Simulation and Analysis of Single-Stage Grid-Connected Solar PV System Using ANN

Mukul Singh, Omveer Singh, M.A.Ansari, and Vishwamitra Singh

Abstract The research paper presents a single-stage solar photovoltaic battery grid-tied system with a simple phase-locked loop which needs less control to operate. The system losses are decreased because of the exclusion of boost converter and addition of a storage battery. Earlier, many other techniques were implemented to extract maximum power from the solar panels such as incremental conductance (InCond) and perturb and observe (P and O). Now, the maximum power is being tried to be extracted by using the artificial intelligence's artificial neural network (ANN) technique. Tests results for the system operations are studied from doing the simulations of the proposed model. The operation conducts on two modes, i.e., fixed power and variable power in compliance with IEEE-519 standards. The power given as input to the grid is fixed during mode 1 and varies during mode 2. It is very essential to extract maximum power from the solar panels by increasing the efficiency, reducing the losses, and evading any possible faults. Hence, Simulink model of solar PV system using the artificial neural network is being built and simulated. The obtained results are observed and analyzed in the research paper.

Keywords Stand-alone PV system · Solar power · Maximum power point tracking · Artificial neural network · Voltage source converter · MATLAB Simulink · Etc

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1 Introduction

After the development of solar cell, there is a new era comes in the field of harnessing electricity from the solar energy. Many researchers start their research in the field of photovoltaics systems. In present, there are more than a lakh of research paper present. Different techniques and topologies have been developed, and new research work is continuingly being in progress. The demand for clean energy and improving power quality is so high that power filtering is now being introduced by my researcher, but it has constraints of reactive power being inserted into the system [1].

$$vd = ed + L(\mathrm{did}/\mathrm{d}t) - \omega.\mathrm{Liq} \tag{1}$$

$$vq = eq + L(diq/\mathrm{d}t) + \omega.\mathrm{Lid} \tag{2}$$

The PI controller is used by the system to calculate and minimize the error between reference current and actual current by implementing the calculation algorithm which include proportional gain and integral gain as K_p and K_i [2]. The lightning may cause serious damage to the installed solar panels. Hence, the areas near the solar PV should be properly fenced to have minimal injuries and avoid any damage to humans or animals [3]. The disconnection of PV by any reason, whether lightening or anything else, causes power loss and hence not economically preferential for PV systems connected to the grid or microgrid [4]. Single-phase inverter converts DC to AC and is used frequently because the appliances connected to AC grid are AC type [5]. FFT can be performed on the grid currents to satisfy IEEE-519 standards. Power quality can be improved by using SPV system to provide alleviation in harmonics and correction in power factor [6]. Input given by the use of only one inductor provides symmetric operation during two consecutive half cycles of microgrid thus producing less switching losses [7]. When operating point changes, the performance of PI controller is ensured by feed-forward neural network which renews the PI parameters [8]. The efficiency of the system is decreased due to the involvement of transformers because of the losses incurred by them when isolating and protecting the system from the leakage current produced between the PV panel and the earth. This can be avoided by the transformer-less operation which will increase the efficiency while decreasing the size and cost of operation. But, this will remove the galvanic isolation provided by the transformer, and leakage current may increase the harmonic distortion in voltage and current of inverter. Hence, limit is set on the value of leakage current to avoid any major harmonic distortion or disconnection [9]. More than one conversion stage of inverter maybe required depending upon the voltage level of the string terminal of the PV [10]. Two-stage converter is shown in Fig. 1a, and single-stage converter is shown in Fig. 1b. It is best to use single-stage converter preferably as it will make the system compact [11].

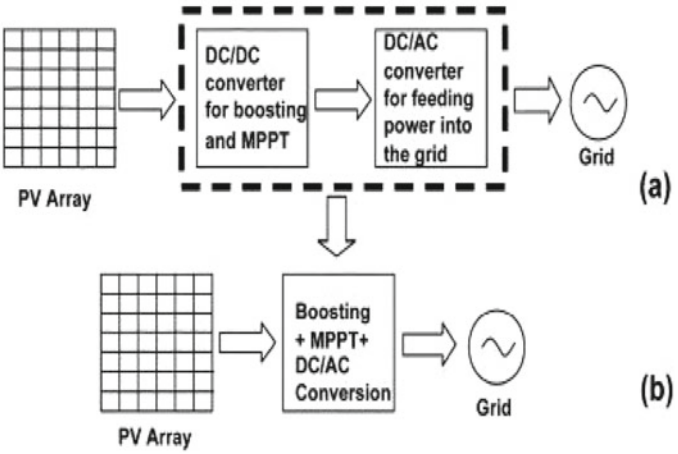

Fig. 1 Solar PV topologies of grid-connected system: **a** two-stage converter and **b** single-stage converter

