PERFORMANCE EVALUATION OF STAND-ALONE PHOTOVOLTAIC (SAPV) ARRAY SYSTEM

by

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Centre for Energy Studies

Submitted

in fulfillment of the requirements of the degree of

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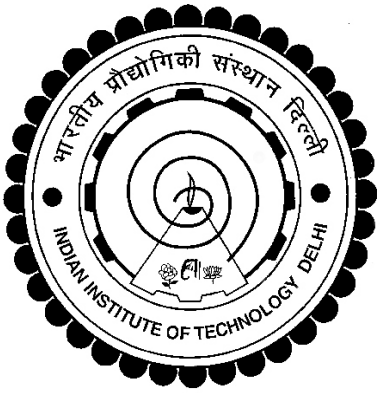

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Certificate

This is to certify that the thesis entitled **"Performance Evaluation of Stand-alone Photovoltaic (SAPV) Array System"**, being submitted by **Rakhi Sharma** to the Indian Institute of Technology Delhi, is worthy of consideration for the award of the degree of **'Doctor of Philosophy'** and is a **record of the original** bonafide research work carried out by her under our guidance and supervision. The results contained in the thesis have not been submitted in part or full, to any other University or Institute for the award of any degree or diploma.

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Date: July, 2012 **(Rakhi Sharma)**

Abstract

In developing countries, wide varieties of renewable energy projects are in progress and among them photovoltaic system has emerged as most promising as a future energy technology. There is a large scope for utilization of solar energy, and if sustained efforts are made, renewable energy sources can meet a significant part of the energy needs. The renewable global status report (2007) indicates that the power production by way of solar photovoltaic (PV) has grown more than any other renewable energy source. There still exist many constraints, and the problems that need to be examined from the economic, technical, operational and institutional viewpoints. It has also become necessary to evaluate on field performance of existing old PV system to assess its on field performance degradation. Utilization of this Photovoltaic technology could be stimulated through dissemination of information, training services, subsidies and credit facilities. Installation and performance evaluation of few small to medium capacity photovoltaic (PV) units is very essential. It is essential that potential users should be made aware of the technology through the fundamental principles on which it is based and increased understanding of the processes.

Most of performance assessment methods for on-field performance evaluation of stand-alone PV array system found in literatures are either needed detailed data or complex to use or usually restricted to economic performance evaluation. A convenient low-cost alternative is needed for developing countries to monitor on field array performance.

In the present thesis an attempt has been made to develop simplified methodology and mathematical model to evaluate on-field daily and subsequently monthly and then annual performance of a photovoltaic (PV) array and its individual component subarrays in terms of electrical energy output and actual electrical efficiency or power conversion efficiency. To obtain more effective and realistic assessment calculated on-field technical performance

results obtained from experimental observations have been compared with the potential performance results obtained from the expressions developed for estimating rated/max. performance indices of PV array/subarrays. From the on-field hourly measured experimental observations over a day on two individual component subarrays of 1.2 kW_p and 1.12 kW_p of 2.32 kW_p stand-alone PV array system, installed at IIT Delhi, India, it was found that the performance indices calculated for subarray1: 1.2 kW_p (Siemens) were quite considerable, but poor performance of subarray2: 1.12 kW_p in turn significantly affecting the entire PV array: 2.32 kW_p by reducing its overall technical performance.

Annual performance evaluation of existing PV array/subarrays on the basis of on field measured experimental observations and numeric computation have been presented. Extensive experiments have been carried out to obtain a clear day observations in each month during a year from July'2009 to June'2010 on existing on two component subarrays of 2.32kW_p PV array system. As per proposed methodology of performance assessment a new set of analytical expressions has been evolved. It was found that in actual on field operating conditions out of total experimentally calculated PV array electrical energy generation of 1442.5kWh/year ,subarray1(Siemens) shares 899.9kWh/year (62.4%) and subarray2 (CEL) shares 542.6kWh/year (37.6%). PV array/subarrays production factor has been evaluated. For existing PV array system Power conversion efficiency has been calculated 7.7% for subarray1, 3.5% for subarray2 and 5.3% for entire PV array on the basis of over a year experimental measurement. Whereas, estimated maximum power conversion efficiency with same actual experimental environmental conditions (i.e. solar intensity, ambient temperature and PV operating temperature conditions) should be 11.41% for subarray1, 7.99% for subarray2 and 9.45% for entire PV array consisting of both subarrays in operation.

A new terminology overall PV degradation loss factor has been proposed and simplified methodology and analytical expressions to evaluate the overall PV degradation

loss factor for PV array has also been developed. On the basis of on field monthly electrical energy output performance of PV array/subarrays obtained from clear day observations in each month during a year and numeric computations, overall PV degradation loss factors due to combine effect of various losses caused by monthly climatic variation over a year and long term exposure of existing PV array/subarrays have been evaluated in the range of 0.230 to 0.429 for subarray1 (Siemens make), 0.497 to 0.648 for subarray2 (CEL make) and 0.363 to 0.538 for entire existing PV array of 2.32 kW_p. Temperature dependent loss factor for subarray1 and subarray2 has been found almost same in the range of 0.014-0.138. Experimental results on a practical system can be useful for assessing and predicting PV modules/subarrays/arrays effectiveness for onsite power generation.

Need of minimum battery sizing under certain suitable operating conditions and applications to obtain minimum cost and less maintenance batteries in PV system has been expressed. Simplified battery sizing methodology to estimate required and installed battery bank size of given rated power stand alone PV system on the basis of night load demand and peak sunshine hours conditions has been presented . Minimum battery bank capacity for given rated power of stand-alone PV (SAPV) system has been estimated for different mode of operations using conventional and proposed modified battery sizing methods.

Expressions and calculations of basic Energy Matrices, Energy Payback Time (EPBT); Energy Production Factor (EPF); Life Cycle Conversion Efficiency (LCCE) in order to evaluate overall performance of given rated PV systems have been incorporated. Life cycle cost analysis for SAPV systems based on cost per unit energy has been estimated. Carbon credit earned by stand-alone solar photovoltaic system has also been evaluated. The life cycle analysis of the existing outdoor stand-alone PV (SAPV) system (almost 20 years old) with actual on field performance evaluates present unit cost of electricity Rs. 47.62 per kWh as rooftop mounted system and Rs. 66.78 per kWh as ground mounted system.

Whereas this same SAPV system with potential (max.) performance estimated at on-field existing experimental environmental conditions (as newly installed system) evaluates the unit cost of electricity Rs. 26.30 /kWh and Rs. 34.19/kWh for rooftop mounting and ground mounting respectively.

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