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Modeling of Grid Integrated PV-BES DC Microgrids Using SRF Control Theory

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Abstract

This paper proposes a grid integrated with a solar photovoltaic system along with the battery energy storage (BES) to the three-phase grid feeding the load. In the process of dc to ac conversion, the synchronous reference frame (SRF) theory method is used for switching controlling purposes. The entire power-producing system comprises of SPV arrangement, dc-dc boost converter, perturb and observe based maximum power point tracking (P&O-MPPT), voltage source converter (VSC), LC channel, various kinds of burdens, and three-phase grid. The system performance of the proposed approach is verified by using MATLAB/Simulink tool.

Disciplinary: Renewable Energy, Photovoltaics and Solar Energy Engineering.

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1 Introduction

Energy production is facing a major challenge in meeting demand in the final hours of the day. Due to a lack of nonrenewable energy resources, electric utilities are increasingly turning to petroleum derivatives. Because of this, scientists and researchers are investigating the possibility of using some form of the distributed generator to supplement the grid's power supply during particularly long stretches of time. They can meet the load demand during that time period thanks to solar-based power. Specialists and industrialists are beginning to take notice of grid-connected photovoltaic (PV) systems as a way to reduce the use of fossil fuels. Worldwide, the need for energy is increasing all the time. Coal, oil, gas, and other fossil fuels once met the bulk of the world's energy needs. In any case, they've been dwindling at a faster rate recently. In other words, experts and researchers are working to discover a few alternative solutions to the rising demand for energy. For a wide range of burdens that need environmentally friendly power energy that doesn't cost an arm and a leg, renewable sources like sunlight, wind, biomass, and so on are cost-effective and pollution-free options. However, because of its accessibility and promise for a wide range of power applications, solar-based energy is the preeminent choice among sustainable sources. The weight of the online generators required to meet the load requirement can be reduced by using sun-oriented energy during peak load hours. With this shift in focus, researchers are now looking into grid-integrated photovoltaic systems. Grid-integrated solar systems face a number of challenges, including synchronization with the utility and power quality issues such as voltage/current harmonics, reactive power compensation, voltage flickering, voltage regulations, etc. As the rate of temperature and irradiance change increases, so do the features of the PV system. A maximum power point tracker (MPPT) is used to get the most out of a PV array in a variety of conditions. A MPPT is implemented using a boost converter in this project. MPPT methods like perturb and observe (P&O) have come highly recommended for the author [5].

A solar energy conversion system is comprised of photovoltaic cells powered by the sun and power electronics converters. Depending on the network's accessibility, this system can be used in grid-related or grid-independent modes. Battery storage is necessary for an isolated solar-based PV system, which raises the system's initial investment and ongoing maintenance costs [6]. Using a DC-DC converter, solar power can be converted to a different voltage level for the desired application [7]. The boost converter's dc voltage gain is linked to a three-stage voltage source converter (VSC), which is used to connect a PV system to the utility grid. Instantaneous reactive power (IRPT) and synchronous reference frame theory (SRF) are used in the existing method to control the VSI. Attaching energy storage systems (ESSs) has several important applications in network adjustment, stable power quality, load balancing and grid operation support as well as smooth power injection into the grid. Many power smoothing strategies have been discussed in the literature [9,10], but the battery energy storage system (BESS) is chosen to keep up with power and energy balance, as well as to further develop power quality. The most prominent advantage to incorporate a battery energy storage is the assurance of energy during a utility failure [10].

The main contribution of this paper is to combine PV array and battery is integrated with grid-tied connection through dc-dc converter and inverter. For dc-dc control switching by using perturb and observing maximum power point tracking (PO-MPPT) and inverter Control Switching will be done by using the synchronous reference frame theory method is presented in this presentation. In order to model the proposed system, MATLAB SIMULINK is used.

2 Description of the Proposed Method

Diagram of three-phase grid-tied PV battery system using VSC in Figure 1. Using the DC connector capacitor of the VSC, a PV cluster and bi-directionally controlled battery bank are connected. The nonlinear burden is represented by a three-stage VSC. An extremely high current density, durable, and reliable lead-acid battery was selected for this application. The synchronous reference frame theory, controlled by a connecting inductor, is used to convert DC power to AC. IGBT power converters use insulated gate bipolar transistors (IGBT). Ripple-free voltages and currents can be avoided by using the R-C filter and communicating inductors.

