PEARLPV

The role of modelling in assessing and monitoring PV system performance

Nicola Pearsall

Emerita Professor, Northumbria University, UK

Introduction

- This presentation acts as an introduction to PV system modelling, which will be discussed in more detail in the later presentations in this Training School
- The purpose of modelling PV systems will be discussed, leading to some conclusions about the approaches we can use and the challenges we need to address
- Most modelling approaches aim to determine the output of the system, either as a predictive or diagnostic value
- The specific modelling procedure used depends on the overall purpose, so we will start with considering this aspect

Defining the purpose of the model

- As already noted, we can use modelling for predicting system performance – in this case, we can use the prediction for a range of purposes
- System design – we can compare predictions for various system designs (e.g. different components, different system configurations, fixed versus tracking etc)
- Economic or business case – is the output likely to be sufficient to meet the purpose in a technically and economically feasible way? Can we predict energy profiles and hence predict cash flow profiles? Can we determine the value of including storage?

Model boundaries

- For all types of modelling, we need to set the model boundaries
- The PV system is rather simple in concept, but in most cases also interacts with the overall energy system, so where the model stops, and the implications of the boundary, must be considered

Model boundaries – Example 1

- Consider a medium-sized grid-connected PV system installed on a farm and which is designed to both supply the local load and to export electricity for profit
- If the local grid cannot accommodate the total export amount under some conditions, then curtailment may apply
- Does the model include the interaction with the grid? If so, how do we assess when curtailment may happen? How do we include other PV or renewable energy systems on the grid?

Image: Sunstore UK

Model boundaries – Example 2

- A multifunctional building integrated PV system, where the PV array contributes to, for example, internal shading or ventilation, is designed to provide more than electrical output
- Does the model also include the additional functions?
- If not, are there any implications for the determination of the electrical performance?

Image: Doxford Solar Office

Solar Resource

- The output of any PV system is directly related to the input of solar energy, both in terms of the total output and the output profile, so it is clearly important to consider the solar resource
- There are several sources of measured solar data, using some combination of ground or satellite measurement, with different periods of measurement and levels of accuracy – so different data sources often give different output predictions for the same basic system assumptions
- The algorithms for translating the measurements to the inclined module surface may also differ

Solar Resource

- For some systems, however, it is necessary to consider the solar input in a more detailed manner
- For example, bifacial systems need data for both front and back surfaces of the module and so the treatment of albedo and its variation across the day and season is required
- For building mounted or integrated systems in an urban environment, shading is an important factor in determining the likely system output
- Where more detailed analysis is required, ray tracing software may be need to be used

Robledo et al, Solar Energy, 193 (2019

Average output versus operating limits

- Most system performance predictions are based on average operating conditions over the period of the prediction, whatever the time resolution of the model – this is the most useful approach for determining likely output
- For some system types (e.g. those required to meet a specific load, those operating in extreme environments), it may be necessary to consider extreme operating conditions of solar irradiance, temperature etc
- This approach can help to determine whether system components can withstand those conditions
- However, it can sometimes be difficult to obtain the relevant input data to define the limits of operation

Temperature

- The module operating temperature is an important factor in determining output
- It is fairly well defined for simple ground mounted systems

Source: © NB Institute for Rural Technology.

- It is less well understood for complex systems, such as building integration (e.g temperature differentials between top and bottom of a facade) and PV systems on water

Component specifications

- The most obvious of these is the choice of module type, both PV technology and module configuration – this can affect spectral response, low light level performance, thermal behaviour, shading tolerance and degradation
- Special attention is required when modelling non-standard modules, such as semi-transparent and coloured modules
- For power conditioning, the information on, for example, the variation of inverter efficiency with input voltage is not always available, but can be influential in comparing inverters
- When battery storage is included, it is important to consider the state-of-charge and its effect on battery efficiency as well as load profiles

Initial versus lifetime

- Many models will provide a prediction of initial output, based on the system configuration and the average operating conditions
- For lifetime output calculations, some level of performance reduction (degradation) needs to be assumed, often referred to as the Performance Loss Rate (PLR)

