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Design of Active and Reactive Power Control of Grid Tied Photovoltaics

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Abstract : Solar Energy which planet's most plentiful and one of the best renewable energy source. Photovoltaics as a power source is good option since long time. Photovoltaics have been touted as clean sources of energy that can replace the coal powered plants. But the effective use of these solar energy and to optimize the efficiency of solar panel system is still challenging. Microgrids are localised grids which have their own generation sources along with the utility grid. This enables microgrids to achieve self-sustenance without having to rely on the utility for power. This project's objective is To demonstrate the capability of introducing a robust self-healing grid which can work as an islanded or non-islanded mode of operation using photovoltaics as distributed generation sources. These sources should also be capable of regulating the voltage and frequency of the grid at the feeder level.

This research work is focused to design an algorithm for optimization of the extraction of the power. It is needed to develop a maximum power point tracking algorithm. This is achieved by using a boost converter which is cascaded by another buck converter which aims at battery charging. This is followed by an inverter which converts the DC voltage into 3 phase AC which is tied to the utility grid. This inverter is also able to control the voltage and be able to synchronize its output to the grid. After simulating the photovoltaic system with its components several results were noted; The maximum power point tracking algorithm was able to extract the power at an efficiency of around 94% and the battery charging algorithm was able to charge the battery at any required current. The inverter was able to synchronize its output to the grid using a PLL system and was able to regulate the active and reactive power output as desired by the grid.

Keywords : Photovoltaics, Microgrids, Grid Synchronization, PLL.

1. INTRODUCTION

Photovoltaics are made up of semiconductor materials which exibit the photovoltaic effect. Solar panels are made up of array of photovoltaic cell. This photovoltaic cells converts the solar energy into current. Photovoltaics first found their use in Aerospace applications for powering satellites and manned modules in conjunction with battery storage systems. Photovoltaics have been touted as a clean replacement for centralized fossil fuel generation through decentralized clean energy systems. This allows for a clean source of energy to power the grid efficiently. The downside of using photovoltaics is the intermittent sunlight which does not allow a constant source of power out from the system. The decrease in power output during lower solar illumination can be compensated using battery storage which compensates the excess or lesser power generated by the system by charging or discharging. The advancement in power electronics and digital control systems has allowed for controlling and regulating power outputs better and has allowed for greater flexibility in the grid architectures. The project involves the simulation of a Grid Tied Photovoltaic with battery backup connected to a 3- phase bidirectional inverter that operates the photovoltaic system as a distributed energy source. This allows for localized voltage and frequency control along with islanding of grids.

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The current electrical grid has become a vast network of interconnected sources and loads at various levels which has increased in complexity. This has brought a need for higher efficiency, greater backup capability, and voltage & frequency regulation. Also, with the ever increasing need to ensure reliability of power supply and requirement to allow higher penetration of renewable energy, there is a large potential for distributed generation to aid this issue. With the help of robust, faster and high voltage tolerant power electronics and higher efficiency photovoltaics, it is possible to generate power at the distributed generation level of the grid, localized control which helps in reducing the transmission losses and promoting islanded grids which can form self-sustaining and self-healing entities. The motivation of the project it to demonstrate the capability of introducing a robust self-healing grid this can work in an islanded or non-islanded mode of operation using photovoltaics as distribution generation sources. The bi-directional inverter must be able to regulate the incoming grid, battery and Photovoltaic power efficiently by switching between various modes of operation and be capable of regulating the voltage and frequency of the grid at the feeder level.

2. PROPOSED PHOTOVOLTAIC SYSTEM

This entire photovoltaic system is with Photovoltaic array, Utility grid and is connected to the load. For maximum power point tracking (MPPT) boost converter has been added. Bi directional inverter is proposed for the synchronizing between the PV arrays and utility grid. Conventional method in which solar energy is converted into electrical energy is not used effectively. To optimize the utilization of the power generated a battery-storage is proposed. Battery-storage system helps to store the excess amount of energy generated and it is used when the demand for the energy is more.

The maximum power point will extract maximum energy from the solar panels while the battery charge controller will charge or discharge required power from the battery. The bidirectional inverter will accept power from the battery or charge it depending on the requirement while also maintaining the link capacitor voltage. This will allow for a dynamic system that always tried to go for an islanded system which accommodate for shortage of power also. Fig. 1 shows the photovoltaic system along with the battery storage system which is tied to the grid.