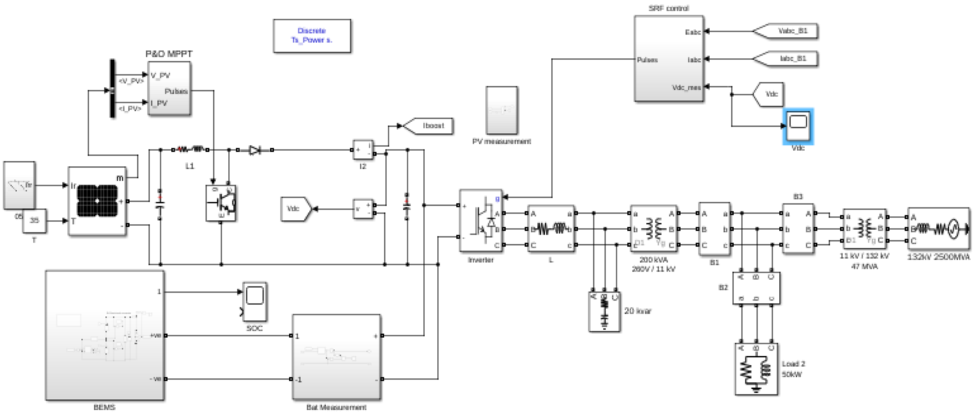

Figure 1: Simulink diagram of the proposed PV and Battery multi-sources grid connected system.

The proposed grid associated solar PV System with a VSC converter is shown in Fig1, which incorporates (i) PV array, (ii) DC-DC converter (iii) a three-stage VSC alongside its regulators (iv) LC channel to improve total harmonic distortion (THD) and changing the staircase voltage over to a close to sinusoidal waveform by lessening the THD, (iv) grid interface transformer and (v) power grid.

2.1 Numerical Modeling of sun based PV

Sun-based energy is essential to the PV framework, and the PV cell is the most fundamental generation component in PV. Figure 2 depicts the PV cell as being framed by a diode and having a current source connected anti-parallel to a series resistance [2]. The single-diode cell's current and voltage connections can be summarised as:

$$\mathbf{I_{PV}}=\mathbf{I_{ph}}-\mathbf{I_{O}}\left(\exp\left(\frac{q(V_{PV}-R_s I_{PV})}{AKT}\right)-1\right) \quad (1)$$

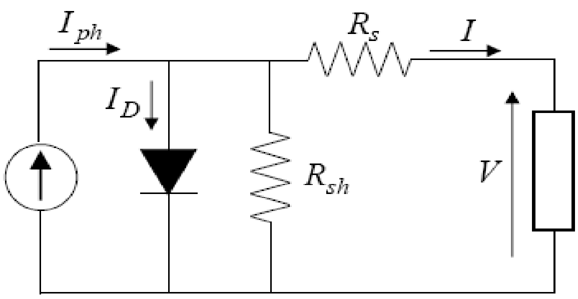

Figure 2: Equivalent circuit of PV cell

2.2 DC/DC Boost Converter and PO Maximum Power Point Tracking (P&O MPPT)

A boost converter is used in addition to solar PV in this paper, is a step-up DC/DC converter that improves the solar voltage to desired output voltage is given as input to the inverter conversion purpose. The configuration is shown in Figure 3, which involves a DC input voltage Vin, inductor L, switch S, diode D1, and capacitor C for the filter.

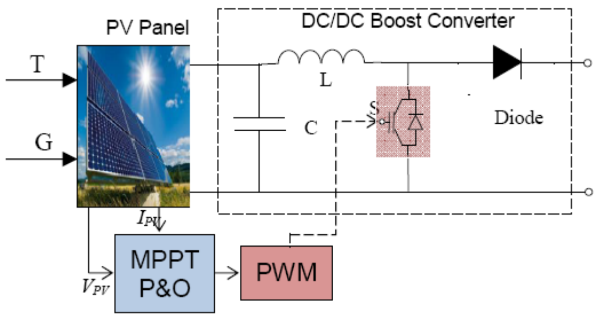

Figure 3: Boost converter with MPPT control

Solar panel performance is improved by the usage of MPPT method. The MPPT is a device controller that extracts maximum power from the solar cell at regular time intervals. The maximum power point for voltage and currently pursued by perturbing and observing method of MPPT. MPPT controller is mainly used to control the duty cycles to turn on and turn off the switch present in the dc-dc converter. For the system intended for examination, DC interface voltage is chosen as 500V for modulation index taken as 0.85 & V_{LL} is 260 volt.