2 Literature Review

PV system is also classified on the basis of connection with the grid. The systems connected with the grid are called grid-connected PV systems, whereas those which are working in the isolated environment are referred as stand-alone PV system. Stand-alone PV systems are mainly used with isolated microgrid [12]. The new LCL filter-based controllers boost the performance and robustness of the systems connected to the grid by reducing the grid disturbance associated with 5th and 7th harmonics and improving the power quality [13]. To synchronize the PV system when direct current component is rejected and supply is distorted because of transfer function which is mainly dependent on input signal, enhanced LTI-EPLL algorithm is can be used [14].

With the passage of time, there has been an advancement in harvesting approaches of solar energy as shown in Fig. 2. Initially, a central inverter was used as a more distributed approach with multiple PV array connected in series and parallel as shown in Fig. 2a. After that string inverter was used to be connected only with particular set of strings of PV array as shown in Fig. 2b. Later inverters were used alongside with DC optimizer as shown in Fig. 2c. Finally, micro-inverters are designed to be built into the individual panels at the back to make system more compact, efficient, and reliable as shown in Fig. 2d. This also eliminated the requirement of any low frequency-based power transformers [15]. To achieve optimized operation of power supply to residential load, linear quadratic regulator integral (LQRI) is used for multi-functional work associated with single-stage PV system. Nonlinear currents along with unbalanced loads cause harmonic currents at PCC. These harmonics can be eliminated by using adaptive feed-forward harmonic cancellation technique which also inserts active power into the grid or microgrid when control over grid current

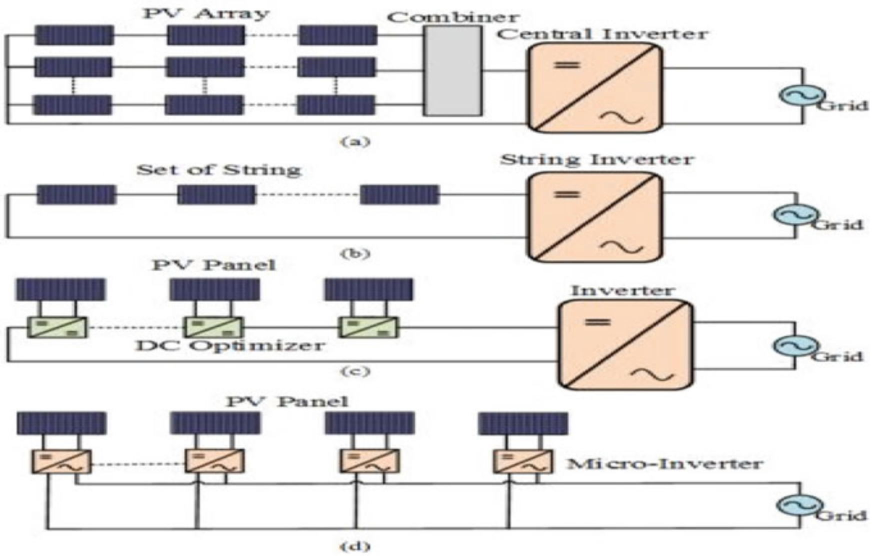

Fig. 2 Energy harvesting methods from PV grid-connected system

is required by the PV system connected to the grid [16]. During voltage unbalance or distortion, the amplitude of the fundamental part of current associated with the load can be extracted by the (MINF) multiple improved notch filter scheme as it decreases the harmonic components by DC offset rejection which under abnormal circumstances enhance power quality of the PV system connected to the grid [17].

$$I_c = I_{ph} - I_d - I_p \tag{3}$$

$$I_{ph} = G/1000(I_{sc} + k_{sc}(T - T_a)) \tag{4}$$

A single-diode solar PV cell used around the globe is shown in Fig. 3 where I_c is

