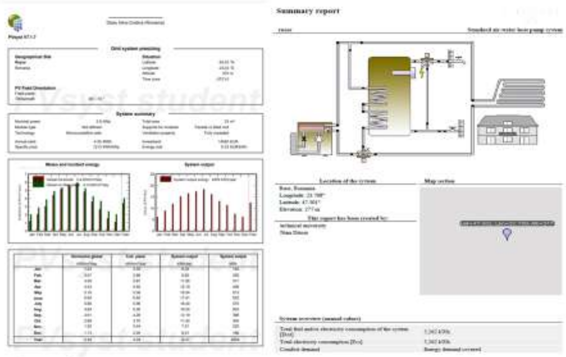

Figure 3: Preliminary design stage reports from dedicated software Pvsyst - https://www.pvsyst.com/ Polysun- https://www.velasolaris.com/

Disseminations / References

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Simulation tools and models for the analysis of PV system performance

DigiTwin PV Digital Twins in Photovoltaics for failure detection

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Introduction

Ongoing digitalization leads to the necessity for more digital models of hardware components which are only described in an analog way up to now. The focus of interest is on describing photovoltaic (PV) modules' behavior under different failure modes. In the project DigiTwin PV, the modeling of PV modules and components will mainly performed by physical models. The model approach will consider the integration of a defective module in an operational string or a functioning module in an underperforming string. The full digital models will describe PV behavior in a simulated environment (e.g. string) for a physical counterpart (e.g. module). The models will be transferrable to other modules types and technologies or to strings of entire PV power plants (see Figure 1).

Figure 1: Digital Twin of Photovoltaic systems (Source: Reuniwat SunSat™)

Research Aims

- Failure of modules and strings
- Investigating ageing of modules
- More precise energy yield predictions

These aims will be achieved by expanded physical models, validation through real modules and integration of thermal simulation model of AIT.

Research Problems, Questions, Hypotheses

The main problems addressed in DigiTwin PV are:

- The usefulness for digitalization of physical PV modules
- Lack of correlation of correlation between systematic laboratory failure analysis and digital models of modules
- The precision of models to identify physical failure by comparing or fitting experimental data
- Lack of representation of thermal characteristics in electric models
- The possibility to transport digital models of failures to HIL setups for investigation and testing

The work hypothesis is a sound and generalized physical model of PV modules allowing;

- to more reliably find failures in modules and strings under measurement
- to identify failures and ageing in measured electric characteristics of modules, strings or power plants at an early stage
- to be coupled with electrical and thermal behavior

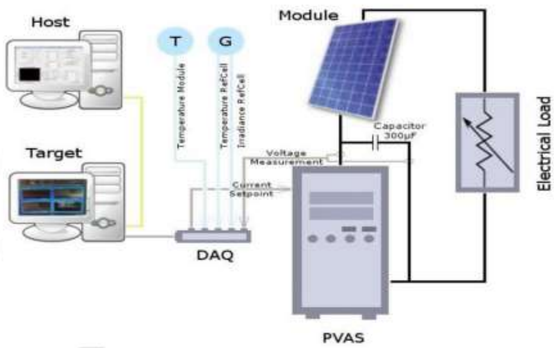

Figure 2: Hardware in the loop (HIL) setup to evaluate the behaviour of an individual module under simulated weathering with the rest of the string being simulated (Source: DOI: 10.25365 / thesis.35702)

Research Methodology

- Parametrization of the modules using existing and expanded physical models of solar cells and modules
- Validation of the models using real modules showing certain failure patterns

Real damaged modules will be connected to a HIL environment of simulated functioning modules of a string (see Figure 2). The modules will also be analyzed using standard characterization methods.

- Implementation of AIT thermal model

The digital twin will couple a temperature dependent electrical cell production with a thermal model of the PV module.

The model will be used to create the "Digital Twin" of real defective modules in a HIL environment.

Research Results / planned

Digital Module Twin (DMT)

- Digital models for damaged modules of different error classes
- Influence of complex shading on IV-characteristics

Digital PV Plant Twin

- Facility performance evaluation regarding early determination of degradation or failure
- Determination of power induced degradation from monitoring data streams
- Analysis of function, performance and failure of modules with integrated electronics

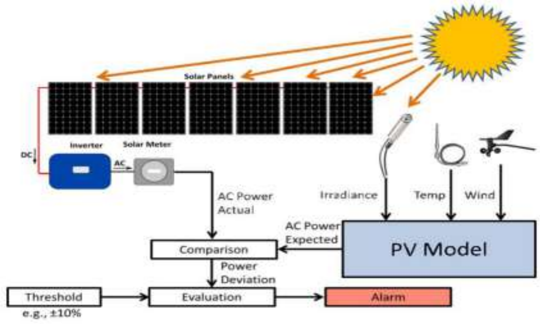

Figure 3: Schematic of PV prognostics and health management system (Source: DOI:10.1109/PVSC.2012.6317887)

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Bernhard Kubicek, Scientist at AIT

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Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

Detection and diagnosis of failure modes based on the array state parameters

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tecnalia MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

Introduction

- Expected lifetime of photovoltaic (PV) plants is of the order of 30 years
- Operation and Maintenance (O&M) tasks are required to maintain PV plant performance
- Nowadays preventive O&M tasks are carried out on-field, based on a schedule, meaning higher costs
- Predictive O&M based on the remote analysis of SCADA data is required to improve LCOE of new PV plants

Research Aims

- Development of algorithms to check or improve the reliability of the SCADA data
- Development of algorithms for failure detection and diagnosis from SCADA data of PV plants
- Forecast of energy loss in case that failure modes are detected

Research Problems, Questions, Hypotheses

- Is it possible to decouple/distinguish the effect of different simultaneous failure modes affecting the PV array?
- Is it possible to detect severe failure modes if they only affect a small number of PV module in a large PV array?
- What sensitivity level can be achieved for failure detection based on uncertainty of the measurements?
- How can the operation conditions influence on the reliability of the detection and diagnosis of failure modes?

Research Methodology

- Disaggregated analysis of maximum power point voltage and maximum power point current
- Analysis from a hybrid physical – statistical approach (Figure 1)
- Use of existing physical models to understand PV array behavior and detect failure with short datasets
- Use of data-driven techniques to improve reliability of the PV models and the sensitivity for failure detection

Research Results / planned or achieved

- Assessment of the open circuit voltage (Voc) at PV array level under standard test conditions (Figure 2)
- Assessment of series resistance of the PV array at high irradiance conditions (Figure 3)
- Expected the detection of failure modes based on these and additional array state parameters

Disseminations / References

- J.D. Santos, G. Maugeri, "Detection and Diagnosis of failure modes based on the array state parameters, PV metrics & ML approach", GoPV project, What's Hot In European Solar R&D – Overview on First Results of EU funded Horizon2020 PV Projects , TaiyangNews (online event)
- GoPV project - https://www.gopvproject.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 792059

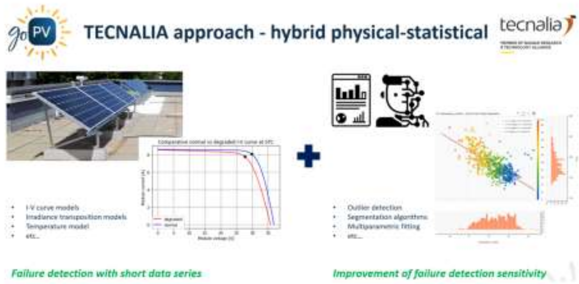

Figure 1: Proposed hybrid physical-statistical approach for failure detection and diagnosis algorithms

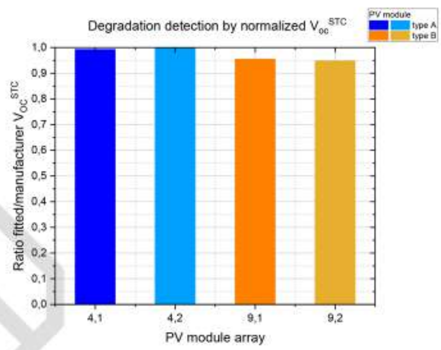

Figure 2: Two PV arrays of different module technologies present differences in the degradation level of Voc, which could be linked to a specific set of failure modes.

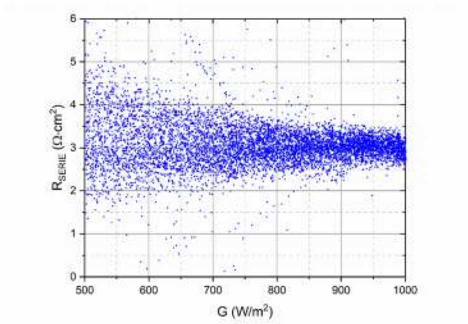

Figure 3: Estimation of series resistance based on the combined information of open circuit voltage and maximum power point voltage

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Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

Estimation of Photovoltaic Soiling using environmental parameters

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Introduction

- Monitor soiling is essential to achieve an optimal mitigation strategy.
- There are several tools to monitor soiling: soiling stations, soiling extraction algorithms and soiling estimation models (Fig.1).
- Estimation models are based on: the variability of and the interaction between environmental parameters, as well site characteristics and system configuration.
- Constantly updated satellite data is available worldwide at fine temporal and spatial resolutions.
- Existing models are based on a single or a few sites, nevertheless need to be globally implemented.

Research Aims

(i) Compare the different existing estimation models and validate them in different locations ;

(ii) Create a robust estimation model using environmental parameters for a worldwide applicability and mapping PV soiling losses,

(iii) Use the estimation models to optimize the mitigation strategy and optimize the O&M activities .

These aims/objectives will be achieved by modelling soiling using satellite environmental data available at large temporal and spatial scales and ground-measured PV and soiling data.

Research Problems, Questions, Hypotheses

- Soiling is a site specific phenomena with spatial and temporal variability;
- Different accuracy between satellite and ground-measured environmental data is observed;
- The existing estimation models are developed using data from a single or, at most, few sites. Comparative analysis are still lacking.
- How accurate is possible to estimate the soiling losses with satellite environmental data?

Research Methodology

The current research methodology (Fig.2) includes:

- Comparison of four existing estimation models;
- For each model, a soiling profile (i.e. saw-tooth wave with alternating periods of dust accumulation and cleanings) will be generated by using only environmental data sourced from MERRA-2 and a local weather station;
- The models will be validated with the ground-measurements from the soiling station,
- The quality of the models will be compared also with different levels of rain that restore the model to the cleaned level (i.e., cleaning threshold).

Research Results / planned or achieved

- Four models presented in the literature (i.e. Bergin, Coello, Toth and You) were tested in Jaén,Spain and validated against a ground-based soiling station (Fig.3).
- High overestimation (4%) using Bergin's model observed in dry periods with a high concentration of organic carbon in the atmosphere.
- Coello's and You's models returned the best correlation with the soiling station for this specific location;
- The modelling error increases as the cleaning threshold increases. The model less affected by the increase in the cleaning threshold is You's model.

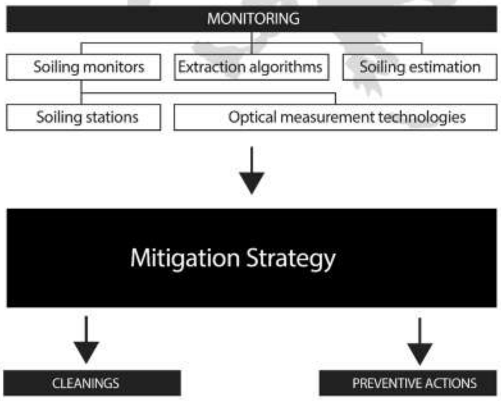

Figure 1: Description of the soiling monitoring and mitigation strategies.

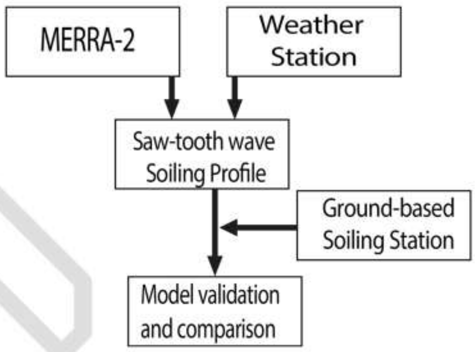

Figure 2: Methodology used to model the soiling profile, where the satellite data and the local environmental data are used as inputs. The validation is performed with a commercial soiling station. The result of the modelling can be either a long-term average or a daily soiling losses.

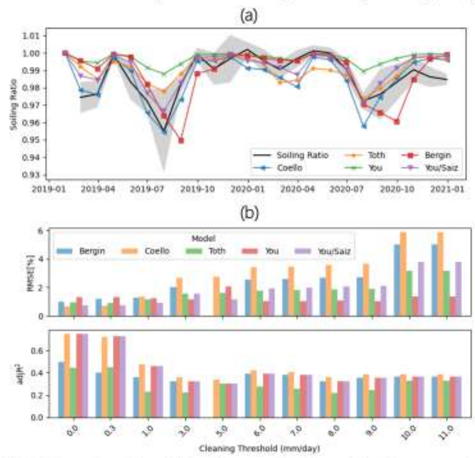

Figure 3: (a) Comparison of modelled and measured soiling profiles. The measured average soiling ratio and the standard deviation are represented in the black line and by the shaded area. (b) The RMSE and the R^2 for the different models and their correlation with distinct cleaning thresholds (i.e. minimum amount of rainfall to clean the PV modules).

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PV fault diagnosis using full I-V curves and machine learning

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Introduction

Current-voltage characteristics (I-V curves) contain rich information about the health status of PV array. In literature, commonly only partial information of I-V curves is used for PV diagnosis. It is rarely presented a strategy to make full use of the I-V curve for multiple PV fault diagnosis.

Research highlights

(i) A novel methodology based on full I-V curves is proposed and outperforms traditional methodology based on partial information of I-V curves;

(ii) Two feature transformation techniques are firstly applied with I-V curves and proved able to improve the discriminability of features

PV array modelling

A small-scale PV array model (Figure 1), which corresponds to the field test, is constructed under Matlab Simulink. The array consists of 6 sc-Si modules. 8 conditions are studied, healthy, partial shading (PS) (1 or 2 modules shaded), short-circuit (SC) (1 or 2 modules SC), open-circuit (OC), Rs and Rsh degradation.