The DC interface capacitor voltage of VSC is given by [12] condition

$$V_{dc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}m} \quad (2)$$

2.3 Battery modeling

The lead-acid battery is generally utilized as a capacity component in PV arrangement. The primary capacity of lead-acid batteries is the capacity and the generation of energy in a PV framework. The stored energy is a substance that can be changed over into electrical as well as the other way around. The electrochemical responses are portrayed by the accompanying responses.

$$PbO_2 + 2H_2SO_4 + Pb \rightarrow 2PbSO_4 + 2H_2O \quad (3)$$

In general, the battery's conduct is portrayed by its voltages. Along these lines, the resulting voltage of the battery is:

$$V_{bat} = V_{OC} \mp I_{bat}\mathrm{R} \quad (4)$$

A battery's State of Charge (SOC), Temperature, and Internal Resistance (R) all play a role in determining its Open Circuit Voltage (Voc).

3 Control Method

3.1 Battery Control Scheme

In this battery control structure, the goal of the system is to direct the battery current in order to obtain the required amount of energy. As shown in Figure 4, the BESS is connected to the DC interface voltage via a bi-directional Buck-Boost DC/DC converter.

The BESS will work in charging, discharging or drifting modes relying upon the energy prerequisites while considering dynamic power rating across grid integrated terminal value and these modes are overseen as indicated by the DC connect voltage. The battery energy storage framework requires a precise energy management control scheme as displayed in Figure 5.

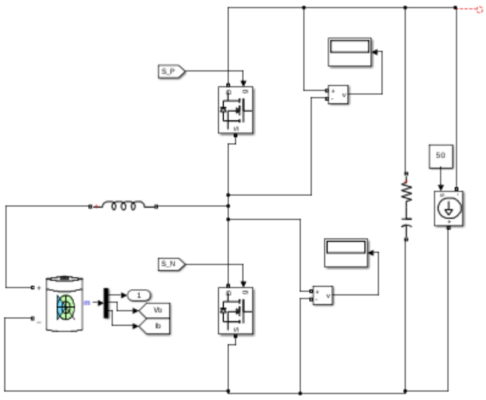

Figure 4: bidirectional buck boost DC/DC converter.

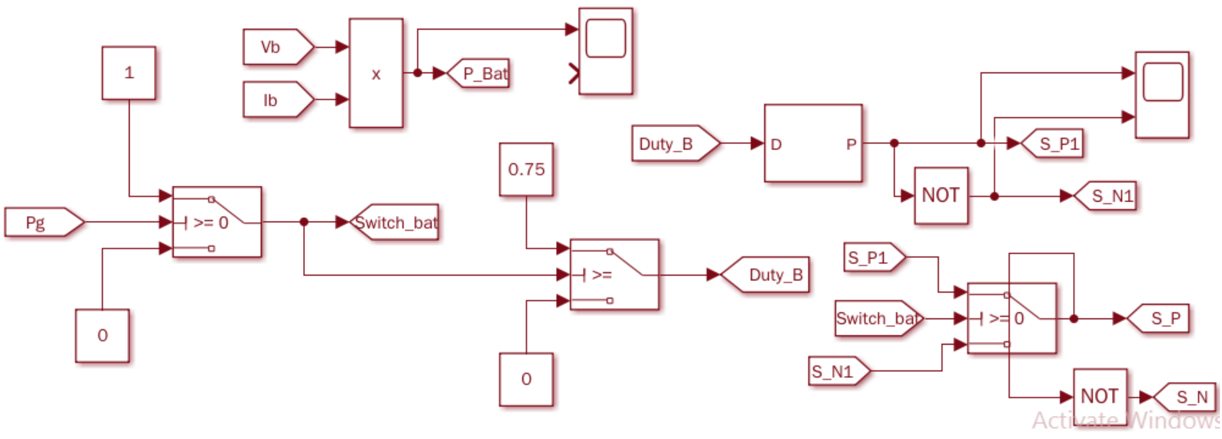

Figure 5: Energy management control scheme for BESS

3.2 Inverter Control Strategy

For controlling VSC switching purposes synchronous reference frame method is utilized for analyzing turn on and turn off switches.