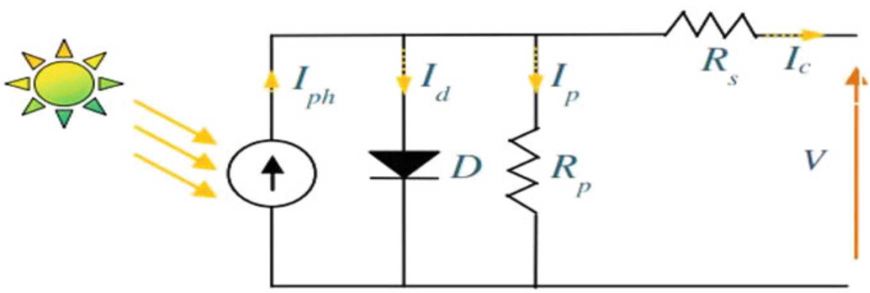

Fig. 3 Solar PV cell equivalent circuit of one diode

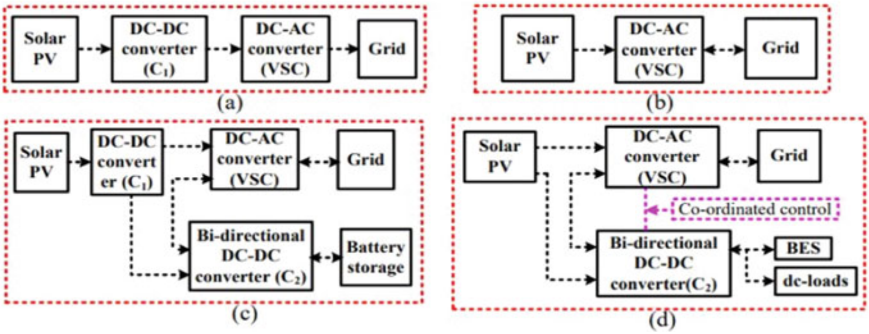

Fig. 4 Grid-connected solar PV stage advancement

the output current obtained from the solar cell, I_{ph} is the photonic current, Ip is the current passing through the shunt resistance, Id is the diode current passing through the $p - n$ junction, G is the solar irradiance [18]. Cascaded two-level inverter (CTLI) uses $p - q$ theory to generate the reference currents for the purpose of synchronization using hysteresis current controller to generate reference power which is inserted into the grid [19]. To maintain grid current free from harmonics and balanced, least mean square control algorithm is proposed to be used along with DC-DC buck-boost converter. Figure 4 shows the advancement in grid-connected solar PV connected with battery energy storage system over a period of time that is from two-stage to single-stage grid connected with VSC, later with BES, and finally single-stage connected with BES [20].

The grounded pole topology is used to mitigate the leakage current problem using the impedance source inverter which applies three-switch three-state technique to get the required AC voltage as output [21].

During disturbed grid voltage, INC algorithm along with modified proportional resonant (MPR) controller is used for fast tracking and reduction of harmonics by applying α-β reference frame linked with d-q reference frame for voltage control using controller. Amplification is not required except for AC modules and AC cells, so there is no need for centralized single-stage inverters [22]. SPWM voltage controller along with hysteresis current control can be used while operating with microgrid integrated with RES like solar PV, wind farm, diesel engine, and BES. The flowchart of management of power for PV and battery system connected to the grid is shown in Fig. 5. The flowchart signifies the two conditions when generated and measured PV power is more or less than the power needed by the load integrated to the grid. Both conditions are subdivided into two separate conditions such that whether the operating condition of the grid and the PV system is during peak hours or during off-peak hours of the day and night. During peak hours, the battery is discharged to supply desired amount of energy to the grid to meet the necessity of the grid due to high energy utilization by the loads attached. During off-peak hours, when PV and other energy sources successfully meet the requirement of the energy of the loads integrated, the battery is charged during daytime using the surplus of the energy