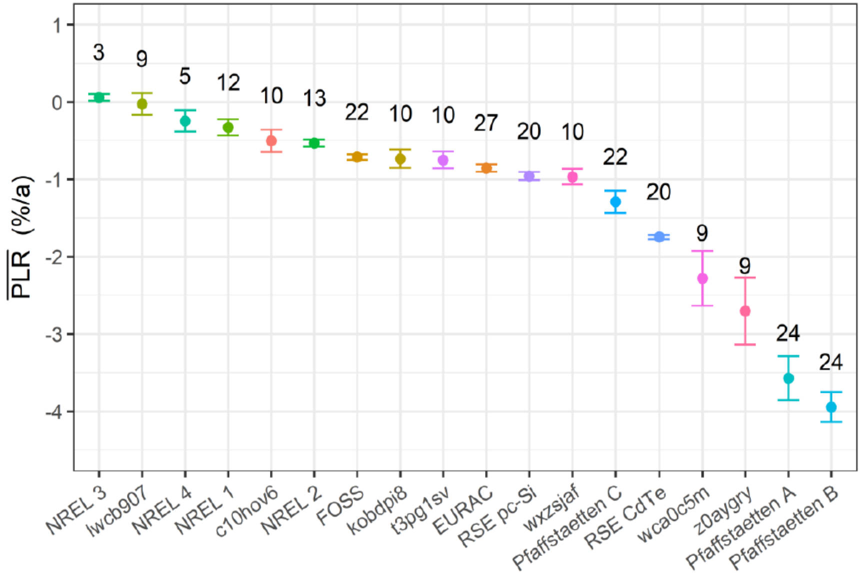

Figure 22, IEA PVPS T13-22:2021

- The simplest approach is to assume a linear reduction, although this does not represent the actual behaviour of most systems
- A recent IEA PVPS report (T13-22:2021) considers the calculation of PLR based on 19 research systems with the study intended as a precursor to a new IEC standard
- How performance change is incorporated will directly affect the predicted lifetime output and therefore the perceived feasibility of the system

Uncertainties and approximations

- All system models make assumptions about component performance versus operating conditions and so have an 'in-built' uncertainty in the predicted performance
- One of the largest sources of uncertainty is in the average irradiation value itself
- This uncertainty is then increased by incorporating an assumed annual reduction in performance
- The uncertainty should be assessed and expressed when presenting the prediction

Using modelling to assess field performance

- So far, we have considered the use of a system model to predict performance but we can also use it to help us assess field (actual) performance by comparing measured outputs with predicted outputs
- For this, we need some monitored data from the plant – note that the measured parameters do not always fully match the modelling parameters
- We also need to include any expectation of performance change, depending on the length of operation
- We can only directly compare the model and real systems if we are confident that the two are sufficiently similar in operating conditions and technical assumptions

Faults versus losses

- All PV systems have losses and we need to make sure that our model includes them in a realistic manner
- System faults can be considered as behaviour which results in larger losses than expected from the design and which could be addressed (e.g. by replacement of components)
- The easiest fault to identify is complete failure of a component, the most difficult is a small but progressive fault
- Identification is often best achieved by comparison of similar systems or subsystems and by the observation of patterns in the data, hence the growing use of intelligent data analysis approaches

Uncertainties (again)

- Any variations between the real system and the model should be determined and then assessed to see if :
  - (a) they can be incorporated in a consistent way with sufficient knowledge of their effect
  - (b) they are small enough to be ignored
  - (c) they are significant but not known sufficiently or too complex to include
- This then informs the judgement of the uncertainty of the model
- Note that the more complexity introduced, the more the model may relate to your actual system but the uncertainty does not necessarily reduce since you introduce more parameters
- For fault/loss detection, it is important to take into account the uncertainty in the comparison when determining if there is any concern

Summary

- In this introductory talk for the Training School, we have noted the dual role of modelling a PV system – to predict performance at the design stage and to assess performance at the operational stage
- We have considered the need for determining the purpose of the modelling, the model boundaries and the uncertainties embedded in the model
- The issues discussed here should be considered during the remaining presentations in the Training School, which will address specific modelling methods and applications