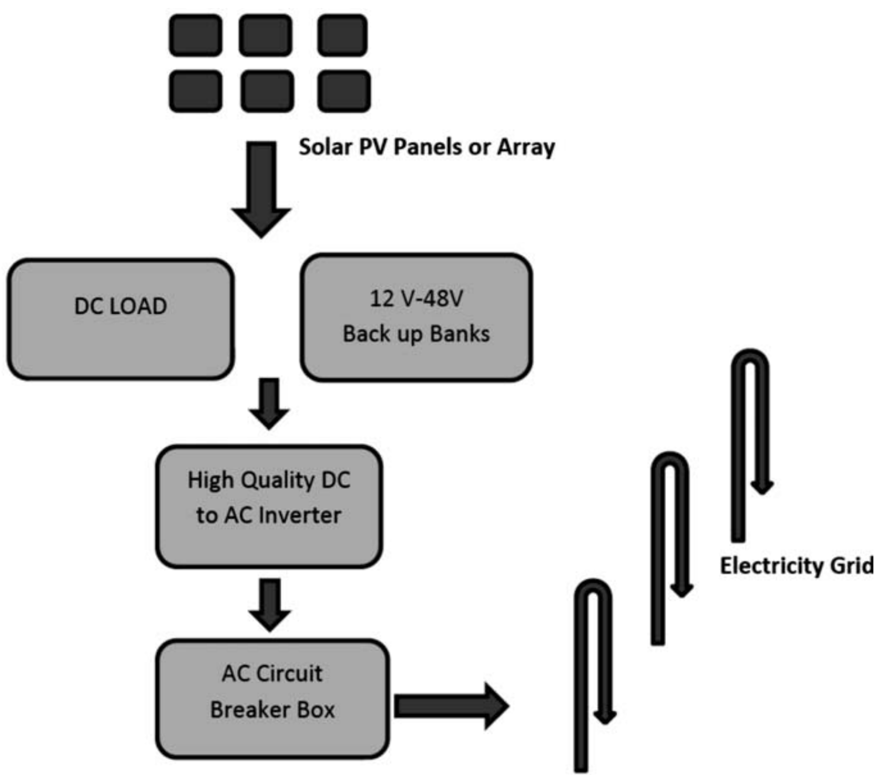

Figure 1: Architecture of the proposed Photovoltaic System

Solar Panel Modeling

A 1.2KW solar panel was modeled in Simulink using the solar cell block for various intensities. A variable resistor was connected to it which varied the resistance from zero to infinity to operate the solar panel at various Q points. The parallel diode was also modeled to account for the shift in current due to rise in temperature. This provided an accurate model of the solar panel which provided the output voltage for various intensities and temperatures. Since the Solar panel is a purely a current source, a lookup table was created based on the 2 output parameters *i.e* Current and Voltage using the input parameters Irradiance and the Temperature along with the shunt and series resistance. The environment for simulating the data for the solar panel is given in Fig. 2.