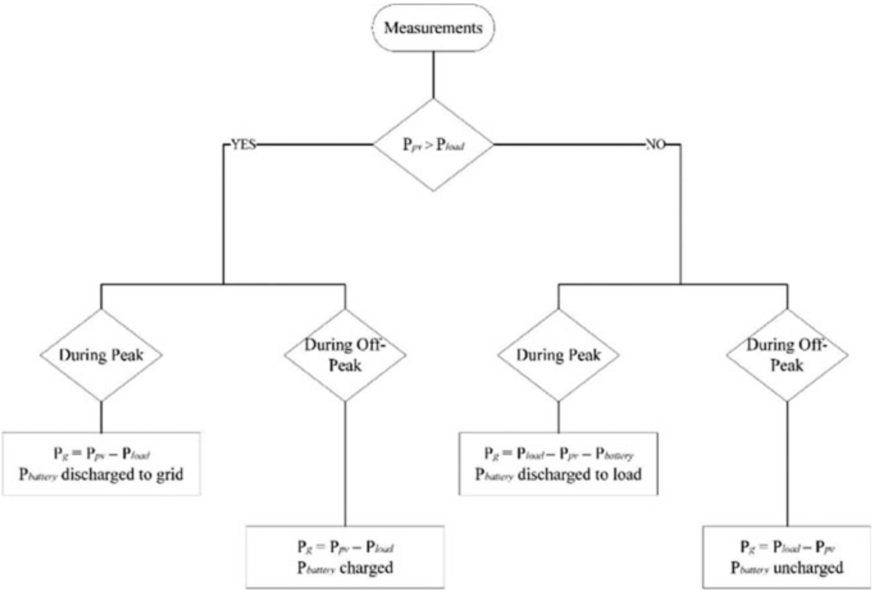

Fig. 5 Flowchart for power management of PV system

generated by the PV system. This is achieved by using the bidirectional DC-DC converter. Independently, separate PI, fuzzy, and ANN controllers can be integrated and used together successfully to reduce THD and voltage regulation using CHB [23]. The single-phase transformer-less inverter using PI and fuzzy logic scheme is used to operate serially connected PV panels connected to the grid or microgrid working under distinct irradiance and temperature conditions [24]. The circuits became more compact, and burden of control is decreased by using one bidirectional switch along with six unidirectional switches which provides a seven-level output to achieve steady state. The non-iterative scheme is implemented to generate maximum power using fill factor available through the PV datasheet parameters [25].

3 Simulation Models and Blocks

The Simulink MATLAB model of solar PV system connected to grid along with BES and nonlinear load via bidirectional converter and voltage source converter is shown in Fig. 6. Figure 7 shows PV system and MPPT block used in the MATLAB Simulink. Figure 8 shows the MPPT controller block based on artificial neural network connected with integral regulator implemented in above shown Simulink model.

Figure 9 shows the VSC used for conversion of energy transmitted on grid. Figure 10 shows the bidirectional DC-DC converter used before battery subsystem

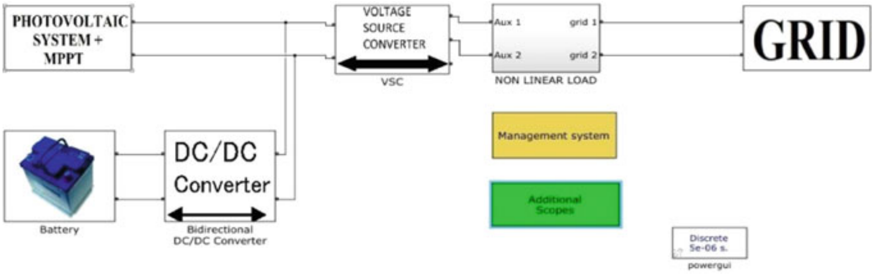

Fig. 6 Simplified model of single-stage grid-connected solar PV-battery grid-tied system