Based on the model, two datasets are generated, one for training and another for test. For each curve in the dataset, G is varied in [400,1200] W/m2 and Tm in [10, 80] ° C. With the disturbance added, the training dataset contains 12000 I-V curves (each condition has 1500 curves). The test dataset contains 2400 curves with each condition of 300 curves with examples in Figure 2.

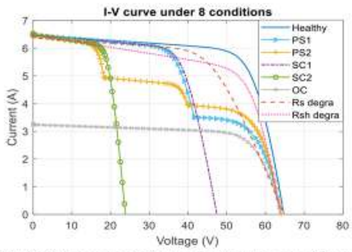

Figure 2: Examples of simulated I-V curves under 8 conditions

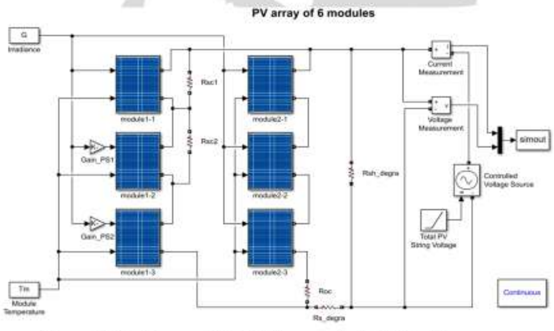

Figure 1: Simulation model of the PV array under Matlab Simulink

Feature pre-processing and extraction

Different methodologies are considered to achieve corresponding objectives:

(i) **Correction of I-V curves:** I-V curves are corrected to standard test condition (STC) using a novel procedure [1]:

$$I_2 = I_1\left(1+\alpha_{rel}(T_{m2}-T_{m1})\right)G_2/G_1$$

$$V_2 = V_1 + V_{oc1}[1+\beta_{rel}(25-T_1)][\beta_{rel}(T_{m2}-T_{m1}) + a\cdot ln(G_2/G_1)] - R_s(I_2-I_1) - \kappa\cdot I_2(T_{m2}-T_{m1})$$

where, I_1 and I_2, V_1 and V_2, T_{m1} and T_{m2}, G_1 and G_2 are the current, voltage, T_m, and G before and after correction; R_s is series resistance; a and κ are the curve correction factors; R_s, a, and κ are determined via simulation.

This procedure permits a better correction of I-V curves of faulty PV array than the IEC 60891 methods.

(ii) **Resampling of I-V curves:** Resampling is performed to make every I-V curve has identical number of points and also to guarantee a uniform distribution of points of curves. Specifically, a voltage vector with 50 points is constructed, at each voltage point, find the nearest point to form up a vector of current.

(iii) **Feature transformation:** Gramian Angular Difference Field (GADF) and Recurrence Plot (RP) are applied to transform resampled current vector into 2-D features. Besides, the direct use of current vector is named 'direct I-V'.

(iv) **Dimension reduction:** Principal component analysis (PCA) is applied to reduce the redundancy of feature information with the number of principal explaining at least 98% of the variance of the original data.

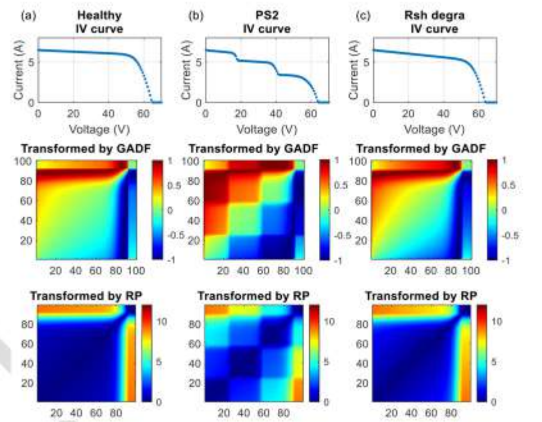

Figure 3: Examples of matrices transformed by GADF and RP: (a) Healthy, (b) PS2, (c) Rsh degradation (the value of each component on the matrix is marked by colormap)

Diagnosis results

In total, 6 MLT classifiers are applied: Artificial Neural Network (ANN) [2], Support Vector Machine (SVM), k-Nearest Neighbors (kNN), Decision Tree (DT), Random Forest (RF), and Naive Bayesian Classifier (NBC). The hyperparameters of the classifiers are determined by 5-fold technique. Direct I-V, RP and GADF is also compared with a typical method using partial curve information, i.e, 8 key features (named '8paras'), i.e.,G,T_m, V_{MPP} ,I_{MPP} ,V_{OC} ,I_{SC} ,R_s and R_{sh}.

The test results in presentd in Fig.5, full I-V curve-based methods (direct I-V, RP, and GADF) achieve better classification results than partial usage (8paras) with the best reaching 100%.

The random measurement error is varied from 0 to a higher level than that used in old test dataset to evaluate the robustness of classifiers. The results is detailed in Figure 5. It is observed that GADF experiences less decrease of performance with the increase of error. This demonstrates that GADF exhibits overall better robustness to the measurement disturbance than other types of features.

Besides, the best classifier is also validated by field test (shown in Figure 6) with 120 real I-V curves. Its performance also reaches 100% classification accuracy.

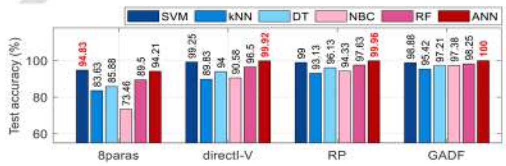

Figure 4: Test accuracy of all classifiers (the best accuracy is marked in red bold)

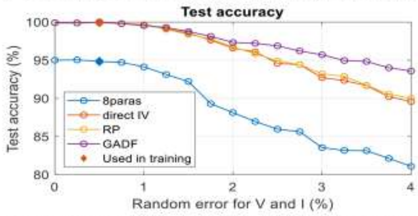

Figure 5: Best classification accuracy using test dataset with varying level of error

Figure 6: Setup of field test

Conclusions

- Full I-V curve-based methods achieve better classification results than partial usage
- Transformation of features (GADF) could improve the discriminability and the robustness of classifiers

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PEARL PV

3rd TRAINING SCHOOL

Braşov, Romania, July 2021

Simulation tools and models for the analysis of PV system performance

PV system monitoring and performance analysis in high latitude locations

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Introduction

Reliable monitoring with effective data processing is essential to establish efficient fault detection and performance analysis for PV systems. The existing solutions for affordable monitoring and analysis of commercial PV systems are however inadequate for high latitude locations (Fig. 1), where snow and highly varying weather result in unstable performance metrics. The aim of this work is to decrease instability in performance metrics, and additionally give improved understanding of the effect of snow, to enable more robust monitoring and improved performance analysis for PV systems installed in high latitude locations.

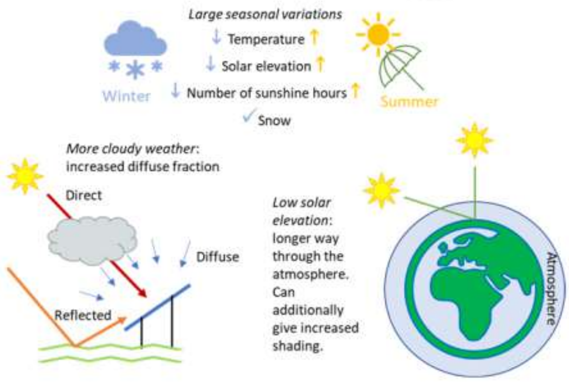

Figure 1: Nordic weather and irradiance conditions. Large seasonal variations in temperature and irradiance intensity, snow, cloudy weather and low solar elevation is typical for the Nordic countries and other high latitude locations.

Research Aims

(i) Improve PV system monitoring and performance analysis for high latitude locations.

(ii) Understand and predict the effect of snow on PV systems.

These objectives will be achieved by analysis of a MWp sized dataset of PV systems in Norway.

Research Problems

(i) Which challenges do we have in PV monitoring and modelling at high latitudes? [1, 2]

- It is assumed that cloudy weather, snow, and large variations in solar position and irradiance levels through the year will give conditions which are difficult to model. A consequence of this can be noise in performance metrics.

(i) How can these challenges be solved? [1, 2, 3]

- Possible solutions can be filtering, seasonal corrections, improved modeling - e.g. machine learning based modeling.

(i) How can the losses caused by snow be identified and predicted? [4]

- Is snow giving signatures in PV data that are different from system faults?
- What is the limitation of existing snow loss models? And can they be solved?

Research Methodology

Analyzed dataset:

- Commercial systems (Fig. 2): installed on flat roofs, >100 kW, 10° tilt, East/West orientation. Instrumented with reference cells and module temperature sensors.
- Residential systems: tilted roof, < 10kW, varying tilt and azimuth. No on site instrumentation.
- Other/research systems: farm house (tilted roof, 57 kW), ground mounted systems (< 30kW, with and without bifacial modules). Varying instrumentation.

Pvlib Python is used for modeling of PV and irradiance parameters. Where on site instrumentations are lacking, measurements from nearby weather stations are used.

Figure 2: Picture of one of the analyzed commercial systems. All the commercial systems have the same technical configuration.

Research Results

- Low irradiance, low solar elevation, cloudy weather, shading and snow introduces substantial noise in the analyzed datasets. Additionally observed analysis challenges are sensor data quality, and for the larger commercial system: topography variations. [1, 2, 5]
- Filtering, seasonal corrections and machine learning modeling can solve some of the detected challenges. [1, 2, 3]
- Snow gives characteristic signatures in PV data which is possible to separate from faults. [4]
- Of tested snow loss models, the Marion snow loss model gives best fit with measured snow loss data. The model can be improved by taking into account the effect of different snow and weather conditions on snow clearing (Fig. 3). [4]

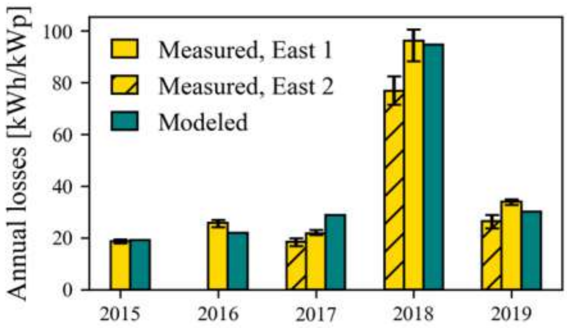

Figure 3: Measured and modelled snow losses for two of the commercial PV systems, installed in the same location in Eastern Norway, but on different roofs. The differences in losses is caused by difference in heat leakage from the building. The snow loss is modeled with tthe Marion model, but with assumed faster snow clearing for thin snow covers.

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APPENDIX 3 - Posters representing Current Research of Training School 4 participants

Posters representing the current research of trainees who participated in the Training School IV held in March 2022 at the University of Twente, Enschede, The Netherlands.

P ARL PV 4th TRAINING SCHOOL

University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Importance of Solar Resource & Weather Monitoring in the Performance of PV Power Plants

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Introduction

Renewable Energy, particularly solar PV is gaining importance because of its ability to mitigate climate change as a carbon free technology. Solar PV is the most popular method of energy generation in the world now with utility-scale PV plants constituting major share for energy generation. Solar Resource and Weather influence the performance of a PV Power Plant to a great extent.

Figure 1: A 2MW solar PV plat in South India

Research Aims

(i) Advanced Solar Resource and Weather Monitoring
(ii) Performance Analysis and finding the gap in performance
(iii) Improved O&M Practices for better performance

These aims/objectives will be achieved by 31 March 2022

Research Problems, Questions, Hypotheses

Many PV Power Plants are not performing well during their design life due to various technical issues. Advanced Solar Resource Monitoring is absent in many PV power plants. The quality of data collection is influenced by the accuracy of instruments and the methodology used for data collection at the site of PV plants. Advanced Solar Resource and Weather Monitoring can improve the performance of the PV plants.

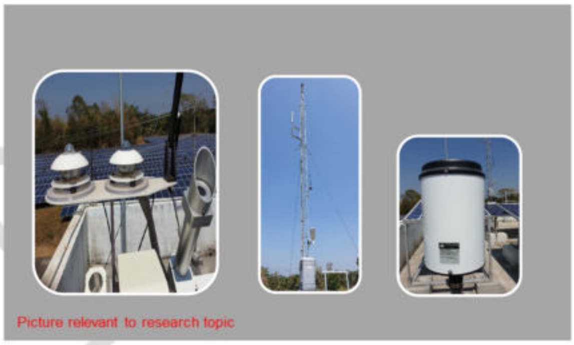

Figure 2: Advanced Instruments for Monitoring the PV Plant

Research Methodology

1.Advanced Weather Station for Solar Resource and Weather Monitoring
2. Performance Analysis utilising Software Tools
4. Methodology for improved O&M practices

Research Results / Achieved

1. Performance Analysis and finding the gaps in performance of the PV plant
2. Improved O&M Practices
3. Improved Performance Metrics

Figure 3: A view of the 2MWp PV Power Plant and Site Inspections

Disseminations / References

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Supervisor (Dr. Sudhakar Kumarasami, Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, Malaysia.

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University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Daily performance evaluation for a FPV System located on the reservoir of a hydro power plant under the Mediterranean climate conditions

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Introduction

This work is focused on experimental analysis of a floating photovoltaic system employed on the water reservoir of a hydro power plant with an installed capacity of 72 MW.

The trial unit is the biggest of its kind with an installed capacity of **500** kW_p and a floater diameter of $\varnothing = 68.8$ m.

Research Aims

It will serve as a testing unit regarding:

(i) the performance,

(ii) the reliability, and

(iii) will provide valuable information for its operation under Mediterranean climate conditions.

These aims/objectives will be achieved by using daily data (clear and cloudy typical days).

Research Problems

The daily energy performance of a trial floating photovoltaic unit located in a region with typical Mediterranean climate conditions belonging to the “Cs” group is carried out.

It was important to notice any operational problem for this unit (stability, etc.).

Research Methodology

It is based on:

a) the measured values of irradiance on photovoltaic array plane for the selected days (clear and cloudy).

b) the energy yield;

c) the final yield;

d) the performance ratio;

e) the capacity factor, and

f) the system efficiency.

