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Special Issue: Performance Assessment and Condition Monitoring of Photovoltaic Systems for Improved Energy Yield

Guest Editorial

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The on-going exponential growth of photovoltaic (PV) solar energy installations has lead to a total capacity of over 300 GW (at the end of 2016), which according to the most recent data reported by the PV power systems programme (PVPS) of the International Energy Agency (IEA) [1], is providing approximately 2% of the global electricity demand. It is imperative for the security of the energy supply as well as for investors in such installations that performance is monitored and predicted energy yields are actually reached. In other words, monitoring will show whether systems are functioning properly. The financial success of large-scale PV projects depends, in part, on demonstrated reliability and low uncertainty performance predictions and measurements.

Best practices for environmental and PV production monitoring are constantly evolving, seeing a rise of new web-enabled technologies, the streamlining of measurement collection, transmission and storage and the use of aerial imaging for PV system health monitoring. For example, the development of new types of instrumentation, such as dust accumulation, cloud coverage sensors and on-line current-voltage characterisation, has brought new functionality and new ways to assess the performance of PV systems in the field. Also, new statistical measurement methods have introduced unsupervised analysis of PV performance and a range of other fault detection methods, enabling PV system managers to make informed decisions about faults, maintenance, degradation including potential induced degradation (PID) and warranties. Given the need for performance assessment of PV systems, forecasting of their energy yields is a field of research that is receiving increased attention.

This Special Issue entitled *'Performance Assessment and Condition Monitoring of Photovoltaic Systems for Improved Energy Yield'*, contains ten papers that discuss various aspects in performance assessment, thus bringing the reader up to date with the present state-of-the-art technologies. In particular, the following topics are addressed:

- System performance monitoring
- Operational analysis and design
- Solar forecasting

System performance monitoring

Monitoring of large PV plants using light Unmanned Aerial Vehicles (UAVs) is proposed in the paper *'PV plant digital mapping for modules' defects detection by unmanned aerial vehicles'* by Grimaccia *et al*. An image post-processing tool for remote aerial images is developed that allows operators of PV plants to detect defects in PV modules easily. The described procedures have been tested on real PV plant systems using different kinds of sensors for visual inspection and infrared thermography. Detection of defects is visualized in color-coded maps, by which healthy modules, hot spot errors, broken bypass diodes and disconnected modules can be distinguished. Operators can thus promptly react to perform necessary maintenance.

Tsafarakis *et al*. describe PV performance analysis using a statistical approach for a country-wide set of systems in the Netherlands in their paper *'Three years experience in a Dutch public awareness campaign on photovoltaic system performance'*. A public campaign was organised for one week in three consecutive years to raise awareness amongst PV system owners on the importance of monitoring. Results reveal that, on average, the 5000 participating systems function well, as evidenced by a performance ratio of 0.74, with a left-skewed distribution. Further detailed analysis showed variation in the ratio of inverter AC nominal power and system DC rated power, which affected inverter performance in low radiation conditions. Differences between mono- and multi-crystalline silicon module performance was shown to be small and micro inverters or power optimises are shown to be effective in reaching high performance for PV systems that suffer from shading.

Operational analysis and design

Li *et al.* report on the detection of two widely available visible PV module defects; snail trails and dust shading, using an automated UAV system in their paper *'Visible defects detection based on UAV-based inspection in large-scale photovoltaic systems'*. UAVs equipped with visual cameras are flown over various multi-megawatt sized PV parks in the paper and various example photographs of observations are reported. Using an image filtering method based-on the first-order derivative of Gaussian functions (FODG), both snail trails and dust shading can be identified.

Accurate prediction of performance degradation is important in assessing the reliability of PV systems. This is the topic of the paper by Pieri *et al.* entitled *'Forecasting degradation rates of different photovoltaic systems using robust principal component analysis and ARIMA'*. The paper describes combining a Seasonal Auto Regressive Integrating Moving Average (SARIMA) model with robust principal component analysis (RPCA) to predict the performance ratio as a function of time. It was found that the approach predicted degradation rates for multi-crystalline silicon and thin film technologies that were close to measured rates of functioning systems, but larger deviations are calculated for mono-crystalline silicon. In fact, it is argued that mathematical statistical techniques must be used in large PV field systems that are subjected to environmental and operational variability.