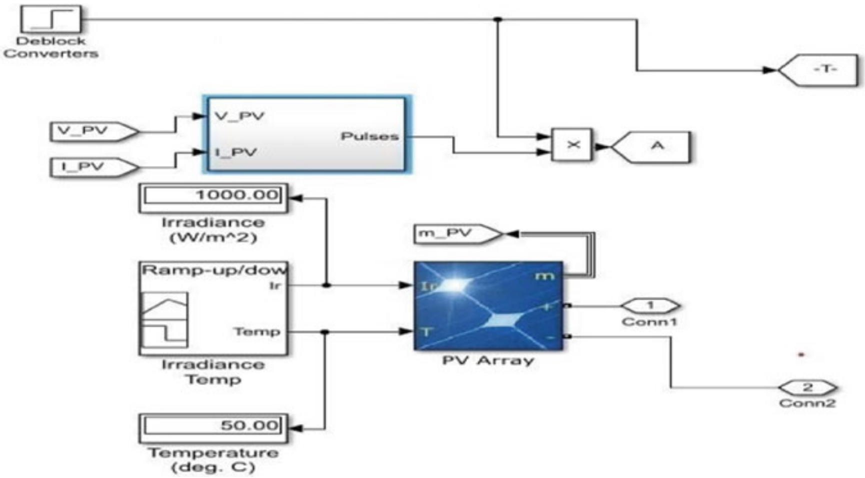

Fig. 7 PV system with MPPT block

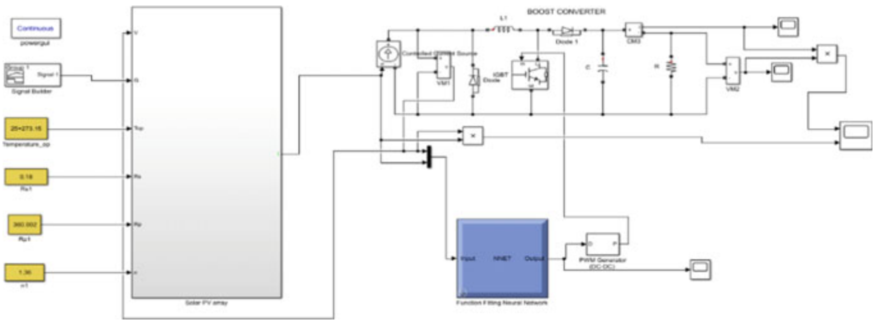

Fig. 8 ANN-based MPPT controller with integral regulator

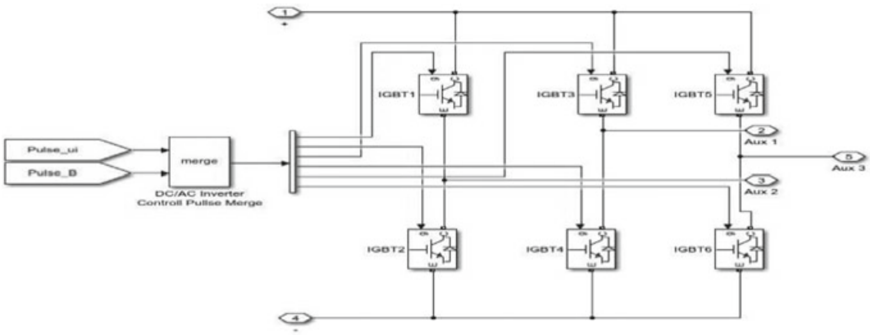

Fig. 9 Voltage source converter used in MATLAB Simulink

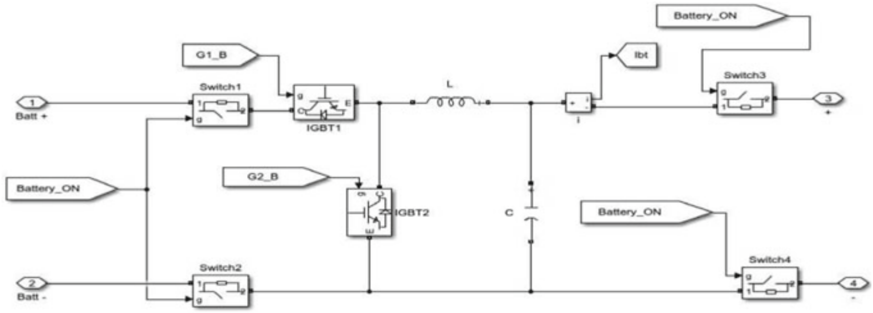

Fig. 10 Bidirectional DC-DC converter used in MATLAB Simulink

to provide DC input of energy to the battery for charging at 50 Hz frequency supplied directly by the PV system to the battery. Also, during discharging condition, fixed DC output is provided at 50 Hz with the help of DC-DC converter. Figure 11 shows the expanded battery subsystem used for charging and discharging as per requirement is integrated in the Simulink model into the grid after the PV system as shown in Fig. 6. Charging occurs during surplus energy generation, while discharging occurs when

