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Modeling of Energy Performance of Stand-Alone SPV System Using HOMER Pro

M. K. Deshmukh[a,] *, Athokpam Bharatbushan Singh[a]

[a]*Electrical and Electronics Enegineering, BITS Pilani, K. K. Birla Goa Campus, Zuarinagar, Goa, 403726, India*

Abstract

Stand-alone solar photovoltaic (SA-SPV) systems are attractive option for rural electrification programs in many countries. These systems are invariably provided with battery energy storage (BES) for using stored electricity during nighttime. Availability of bi-directional power electronic converter promises to enhance application of these SA-SPV systems for generating, storing and feeding electricity to local micro-grids. Further, the advantages of such systems can be maximized by minimizing energy losses at different sub-system levels in the system. In the present work, we demonstrate use of HOMER Pro simulation software for simulation of energy performance of SA-SPV (6.75 kW_p) system installed in Renewable Energy Systems Laboratory in our Institute, aiming at quantitative estimation of energy losses due to stand-alone mode of operation. The system is provided with battery energy storage (800 Ah) that is used for supplying electricity for night time street lighting on campus up to eleven hours per day. The results of simulation show that when the existing SA-SPV system is upgraded to grid-tied SPV system, by incorporating bi-directional converter, the system will produce total 11086 kWh annually at the site, out of which 4536 kWh will be fed to the local single-phase micro-grid, which accounts for energy lost if the system continues to operate as SA-SPV system.

Keywords: Stand-alone SPV system; HOMER Pro; Grid-tied bidirectional converter

* Corresponding author. Tel.: +91-832-258-0316; fax: +91-880-512-7080
E-mail address: mkd.goa@gmail.com; bbsan2043@gmail.com

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1. Introduction

Solar Photovoltaic systems can be used in stand-alone as well as grid tied mode, for achieving Renewable Energy Obligation (RPO) targets. Whereas SA-SPV systems are useful for electrification of remotely located villages away from conventional grids, the grid-tied SPV systems are useful for meeting RPO targets in rural as well as urban areas. In recent times, bi-directional power converters have become widely available, which provide options for upgrading already installed SA-SPV systems to grid-tied SPV systems. Grid tied SPV system, with bi-directional converter, can yield benefits of both SA-SPV as well as grid-tied SPV systems. With increasing support from Governments in terms of proactive policies and plans, there is great potential for business and market development in favour of SPV systems. The availability of industry standard software tools for simulation of energy performance of renewable energy systems enables simulation of SPV systems in conjunction with wind, small hydro and bio-energy systems, for developing hybrid energy systems for implementation [1] – [3]. In India, the implementation of renewable energy systems is spear-headed by the Ministry of New and Renewable Energy (MNRE), Govt. of India, which in turn is supported by the State Nodal Agencies (SNAs) for implementation in respective states. The State Governments are empowered to develop plans, policies and strategies for implementation of renewable energy systems in respective states. Goa, is one of the smallest but progressive and eco-sensitive state in India, which has recently adopted Goa State Solar Policy-2017, thereby legalizing sale of solar electricity to grid [4]. The State Government encourages participation of small as well as large consumers to generate solar electricity and sale to grid under 'net-metering scheme' or 'gross-metering scheme'.

In the present work, we demonstrate use of HOMER Pro software for simulating performance of existing SA-SPV system in grid-tied mode, using bi-directional converter, with the objective of estimating annual electricity produced, which will be partly utilized for charging battery energy storage (BES) and feeding to single-phase micro-grid.

2. HOMER Pro Software

The HOMER Pro, a micro-grid software by HOMER Energy, is the global standard for optimizing microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. Originally developed at the National Renewable Energy Laboratory, USA, and enhanced and distributed by HOMER Energy. HOMER (Hybrid Optimization Model for Multiple Energy Resources) nests three powerful tools in one software product, so that engineering and economics work side by side. At its core, HOMER is a simulation model. It will attempt to simulate a viable system for all possible combinations of the equipment under consideration. HOMER simulates the operation of a hybrid micro-grid for a period of year, in time steps from one minute to one hour.

3. System description

The SA-SPV system considered in the present work is a roof mounted SPV system (6.75 kW_p) on the campus of our institute, in the state of Goa, India. In stand-alone mode, a dedicated BES consisting of twenty-four Gel type batteries (800 Ah) is used to store electricity produced. A unidirectional inverter (5 kW) is provided for converting stored energy to AC for street lighting (3 kW) on campus during night time up to eleven hours per day [5].

