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Grid-connected PV systems in the Pacific Island Countries

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ABSTRACT

Grid connected solar photovoltaic (GCPV) systems are fast becoming a regular feature of electricity power networks in urban and peri-urban areas within most Pacific Island Countries. A number of systems have been installed with many in the pipeline. This relatively new technology, utilizing the intermittent solar energy resource has presented new challenges to small island utilities that were hitherto almost completely dependent on diesel generators and hydropower. The present paper describes the current status of GCPV systems in the Pacific region and reviews some of the issues that arise in the deployment of this technology. It also reports a case study involving a 45 kW_p GCPV system located at the University of the South Pacific (USP) marine campus in Fiji. One of the first two GCPV systems established in Fiji, this system has an annual production of ~54,000 kW h and supplies about 10% of the electricity requirements of the campus. The actual system performance agreed well with the simulated results. This system also reduces USP's annual carbon footprint by more than 27,000 kg CO_{2e}.

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1. Introduction

In the past few years there has been a dramatic rise in renewable energy (RE) development and deployment on global scale. According to the recent REN 21 report [1], the global RE capacity was approximately 1560 GW in 2013 which was around 8.3% increase from 2012. Excluding hydropower, global RE installed capacity was 560 GW in 2013 with China leading followed by United States, Germany, Spain, Italy and then India. At the end of 2013, renewable energy based systems generated 22.1% of the global electricity [1]. Between 2000 and 2013, global renewable energy based electricity capacity more than doubled in size reaching 27% of the total capacity [2]. However, development of RE projects requires a lot of consideration as the cost of renewables (solar, wind, biomass geothermal and small hydro) is very site specific due to the uneven distribution of resources throughout regions, countries and even within a country [3].

Globally, solar PV industry has made significant progress in the recent years, which is mostly attributed to the decreasing cost of solar PV per kilowatt. Singh [4] provides a detailed review on the research and development that has been done in solar power generation since its commencement. The solar PV capacity reached 139 GW with 39 GW added in 2013 alone [1]. Most of the new PV capacity is in the form of grid-connected systems. China is the leader in global PV market followed by Japan and United States [5]. Raugei and Frankl [6] in their long-term scenarios for PV development predicted that there will be a huge increase in global cumulative PV capacity in the next few decades. Their preliminary results of life cycle analysis indicated that due to the current advancement in PV technology and emerging technology will lead marked lower cost per-kW h over the next few decades. IEA's solar technology roadmap envisions 4600 GW of solar PV by 2050 which would contribute to 16% of global electricity [5]. It stresses that appropriate regulatory framework and well-designed electricity market would be needed to achieve this vision.

A GCPV system allows the consumer to sell PV electrical energy at an agreed rate to the utility during production of excess electricity and to buy electricity from the grid during night. Since GCPV systems deal with large voltages and networks, their performance and interaction with the grid needs to be thoroughly investigated in each case especially for the larger systems. The experimental results during a performance analysis of a 2.7 kW_p GCPV at a university in Italy provided evidence that solar radiation and cell temperature affected the module efficiency [7]. Performance results of four 3 kW_p GCPV systems in Korea were obtained for one year to investigate operational characteristics of the system [8]. Other researchers [9–17] have also carried out performance analysis of small ($<1000\ kW_p$) GCPV systems using different methods to estimate energy output from PV systems and have also investigated their socio-economic impacts.

Bernal-Agustin and Dufo-Lopez [18] studied the environmental and economic performance of GCPV systems in Spain where environmental benefits were determined using Life Cycle Analysis (LCA) theory of the systems, calculating the recuperation time of the invested energy, the emissions avoided and the externality costs. LCA have been carried out by Bayod-Rujula et al. [19] for GCPV with 2-axis tracking and fixed modules systems. A knowledge of reliability of GCPV systems is paramount since it has a high capital investment and a sound business plan demand a long system life. Zini et al. [20] present a method based on fault tree and probability analysis to analyse and quantify the reliability of large-scale grid-connected PV systems.

1.1. GCPV systems: technical issues

Passey et al. [21] have reviewed the impacts on electricity grids when distributed generators (DG) employing renewable energy sources, especially PV, are connected. A number of effects viz. grid-derived voltage fluctuations, voltage imbalance, voltage rise and reverse power flow, power output fluctuations, frequency variation, harmonics and unintentional islanding can appear as a result of this interconnection Low penetration of DG can be tolerated by the grid provided they are within a minimum threshold. However, to accommodate increased levels of DG penetration, changes to the network have to be made such as minimizing reactive power flows, power factor correction, increased voltage regulation in the network and careful consideration of protection issues [21]. Extensive literature has been reviewed by Shah et al. [22] which showed that impacts of high levels of PV penetration on the power system are influenced by size, nature and location of PV installations, availability of adequate reserve in the system, reactive power compensation method among other factors. They suggest that dispatching strategy and spinning reserve should be studied for grid stability. Tarroja et al. [23] developed an array of metrics to evaluate the impact of intermittent renewable generation (such as wind and solar) on the electric load demand which allowed high penetration level of DG to be examined. Alsayegh et al. [24] proposed a two supervisory hierarchy scheme where local autonomous supervisory system (LSC) was configured to examine the performance of renewable energy source systems (RESs) by preventing negative influences by the RESs on the national grid, optimizing the usage of RESs and monitoring and controlling access to national and regional control centres.

ElNozahy and Salama [25] discussed that PV arrays providing electrical energy at the load side of the distribution network reduce the feeder active power loading which improved the voltage profile. Eltawil and Zhao [26] reviewed the challenges posed by high penetration of PV into the grid. Based on an extensive literature survey discussing the potential problems associated with high penetration of grid-tied PV, they recommend that GCPV inverters should operate at unity power factor since variable power factor would increase the probability of islanding during high penetration levels. The impact of large scale PV ($>500\ kW_p$) on transmission/sub-transmission networks is discussed in a study by Paatero and Lund [27]. There is an increasing requirement of ancillary services due to the variable output of GCPV (when PV production reduces due to cloud cover). This would mean that utilities need to provide fast ramping power generation to compensate for the variable power output from PV to maintain the voltage and frequency of the grid within allowable limits. It is