PERFORMANCE MODELING AND ANALYSIS OF A UTILITY SCALE SOLAR PHOTOVOLTAIC POWER PLANT IN A TROPICAL REGION

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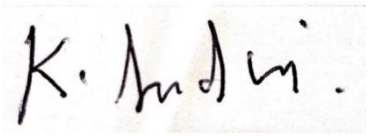
DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that We have checked this thesis, and, in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.



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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Fotovoltaik solar telah muncul sebagai salah satu teknologi tenaga yang boleh diperbaharui untuk menjana kuasa. Kawasan tropika adalah kawasan tumpuan untuk pemasangan loji kuasa PV skala utiliti yang sangat dipengaruhi oleh parameter cuaca semasa seperti sinaran suria, variasi suhu, kelajuan angin, kelembapan, tekanan atmosfera dan lain-lain.Penilaian prestasi loji PV dipengaruhi oleh kualiti data dan ketepatan instrumentasi. Metrik nisbah prestasi biasa (PR) mempunyai had, apabila digunakan untuk penilaian prestasi loji PV skala utiliti. Pengaruh cuaca terhadap prestasi dan model ramalan lanjutan yang berkaitan jarang dikaji di loji operasi. Literatur hanya menyediakan contoh terhad analisis ekonomi dan alam sekitar bagi loji PV utiliti yang dipasang di kawasan tropika. Objektif penyelidikan ini meliputi analisis prestasi loji kuasa PV skala utiliti yang dipasang di kawasan tropika menggunakan data stesen cuaca canggih, memodelkan prestasi berdasarkan parameter cuaca, penilaian ekonomi dan alam sekitar berdasarkan data yang diukur jangka masa panjang. Penilaian prestasi ladang solar dilaksanakan berdasarkan piawaian prestasi IEC 61724 dan nisbah prestasi biasa. Selanjutnya, nisbah prestasi yang diperbetulkan cuaca dianggarkan dengan menggabungkan ciri-ciri cuaca tempatan di laman web ini. Pemodelan prestasi dicapai menggunakan alat Minitab dan AI seperti metodologi Permukaan Respons (RSM), Rangkaian Neural Buatan (ANN), dan Sistem Inferens Neuro-Fuzzy Adaptif (ANFIS). Aspek ekonomi dan alam sekitar dinilai menggunakan platform perisian RETScreen.Analisis tenaga loji janakuasa PV berskala utiliti mendedahkan bahawa musim monsun barat daya (SWM) yang berlaku di kawasan lembap tropika mempunyai pengaruh yang besar terhadap corak penjanaan loji yang mengakibatkan penurunan 36% dalam penjanaan tenaga tahunan.Nisbah prestasi purata (PR) loji solar PV adalah 74.45%, dengan faktor penggunaan kapasiti 15.55% (CUF) dan purata penjanaan harian 2728.215 kWj sepanjang tempoh kajian (2017-2020). Kajian perbandingan PR biasa dan PR yang diperbetulkan cuaca menunjukkan kurang variasi pada kawasan tropika untuk tumbuhan yang dikaji berbanding dengan kawasan yang lebih sejuk.Model prestasi yang unik telah dibangunkan untuk meramalkan penjanaan untuk musim cuaca yang berbeza.Model ramalan tenaga soar berasaskan penyinaran global juga dirumuskan dengan ralat kurang daripada 4%.Di antara model berasaskan AI, model ANFIS diperhatikan lebih cekap untuk ramalan prestasi.Ladang solar yang dianalisis yang dipasang di rantau tropika mempunyai penjimatan kitaran hayat tahunan sebanyak 35,312 USD / Yr.Analisis alam sekitar mendedahkan keupayaan loji solar dalam mengurangkan 2827 tan karbon setahun.Hasil kerja penyelidikan ini akan menyumbang kepada penilaian prestasi dan penanda aras loji janakuasa PV berskala utiliti yang dipasang di seluruh dunia.Ia juga akan memberi

ABSTRACT

Solar photovoltaics has emerged as the major renewable energy technology for generating power. Tropical regions are the hotspots for utility-scale PV power plants and are highly influenced by the prevailing weather parameters like solar radiation, temperature variations, wind speed, humidity, atmospheric pressure, etc. The performance assessment of PV plants is influenced by the quality of data and the accuracy of instrumentation. The normal performance ratio (PR) metric has limitations when used for performance assessments of utility-scale PV plants. The influence of weather on the performance and the associated advanced prediction models are rarely studied in operational plants. Literature provides only limited examples of economic and environmental analysis of utility PV plants installed in tropical regions. The objective of this research includes the performance analysis of utility-scale PV power plants installed in tropical regions utilizing advanced weather station data, modeling the performance based on important weather parameters and economic & environmental assessment based on long-term measured data. The performance assessment of the solar farm is carried out based on IEC 61724 standards and on a normal performance ratio. Further, the weather-corrected performance ratio is estimated by incorporating the local weather characteristics of the site. Performance modeling is accomplished using Minitab and AI tools like Response Surface methodology (RSM), Artificial Neural Network (ANN), and Adaptive Neuro-Fuzzy Inference System (ANFIS). Economic and Environmental aspects are assessed utilizing the RETScreen software platform. The energy analysis of a utility-scale PV power plant revealed that the southwest monsoon (SWM) season prevailing in a tropical humid region has a substantial influence on the generation pattern of the plant resulting in a 36% drop in annual energy generation. The solar PV plant's average performance ratio (PR) is 74.45 %, with a 15.55 % capacity utilization factor (CUF) and an average daily generation of 2728.215 kWh over the study period (2017-2020). A comparative study of normal PR and weather-corrected PR revealed less variation on tropical regions for the studied plant compared to the colder regions. A unique performance model has been developed for predicting the generation for different weather seasons. Global tilted irradiation-based soar energy prediction model is also formulated with less than 4 % error. Among the AI-based models, the ANFIS model is observed to be more efficient for performance prediction. The analyzed solar farm installed in the tropical region has an annual life cycle savings of 35,312 USD/Yr. The environmental analysis revealed the capability of solar plants in mitigating 2827 tonnes of carbon per year. The outcome of this research work will contribute to the performance assessment and benchmarking of utility-scale PV power plants installed worldwide. It will also directly benefit the policymakers, consultants, utilities agencies, and developers.

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