Performance Comparison of 3kW Residential Grid-Connected Photovoltaic System between Microinverter and String Inverter Topology using System Advisor Model

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Abstract - *Grid connected rooftop PV systems are the most common form of solar energy utilization that helps home owners to reduce carbon footprint and save money in utility bills. This project focuses on the design and modelling of a 3KW residential PV system connected to a 240V single phase grid.*

The purpose of this study was to conduct an independent experiment on two photovoltaic systems, one with a central inverter and the other with microinverters, to determine their comparative performance characteristics.

Both systems have fixed tilt angle and fixed azimuth angle. In order to analyze the performance of the systems, the Energy Yield, Performance Ratio, Capacity factor and Annual Energy have been used. This allowed to obtain a correct comparison even with different Irradiance values and different Peak Powers.

In the central inverters, several strings of PV modules are combined in order to achieve the power required from the inverter to operate. Strings are connected in parallel and then these strings are led to the inverter after running several meters of DC cables.

These cables are often very thick and as a result are very expensive while at the same time, they add losses to the overall system. On the other hand, AC cables are much less expensive and they have fewer losses.

A residential system was designed in SAM using specific weather data. The simulation results supported the fact that micro inverters outperform the traditional string inverters in both shaded and non-shaded conditions.

A significant advantage of Micro Inverters is the avoidance of shading losses and mismatch among different PV technologies which consists a great challenge on PV installations.

This thesis presents experimental data that supports the conclusion that microinverters can outperform central inverters in both unshaded and shaded conditions The Micro Inverter system produced an annual energy of 4916 kWh in the first year with no shading and 4332 kWh in the first year with shading losses.

The String Inverter system produced an annual energy of 4763 kWh in the first year with no shading and 4286 kWh in the first year with shading losses.

Key Words: Inverters, Photovoltaic cells, Photovoltaic systems, Solar energy, Solar panels.

1.INTRODUCTION

The use of module level power electronic devices (MLPE) has been proposed to mitigate electrical and thermal mismatch losses in the field by tracking the maximum power point of individual modules. In general, MLPE devices consist of two main categories: micro inverters and power optimizers. In this paper micro inverters and boost power optimizers are considered.[1].

The key challenges of partial shading PV models are therefore to generate accurate yield predictions under heterogeneous irradiance conditions with reduced simulation time. In this paper a model is presented that considers cell shading fractions determined by a 3D model and applies an irradiance model to determine the effective irradiance on a partially shaded cell. Moreover, the model takes into consideration the system architecture and associated power electronics efficiency losses.[2]

Partial shading is considered as the major challenge faced by the roof-top PV system that aims to reduce the power output of the system. All the modules in a string connected in series carries the same current. Partially shaded modules which generate less photon current forcefully carry the current equivalent to the non-shaded modules. Shaded modules, once reverse biased behave as loads and deplete the power from non-shaded modules. The absence of suitable protection for the system can lead to the hot-spot formation and in the worst scenario will cause permanent damage [3].

Integration of PV Systems to existing buildings poses another problem of inevitable partial shading due to neighbouring structures for different seasons. In standard PV systems this shading reduces the total power production to a larger extent than anticipated, leading to higher capital costs as more modules are required. This makes the PV systems less appealing to customers. Hence, the study of partial shading is very important. Also, to make PV systems reliable for all conditions their characteristics under different partial shading conditions needs to be understood.

In the last few years, effects of partial shading on PV system have been thoroughly studied [4], [5]. Since field trial of physical PV modules for partial shading study is expensive, slow and highly dependent on the ongoing atmospheric conditions, it is impractical to examine the effects of partial shading using physical PV modules. Also, it is hard to continue the similar shading type with a greater shaded units and completely unshaded cells for the entire experiment. Hence, it is easier to perform the experiment using a simulation model. In a majority of the studies, partial shading effects which reduce the power output of the PV system have been examined [6], [7].

In this paper, we consider a 3kW system and perform a comparison of the microinverter-based system to the string inverter-based system.

To compare these two different technologies, a side-by-side comparison was conducted using as many identical system components as possible. Eight identical panels were used in both of the systems, one with microinverters and the other with an appropriately sized central inverter. This method reduced the number of confounding variables of the experiment.

By comparing the AC outputs of the unshaded and shaded setups and statistically analysing the results, it was possible to determine if using microinverters increased the total power output of the system.

A microinverter connected to a single PV module has become a trend for residential grid-connected PV systems, replacing a single inverter connected to a string of series-connected PV modules for many reasons including:

- improved energy harvest
- improved system efficiency
- lower installation costs
- plug-N-play operation and
- enhanced flexibility and modularity [8, 9, 10]

At first glance, the string inverter appears to have a lower per-watt capital cost when just the inverter is considered. However, the inverter represents only about 15% of the entire PV system cost whereas the installation labour and balance of system (BOS) cost account for 40%, depending on the system configuration and inverter technology. These factors have made it difficult to perform a comparative cost study.