To use the SRF method, a three-phase inverter output current must be transformed into a synchronously rotating D-Q frame (i.e. from abc to dqo) and then back into abc (i.e. from dqo to abc). Pulse width modulation (PWM) is used to generate pulses for the voltage source converter switches to turn on and off.

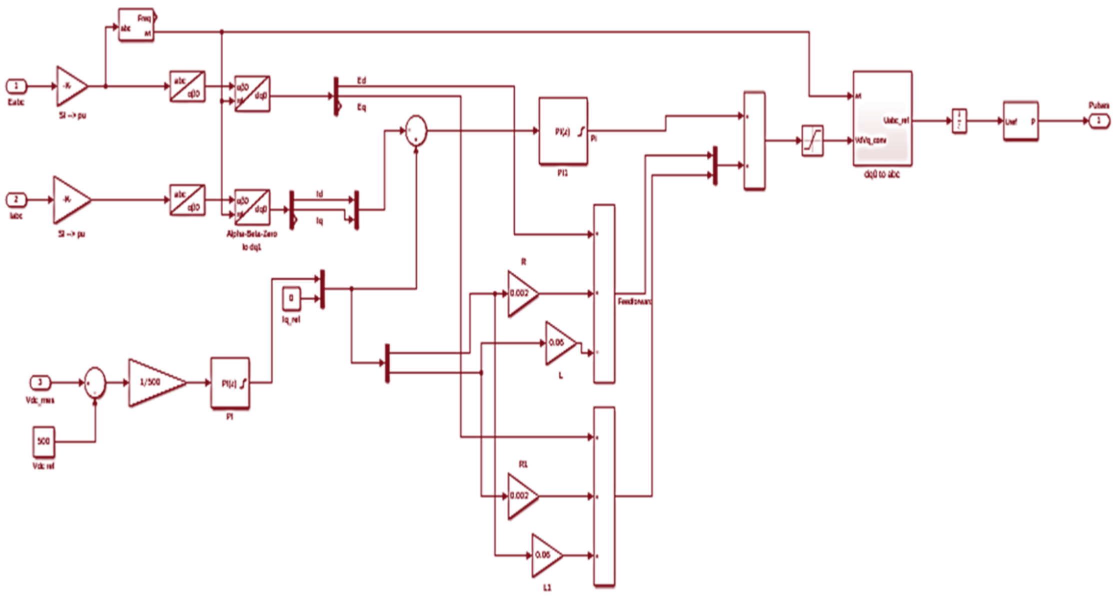

Figure 6: Synchronous reference frame (SRF) control.

4 Result and Discussion

This section presents a comprehensive approval of the proposed converter in an interfacing sun-oriented PV framework with the utility grid through a comprehensive simulation study utilizing the MATLAB/SimpowerSystem toolbox in this part.

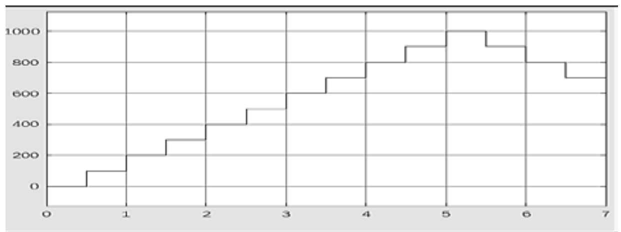

Figure 7: simulation result for change of radiation with respect to time

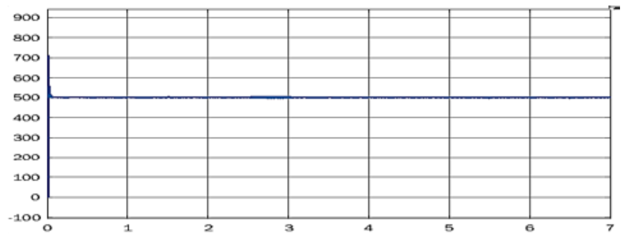

Figure 8: the simulation result for dc link voltage.