Research Results / planned or achieved

For the considered days, the daily irradiation on photovoltaic array plane are
$H^d_{T-s} = 8.397$ kWh/(m²·day) for the sunny day and
$H^d_{T-cl} = 3.894$ kWh/(m²·day) for the cloudy one.

The daily energy generated is $E^d_{gen-s} = 3644$ kWh/day and $E^d_{gen-cl} = 1786$ kWh/day during the sunny and the cloudy day, respectively.

The daily final yields for the FPV system are $Y_{F,d-s} = 7.289$ kWh/(kW_p·day) and $Y_{F,d-cl} = 3.572$ kWh/(kW_p·day), respectively.

Daily values of the performance ratio for the considered FPV system are calculated to be $PR^d_s = 86.9$ % (sunny day) and $PR^d_{cl} = 89.8$ % (cloudy day).

Daily values of the capacity factor are $CF^d_s = 30.4$ % and $CF^d_{cl} = 14.9$ %, respectively for the sunny and cloudy day.

The sunny day has a daily value of system efficiency $\eta^d_{sys-s} = 17.4$ %, while for the cloudy one it is $\eta^d_{sys-cl} = 17.9$ %.

Disseminations / References

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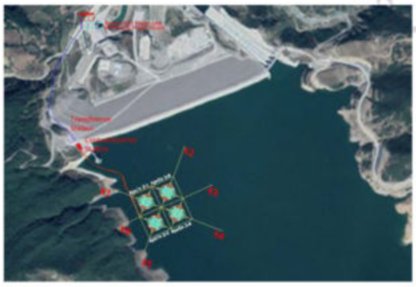

Figure 1: The placement of the FPV units on the reservoir surface of the Banja hydro power plant (Maraj et. al. 2021)

Figure 2: The utilized FPV unit (Maraj et. al. 2021).

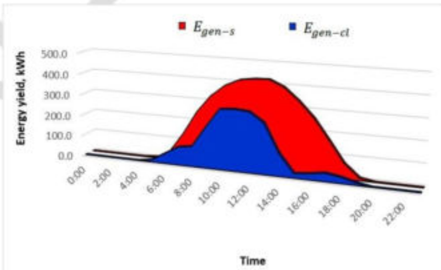

Figure 3: The generated energy (Maraj et. al. 2021).

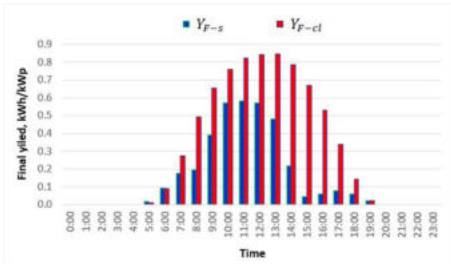

Figure 4: The final yield (Maraj et. al. 2021).

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Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Novel Low-Cost Soiling Detection Methods to Increase the Competitiveness of PV Systems

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CEACTEMA

Introduction

This project focuses on the design, development and optimization of innovative sensors for monitoring soiling depositing on photovoltaic (PV) modules worldwide. The aim is contributing to enhance the operation and maintenance (O&M) procedures in PV, to improve the energy yield and the revenues of the systems, while minimizing the correlated costs.

Soiling consists of the accumulation of dust, particles and contaminants on the surface of PV modules and affects PV systems worldwide. The soiling accumulated on the module reduces the intensity of the light reaching the PV cells and therefore the amount of energy converted by the module (see Figure 1).

Research Aims

Primary objectives

(i) Lowering the costs of PV soiling monitoring while maintaining high measurement quality.

(ii) Investigating different solutions and techniques for a better characterization of soiling.

Secondary objective

(i) Contributing to improve soiling mitigation approaches.

Research Problems, Questions, Hypotheses

Hypotheses

(i) Soiling can be estimated by using a single-measurement system, without need of a two-measurement station or of regular cleanings.

(ii) Low-cost and low-maintenance soiling detectors are required to provide a reliable and accessible soiling monitoring and can achieve high signal-to-ratio and high-quality soiling measurements.

Research questions

(i) Is it possible to develop a soiling sensor that takes into account the spectral dependence of soiling?

(ii) Can PV modules themselves be converted into real-time soiling monitors?

Research Methodology

My research methodology includes:

- The characterization and indoor validation of the PV optical soiling sensor "DUSST".
- The outdoor validation of the optical soiling sensor against commercial PV soiling stations. (see Figure 2).
- The field PV data analysis to extract soiling losses in real-time.

Research Results

- The operation of the soiling sensor DUSST has been validated both indoors [1] and outdoors [2]. Differences less than 1 % between the sensor results and the measurements of commercial soiling stations were returned for soiling losses up to 15 %.
- Soiling losses were directly estimated from the PV field performance of modules of different technologies. Different analytical methods were applied (see Figure 3). For some of them, differences lower than 2% between the measured soiling losses and the estimated ones were returned [3, 4].

Disseminations & References

[1] Á. Fernández-Solas, L. Micheli, M. Muller, F. Almonacid, and E. F. Fernández, "Design, Characterization and Indoor Validation of the Optical Soiling Detector 'DUSST'," Sol. Energy, vol. 211, pp. 1459–1468, 2020.

[2] M. Muller et al., "An in-depth field validation of 'DUSST': a novel low-maintenance soiling measurement device," Prog. Photovoltaics Res. Appl., no. 29, pp. 953–967, 2021.

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(a) (b)

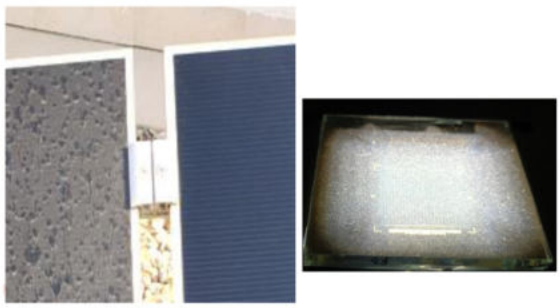

Figure 1: Soiling deposition. (a) Comparison between a soiled and a clean PV module. The image corresponds to a-Si PV modules installed at the University of Jaén.

(b) Artificially soiled PV cell under the light of a solar simulator.

Figure 2: Outdoor DUSST sensor side-by-side with an automatic soiling station as well as at a pyranometer installed at the University of Jaén, Spain..

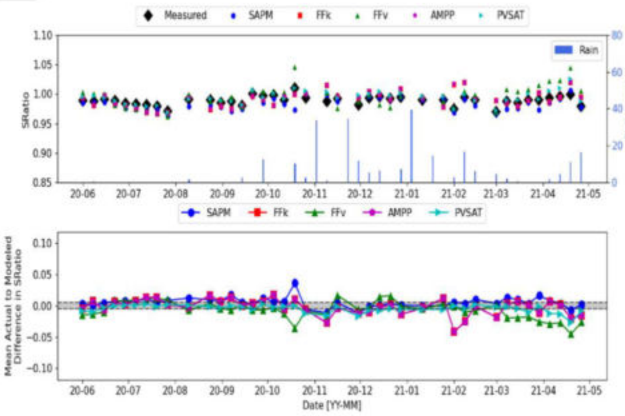

Figure 3: Soiling losses estimation from PV field data. Comparison of different analytical methods. Top: Measured and modeled weekly-averaged SRatio values for the m-Si technology. The blue bars represent the accumulated precipitation within a week. Bottom: Difference between weekly mean actual and modeled SRatio. The grey area represents a tolerance margin of ±0.005..

Supervisors:

Dr. Eduardo Fernández Fernández, University of Jaén

Dr. Florencia Almonacid Cruz, University of Jaén

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Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Fair power quality control for low voltage grids

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UNIVERSITY OF TWENTE.

Introduction

Grid codes dictate that photovoltaic (PV) inverters should cease generation if the voltage exceeds the specified limits.

As a result the farmers located at the end of the low voltage distribution network suffers from unwanted loss of generation due to over-voltage.

By smart coordination of distributed generation in low voltage network, different power quality issues in the LV network can be tackled considering the fairness among the prosumers.

In addition to this, the hosting capacity of the grid is also improved.

Research Aims

(i) Develop control methods for (groups of) generation assets (mainly PV) in rural farming areas where the hosting capacity of the grid is scarce that limits the integration of renewable energy sources.

(i) Fairness for prosumers considering different factors influencing fairness.

(ii) Tackle issues of over-voltage, undervoltage, and unbalance.

(ii) Modelling of a diary farm.

(iii) Develop energy management systems for a dairy farm taking into account the power quality of the network.

Research Problems, Questions, Hypotheses

(i) How can a heterogeneous set of PV inverters be controlled to curtail power in a fair way, respecting grid limitations?

(ii) How should fairness be defined?

- Different factors that influence fairness are interdependent. Thus, definition of fairness can depends on the primary objective of the user.

(iii) Can optimum hosting capacity of the feeder be achieved by improving the power quality of the network utilising PV inverters?

Research Methodology

(i) Sensors are installed at the point of common coupling of the dairy farm and other interesting locations in the radial feeder. This data is used to examine the real case scenarios.

(ii) Advanced control algorithms are developed taking into account the available data.

(iii) Current algorithms are developed in the Toolkit (DEMKit) developed by our group. This toolkit will be incorporated in the hardware developed by our project partner.

(iv) Trails, experimentation, improvision and validation.

-The hardware developed will be utilised for this step.

Research Results / planned or achieved

(i) A novel analytical control algorithm for fair overvoltage control in low voltage distribution network.

(ii) The designed analytical control algorithm maintains fairness in terms of PV harvesting.

(ii) The proposed technique is computationally efficient compared to classical perturb and observe method for sensitivity analysis.

(iii) A solution for unbalance mitigation utilising PV inverter.

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prof.dr. J.L. Hurink

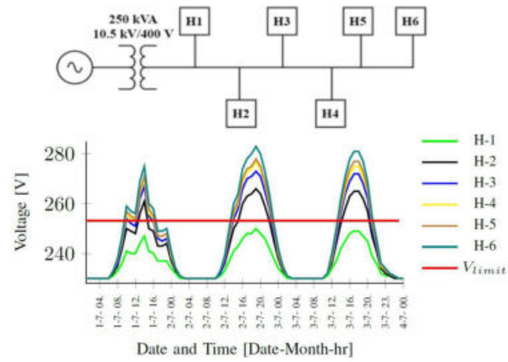

Figure 1: Voltages at different Point of Common Coupling

Figure 2: Different factors influencing Fairness .

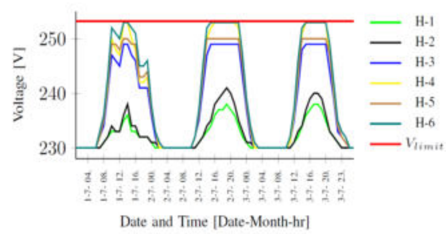

Figure 3: Voltages at different Point of Common Coupling after control

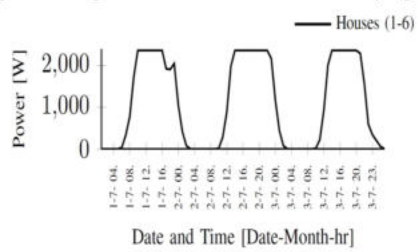

Figure 4: PV power output for all houses connected to the radial feeder.

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Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Machine Learning to Understand Solar Cell Performance

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University of Glasgow

Introduction

- Abstract

A machine learning approach for extracting information from perovskite solar cell (PSC) cell data is presented. A database consisting of 7026 entries of device characteristics, performance and stability data is utilised and a sequential minimal optimisation regression (SMOreg) model is employed as a means of determining the most influential factors governing the solar cell power conversion efficiency (PCE). The aim is to capture and analyse trends in PCE data through machine learning technologies to generate models and heuristics for predicting performance. Different machine learning models were tested, with random forest providing the best results in predicting PSCs efficiency. However, to better deduce the factors that influence solar power conversion efficiency (PCE), the SMOreg model was also used. The attribute weights which show the relative influence of a material or process upon cell performance. The results of the research allow for the identification of features and layers that may result in improvement in PCE through device design, as well as highlighting the role of various elements in PSC deterioration.

- Perovskites based PV cells

Perovskites are a group of materials that form a molecular structure of ABX3, and it is derived initially from the CaTiO3 compound. Within a decade of the first report, the efficiency of PSCs increased to 25.2 %, and still further research and developments studies are being conducted to improve stability and efficiency [1].

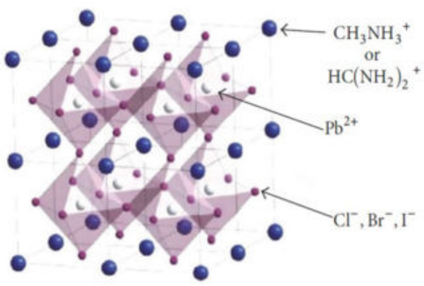

Figure 1: Hybrid perovskite-crystal structure [2]

Research Objectives

- General objective : To analyse the efficiency of PSCs using statistical and machine learning techniques based on large datasets from literature research.

- Specific objectives :
  - To understand the trends in PSC efficiency by visualizing and analysing a large dataset of PSC performance data
  - To Review machine learning approaches and find out the most appropriate approach for the given dataset.
  - To determine the top attributes that influence PSC efficiency

Research Methodology

- Data Gathering and Cleaning : A careful examination of the data is necessary to verify that no unanticipated values exist, which might have a substantial impact on the outcome. Data obtained from the literatures need to undergo cleaning. In this stage, irrelevant parts of data are eliminated, and these include missing and inaccurate values, unrecognizable symbols.
- Data Exploration and Modelling :After the cleaning phase, the data becomes consistent in structure, allowing patterns, relationships, and trends in the data to be examined using data exploration and modelling. The final step is interpretation of the models generated. The goal of data exploration is to discover patterns and correlations in data. In this study, violin plots were used.

Research Results

- Data visualization

The aim of data visualization is to find patterns and correlations in data by visualizing various attributes against device efficiency thru violin plots. The distribution of JV reverse scan for a PSCs and the type of electrode1, is shown in the Figure 2.

