PERFORMANCE ASSESSMENT OF DIFFERENT PV TECHNOLOGIES ON WATER BODIES

Ph. D. THESIS

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ABSTRACT

The significant rise in the energy demand and fast depletion of fossil fuels along with environmental concerns during recent years has led to the installation of more and more renewable energy systems. In particular, solar energy harvested from solar photovoltaic (PV) is considered to be one of the most promising renewable energy alternatives to generate electricity. The utility-scale PV systems require a large land area which is always a premium commodity. In rural areas, PV plants use agriculture land which can affect the livelihood of local people. An attractive alternative to the land-based PV systems is to utilize the surface of existing water bodies like canals, reservoirs, and ponds for the PV installations. It is a new and innovative way of power generation which avoids the use of land and reduces evaporation loss from water bodies. Canal-Top and floating PV power plants are examples of water bodies-based PV systems. The solar PV system on the water bodies is an emerging large scale PV deployment option for several countries like India having a large network of irrigation canals, reservoirs and ponds; hence the extensive research and development are required for its further improvements.

The cost-effective electricity generation from water bodies-based PV systems is a major challenge. Various parameters need to be identified which can reduce the cost of electricity generation by water bodies-based PV systems. The PV module's performance and degradation are the main parameters which affect the energy payback duration and cost of electricity generation. Therefore, the longer lifetime and reliability of the PV module on water bodies are essential for their commercial viability.

The performance of PV systems varies with the local environmental conditions and technology of the PV module. The PV modules tend to degrade after their long-term operation in field conditions and their degradation rate depends on the local environmental conditions. The environmental conditions in the surroundings of water bodies-based PV systems differ from the land-based PV systems because of their proximity to water and evaporation process.

The deployment of PV systems on water bodies provides the evaporative cooling to the PV modules and results in the reduction in the module temperature. The decrease in module temperature increases the efficiency of PV systems. However, it is to be noted that the surroundings of the water-

bodies have high humidity due to the evaporation process and thus high humid environment is a serious cause of concern for the performance of PV systems since it reduces the conversion efficiency of modules. Thus, the general perception of performance enhancement of PV systems on the water bodies is still ambiguous and need to be studied in details with field and experimental setups.

The prolonged exposure of PV systems to the high humid climatic condition of water-bodies can alter the performance characteristics of the system. In addition, the moist climate of water bodies may accelerate the degradation rate of PV systems. Therefore, performance and degradation analysis of various PV technologies on the water bodies is essential for reliable, cost-effective and commercially viable PV system installations on the water bodies. The long-term performance and degradation analysis of different PV technologies on water bodies have not been reported to the best of author's knowledge.

The performance of conventional land-based PV systems has been researched and reported extensively in the literature. On the other hand, the earlier reported studies on water bodies-based PV systems mainly dealt with the design, potential estimation and feasibility analysis of PV systems on the water bodies. Therefore, the present study is important to understand the performance characteristics and degradation of different PV technologies on the water surface.

At present, multicrystalline silicon (Multi-Si) PV modules are widely used for canal-top and floating PV systems. The high humidity due to the presence of water can disturb the performance of water bodies-based PV systems. The recent advancements in Heterojunction with Intrinsic Thin layer (HIT) and Cadmium Telluride (CdTe) PV modules prove their potential to be utilized as commercial PV technologies. Therefore, the performance assessment of different PV technologies on the water surface is important for the selection of suitable PV technology for their large-scale installation on water bodies and for their reliability, cost-effectiveness and scope of improvement.

An experimental setup has been designed, fabricated and installed at the outdoor PV research facility of Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, India to simulate the time elapsed performance assessment of three different PV technologies on water-bodies and to compare their performance with respective land-based PV technologies. The Multi-Si, HIT and CdTe are three PV technologies which have been used in the present experimental setup. The experimental data were measured for the 13 months duration at outdoor conditions.

The water tanks are utilized to simulate the water bodies at the experimental setup including the facility of continuous water flow through pipes. The performance of PV technologies installed on the water tanks has been analyzed and compared with respective PV technologies installed on land. The purpose of performance comparison is to select the suitable PV technology and to know the differences in efficiency, performance and degradation rate between the water bodies-based and land-based PV systems.

In addition, the amount of water saved by the PV installations on the water bodies plays an important role in economical feasibilities and life cycle cost analysis of water bodies-based PV systems. The amount of evaporation reduction by installing the PV systems on water bodies is not available widely. To find out the difference in evaporation between PV module covered and uncovered water bodies, the same experimental setup was used to measure the loss of water during one year period. Furthermore, the analytical model to determine the evaporation in water bodies-based PV systems has also been developed.

Additionally, the actual water bodies-based PV system has been evaluated for a deeper understanding of performance and degradation of these systems in actual circumstances. The performance and degradation analysis of world's first commercial Multi-Si based 10 MWp grid-connected canal-top PV system installed in the Indian state of Gujarat has been carried out for its initial 2 years 8 months operation.

The quantitative and qualitative performance assessment methodologies have been used to analyze the performance characteristics of PV systems or modules. The quantitative performance parameters reveal the overall performance of the PV system with respect to energy yield, input solar radiation and the effect of various losses. On the other hand, qualitative performance assessment measure various thermal losses associated with PV system due to its interaction with the external environment.

Degradation analysis of all PV modules has been carried out using various approaches after their one year outdoor operation. The alternating reporting conditions (ARC) technique has been used to measure the degradation in electrical parameters of all PV modules during outdoor operation. In addition, mathematical PV model has been developed to analyze the degradation in the internal parameters such as series resistance and shunt resistance of each PV module. Visual inspection and

thermal imaging have also been carried out to identify the various defects in all PV modules during outdoor operation.

The average performance ratio of the HIT and Multi-Si modules on the water tanks are found to be 0.4% and 2.7% lower than the respective land-based modules despite their low module temperature due to evaporative cooling, respectively. On the other hand, the average performance ratio of the water tank-based CdTe module is increased by 3.1% as compared to land-based CdTe module. The lower performance of HIT and Multi-Si technologies on water bodies are contrary to the general perception of higher power generation on water bodies. However, the CdTe module on the water surface has performed better than the land-based CdTe module. Additionally, the experimental results show that the PV module cover on the water bodies can reduce the evaporation by 29% in comparison to the uncovered water bodies. However, the measured evaporation from the experimental setup shall be subject to the multiplication of pan coefficient under actual conditions.

The degradation of HIT PV modules is found almost similar under both climatic conditions. On the other hand, the degradation in Multi-Si modules on the water and land surfaces are found to be 1.32% and 0.93%, respectively. The degradation in CdTe modules on the water and land surfaces are found to be 1.68% and 1.41%, respectively. In the climatic conditions of water bodies, the degradation rate of Multi-Si module increases significantly whereas the CdTe module has a modest increase.

The annual average performance ratio and degradation rate of Multi-Si based 10 MWp grid-connected canal-top PV system are found to be 77.85% and 1.93 ± 0.28%/year, respectively. The 10 MWp canal-top PV system has a very high degradation rate at its early stage of the operating period. Thus, the results of the experimental study and actual system confirm the high degradation rate of Multi-Si module on the water bodies which could be the cause of concern for the longer lifetime and cost-effective power generation. Based on the findings of present study, the CdTe and HIT technologies are found suitable for large scale deployment on water bodies.