3.1. Operation mode of SA-SPV System

The system is operated as stand-alone mode of operation. The energy generated by SPV arrays is stored in BES through MPPT charge controllers. If the BES is fully charged, MPPT charge controller cuts off supply of power to BES. In this mode, once the BES is fully charged during day, the excess electricity produced cannot be utilized as there is no other equipment other than BES connected to it.

The system is provided with automatic timer which controls turning ON and OFF streetlights during night time. Normally, the automatic timer is set to turn ON the streetlights at 7 P.M. and turn OFF at 6 A.M. During night time, the energy is supplied from BES until battery voltage drops to its lower voltage cut-off level, i.e., 42 V. Thereafter, the required energy is drawn from the grid. During day time, the MPPT charge controller cuts off charging current to BES, when BES voltage reaches maximum voltage cut-off level, i.e., 56 V. Thus, the system effectively maintains BES voltage between maximum and minimum cut-off voltage levels, set by the operator.

4. HOMER Pro simulation of SA-SPV system

The SA-SPV system is simulated with bi-directional converter in place of unidirectional converter, in HOMER Pro simulation environment. The operation of the system is prioritized so as to charge the BES until it is fully charged during day time, and then discharge during night time when the lights are turned 'ON', until BES voltage drops to 42 V. In this mode of operation, once the BES is fully charged during day time, the electricity produced is fed to the grid. Thus, the bi-directional inverter ensures daily charging, discharging and feeding electricity to grid, thereby maximizing utilization of installed capacity of SA-SPV system. The schematic diagram of the SA-SPV system with bi-directional converter simulated using HOMER Pro software is shown in Fig. 1.

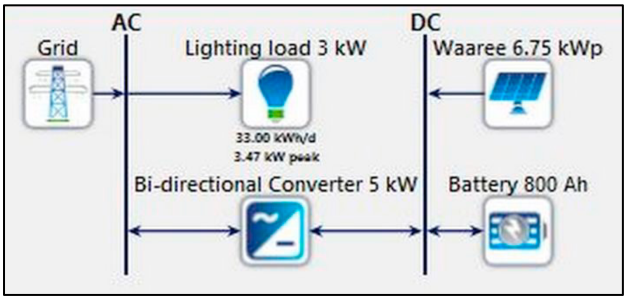

Fig. 1. Schematic diagram of SA-SPV system with bi-directional converter simulated using HOMER Pro software.

The technical data for the sub-systems used in simulation is shown in Table 1. The performance of the system is simulated for period of one year.

Table 1. Technical data for sub-systems used in simulation

Component	Parameters
PV Array	6.75 kWp, 15.4% Efficiency
MPPT charge controller	5 kW, 98% Efficiency
Bi-directional inverter	5 kW, 97% Efficiency
Battery bank	800 Ah, Gel type
Lighting load	3000 Watts

The daily average values of Global Horizontal Irradiance (GHI) and ambient temperature at the site for one full year is taken from National Renewable Energy Laboratory (NREL) database included in HOMER Pro software. The load profile (3 kW) due to lighting load is assumed to be defined as "ON" time from 7 P.M. to 6 A.M. everyday. The utility grid is assumed to be available throughout the year to support lighting load when battery is discharged to cut-off voltage level.

5. Results and Discussion

The results of simulation of the SA-SPV system, include daily energy yield of PV array, energy fed to grid and supplied to lighting load through bi-directional inverter and energy drawn from the utility grid for lighting load, for a period of one year. The results obtained are discussed as follows:

5.1 Energy yield of PV array

As per the NREL data base, the site receives an annual average daily GHI of 4.96 kWh/day/m^2. The maximum GHI is available during the month of April at an average of 6.55 kWh/day/m^2, and minimum GHI occurs during the month of July at an average of 4.70 kWh/day/m^2. The monthly average daily solar radiation is relatively low during months of June, July and August (Southwest monsoon season). Variation of 'energy penetration' of PV panels, i.e., SPV electricity produced per day, for a period of one year is shown in Fig. 2. It is seen that the 'energy penetration' due to SPV array varies from 1.3 kWh/m^2/day to 4.80 kWh/m^2/day, with annual gross energy yield of 11086 kWh. For the system, the ratio of PV energy Generated to average load supplied' is reported to be 92%, which confirms that the site is highly recommended for the application of SPV system.