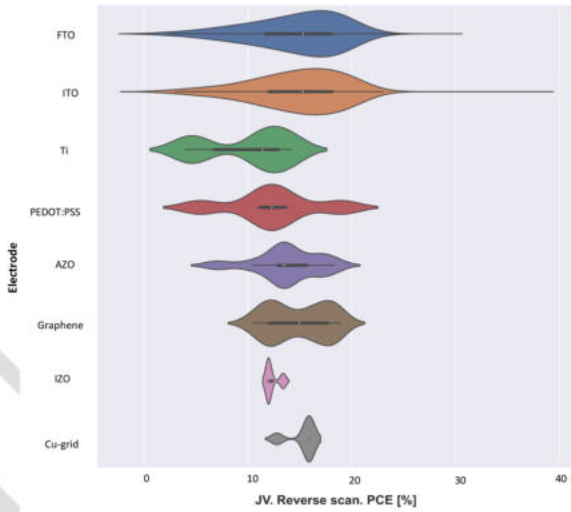

Figure 2: Distribution of different electrode types vs PCE

- Predicting the efficiency by random forest analysis

Table 1: The algorithm performance metrics for the entire dataset , nip ,nip-mp ,nip-mp-carbon and pin using cross validation

Metric	Entire Dataset	Type of Cell architecture			
		nip	nip-mp	nip-mp-carbon	pin
Correlation Coefficient	0.745	0.7349	0.718	0.5974	0.7257
Mean Absolute Error	2.2659	2.2452	2.4173	2.0878	2.1947
Root Mean Squared Error	3.082	3.1103	3.2951	2.7926	2.9397
Relative Absolute Error	61.1725 %	61.7594 %	64.4538 %	75.1694 %	65.0892 %
Root Relative Squared Error	66.8324 %	67.9486 %	69.8927 %	79.8072 %	68.878 %
Number of Instances	5959	2289	1664	280	1724

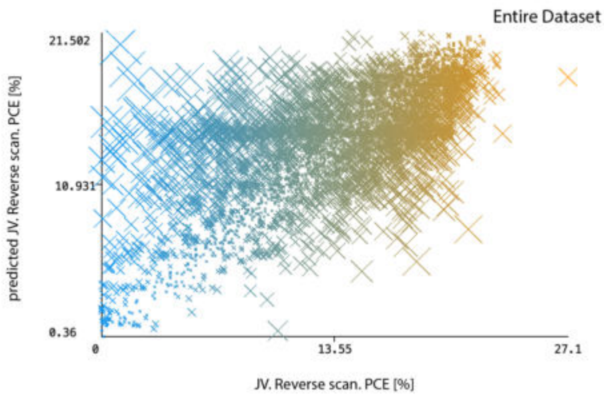

Figure 3: Random forest prediction of PCE plotted against the actual PCE values for the entire dataset

- Using SMOreg algorithm to understand the efficiency data

Table 2: Overall factors for PCE enhancement for all dataset

All Data			
Positive Attributes		Negative Attributes	
Name of Factor	Weight	Name of Factor	Weight
TL7-back	0.1248	Perovskite composition C-ions	-0.7879
TL2-front	0.1151	Band gap	-0.6205
TL3-front	0.0952	Perovskite composition B-ions	-0.5852
TL6-back	0.0669	Electrode2	-0.168
TL5-back	0.0408	Substrate	-0.1247
Perovskite composition A-ions	0.0322	Module	-0.0997
		Electrode	-0.0674
-	-	Cell. Architecture	-0.0302
-	-	TL4-back	-0.0104
-	-	TL1-front	-0.0004
-	-	-	-

Sequential minimal optimization regression was applied to identify the overall key factors contributing to high efficiency in PSCs and determine the degradation factors if possible.

Supervisor

Dr. Jeff Kettle ,University of Glasgow

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University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Potential Improvements to PV Systems O&M through Automatic Fault Detection

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TÉCNICO LISBOA

Introduction

The traditional maintenance of PV systems is mainly based on periodic inspections. Those practices cannot guarantee optimum performance. O&M companies are increasingly investing in online monitoring for remote problem identification. This is an emerging topic that requires further research into the effectiveness of different emerging automatic fault detection technologies, as well as the potential gains from their adoption.

Research Aims

(i) Quantify the potential energy gains from adopting automatic fault detection in online monitoring of PV systems.
(ii) Estimate the energy losses due to the delay in detecting problems with conventional inspection routines.
(iii)Measure the effectiveness of the most common methods for automatic fault detection.
These aims/objectives will be achieved by ...

Research Problems, Questions, Hypotheses

How much energy gains can be expected by adopting automatic fault detection within the online monitoring routine?
In a portfolio of medium sized PV systems, how much energy is lost on average until failures are detected in annual preventive inspections?
How effective are the current methods for automatic fault detection in PV systems?

Research Methodology

Gather from the literature the characteristics of the most common failures.
Develop a simulation framework to calculate their impacts according to systems topology.
Estimate fault energy losses while waiting for the annual inspections.
Use field data to measure the efficiency of most common fault detection methods.

Research Results / planned or achieved

Failures' characteristics have been gathered from a careful selection of data from the literature [1]. See figure 1.
A simulation framework suitable for PV arrays under mismatch conditions has been developed [2]. See figure 2.
Estimating energy losses due to yet undetected faults in a portfolio is currently under development.
The tests of automatic fault detection algorithms with field data are being finalized. Preliminary results have shown a potential to detect up to 47% of the problems and 95% of the energy losses [4]. See figure 3.

Disseminations / References

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Supervisor (Prof. Ph.D., Paulo J. da C. Branco, IST-UL)

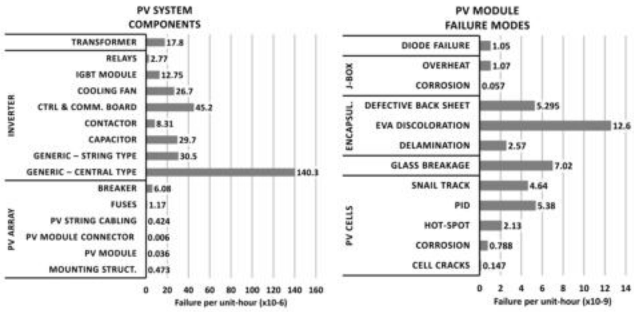

Figure 1: PV system components failure rates obtained from the literature [1].

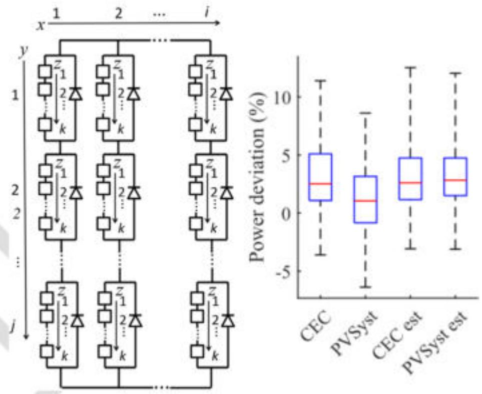

Figure 2: Cell connection layout used for the PV array simulation under mismatch conditions. Distribution of resulting errors in the MPP simulation for four sets of reference parameters. [2]

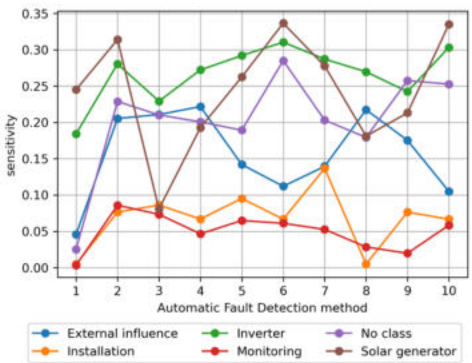

Figure 3: Result from sensitivity tests according to fault type for ten automatic fault detection methods [3].

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Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Quantifying the rear and front long-term spectral impact on bifacial photovoltaic modules

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Universidad de Jaén

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Introduction

- Bifacial photovoltaic modules main advantage is the ability to capture the irradiance from both front and rear sides.
- These modules are spectrally sensitive as any photovoltaic device.
- One of the main pending analysis for the b-PV technology is the spectral impact, especially the influence of the rear incident spectrum, which changes depending on the ground type.
- Three locations are considered (Tabernas (Spain), Solar Village (Saudi Arabia) and Alta Floresta (Brazil)) ,with four ground types (light soil, white sand, green grass and concrete slab).

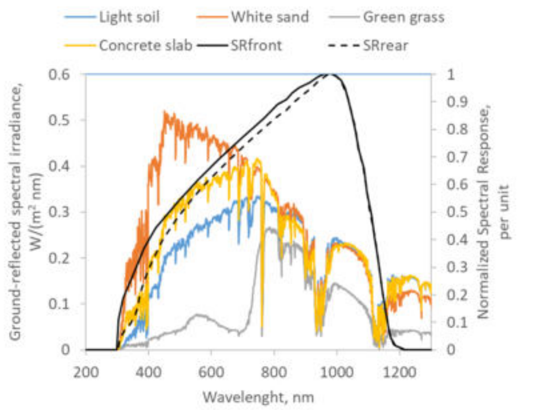

Figure 1: Ground-reflected spectral irradiance of the four selected ground types and typical normalized spectral response of the front and rear sides of a crystalline silicon bifacial cell.

Research Aim

Goal: Quantifying the rear and front long-term spectral impact on bifacial photovoltaic modules.
This will be done by studying:

- The front spectral factor (SFfront) for the facing sun side of the b-PV module.
- The SFrear, that was defined by an analogy to the SFfront, to quantify the impact on the rear side.
- The Bifacial Spectral Factor BSF, is our definition for an index that quantified the combined front and rear spectral impact.
- The crystalline silicon bifacial photovoltaic module was considered.

Research Problems, Questions, Hypotheses

The problematic of this work is :

- Spectral correction to the front, rear and total power output of a bifacial photovoltaic module.
- The variation of the SFfront and SFrear with the atmosphere conditions, and with the reflective characteristics of the ground.

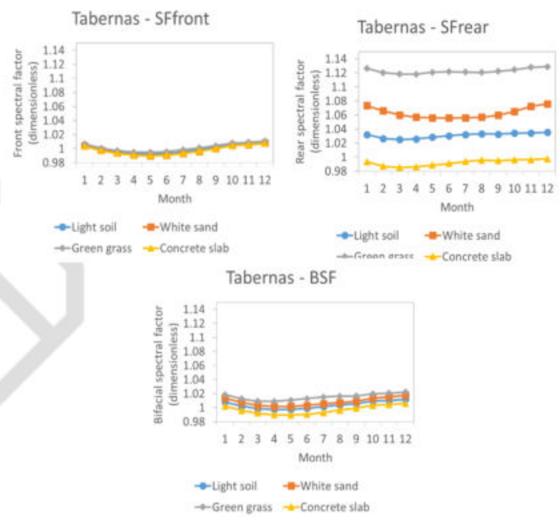

Figure 2: Monthly behavior of SFfront (up left), SFrear (up right) and BSF (down) in Tabernas considering the four types of analysed grounds.

Research Methodology

The front side:

- The SFfront is mainly determined by the changing characteristics of the atmosphere. (AM,AOD,PW…)

The rear side :

- The view factor theory, was used for the rear side irradiance.
- The ground types analysed in are light soil, green grass, white sand and concrete slab.
- The grounds spectral albedos were simulated with SMARTS.

The combined impact:

- The combined front/rear spectral impact was quantified with **the BSF (bifacial spectral factor)**
- BSF > 1 mean's that the combined spectral effects of the front and rear sides are positive for the electrical power.

Research Results / planned or achieved

- Monthly results shows a large variation of SFrear with ground type, and a modest one for the SFfront (Fig2).
- Green grass is the most spectrally favorable ground, followed by white sand, light soil and concrete slab.
- The maximum SFrear takes place in January in Alta Floresta for green grass with a value of **1.156**, while the minimum SFrear takes place in March in Tabernas for concrete slab with a value of **0.985**.
- The maximum BSF takes place in this case in December in Alta Floresta for green grass with a value of **1.026**, while the minimum BSF takes place in June in Solar Village for concrete slab with a value of **0.985**
- When SFrear is very high (e.g. green grass), the traditional SFfront need to be increased up to **2.5%** for performing an accurate bifacial spectral correction.
- The difference between the annual BSF and SFfront depend mainly on the ground type. For the most spectrally favorable ground green grass ,the BSF would be underestimated between **1.19% and 1.65%.**
- For the most spectrally unfavorable ground, the concrete slab, the traditional methodology would perform better, from **0.12%** of underestimation to **0.27%** of overestimation (Fig3).

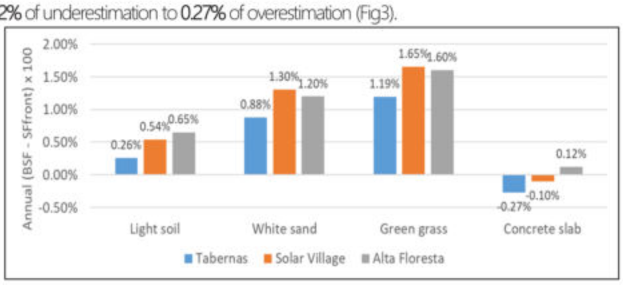

Figure 3: Difference between the annual bifacial spectral factor and the annual front spectral factor in percentage in Tabernas, Solar Village and Alta Floresta considering the four types of analysed grounds.

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PEARL PV 4th TRAINING SCHOOL

University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

A GIS-AHP approach for floating PV systems in Turkey

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Kemal Koca, Sivas Cumhuriyet University, Sivas, Turkey

Introduction

Renewable energy systems have gained the more reputation to tackle the global warming around the world. Because of the decrease the suitable land regions and protect the productive agricultural regions, floating PV system is the most promising option to produce electricity. Floating solar PV system is the explored technology which uses the water surface for energy production. Water sources or bodies such as canals, lakes, ocean and irrigation dams can be used for floating solar PV [1]. Because of the cooling effect of water surface, the floating solar PV system has a lower temperature. As the lower cell temperature of solar panels, floating solar systems can produce 11% more energy than the land-based solar panels [2]. This study investigated the suitability of determined three lakes in Turkey for floating solar systems under technical, environmental and accessibility criteria set using GIS-AHP approach.

Figure 1: Floating solar photovoltaic power plant.

Research Aims

State clearly the primary and secondary objectives of the research

(i) Determining the weight scores of each criterion for floating solar PV systems installations with experts' options,,

(ii) Evaluating the suitability of determined three lakes using ten sub-criteria,

(iii) Creating the novel method and road map for potential floating PV systems installation in Turkey.