Buerhop *et al.* describe the analysis of potential induced degradation -induced degradation in their paper entitled *'Analysis of inhomogeneous local distribution of potential induced degradation at a rooftop photovoltaic installation'*. Interestingly, analysis of the annual yield and monthly expected yield of a functioning PV system did not reveal any degradation. This was reported to be due tothe complex plant layout with shading influencing irradiation on modules. However, evaluation of the DC performance ratio showed degradation, with its origin being proven by IR imaging. This paper is therefore a good example of the need to deeply analyse PV performance data to properly understand local and global energy yield deviations of PV systems.

Performance of fixed tilt PV systems is directly linked with finding the optimum solar cell tilt, with tracking systems improving energy yields at a cost penalty. An alternative approach is suggested by Akhlaghi *et al.* in their paper *'Efficient operation of residential solar panels with determination of the optimal tilt angle and optimal intervals based on forecasting model'*. A novel procedure is proposed that involves changing the tilt angle a limited amount of times during the year. The number of intervals and their durations are determined by solving an optimisation problem. The effectiveness of the proposed approach is studied at nine different locations across the US. The reported results show improvement of the solar power generation by using the optimal tilt approach, with the overall energy gain for different locations depending on the geographical features and weather conditions in the local region.

Solar forecasting

Kim *et al.* in their paper entitled *'Daily prediction of solar power generation based on weather forecast information in Korea'* report the development of a model to predict daily solar power using actual weather forecasts. Cloud and temperature data available from weather forecasts, along with degradation effects and failures of the PV systems are included in the model. The developed model is tested for a commercial PV system in Korea and is reported to outperform existing neural network forecasting models. Evidently, errors in weather forecasting will be parsed through in solar forecasting models. This is studied in the paper by Sangrody *et al.* entitled *'Weather Forecasting Error in Solar Energy Forecasting'*. Several parameters from the weather forecast for the US from the National Oceanic and Atmospheric Administration (NOAA) were analysed. It was found in their error analysis that wind speed is underestimated while other parameters such as sky cover, relative humidity, and temperature show bias and overestimation. These latter overestimated parameters were selected for energy forecasting model training using an artificial neural network (ANN) model. It is shown that although inaccuracies are observed in these parameters, training the ANN nevertheless provides good solar forecasting.

Liu *et al.* present in their paper *'Takagi–Sugeno fuzzy model-based approach considering multiple weather factors for the photovoltaic power short-term forecasting'* a new model for hourly prediction of PV power, with validation carried out in in Queensland, Australia. In their model, hourly air temperature, humidity, and insolation are considered as the input variables of the forecasting model. This non-linear forecasting system can be linearised using a Takagi-Sugeno (T-S) fuzzy method, which applies parameter clustering based on the correlation of their variation with PV power variation. The T-S method is compared to a support-vector machine (SVM) model, and two neural network methods. Reported results indicate that the T-S fuzzy based forecasting approach yields a better forecast.

Gibson *et al.* discuss the errors made in the analysis of PV performance due to the use of hourly averaged data from meteorological stations. In the paper entitled *'Compensation of temporal averaging bias in solar irradiance data'*, the combined impact of temporal averaging, component deconstruction and plane translation mechanisms on uncertainty is analysed. A new clearness index redistribution method is proposed, which is based on the statistical redistribution of clearness indices. It is shown that the method largely corrects the bias error introduced by temporal averaging. As a consequence, using data from the UK, a large reduction in diffuse, beam and global yield of hourly averaged data was observed.

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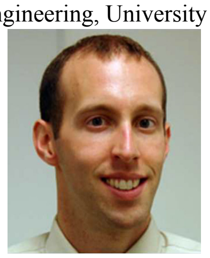

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