DEVELOPMENT OF ONLINE MONITORING SYSTEM FOR A GRID CONNECTED SOLAR PHOTOVOLTAIC PLANT

Ph.D. THESIS

by

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A THESIS

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"DEVELOPMENT OF ONLINE MONITORING SYSTEM FOR A GRID CONNECTED SOLAR PHOTOVOLTAIC PLANT"** in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Alternate Hydro Energy Center of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from July, 2014 to February, 2018 under the supervision of Dr. S. N. Singh, Senior Scientific Officer, Alternate Hydro Energy Center, Indian Institute of Technology Roorkee, Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institution.

Signature of Candidate

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Signature of Supervisor (s)

The Ph. D. Viva-Voce Examination of Siva Rama Krishna Madeti, Research Scholar, has been held on June 19, 2018.

Chairman, SRC **Signature of External Examiner**

This is to certify that the student has made all the corrections in the thesis.

Signature of Supervisor (s) **Head of the Department**
Date:

ABSTRACT

This Doctoral Thesis entitled "Development of online monitoring system for a grid connected solar photovoltaic power plant" is aimed to develop the methods/techniques/concepts to improve the performance of the photovoltaic (PV) plants. Though the amount of energy that a PV module generate depends mainly on the incident irradiance, there are different factors/faults/losses (such as, ambient temperature, shading effects, dust or snow accumulation on the surface of the solar panels, maximum power point tracking error and electrical disconnection) which may negatively affect the energy yield. These factors would directly affect the PV module operating parameters and hence its performance. Therefore, it is essential for a PV plant to have an effective and dedicated monitoring system, in order to detect and locate the loss/fault at module level, and to perform the subsequent diagnosis. This thesis starts with the literature overview of various PV monitoring systems, which includes, detailed overview of all the major PV monitoring and evaluation techniques in terms of their relative performances, sensors used along with their working principles, controller(s) used in data acquisition systems, data transmission methods, and data storage and analysis. Moreover, a detailed review of popular fault detection techniques with their relative performances, addressing all major types of faults in PV systems is covered.

An overview is made of the PV modules operational parameters and their dependence on applying atmospheric conditions. These are:

(i) Short circuit current: I_{sc}
(ii) Open circuit voltage: V_{oc}
(iii) Current at maximum power point: I_{mp}
(iv) Voltage at maximum power point: V_{mp}
(v) Power at maximum power point: P_{mp}

The translation procedures of referred parameters from Standard Test Conditions (STC) to Real Operating Conditions (ROC) are defined.

The proposed model is validated using consolidated data obtained in the Solar Energy Laboratory, Alternate Hydro Energy Center (AHEC), Indian Institute of Technology Roorkee (IITR) through a PV analyzer of HT instruments. The procedure applied has been to generate the

I-V curve values from proposed model, according to reported ambient conditions and then the results are compared in order to quantify the resulting Relative Error (RE).

A total of 10 sets of measurements have been made under different conditions. The $I-V$ curves at STC have been obtained and further translated to ROC. The Relative Error (RE) of main operational parameters such as short circuit current (I_{sc}), open circuit voltage (V_{oc}), power at maximum power point (P_{mp}) and corresponding voltage (V_{mp}) and current (I_{mp}) as well has been calculated.

The same procedure has been applied to the Smart Monitoring and Communications Module (SMCM) obtained experimental results generated in the Solar Energy Laboratory installed JJP60F230 PV modules, once they have been previously validated. PV modules has been equipped with one SMCM, which has been in charge of monitoring its operational parameters $(V, I \; and \; T_m)$, and further transmit them to the Central Control System (CCS), by means of the Power Line Communication (PLC) technology using already existing DC power lines. The master-SMCM version is in charge of data routing to the CCS for further processing. Additionally, it processes the parameters of the calibrated cell which gives the effective incident irradiance and the ambient temperature sensor.

A new low cost monitoring system is developed in this thesis, which uses SMCM configuration, and the PLC based physical communications layer. The SMCM is a smart device based on TI MSP 430 high performance and low cost microcontroller. Considering the SMCM as an electronic measurement device, its associated uncertainty is quantified.

Moreover, an online monitoring system with new fault diagnosis technique is proposed for the solar PV systems operating under grid-tied and off-grid modes. This technique is experimentally validated using the PV system built at Solar Energy Laboratory. A user friendly web application is developed for easy access of monitored data via Internet. Experimental evaluations are carried out to demonstrate the effectiveness of proposed technique in detecting the various fault occurrences in both grid-tied and off-grid PV system.

Furthermore, another low cost online monitoring and fault diagnosis technique with optimized voltage sensor locations, and corresponding web application are proposed for gird-tied PV systems. Economic analysis is carried out to study the cost effectiveness of this improved fault

detection technique considering different values of interest rate and energy tariffs. Experimental results are obtained to demonstrate the effectiveness of proposed fault detection technique.

Finally, a health monitoring method for PV systems based on k-nearest neighbors (kNN) is proposed. To implement and validate the proposed method in computer programs, a new approach for modeling PV systems is proposed that only requires information from manufacturer's datasheet reported under normal-operating cell temperature (NOCT) conditions and standard-operating test conditions (STCs). The proposed model precisely represents characteristics of PV systems at different temperatures, as the temperature dependency of parameters such as ideality factor, series resistance, and thermal voltage is considered in the proposed model.