These aims/objectives will be achieved by an article study.

Research Problems, Questions, Hypotheses

- It may be encountered with an issue in terms of obtaining the recent data with regards to daily sun exposure for related lakes.
- As mentioned before, critical questions with regards to installation of a floating solar panels will be asked for the experts, academicians and researchers during the presentation in Training School. For more accuracy output from the research, the questions should be asked to as many researchers as possible. In this Covid-19 period, it is a big question mark if we have enough people in order to direct these questions.

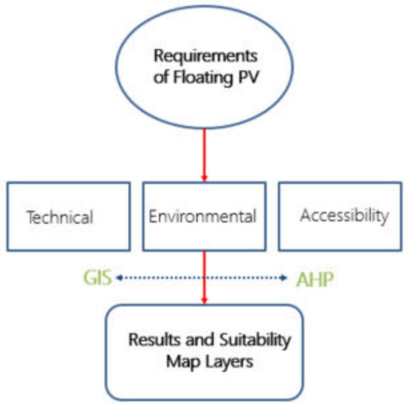

Figure 2: Methodology chart of the study.

Research Methodology

The research methodology consisted of three important steps. Firstly, requirements of floating PV were determined with deep literature investigation. Ten important criteria were determined under three main criteria in the second step. After ensuring the experts' opinions in the Training School, Analytical Hierarchy Process (AHP) structure will be concluded, and results map layers will be obtained in the last step. Figure 2 represented the roadmap of study.

Research Results / planned

The objective of this research was to study with regard to suitable site selection of a floating solar PV panels for selected three lakes located in Turkey. Firstly, AHP structure was created, surveys need to be filled in experts who will be participated in the PEARL PV in Training School. After filling in surveys, consistency index is going to analyze and pairwise comparison matrices will be prepared. With completed the AHP studies and ensured weight score, map layers will be prepared. Depend on all criteria analysis, result map layer will be obtained and suitability of determined three lakes for floating PV systems will be discussed. Figure 3 shows that the global horizontal irradiance and water bodies in Turkey prepared by using GIS.

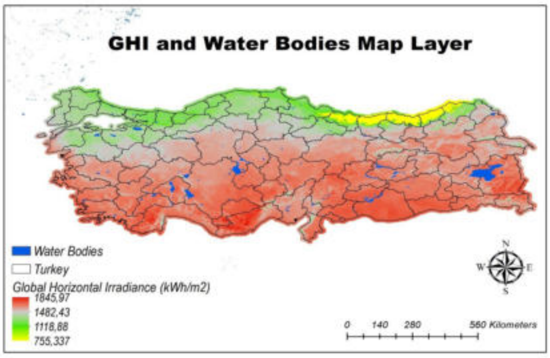

Figure 3: Global horizontal irradiance and water bodies Turkey prepared by GIS.

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PEARL PV

4th TRAINING SCHOOL

University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Solar irradiance classification for improved PV performance assessments

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Introduction

Solar resource assessments offer valuable information in photovoltaic (PV) system analyses, and day type classification of irradiance patterns is a simple application with wide ranging use cases. A novel methodology is developed based on either satellite direct normal irradiance (Dni) data or DC output data from the analysed PV installation, with initial calibration using ground-based cloud coverage data. Four weather types are differentiated: overcast, cloudy, nearly cloudless and cloudless (see Figure 1).

Research Aims

The main objectives of this research are the following:

(i) Create a robust, versatile and easy-to-use daily weather classification tool,

(ii) Benchmark the tool with meteorological data and compare with other methodologies,

(iii) Highlight the potential uses and added value of weather classification in PV monitoring.

These aims will be achieved through careful tuning of the classification algorithm, and showcasing the uses with real PV system data.

Research Problems, Questions, Hypotheses

As highlighted by the IEA PVPS Task 13 experts, data filtering and pre-processing is a vital PV system analysis and monitoring, and yet can often be neglected or insufficient. Current methods for weather type classification in PV rely on simple clear-sky filters, often based on one parameter and threshold cut-off, which can be limiting when looking to differentiate more than one weather type. The proposed day type classification can therefore be a valuable addition to analysis pipelines. Moreover, solar irradiance categorisations generally lack clear calibration methods, which can create robustness issues when comparing different tools. The end goal is to use this tool to enhance PV monitoring outcomes, such as fault detection or long-term performance assessments.

Research Methodology

The research methodology includes (i) Deterministic clustering approach for day types using support vector classification (SVC) and linear thresholds, based one three parameters: transmittance index, a quantification of daily signal variability, and the Pearson correlation between actual and clear-sky signals, (ii) Fault detection and diagnosis algorithm for shading and electrical faults, which makes use of day type classification to identify fault types (see Figure 2), (iii) Performance Loss Rate (PLR) filtering step for the performance ratio (PR) to isolate clear performance trends from PV system data by selecting cloudless or nearly cloudless days (see Figure 3).

Research Results / planned or achieved

Initial calibration of the day type classification tool is carried out using 5 years data of cloud coverage data from MeteoSwiss as a benchmark, and the SVC model reaches 85% accuracy. Initial comparisons with the RdTools library clear-sky index filter show increased robustness with fewer false positives. In terms of use cases, Figures 2 & 3 show results for fault detection and PLR computation, respectively. Recurring shading patterns and snow cover faults are identified for the studied system, and a clear performance trend is observed with the day type filtering.

Further results will include additional weather type filter comparisons, and extensive PV system monitoring using the fault detection and PLR computations.

Disseminations / References

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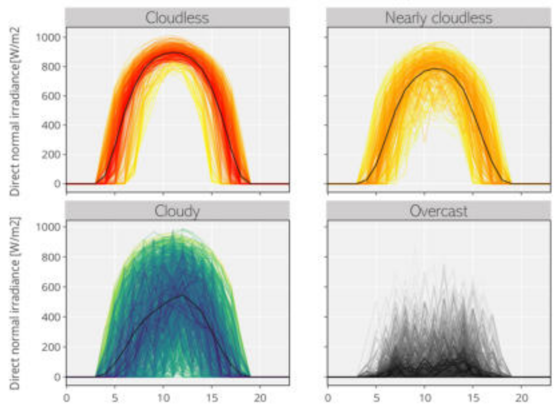

Figure 1: Daily direct normal irradiance profiles for the four identified day types. Colours indicate distance from mean (from light to dark, mean curve indicated with black line).

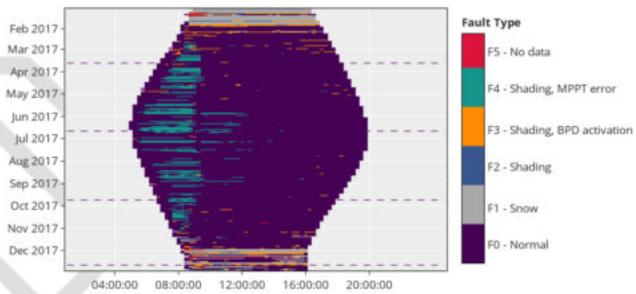

Figure 2: Example use case of day type classification: fault detection and diagnosis algorithm applied to a PV system. Colours indicate the fault types, dashed lines represent seasons.

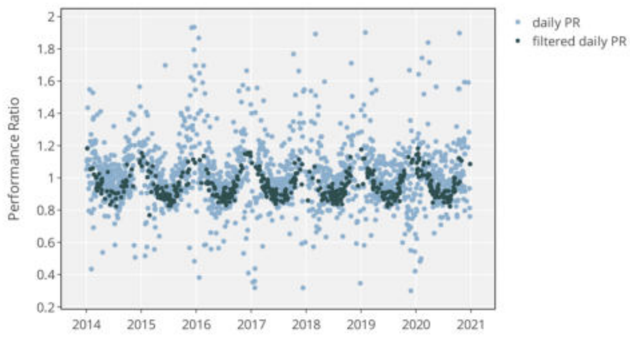

Figure 3: Example use case of day type classification: performance ratio trend used for performance loss rate computation, with cloudless/nearly cloudless day filtering.

Supervisor Prof. Christophe Ballif, EPFL PV-LAB

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University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Analysis of a-Si/a-SiGe tandem solar cell

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Introduction

In amorphous silicon solar cells, the bandgap of the intrinsic layer turns out to play a crucial role in optimizing the performance of the solar cell. This work aim to simulate the performance of thin film solar cells based on amorphous silicon using the update version of wxAMPS. An important design that must give a good performance is the tandem cell a-Si/a-SiGe. Amorphous silicon germanium alloys a-SiGe:H have been used as narrow bandgap i-layers in multi-junction a-Si based solar cell Figures. Compared to micromorph solar cell, higher values of Voc can be obtained with thinner i-layer in a-Si/a-SiGe, because the high absorption coefficient of a-SiGe for visible light. Besides, the light soaking effect was reduced from 30% for a-Si solar cell to 18% and 12% for respectively double and triple junction using a-SiiGe alloy[2]. Unfortunately, the efficiency of a-Si/a-SiGe tandem solar cell is still low in comparing with other technologies.

Research Aims

The object of this work is to improve the absorption profile of the solar cell by using multi bandgaps as absorbing layers. This technique aims to design a long-wavelength absorber for a single junction solar cell. This multi absorber layer not only absorbs a larger number of photons of the incident light but also reduces the mismatch between solar cells and incident solar irradiation. Furthermore, less current is generated because each layer absorbs photons only of part of the solar spectrum .

Research Problems, Questions, Hypotheses

In thin-film solar cells based on a-Si:H, the efficiency of solar cell is limited by different electrical and optical losses, due to the low quality of materials and the recombination of photogenerated electrons and holes as well as the light-induced degradation. So, the efficiency of a-Si:H solar cell is fundamentally limited by the optical losses issue to the non-absorption of low energy photons and the absorption of high-energy photons or thermalization losses. Furthermore, the mismatch between the solar spectrum and absorption profile of the solar cell, in particular, the short-wavelength light lead to important losses in the efficiency. The charge carriers in p-i-n solar cells are generated as a function of the bandgap (Eg) of the absorber layer. Photons with high energy compare to the bandgap of absorber layer (hv≥Eg) have the ability to be absorbed and generate photocurrent; while photons with low energy (hv <EG) will be transmitted across the absorber layer without any gain in the solar cell performance.

Research Methodology

At present, there are several solar cell modeling codes available to the PV community, such as PC1D, SCAPS, AFORS-HET, ASA ...etc. These programs are developed based on the classic semiconductor drift-diffusion model. Some simulator code have been further adapted by incorporating thermionic emission and specific tunneling mechanisms (tunneling through insulator layer [5], intraband tunneling [2], and/or trap-assisted tunneling [3]) to better treat the carrier transport at hetero-interfaces. In terms of monolithically grown multijunction devices, where subcells are interconnected via Esaki tunneling diodes [3], another important tunneling mechanism, band-to-band (BTB) tunneling, must be taken into account to correctly describe the tunneling junction behavior [1]. For example, the AMPS gradient band-gap and drift-dependent mobility approach and the trap-assisted tunneling model cannot reproduce the negative resistance phenomenon that is typical of Esaki diode. However, this BTB tunneling mechanism is missing in most solar cell simulation programs.

Research Results / planned or achieved

wxAMPS 3.0 incorporating the nonlocal BTB tunneling model and updating the numerical algorithm is shown to reproduce realistic behaviors of a variety of devices including Esaki tunneling diodes and tandem solar cells. The simulation results are compared with a commercial TCAD program and demonstrate good consistency. A useful and highly demanded feature, subcell analysis, allows quick diagnosis of current matching and permits examination and optimization of individual components of the tandem efficiently. wxAMPS 3.0 provides a freeware option for researchers to carry out fundamental studies and to facilitate the experimental optimization for tandem solar cells. Future work will further enhance the functionality of the code, such as incorporating more physical mechanisms, like photon recycling and upgrading the numerical algorithm to allow the use of high-performance computing. wxAMPS 3.0 is freely shared to the PV community, and the source code is also available according to open-source license, which allows more researchers to participate in the modeling development, with the possibility of adapting the code into a versatile simulation platform for modern solar cell research.

Disseminations / References

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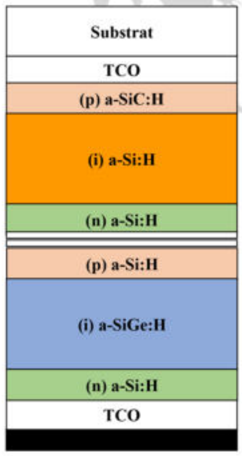

Figure 1: Schematic view of the typical a-Si/a-SiGe tandem solar cell

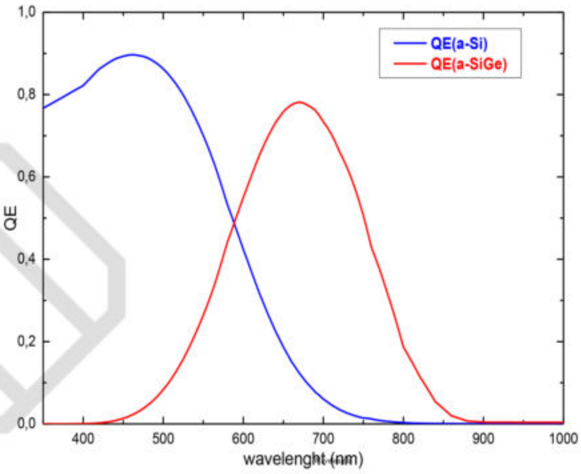

Figure 2: Spectral response curves of the tandem a-Si/a-SiGe solar cell.

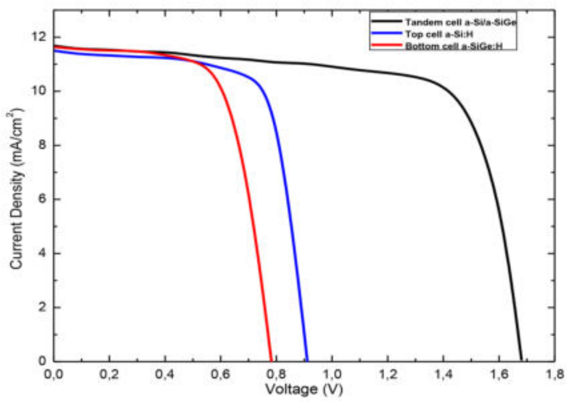

Figure 3: Simulated subcell IV curves and corresponding pseudo-IV curve for the a-Si/a-SiGe double-junction cell investigated in the previous section. The subcell analysis only consumes seconds of computation time with a common computer, and the generated pseudo-IV curve is very close to the curve simulated without simplifying the tunneling junction.