5.2 Operation of bi-directional converter

The bidirectional converter feeds power to utility grid during day time after BES is fully charged, and supplies power to street lighting load during night time. The energy output profile of bi-directional converter during period of one year is shown in Fig. 3. It is seen from Fig. 3 that the bi-directional converter provides power to utility grid on most of the days in the year, after BES is fully charged, except during monsoon season. Also, it is seen from Fig. 3 that the bi-directional inverter provides power to street lighting load on most days in a year, until the battery is discharged to minimum cut-off voltage level. Thereafter, the utility grid supplies power to street lights, bye-passing the inverter. It is seen that the BES reaches its lower cut-off voltage on most days between 1 A.M. to 2 A.M.

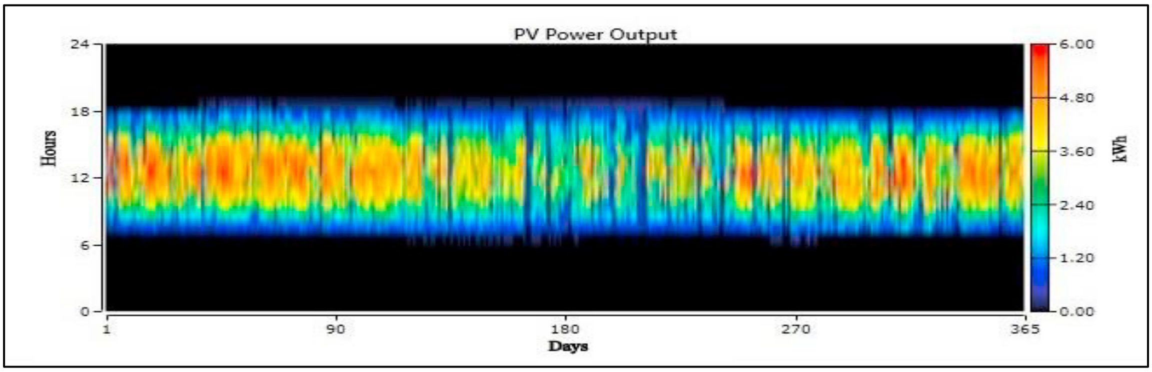

Fig. 2. Annual Energy Penetration of SPV array at the site

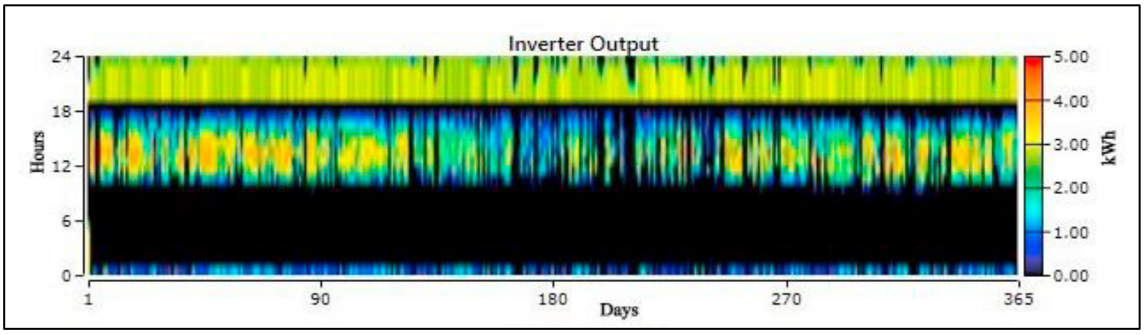

Fig. 3. The energy output profile of bi-directional converter during period of one year.

5.3 Energy drawn from utility grid

The utility grid supports power to load after BES reaches its lower cut-off voltage. The annual profile of energy drawn from utility grid is shown in Fig. 4. It is seen that lighting load draws power from the utility grid mostly during 1 A.M. to 6 A.M. This implies that the storage capacity is inadequate to supply power to lighting load per day.