The proposed system execution with the PO-MPPT is at first assessed under various climatic conditions simulating the day-by-day regular climate vacillations with step changes of sun-based illumination that changes outlined in Figure7.

Figure 8 shows the simulation results of the dc-link voltage obtained at the DC-DC converter's output terminal (see below). Using the PO-MPPT method, a DC-DC converter generates a duty ratio for the output terminal voltage.

Figure 9 illustrates the simulation results for battery power output that came from the bi-directional DC-DC buck-boost converter. The buck-boost converter connected to the battery terminal is used for charging and discharging conditions.

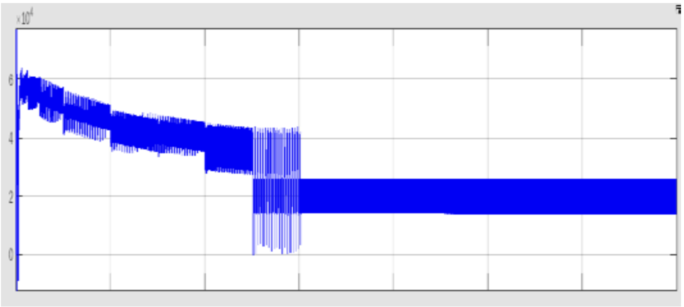

Figure 9: Simulation results for battery power output.

When solar panel attains higher temperature and irradiance produce maximum power which is greater than the required level will be stored in the battery by buck switching operation performed by the converter. When load requires an excess of power in addition to the grid that required power due to the rate of change in load, then the required level is produced by the battery by boost switching operation performed by the converter.

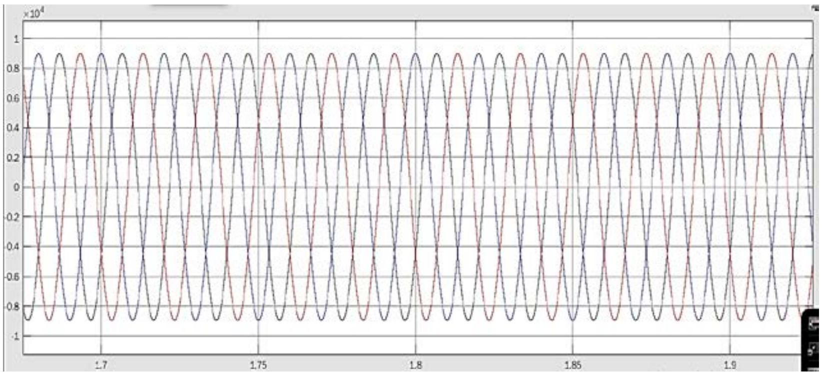

Figure 10: the Simulation result for terminal voltage at bus bar 1

Figure10 illustrates the simulation results for terminal voltage generated at the inverter output. The inverter output voltage is controlled by the synchronous reference frame method.

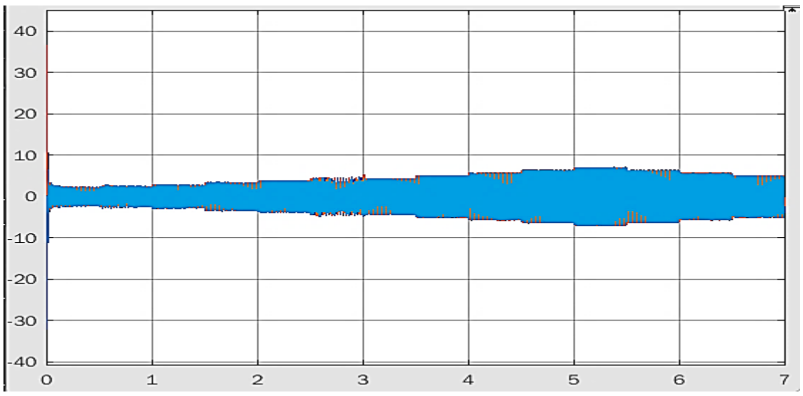

Figure 11: the Simulation result for terminal current at bus bar 1.

Figure11 illustrates the simulation results for terminal current produced at the inverter output. The inverter output current is controlled by the synchronous reference frame method by using the park and inverse park transformation technique. The obtained inverter output current contains less component current ripple with the use of LC filter.