Supervisor Dr Leila Ayat, University of Béchar, Algeria.

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University of Twente, The Netherlands, March 2022

Potential of monitoring tools and advanced operation and maintenance practice for security and predictability of PV performance

Photovoltaic Textiles and Piezoelectric nanofiber yarn

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Introduction

- Solar energy
- Waste mechanical energy
- Flexible, low-cost, easy production
- Possibility of integration on textile structures
- Organic materials

Figure 1: Photovoltaic textiles

Research Aims

(i) Transparent electrode and homogenius conductive thin film studies to apply on textiles ,
(ii) Photovoltaic effect on textiles ,
(iii) Protection of photovoltaic layers from oxygen, moisture, physical impacts etc.
(iv) Generating electricity from body movements and waste mechanical energy

Research Problems, Questions, Hypotheses

Point to the identified problems that lead to your research. In this regard, list the research questions and hypotheses.

- Difficulty of producing homogenius conductvity and transparency on cylindrical(fiber)-shaped substrates
- Having transparent electrode on polymer-based fiber structures
- Homogenius thin film production problem
- An assistive layer on rough textile surfaces might help
- Thicker electrode layers might help with conductivity problems
- A protection layer that is flexible and resistant to textile regarding processes
- Relatively lower tenacity compared to traditional textiles

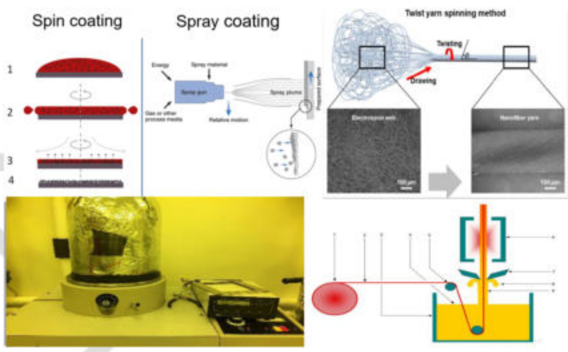

Figure 2: Production techniques used by Borazan et al.

Research Methodology

- Solution-based coating techniques similar to textile processes
- Military and outdoor use are primary using areas
- Energy provide to portable electrical devices
- Yarn production from nanofibers by electrospinning

Research Results / planned or achieved

- 4,5% on glass, 2,4% on ITO coated PET, 2,1% on conventional textile fibers were achieved with organic semiconductors.
- Flexible coating materials are studied for encapsulation
- Transparent electrode studies ongoing

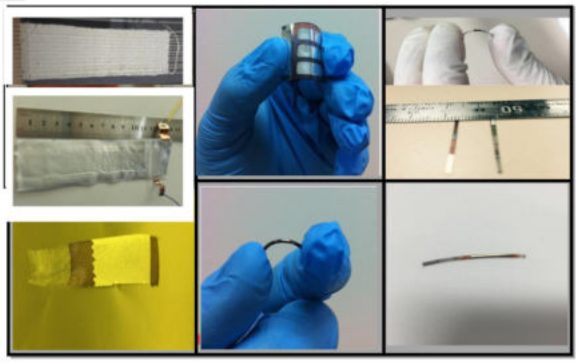

Figure 3: Energy generating textiles fabricated by Borazan et al. During the master and doctorate thesis and postdoctorate research.

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Co-advisor: Prof. Dr. Ayşe Bedeloğlu, Bursa Technical University

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University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Solar Forecasting based on All-Sky Imagers

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Introduction

- Share of solar energy in our electricity grids is growing
- Increasing demand for more accurate solar irradiation nowcasting
- Intra-horizon variability, predominantly driven by clouds, has an overall effect on the dispatching of solar power plants and thus on the electricity grids [1]

Research Aims

- To develop a system for solar nowcasting, i.e. an accurate PV power forecasting at high time resolution and high spatial resolution
- Based on a small network of four all-sky images (ASIs) at UU campus and KNMI (see Figure 2)
- To derive a moving 2D shadow field from stereoscopic analysis of 3D cloud movement using machine learning and optical flow techniques
- Correlation of shadow filed with the power generated by the 4000 PV modules at UU campus

Research Problems, Questions, Hypotheses

- How to address congestion problems in electrical network management?
- Passing clouds will cause large power flow fluctuations in the electricity grid due to PV capacity
- Management and accurate PV power forecast is necessary at a high temporal and spatial resolution

Research Methodology

- In-house developed technique based on Support Vector Machine (SVM) learning classifiers will be used
- Tracking clouds in 3D space is based on an enhanced stereoscopic analysis of the clouds' image features that does not require prior inputs.
- Proposed algorithm separates feature points into cloud and clear sky pixels and has as cloud mask as output.
- Another algorithm is applied to estimate the block-wise cloud base height and cloud movement based on each cloud layer taken from the ASIs.

Research Results / planned or achieved

- Preliminary analysis of the developed algorithm shows the ability to track clearly the clouds motion, see Figure 3, for different cloud conditions. It also presents an appropriate overview on the movement of the next coming clouds. We expect that this algorithm will robustly track and detect clouds' layers.
- For stable irradiance projections with high spatiotemporal resolution the algorithm will be able to extract the relevant global and local features. Physical limitations inherent from the camera's field of view and resolution will be addressed.
- We aim for our algorithm to improve by at least 50% forecasts based on a persistence model.

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This work is developed as part of IEA-PVPS Task 16 and funded by TKI-Urban Energy (SolFaSi project).

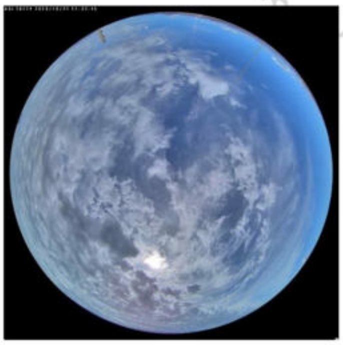

Figure 1: ASI image processed with a field of view of ~2 km at the UU UPOT location [2]

Figure 2: Location of 4 all-sky imagers at UU campus (UPOT, Olympos, Farm) and KNMI. In blue UU PV systems (1.2 MWp in total).

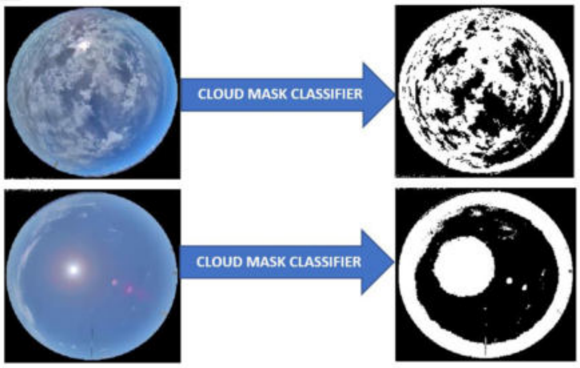

Figure 3: The first pipeline for cloud detection using an SVM classifier and multi-source correction.

Supervisor (Professor, Wilfried van Sark , Utrecht University, Copernicus Institute of Sustainable Development,)

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Machine Learning in Short-Term Electricity Markets

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Introduction

In the face of climate change, the integration of variable renewable energy (VRE) resources marks a stark departure from conventional centralised, fossil-based power systems. As VRE, such as photovoltaics, and most demand are undispatchable, they shall be complemented "dispatchable" demand ("flexibilities"), stemming from storage and sector coupling. Machine Learning (ML), specifically in the supervised set-up, is a powerful tool to efficiently dispatch flexibilities against the backdrop of VRE. Particularly, accurate short-term forecasts of VRE play a major role in this and are a focus of my research. The combination of data-driven ML models with physical models / domain knowledge is of particular interest to me.

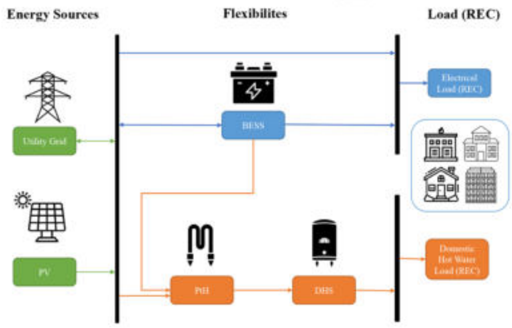

Figure 1: Flexibilities in the Context of a Microgrid with VRE

Research Aims

State clearly the primary and secondary objectives of the research

(i) Develop highly accurate and computationally efficient ML forecasting techniques for multi-step ahead load and VRE generation for real use-cases,

(ii) Enhance ML techniques with domain knowledge and quasi-physical models to enhance their performance

Research Problems, Questions, Hypotheses

ML forecasts depend on the availability and quality of the input features. Depending on the place and the time of the forecast, the importance of these features varies. As such feature selection should be dynamic and be informed by physical surroundings of the technology.

- Hypothesis 1: Dynamic Feature Selection over a forecast horizon can be a tool to improve overall forecasting accuracy
- Hypothesis 2: Physical information of snow, fog, cloud motion vectors can be extracted from live data to be used by ML forecasting methods and improve forecast accuracy in special situations.

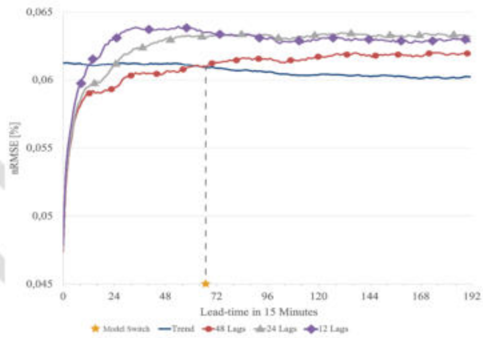

Figure 2: Optimal Point for Model Switch for PV Forecasting by nRMSE

Research Methodology

The methodology is comprised of state-of-the-art supervised learning algorithms, such as artificial neural networks (RNNs) as well as common data-science tools like cross-validation and grid search. Additionally, new methods are developed, which particularly make feature-selection and model switching more systematic (see Figure 2). Furthermore, new loss functions for non-stationary timeseries, as well as novel physical model interfaces to ML models are developed.

Research Results / planned or achieved

Regarding Hypothesis 1, the methodology for dynamic lag feature selection for short-term photovoltaic and electrical load forecasting was developed, which clearly shows accuracy and computational improvements relative to using the standard approach.

Regarding Hypothesis 2, the expected result is an improvement in forecasting accuracy in outlier situations, such as heavy snow fall, broken cloud conditions, and low fog by using physical information from NWP, together with quasi-physical models that can learn from data.

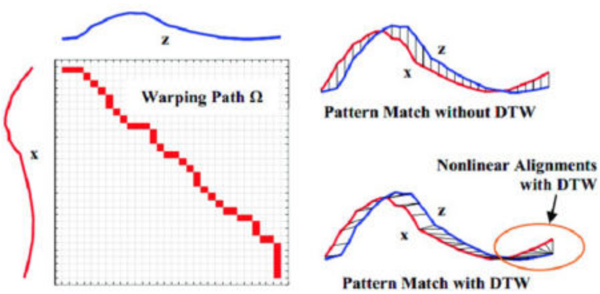

Figure 3: Dynamic Time Warping used for Quasi-Physical Modelling*

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Supervised by:

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Multi-Objective Economic-Environmental Optimisation of Electric Vehicles Charging

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Introduction

Role of Electric Vehicles (EV) in smart grids

- Role of consumers: Changes from passive energy users to active ones
- Role of EVs: Act as distributed energy storage facilities
- EV potential negative effects: Cause EV peak demand coincides with the evening households peak demand

Source: Adobe/Irina Strelnikova

Smart charging and vehicle-to-grid

- Aims to minimize charging costs and CO_2 emissions, maximize self-consumption of renewable energy, or mitigate congestion and power quality problems.

Case study and input data

- In Utrecht, the Netherlands
- Highly-detailed measured EV charging transaction data (provided by 'We Drive Solar")

Research Aims

The research estimates the maximum potential gains in the economic and environmental performance of the electrical-grid operation by optimizing the time of EV charging.

The contributions are:

I. Evaluate optimized individual EV charging potential in terms of cost, emissions, and renewable integration
II. Evaluate the effect of different minimum charging current

Research Methodology

1. Define objective functions to optimize EV-charging sessions [1]
   i. Minimize electricity cost and battery degradation cost
   ii. Minimize CO_2 emissions related to electricity consumption and battery degradation
   iii. Maximize renewable energy use in the utility grid

2. Construct marginal emission profiles in the Netherlands [2], [3].
   a) Construct the merit order profile: Electricity generation mix sorted from lowest to highest marginal operating costs.
   b) Construct the marginal emission profile: Take the day-ahead market clearing prices, determine from this which facility was operating at the margin, and take the emissions of this facility.

3. Algorithm to optimize the time of charging individual EVs considering different minimum charging powers.

Planned Research Results

- Pareto frontier for three objective functions in different years: cost, emission, and renewable share. (See Figure 1 as an example, showing the trade-off between improving one aspect at the expense of another).
- Impact of different minimum charging power on Pareto frontier.

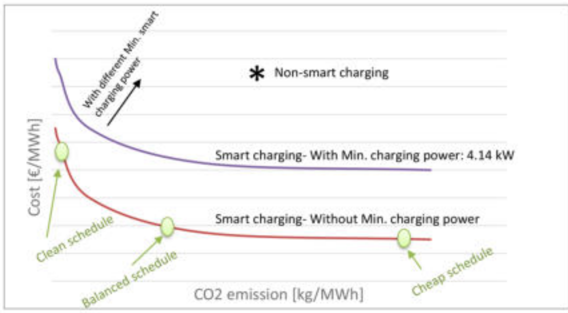

Figure 1: Example of the expected Pareto frontier for multi-objective optimization of costs and CO_2 emissions of EV charging.