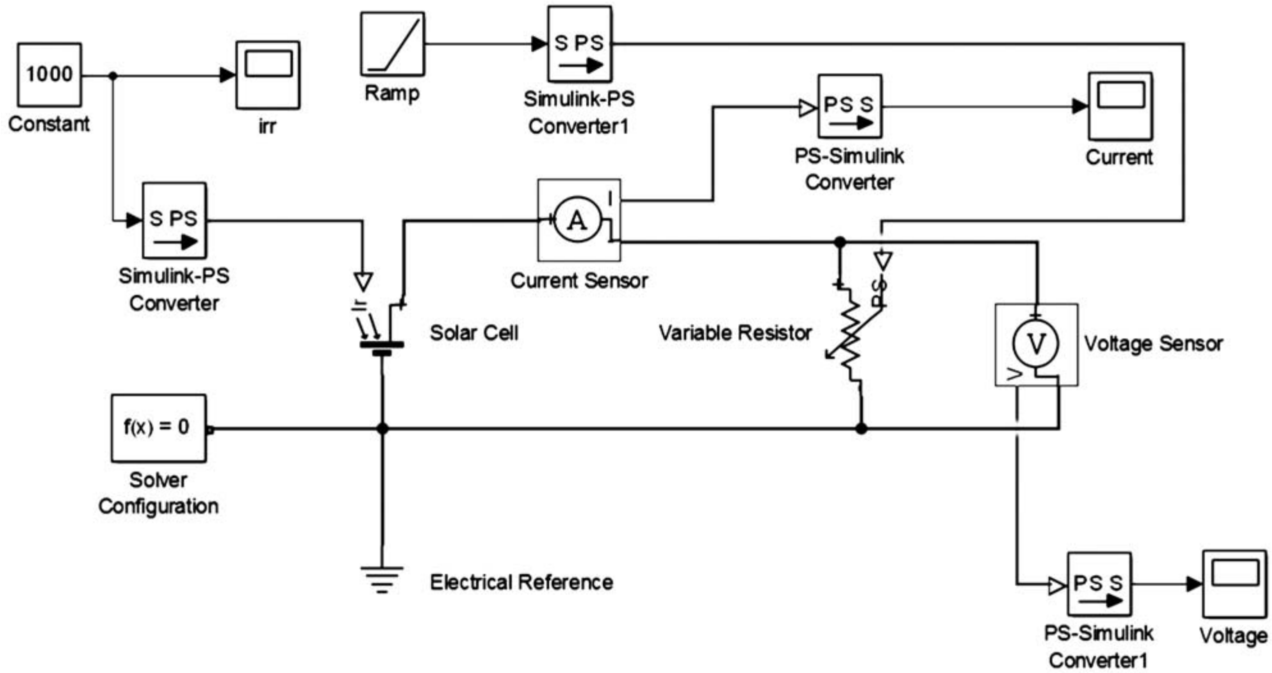

Figure 2: Simulation environment for the simulation of Solar Panel Data

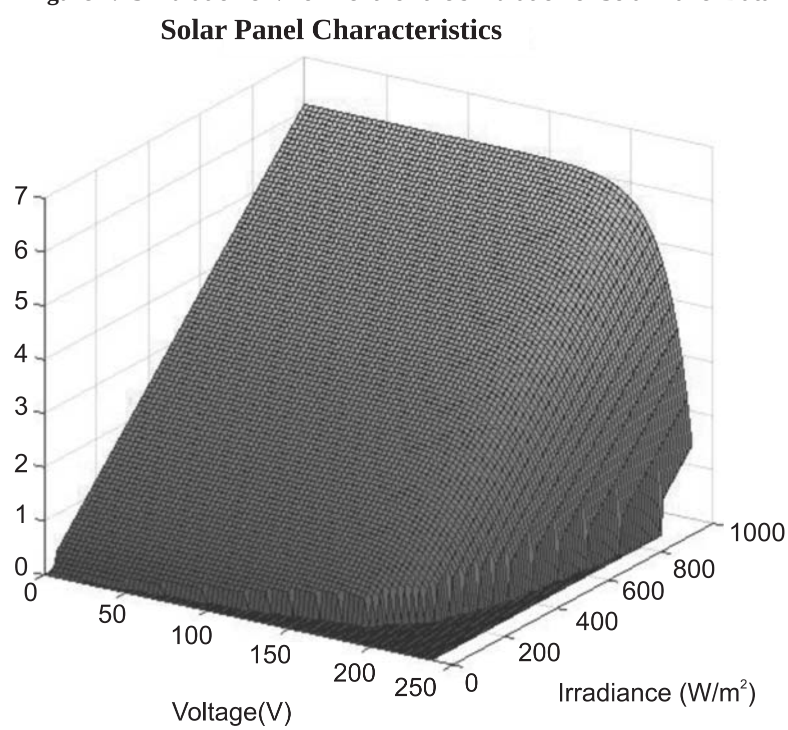

Figure 3: Meshed grid of the Current Source of Solar Panel

Once the solar panel data was available, the data was brought to a curve fitting model which initially modelled the Current Source IL which was dependent on the irradiance and voltage only. Once the curve fitting model was complete, an interpolating 3*d* function was obtained which approximated the output current for a given irradiance. Then the shunt and series resistors were modelled and the equivalent circuit model for the solar panel was complete. This model provided a faster model which allowed for shorter simulation time. The meshed curve fitting model is given in Fig3. The equivalent circuit is given in Fig 4.