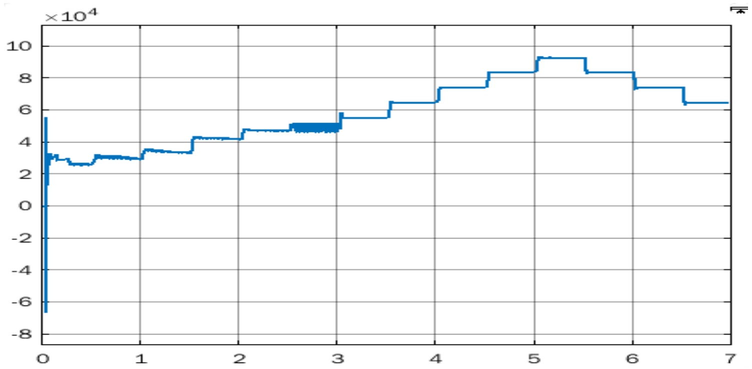

Figure 12: Simulation result for active power at bus bar 1

Figure 12 depicts the simulation results for the inverter output active power. The simulation results for terminal voltage generated at the load bus as displayed in Figure13.

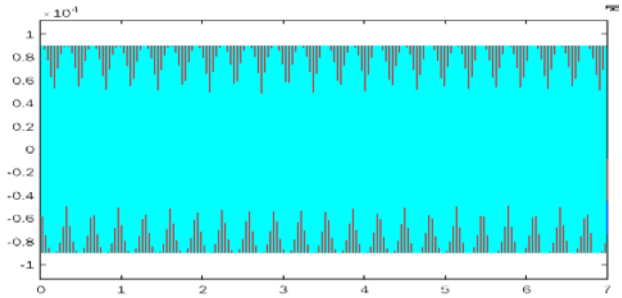
Figure 13: Simulation result for terminal voltage at bus bar 2

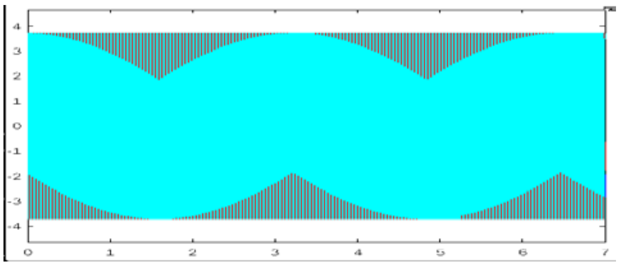
Figure 14: Simulation result for terminal current at bus bar 2

The simulation results for terminal current produced at the load bus can be seen in Figure14.

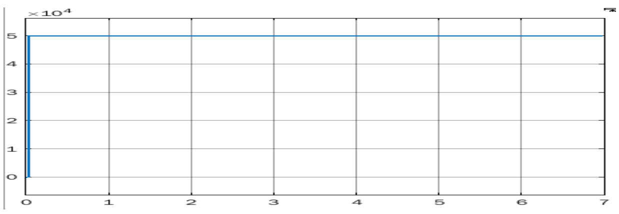
Figure 15: Simulation result for active power at bus bar 2

The power dividing among the distinctive Figure 15 depicts the proposed MG's power sources for supplying a 50-kilowatt residential load.

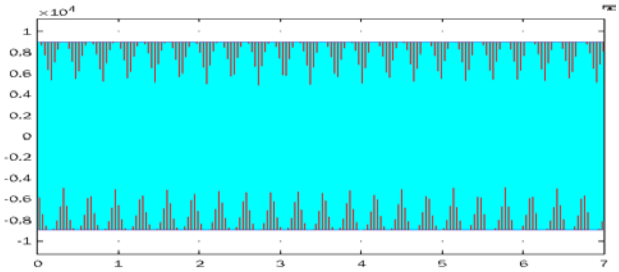

Figure 16: Simulation result for terminal voltage at bus bar 3

The terminal voltage produced by the grid that resulted at the bus bar 3 terminal as shown in Figure 16. The current produced by the grid that resulted at the bus bar 3 terminal as shown in Figure 17