This study is part of the ROBUST project – A future-proof and affordable electricity grid.
https://tki-robust.nl/

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Supervisor: Prof. dr. Wilfried van Sark, Utrecht University

Co-Supervisor: Dr. ir. Ioannis Lampropoulos, Utrecht University

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PV INSTALATION STUDY

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Introduction

The study consist in the implementation of a rooftop PV installation for a number of thermal points in Bucharest, Romania. The electricity obtained from the PV installation will be used to supply the water circulation pumps. More than that, we will determine the optimal solution for utilizing the electricity when the production is higher than the pumps consumption. The alternatives we study are: energy storage, grid injection (tacking into account the impact to the DOS) and suppling an electric vehicles fleet. We also intend to determine the impact of power generation on DSO.

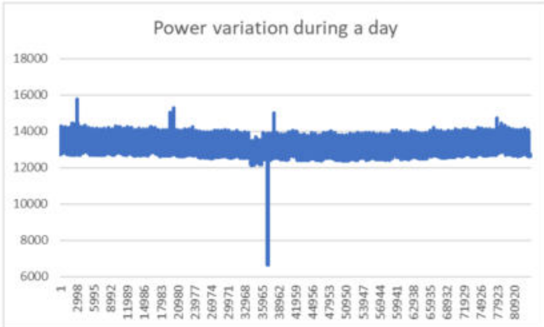

Figure 1: The power variation at the thermal point during a day

Research Aims

(i) Designing a PV installation for one thermal point,

(ii) Finding the optimal solution to use electricity when the production is higher than the consumption,

(iii) Study the impact of PV installation on DOS.

Research Problems, Questions, Hypotheses

(i) It is suposed that the roof surface covered by PVs is 60 % of the total roof surface.

(ii) It is suposed that the roof resistance structure is not affected by the PVs weight.

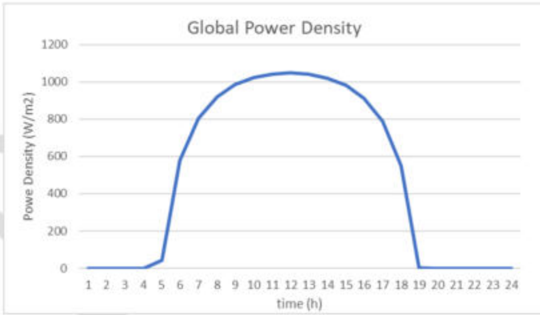

Figure 2: Estimated power density on the roof surface, in May

Research Methodology

The research methodology includes data collection from meters mounted at studied thermal points. The data is output with a frequency of one sample per second, because we are interested in the maximum value of power registered in the electricity consumption of the thermal point. This way, we can properly design the PV installation.

For the photovoltaic panels output estimation, we used power density values corrected with the PV efficiency. Furthermore, we compared the results with real values obtained from the University PV installation.

Research Results / planned or achieved

(i) A data base with the electric measurements imported per second from one thermal point (achieved)

(ii) A brief analyze of the possible installed power of the PV installation and the resulted costs (including storage capacities) (achieved)

(iii) A detailed analyze of the possible installed power of the PV installation and the resulted costs (including storage capacities, grid injection and electric vehicles supply) (planned to achieve)

(iv) A brief impact analyze of the integration of PVs in all thermal points from Bucharest on the DOS (planned to achieve)

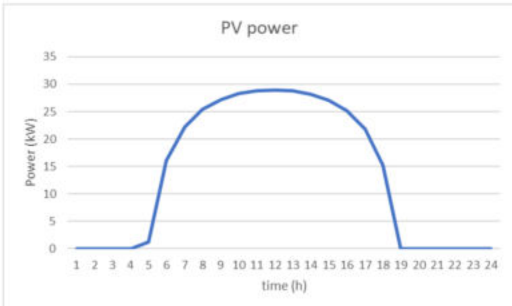

Figure 3: estimated power produced by the PV installation, in May

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Prof. Phd. Eng. Mihaela Albu, Polytechnic University of Bucharest

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Decision Support System

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eurac research

Introduction

A key factor for the growing success of photovoltaics in the last years is certainly the rapid reduction of the cost of PV modules. Since the operational expenditures are related to the capital expenditures, with declining PV system prices also the operation and maintenance market gets restricted to a limited and ever decreasing margin. Thus, there is a need for improvement in O&M for photovoltaic systems to decrease OPEX costs. However, O&M contracts usually do not allow the O&M contractor to efficiently optimize the processes, obliging him to fix any failure as soon as it arises. This research activity shows steps to an alternative approach.

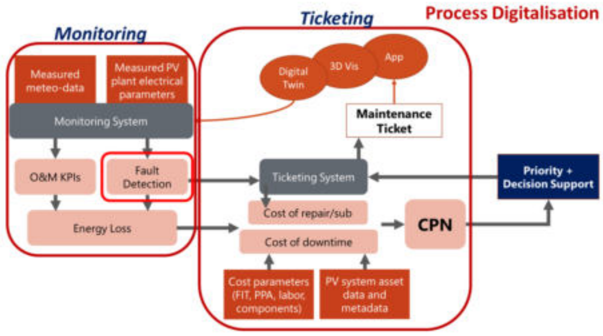

Figure 1: Digital infrastructure for operation and maintenance of PV plants using the CPN methodology.

Research Aims

The aims of this research activity are:

(i) The development of a software platform for fully digitalized O&M workflows including a shared and categorized data infrastructure (see Figure 1).

(ii) To obtain an automatized decision support system that calculates the economic impact of technical risks by applying the Cost Priority Number methodology.

These objectives will be achieved by the construction of a CPN database where up until now roughly 25.000 maintenance tickets from plants of six different countries have been collected. The next step is to automize the calculation of the CPN values by applying a machine learning approach, since the input parameter for the CPN calculation are not always provided by the plant operator.

Research Problems, Questions, Hypotheses

As mentioned above, O&M contracts often do not allow the O&M contractor to efficiently optimize the processes, as they are obliged to repair failures on the plant as soon as possible. However, the increasing availability of PV plant data and the integration of meteorological and real-time monitoring data, but also digitally available PV plant layout and component data into the platform lead to many new O&M strategies. To ensure confidence in the results obtained and to make the transition towards a new type of O&M contracting possible, a well validated method is required.

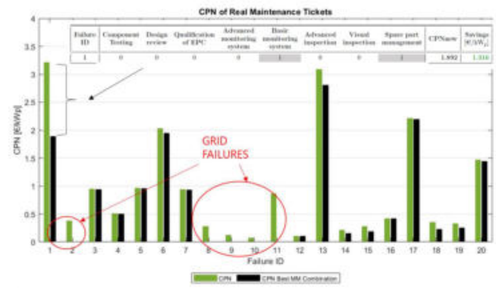

Figure 2: Analysis of twenty real maintenance tickets and calculation of CPN with and without mitigation measures applied.[3]

Research Methodology

Within the project PV4.0[1], based on industry 4.0 concepts, the aim is to improve further failure data collection and to develop a platform (see Figure 1) supporting operation and maintenance operators in taking the most cost-effective decision in case of performance loss. The CPN methodology developed within the Solar Bankability project[2] is the core of the PV4.0 tool and it prioritizes O&M interventions according to the economic impact of technical risks helping so in the decision process.

Research Results / planned or achieved

The results show that the impact of technical risks can be minimized by applying different mitigation measures. Hereby two different groups of measures are identified:

- Preventive and corrective measures reduce the number of failures, the downtime due to detection and response and should therefore be applied during the planning phase (see Figure 2).
- Direct mitigation measures suggest the best solution once the failure happened. Depending on several parameters the O&M operator should fix the failure immediately or wait for the next periodic maintenance (see Figure 3).

The future work might consider safety issues due to failures as well as actual weather data of the monitoring system installed on-site, needed to calculate the irradiation loss.

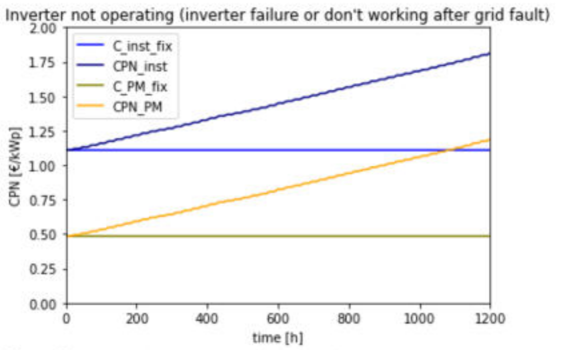

Figure 3: CPN development over time of an inverter failure – Comparison between instant fixing and repair at the next periodic maintenance.[3]

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Supervisor (Senior Researcher, Atse Louwen, EURAC research)

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Innovative Tool For Sustainability Assessment Of Solar Projects

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Introduction

- Solar PV technologies have been widely adopted in many countries
- Least polluting energy technology with negligible carbon footprint
- Conversion efficiency of commercial solar PV modules is low (20% - 23%)
- Vast land is required for the installation of solar PV power plant (3.5 acres/ MW)
- Initial investment still involves huge amount of money.

Research Aims

- To develop an innovative tool for sustainability assessment of solar PV projects,
- To predict the performance of the solar PV system in terms of technical, economic, environmental aspects.
- To evaluate the sustainability of solar PV projects in five sites based on Sustainable Performance Index (SPI) value..

Research Problems

- In several cases, technical and economic parameters failed to reveal the actual performance of the energy system
- Typical techno-economic analysis involve standalone parameters/indicators which do not have adequate linkages
- Numerous indicators for multi-dimensional performance assessments make the decision-making process tedious.

Research Methodology

- Five locations of Malaysia are selected and 5MW solar PV project is proposed in each site.
- RETScreen software is used to predict its energy generation and economic parameters.
- Technical, Economic, Environmental parameters are estimated using an Excel-based mathematical model.
- All the performance data is normalized and multiplied with weights which is calculated using MCDM technique
- Parametric values for each site is aggregated together to obtain a single performance index
- Selected solar PV projects are ranked based on the obtained sustainable performance index

Research Results / planned or achieved

- Developed an innovative sustainability assessment tool covering 24 indicators from Technical, Exergy, Economic, Environmental aspects
- Out of the five sites in Malaysia, highest value of SPI value is observed for Kota Kinabalu location
- SPI value varied between 81.94 & 11.39 and is highly influenced by net present value, carbon reduction, energy loss, and exergy loss
- The solar PV system in Kuching is the least recommended in terms of sustainability due to its lowest SPI score of 11.39

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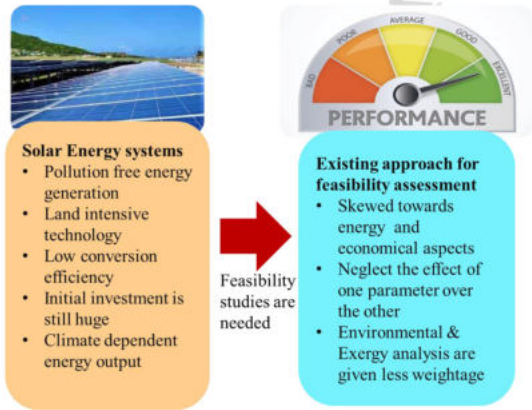

Figure 1: Background of the research

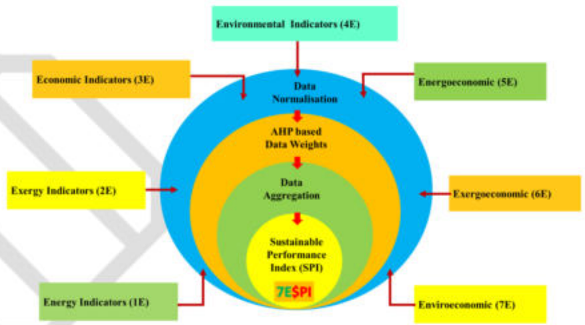

Figure 2: Flowchart representing the proposed methodology for sustainability assessment of solar energy projects.

Site Name	SPI Index	Rank
Kuala Lumpur	61.56	3
Kota Kinabalu	81.94	1
Penang	80.98	2
Kuching	11.39	5
Johor Bahru	51.69	4

Figure 3: SPI value and rank for the selected sites

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Optimising Luminescent Solar Concentrators

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Utrecht University

Introduction

The building integrated solar cell (BIPV) is gaining popularity as a solution to a lack of horizontal space in the built environment. The luminescent solar concentrator (LSC) is a device which generates electricity while at the same time functioning as a window (Figure 1). The LSC will absorb incoming light by means of a luminophore, a (nano-)particle which absorbs and subsequently emits light with a drop in energy and change in direction. Total internal reflection will ensure that the emitted photon reaches the edge of the LSC device where it can be absorbed by an attached PV cell. This research focuses on the balance between transmitted and absorbed light and the analysis of outdoor testing locations where prototypes have been constructed.

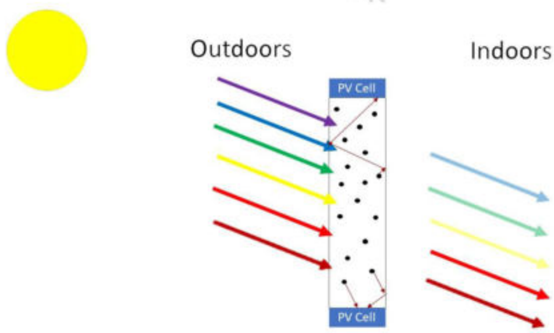

Figure 1: Working principle of an LSC device – incident rays are captured by the luminophore (black dots) which emits them towards the side-attached PV cells via total internal reflection (red arrows). Note that not all wavelengths are absorbed equally.

Research Aims

(i) Defining an optimal balance between transmitted and absorbed light.

(ii) Optimising concentrations for luminophores based on potential power output and transmission.

(iii) Characterizing efficiency decline in an outside testing environment.

These aims/objectives will be achieved by computer simulations and data analysis of actual prototypes.

Research Problems

Current research on LSCs focuses mainly on the development of luminophores. Depending on the absorption spectrum and concentration the power output and transmitted light spectrum will change. Using artificial luminophores with optimised absorption and emission spectra, the optimal efficiency limits for specific lighting requirements can be calculated using a ray trace algorithm (Figure 2a).