An alternating-current photovoltaic module (ACPV) is created when the microinverter is directly attached to a single PV module [19]. The result is a PV module that produces AC power without any extra electronic components. The implication, however, that since the power electronics is indelibly integrated with the PV module, the microinverter must have a lifetime that matches the PV module - namely 25 years. Hence, most of the microinverter manufacturers are now providing a standard 25-year warranty [11, 12, 13].

2. Methodology

A. For this project we will concentrate on the PV system design and analysis. This chapter will focus on a step-by-step approach on how to model residential PV systems using SAM. We take into consideration all the various factors and constraints that need to be considered for an efficient design.

B. System Advisor Model (SAM) is a modelling tool developed by NREL and is funded by the US Department of Energy [22]. SAM is a free software and can be used for technical and economic modelling of sustainable systems such as photovoltaic, wind, and geo-thermal. SAM is a very user-friendly software that has been designed for students, researchers, and professionals. SAM can be used for a feasibility study. With a huge database of PV system components and the manufacturer's pricing and datasheet we can model an actual system and then by entering location specific weather files and utility electricity rates we can run simulations and analyze technical and economic feasibility study before starting any installation work.

C. Simulation parameters

In SAM we can specify the DC system size by either specifying the desired array size and letting SAM automatically calculate the string configuration to best match the required array size, or we can specifically input specific modules and inverters. This could be entered in the system sizing module. All the sizing parameters in SAM are based on the manufacturer's specification sheet as per standard test conditions. The variations in output for actual can only be understood once we run the simulation after selecting specific weather data for specific locations.

- The PV Module Selection for 3kW Micro Inverter and 3kW String Inverter is the same in both the cases which is LG NeON® R Solar Panel 370W High Efficiency LG NeON® R Solar Panel with 60 Cells (6 x 10), Module Efficiency 21.4% Monocrystalline/N-type Cell
- The Inverter selection for 3kW Micro Inverter is Enphase IQ 7+ Micro™ IQ7plus-DS-EN-US 240V
- And for 3kW String Inverter is ABB UNO 2.5 String Inverter ABB UNO-2.5-OUTD-S-US 240V
- The String Configuration for 3kW Micro Inverter is 1S 8P and 3kW String Inverter is 8S 1P
- The Tilt for 3kW Micro Inverter and 3kW String Inverter is the same in both the cases which is fixed 23.15 deg and 180 deg azimuth
- The Shading for 3kW Micro Inverter and 3kW String Inverter is the same in both the cases as shown in Fig 1 and Fig 2