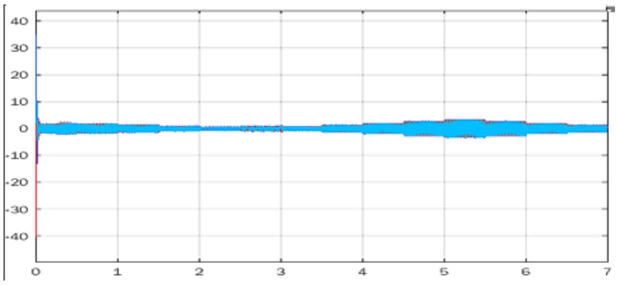

Figure 17: Simulation result for terminal current at bus bar 3

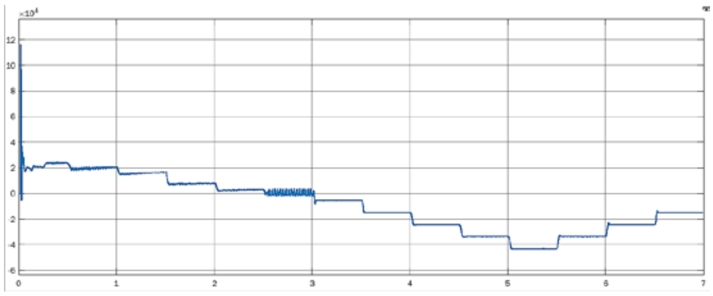

Figure 18: Simulation result for active power at bus bar 3

Figure 18 shows the electrical power produced by the grid that occurred at the bus bar 3 terminal according to the load requirement. The electrical power produced by the grid has rated capacity of 132KW.

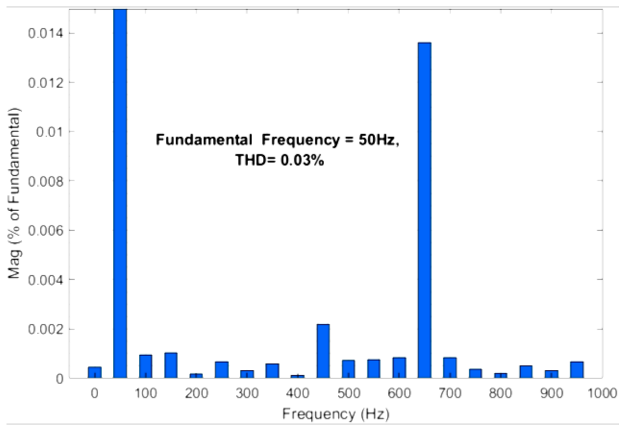

Figure 19: FFT for voltage waveform fed to grid

Fast Fourier transform analysis is used to find out the total harmonic percentage present in the voltage waveform fed to the grid as shown in Figure 19 and THD value is 0.03%.

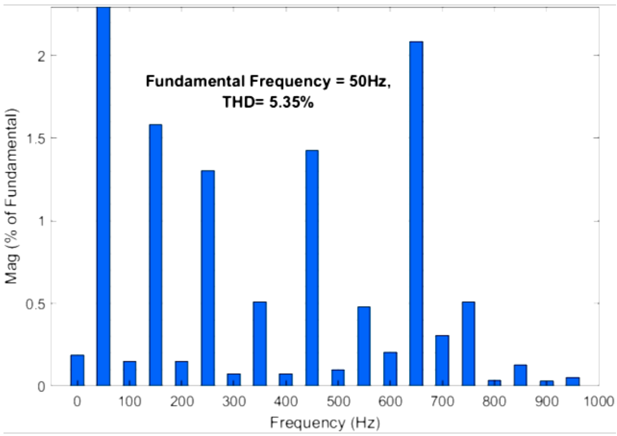

Figure 20: FFT for current waveform fed to the grid

Fast Fourier transform analysis is used to find out the total harmonic percentage present in the current waveform fed to the grid as shown in figure 20 and THD value is 5.35%.

5 Conclusion

In this work, a 3-phase grid-tied solar PV –Battery system has been designed and realized. This system has been operated to feed active power to the loads with power quality compensation features viz. harmonics, immoderate reactive power and unbalancing. An MPPT-controlled boost converter extracts the maximum available power from the PV generation arrangement, which is then fed back into the grid. For different conditions, harmonics elimination and load balancing ensure that the DC bus voltage and PCC voltage are maintained at the desired level for each. Validation of the algorithm's ability to perform under various operating conditions is done through simulation.

6 Availability of Data and Material

The data for this study can be available upon a request made to the corresponding author.

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