The current state of LSCs show high degradation in outside environments. Luminophores made from organic dyes are especially susceptible to efficiency decrease. A promising technology replacing organic dyes are quantum dots. A prototype setting (Figure 2b) shows the testing environment for three quantum dot LSCs.

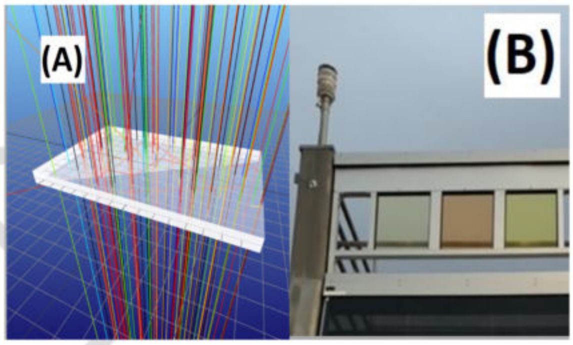

Figure 2: (A) Example of ray trace modelling algorithm using PVtrace. (B) Outside testing environment showing three QD LSCs (from left to right: InP, CIS, CdSe).

Research Methodology

An artificial continuous absorption function is combined with a numerical algorithm calculating the absorbed photons and transmitted spectrum from AM1.5G irradiance. Constraining the average visible transmittance (AVT) and color rendering index (CRI) the number of absorbed photons is maximized by an optimization algorithm. The found absorption functions are used in a ray trace algorithm to calculate the maximum theoretical power output.

At the LSC testing location the IV-curve per PV cell is measured as well as the incoming solar irradiance. The efficiency and its change over time will be analyzed and underlying factors assessed.

Preliminary Results

The first preliminary results for maximized power output for an optimized artificial luminophore are shown in Figure 3. Visible is a high power conversion efficiency (PCE) while still having an acceptable AVT and color rendering. The blue dots show the results by Lunt (2012) using a different approach.

The outside prototypes have provided a year of data and are currently being analyzed. The first results indicate a significant drop in the Lumogen Red f305 luminophore and the CdSe quantum dot, while the InP and CIS luminophore remain relatively stable. Further investigations are underway.

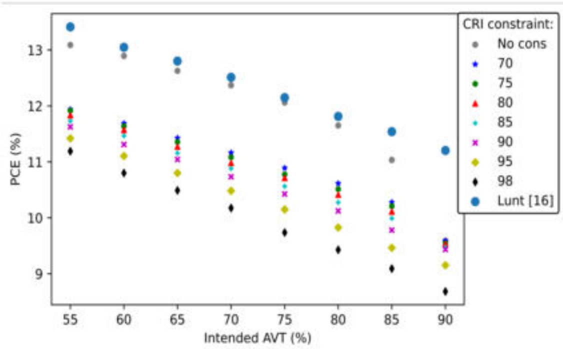

Figure 3: Preliminary results optimal luminophore – The power conversion efficiencies found by a ray trace algorithm for AVT and CRI constraints for the transmitted light.

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Supervisor (Prof. Dr., van Sark, W.G.H.J.M. (Wilfried), Utrecht Unviersity)

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PEARL PV

P A R L P V 4th TRAINING SCHOOL

University of Twente, The Netherlands, March 2022

Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance

Transparent Electrodes for Organic Solar Cell and Carbon Nanofiber Based Electrodes for Supercapacitor Applications

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Introduction

- B.Sc. İn Chemical Engineering, Firat University, Turkey, 2009
- M.Sc. İn Materials Science, University of Wisconsin-Madison, USA, 2014

  MSc. Thesis: Dielectric and Mechanical Properties of Non-Covalently Functionalized Graphene Nananosheets (GNSs)/PDMS Nanocomposites
- Ph.D. İn Polymer Materials Engineering, Bursa Technical University, Turkey, 2020

  PhD Thesis: Carbon nanofiber supercap Development and Characterization of Carbon Nanofiber Supercapacitor Electrodes Modified By Graphene and Conductive Polymers (PEDOT:PSS, PANI)
- Flexible transparent electrodes, Organic solar cells, graphene and graphene derivatives, nanofibers, silver nanowires, conductive polymers (Polyaniline, PEDOT:PSS), polymer nanocomposites, aerogels, graphene hydrogels,, high performance polymers, carbon fiber reinforced polymer composites, nanogenerators, adsorption, etc.

Research Aims

State clearly the primary and secondary objectives of the research

(i) Flexible and self-standing electrodes for solid-state supercapacitors,

(ii) Nanomaterials based transparent electrodes for organic solar cells,

(iii) High-performance polymers and their applications,

(iv) Polymer nanocomposites and fiber-reinforced polymer composites.

Research Problems, Questions, Hypotheses

Point to the identified problems that lead to your research. In this regard, list the research questions and hypotheses.

- Improving the properties of carbon nanofiber-based electrodes as an alternative to activated carbon electrodes used in supercapacitors.
- Increasing the surface area by porosizing the surfaces of carbon nanofiber electrodes.
- Improving the performance of carbon nanofiber electrodes with graphene and conductive polymer additives.
- Development of transparent electrodes that can be used in flexible textile-based substrates.
- Usability of flexible transparent electrodes based on graphene, silver nanowire, and conductive polymer in organic solar cells

Research Methodology

- Solution-based techniques (spin-coating, dip-coating, spray coating, electrospraying, etc.) were used to produced transparent electrodes on glass and flexible substrates.
- The electrospinning method was used to produce polymer nanofibers.
- Stabilization and carbonization process used to produce carbon nanofiber from polyacrylonitrile nanofiber.
- The solution casting method was used to produce polymer nanocomposite films.
- Characterization devices such as FT-IR, TGA, DSC, FE-SEM, AFM, electrochemical characterization (by an electrochemical Workstation), solar simulator and source meter, UV-vis NIR spectrophotometer were used to investigate the properties of materials and devices.

Research Results / planned or achieved

- Semiconducting polymers with different bandgaps were used as active layers in organic solar cells and efficiency was compared.
- Solution-processed transparent conducting electrodes with graphene, silver nanowires, and PEDOT:PSS as an alternative to ITO were developed. PEDOT:PSS/AgNW/graphene construction exhibited 216.67 Ω/sq. sheet resistance with ~ 83% transparency.
- Carbon nanofiber (CNF) surface was modified to increase its surface areas and specific capacitance of supercapacitor electrode was improved by 63,5%.
- CNF surface was modified with PEDOT:PSS via dip-coating method and specific capacitance of supercapacitor electrode was improved by 75%.
- CNF was modified with graphene and PANI to increase the specific capacitance. As a result of the modification, the specific capacitance of CNF was increased by 117%.

Disseminations / References

1. Altin, Y., & Bedeloglu, A. (2020). Polyacrylonitrile nanofiber optimization as precursor of carbon nanofibers for supercapacitors. Journal of Innovative Science and Engineering, 4(2), 69-83.
2. Altin, Y., & Celik Bedeloglu, A. (2021). Polyacrylonitrile/polyvinyl alcohol-based porous carbon nanofiber electrodes for supercapacitor applications. International Journal of Energy Research, 45(11), 16497-16510.
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4. Borazan, I., Altin, Y., Demir, A., & Bedeloglu, A. C. (2019). Characterization of organic solar cells using semiconducting polymers with different bandgaps. Journal of Polymer Engineering, 39(7), 636-641.
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6. Tas, M., Altin, Y., & Bedeloglu, A. (2019). Graphene and graphene oxide-coated polyamide monofilament yarns for fiber-shaped flexible electrodes. The journal of the Textile Institute, 110(1), 67-73.

Supervisor (Prof. Dr. Ayşe BEDELOĞLU, Bursa Technical University)

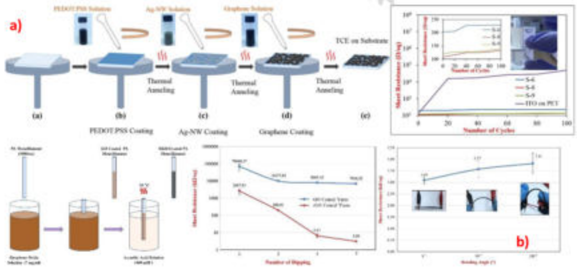

Figure 1: Tranparent electrodes production scheme and sheet resistance results a) [5] b) [6].

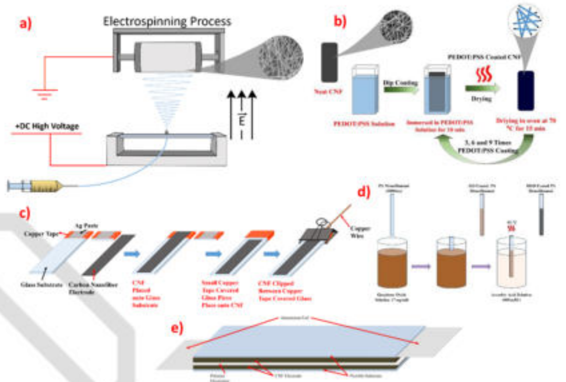

Figure 2: a) Electrospinning process [1], b) Production scheme of PEDOT:PSS modified CNF electrode [3], c) Sample preparation for electrochemical characterization [2], d) Dip-coating method for fiber-based transparent electrode production [6], e) Schematic illustration of solid-state supercapacitors.

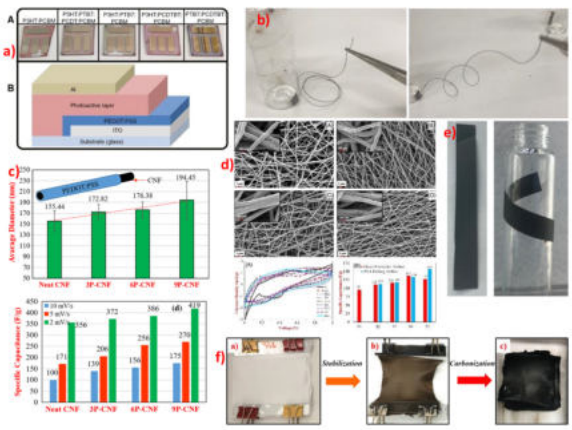

Figure 3: a) Different bandgap organic solar cells [4], b) Carbon nanofiber yarn electrode for supercapacitor, c) Effect of PEDOT:PSS modification on diameter and specific capacitance [3] d) Effect of surface modification on specific capacitance [2] e) Produced porous flexible CNF electrode [2] f)PAN nanofiber, stabilized PAN nanofiber, carbon nanofiber [1].

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 University of Belgrade	Professor Dr. Aleksandra Krstić-Furundžić, Ing.- Arch., University of Belgrade – Faculty of Architecture, Serbia. Several times was the head of the Department of Architectural Technology. She was a visiting professor at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka, BiH. Professional experience as an educator, architectural design practitioner, researcher, and editor. Expert domains: Architectural constructions, Innovative façade and roof technologies, Energy efficient buildings, Passive and active solar systems, Industrialized construction, Building refurbishment technologies. She participated as a trainer in several Training Schools within the COST Action TU1205, dedicated to the design of solar thermal collectors, and the COST Action CA16235. Co-Founder of the International Scientific Conference on Places and Technologies. Author of several books, and a significant number of chapters in international and national monographs and scientific papers.
 University of Twente.	Angèle Reinders is a full professor at TU/e, an Associate Professor at University of Twente and a visiting professor at the School of Photovoltaics & Renewable Energy Engineering of UNSW in Sydney. She studied experimental physics at Utrecht University, where she also received her doctoral degree in chemistry. At present she chairs COST Action PEARL PV which is focused on research on the performance and reliability of photovoltaic systems. Her other research has a design-driven scope and as such it is trans-disciplinary, with a focus on performance of energy technologies, environmental aspects, user interactions as well as prototyping and testing of innovative energy products. In the past she conducted research at - among others - Fraunhofer Institute of Solar Energy in Freiburg, the World Bank in Washington, D.C., ENEA in Naples, Center of Urban Energy in Toronto and in the remote areas of Papua in Indonesia. From 2010 to 2017 she was appointed as a full professor at the Faculty of Industrial Design Engineering in TU Delft. She is known for her books at Wiley's "The Power of Design" (2012) and "Photovoltaic Solar Energy From Fundamentals to Applications" (2017) and her involvement in the IEEE PVSC conference which she chaired in 2014 and 2017. In 2010 she co-founded the Journal of Photovoltaics for which she serves as an editor. In 2014 she received the PVSC Napkin Award in the USA for her contributions to the field of solar photovoltaics. Also she is involved in various tasks of the International Energy Agency PVPS program among which Task 17 on PV for Transport.
 Northumbria University Newcastle	Professor Dr. Nicola Pearsall, Emerita Professor of Renewable Energy at Northumbria University, Newcastle upon Tyne, United Kingdom. She was head of the Newcastle Photovoltaics Applications Group at Northumbria University. Throughout her research career, she has addressed a wide range of topics in photovoltaics, including the development of space solar cells, thin film compound solar cells, building integrated photovoltaic systems and environmental impact assessment. Her current research relates to PV system performance assessment and correlation with system design and implementation, with the aim of obtaining the highest lifetime output of the system. As a world-leading expert on photovoltaics, she was announced as the general chair for the Conference PVSEC 2020.
 EURAC research	Dr. David Moser graduated in physics and coordinates the activities of the Research Group Photovoltaic Systems of the Institute for Renewable Energy, Eurac Research, Bolzano, Italy. His work focuses on characterising indoor and outdoor behaviour, performance, and reliability of PV modules and systems, building integration of PV systems, and monitoring of outdoor PV plants. He is also active in PV potential studies on a regional scale, member of ETIP-PV Steering Committee and vice-chair of COST Action PEARL PV. He is leading the Subtask "Performance of Photovoltaic Systems" of the IEA PVPS Task 13.
 L-Università ta' Malta	Dr Cedric Caruana is a member of the Faculty of Engineering and an associate member of the Institute for Sustainable Energy at the University of Malta, Malta. He is a senior member of the IEEE and a member of the IET. He was a visiting scholar for a period of 12 months at the Petroleum Institute, Abu Dhabi. His current research relates to the control of electrical drives, control and grid integration of renewable energy, energy storage systems and electrification of transport. He has worked on numerous projects concerning PV systems including investigation of MPPT algorithms, integration into power networks and design of distributed large-scale system.

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