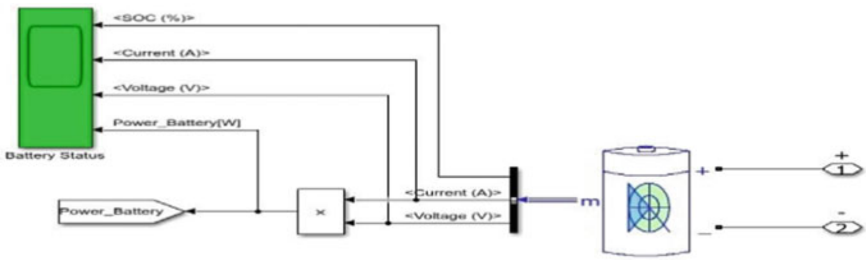

Fig. 11 Battery subsystem used in MATLAB Simulink

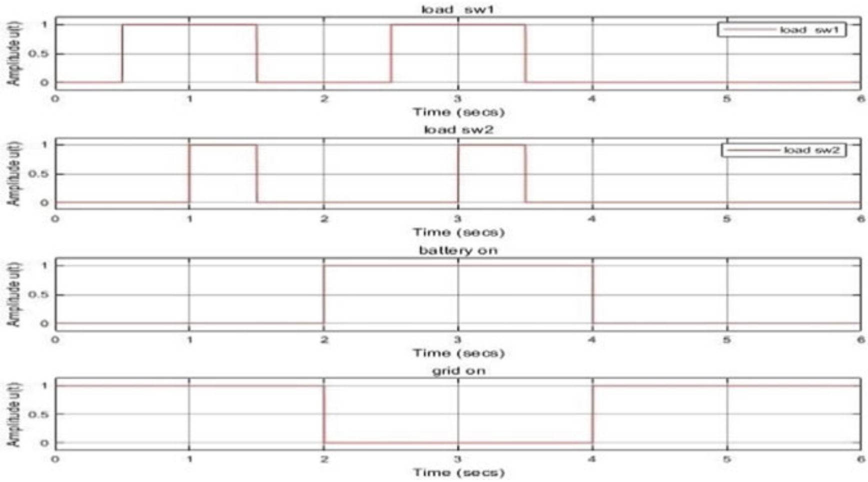

Fig. 12 Results for switching of load 1, load 2, battery, grid in simulation

demand is more than supply. Simulink blocks of VSC controller, battery controller, voltage source controller, nonlinear load block, bidirectional converter were also used during the simulation, but they are not shown in this research paper of the above presented Simulink model [26, 27].

4 Simulation Results

Figure 12 shows the various results of amplitude variation with respect to time for load 1, load 2, battery, and grid during switch ON condition. Variation of power with time when solar PV is connected to the grid along with load 1, load 2, and battery is shown in Fig. 13. Variation of primary and secondary voltage and current with respect to time during grid-connected condition is shown in Fig. 14. PV voltage, current, and DC voltage associated with the panel are plotted with respect to time is shown in Fig. 15.

5 Discussion and Conclusion

The research paper successfully implemented the artificial neural network technique for extracting the maximum power from the photovoltaic system connected to the grid under normal conditions but varying irradiation using a DC-DC boost converter. The best dynamic performance is given by ANN as compared to other MPPT techniques like P and O and InCond even under varying atmospheric conditions. During nonuniform shading, the duty cycle modification method is used for changing the power while using ANN. The performance of ANN is far superior because of its training and prior input information about the possible maximum power point for tracking rather than tracking the variation in MPP while using other techniques. It has been observed that the maximum power tracked by the artificial neural network-based maximum power point tracker is 474.7 Watts with an efficiency of 94.4%.

The ripples obtained in the ANN model for current and voltage associated with the PV are very much less as compared to other MPP techniques. The variation of amplitude, power, voltage, and current with respect to time is observed in the research paper. It can be confidently concluded that the ANN technique, as compared to other techniques, is the best technique which provides highest efficiency and power generation because of its ability to track the maximum power point of a solar PV accurately even when the entire system is connected to the grid.