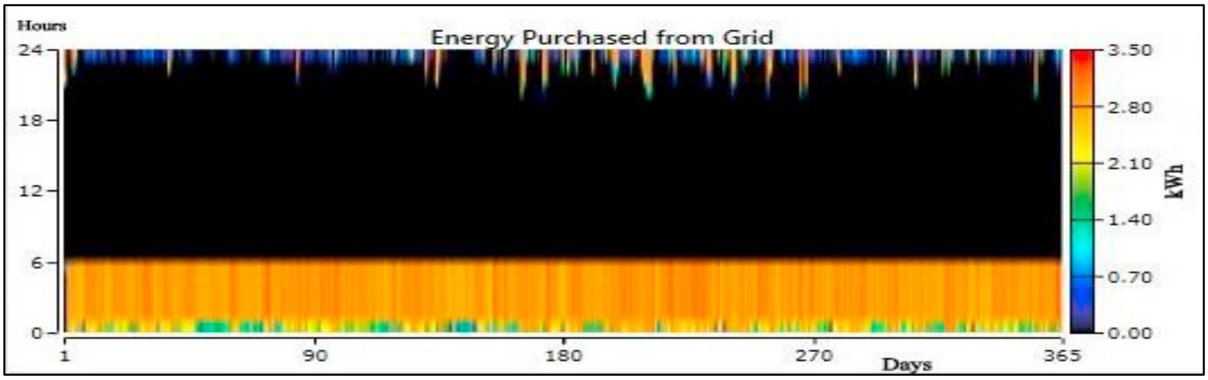

Fig. 4. Annual profile of energy drawn from utility grid.

5.4 Monthly average contribution of energy supplied from BES and Utility Grid

It should be noted that the total energy drawn by the load is sum of energy drawn from BES and the utility grid. Fig. 5 shows month-wise contribution by BES and Utility Grid in power supplied to lighting load throughout the year. The HOMER Pro reported that the energy supplied by BES accounted for 62.52% and the utility grid accounted for 37.49% of the total energy drawn by the load in a year.

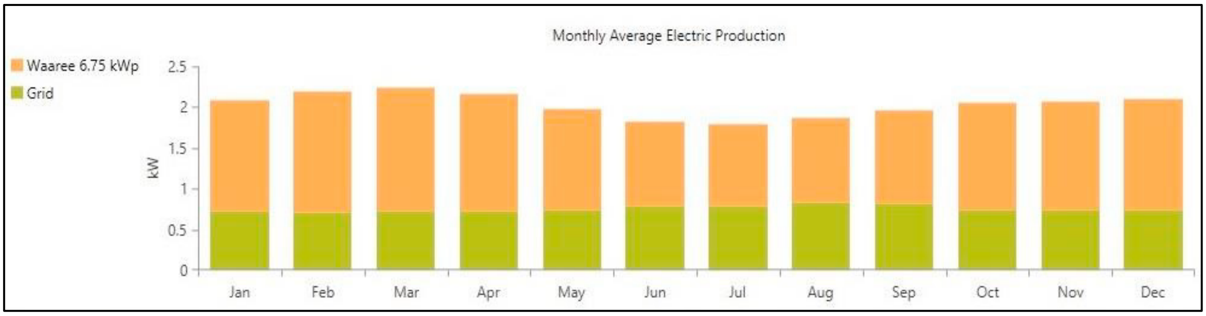

Fig. 5. Monthly average contribution energy system from battery and grid for the period of one year

5.5 *Month-wise total energy fed to grid and drawn from grid*

Table 2 shows total monthly energy fed to the grid and drawn from the grid. It is seen that the total energy fed to the grid is 4538 kWh and the total energy drawn from the grid is 2111 kWh, during the period of one year. It is seen that during monsoon months, the energy fed to the grid is lower and the energy drawn from the grid is higher than in remaining months. Also, it is seen that the energy fed to grid is highest during the month of March and lowest during the month of July and the energy drawn from the utility grid is highest during month of July and lowest during month of March. It should be noted that up-gradation of the existing SA-SPV system to bi-directional SA-SPV system amounts to feeding 4538 units of electricity to utility grid.

Table 2. Total month-wise energy fed to grid and drawn from the grid

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Energy fed to grid (kWh)	451	463	525	456	365	228	221	255	328	393	407	443	4538
Energy drawn from Grid (kWh)	88	18	19	66	183	343	368	365	257	163	130	111	2111

6. Conclusions

HOMER Pro simulation software is used to simulate energy performance of SA-SPV system using bi-directional inverter for a period of one year. The simulation results show that the ratio of 'average power output of the PV array to the average load' for the system is 92% at the site, therefore the site is highly appropriate for application of SPV system for power generation.. Results of simulation show that there is definite scope for enhancing energy performance of the existing SA-SPV system by incorporating bi-directional inverter. Also, there is scope for increasing BES capacity. The up-gradation of the existing SA-SPV system to bi-directional grid-tied SA-SPV system, will enable reaping benefits of Government's feed-in tariff policy in force.

Acknowledgements

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