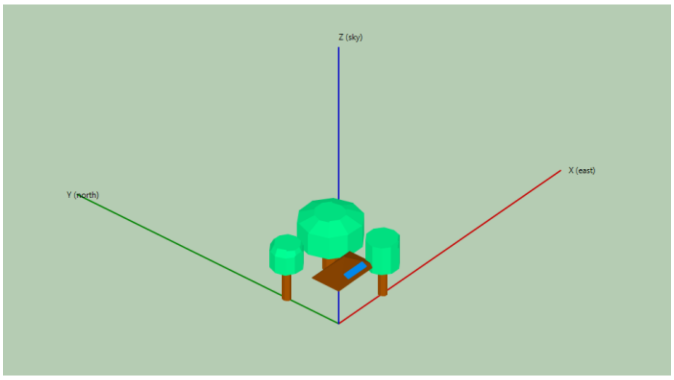

Fig -1: 3D view of the solar array with tree shading

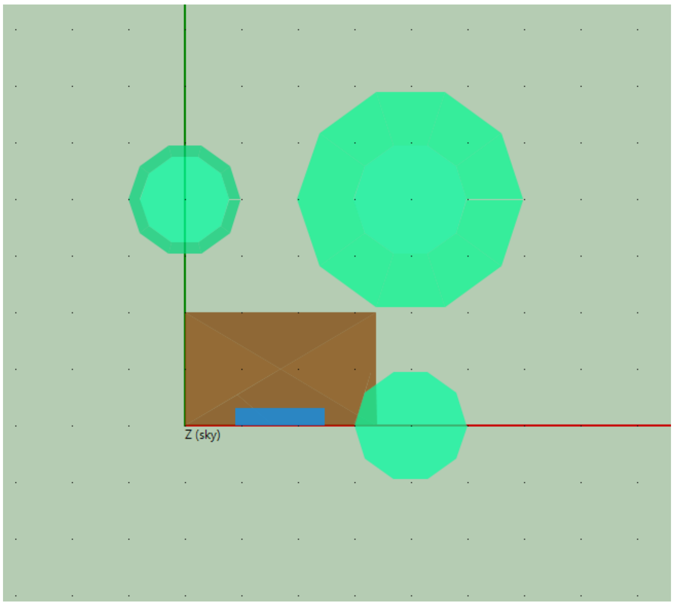

Fig -2: Top view of the solar array with tree shading

Constant sky diffusion shading loss is calculated to be 10.083

3. CONCLUSIONS

To understand the technical analysis SAM is capable of, this project includes a simulation of a 3kW residential rooftop PV system in the city of Jabalpur, Madhya Pradesh, India. Specific weather data were used in this simulation.
Using all the input data and the weather files selected SAM runs a detailed simulation which helps system designers to conduct detailed feasibility study.
This project focused on residential rooftop PV systems. A 3kW grid connected PV system was designed and modelled in SAM. The working and design of different system components were presented. The comparison of micro inverter and string inverter was performed.
A residential system was designed in SAM using specific weather data. The simulation results supported the fact that micro inverters outperform the traditional string inverters in both shaded and non-shaded conditions.
The Micro Inverter system produced an annual energy of 4916 kWh in the first year with no shading and 4332 kWh in the first year with shading losses as shown in Table1 and table 2.
The String Inverter system produced an annual energy of 4763 kWh in the first year with no shading and 4286 kWh in the first year with shading losses as shown in Table 3 and Table 4.
A residential system was designed in SAM using specific weather data. The simulation results supported the fact that micro inverters outperform the traditional string inverters in both shaded and non-shaded conditions.

Table 1 Micro inverter system energy production without shading

Metric	Value
Annual energy (year1)	4916 kWh
Capacity factor (year 1)	18.9%
Energy yield (year 1)	1659 kWh/kW
Performance ratio (year 1)	0.76

Table 2 Micro inverter system energy production with shading

Metric	Value
Annual energy (year1)	4332 kWh
Capacity factor (year 1)	16.7%
Energy yield (year 1)	1462 kWh/kW
Performance ratio (year 1)	0.67

Table 3 String inverter system energy production without shading

Metric	Value
Annual energy (year1)	4763 kWh
Capacity factor (year 1)	18.4%
Energy yield (year 1)	1608 kWh/kW
Performance ratio (year 1)	0.74

Table 4 String inverter system energy production with shading

Metric	Value
Annual energy (year1)	4286 kWh
Capacity factor (year 1)	16.5%
Energy yield (year 1)	1447 kWh/kW
Performance ratio (year 1)	0.67

REFERENCES

[1] D. Kornack and P. Rakic, "Cell Proliferation without Neurogenesis in Adult Primate Neocortex," Science, vol. 294, Dec. 2001, pp. 2127-2130, Poshtkouhi S., Palaniappan V., Fard M., Trescases O., 'A general approach for quantifying the benefit of distributed power electronics for fine grained MPPT in photovoltaic applications using 3-D modelling' Proc IEEE on Power Electronics vol.27, No 11 page 4656-4666, 2012

[2] Hanson A.J, Deline C, A, MacAlpine S. M., Staruth J. T, Sullivan C. R., "Partial-Shading Assessment of Photovoltaic Installations via Module-Level Monitoring" IEEE J. Photovoltaics, Vol. 4 No. 6 November 2014

[3] Zhang, Q., & Li, Q. (2012, June). Temperature and reverse voltage across a partially shaded Si PV cell under hot spot test condition. In Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE (pp. 001344-001347). IEEE.

[4] Satpathy, P. R., Jena, S., Jena, B., & Sharma, R. (2017, April). Comparative study of interconnection schemes of modules in solar PV array network. In Circuit, Power and Computing Technologies (ICCPCT), 2017 International Conference on (pp.1-6). IEEE.

[5] Satpathy, P. R., Jena, S., & Sharma, R. (2017). Power Enhancement from Partially Shaded Modules of Solar PV Arrays through Various Interconnections among Modules.

[6] Bidram, A., Davoudi, A., & Balog, R. S. (2012). Control and circuit techniques to mitigate partial shading effects in photovoltaic arrays. IEEE Journal of Photovoltaics, 2(4), 532-546.

[7] Mäki, A., & Valkealahti, S. (2012). Power losses in long string and parallel-connected short strings of series-connected silicon based photovoltaic modules due to partial shading conditions. IEEE Transactions on Energy Conversion, 27(1), 173-183.

[8] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A review of single-phase grid-connected inverters for photovoltaic modules," IEEE Transactions on Industry Applications, vol. 41, pp. 1292-1306, 2005.

[9] L. Quan and P. Wolfs, "A Review of the Single-Phase Photovoltaic Module Integrated Converter Topologies with Three Different DC Link Configurations," IEEE Transactions on Power Electronics, vol. 23, pp. 1320-1333, 2008.

[10] S. Harb and R. S. Balog, "Reliability of Candidate Photovoltaic Module- Integrated-Inverter (PV-MII) Topologies - A Usage Model Approach," IEEE Transactions on Power Electronics, vol. 28, pp. 3019-3027, 2013.

[11] SolarBridge Technologies Website [Online]. Available: http://solarbridgetech.com

[12] ENPHASE-Micro-Inverter [Online]

[13] PetraSolar Website [Online]. Available: http://www.petrasolar.com