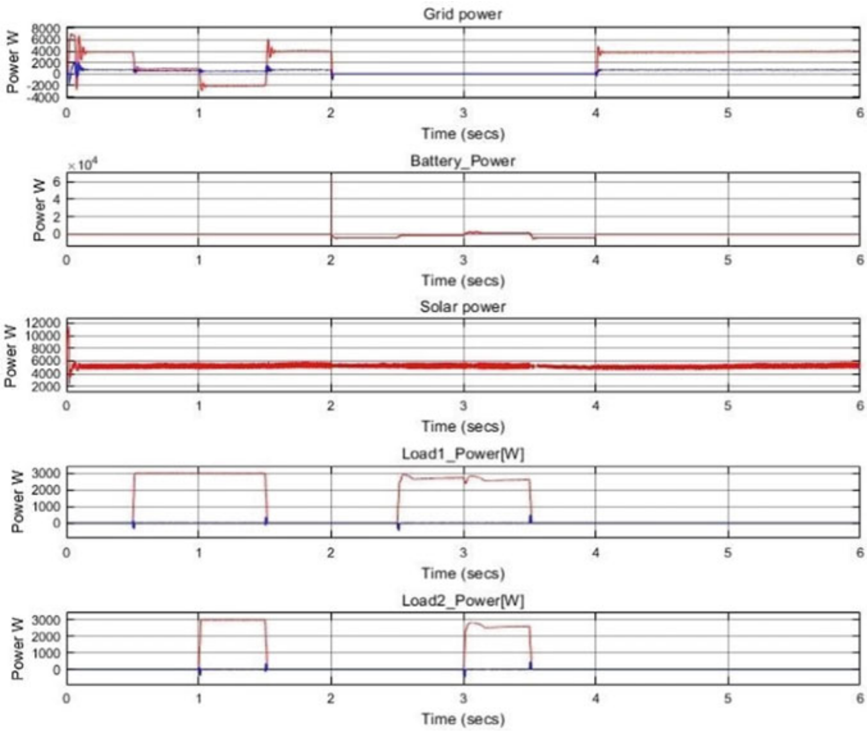

Fig. 13 Result for grid power, solar power, battery power, load-1 power, load-2 power

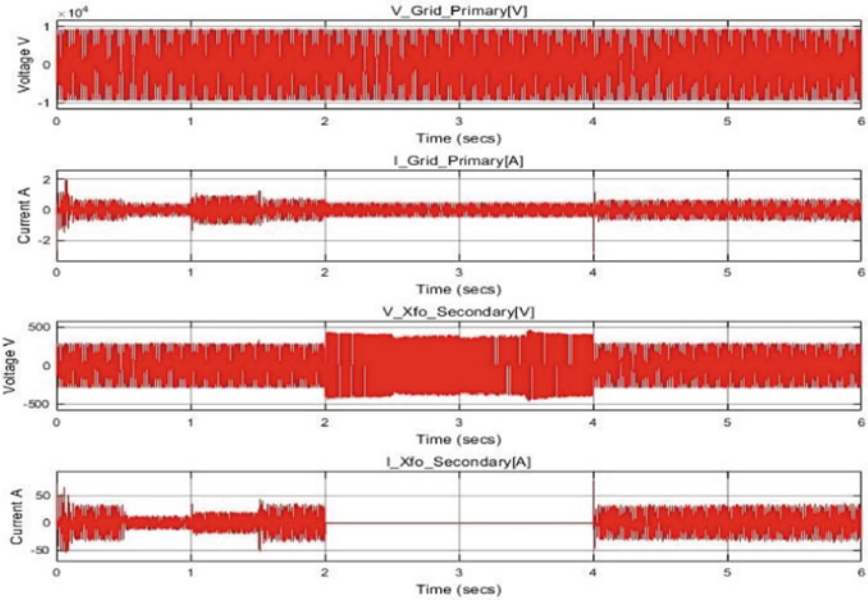

Fig. 14 Grid condition

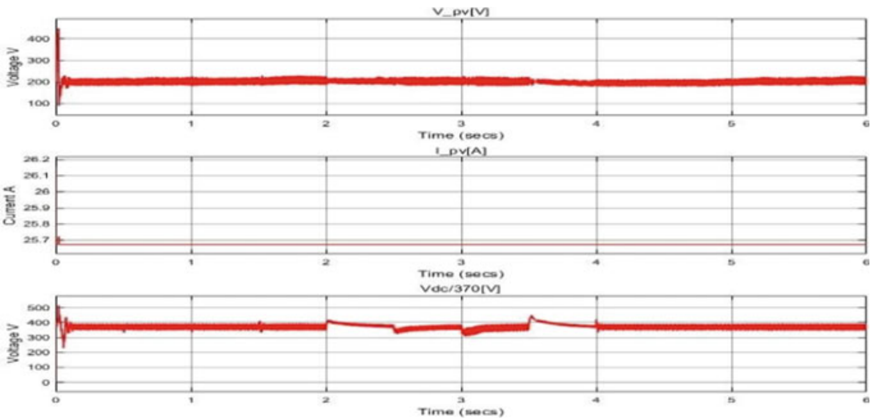

Fig. 15 Grid condition (b) PV panel condition

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