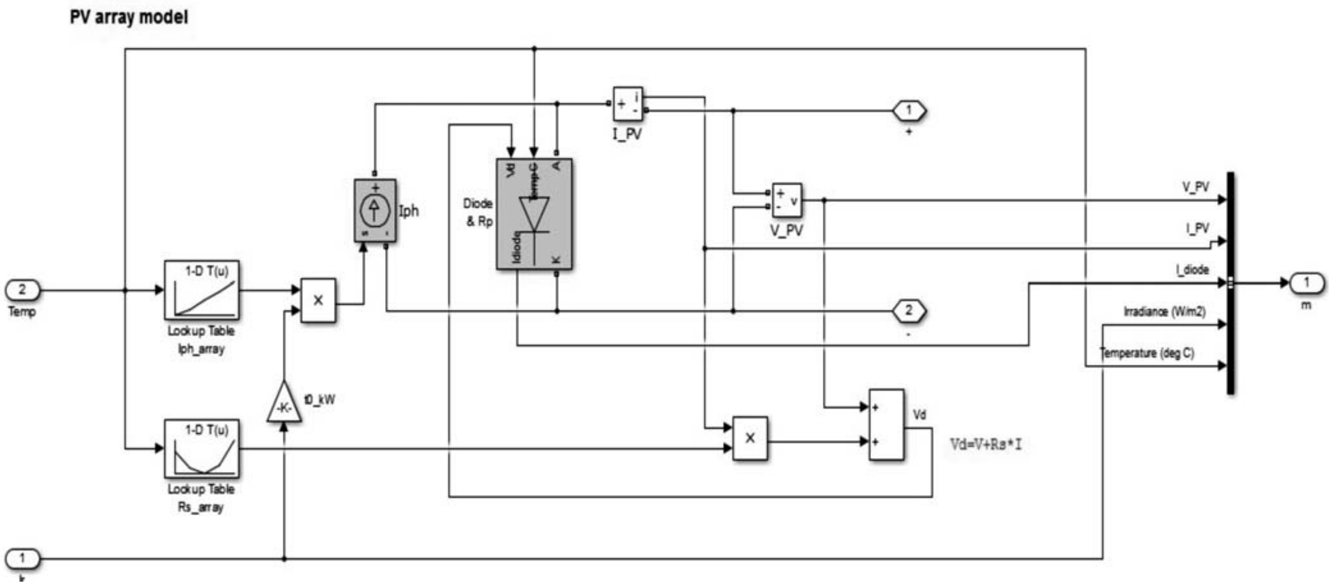

Figure 4: Solar Panel (Equivalent circuit)

Maximum Power Point Tracking

Here method used is incremental conductance method. It is used with integral regulator technique. The advantage of having incremental conductance is that it is a robust controller with lesser ripple. Since incremental conductance with an integral regulator monitors the PV parameters in real time, it reduces down to an integral controller to a 2nd order system. This arrangement leads to a controller with nearly zero steady state error. The derivation for the MPPT controller is as follows:

$$P = VI \tag{1}$$

Applying the chain rule for the derivative of products yields to

$$\frac{\partial P}{\partial V} = \frac{[(VI)]}{\partial V} \tag{2}$$

$$\frac{\partial P}{\partial V} = 0 \tag{3}$$

Thus by solving,

$$\frac{\partial P}{\partial V} + \frac{I}{V} = 0 \tag{4}$$

3. SIMULATION AND EXPERIMENTAL RESULTS

Solar Panel & Battery System

The entire system was simulated using Simulink in the Sim Power System Toolbox. The system contains the Solar Panel (Vmpp – 220V, Impp – 6A at 1000W/m2 and 25deg C), the boost converter, the MPPT controller, the battery charging system, and a load which is connected to the system to emulate the power sent to the grid. The battery has an initial state of 20% and the battery controller is regulating the charging at 4A. The simulation environment is shown in Fig 5. The simulation results show that the MPPT system is able to operate the PV at the MPP point the error in the incremental conductance algorithm has been reduced to zero, the battery is slowly able to charge to 100% capacity in about 1.5 hours and the remaining power has been utilized in sending power to the input of the inverter which is emulated by the load.

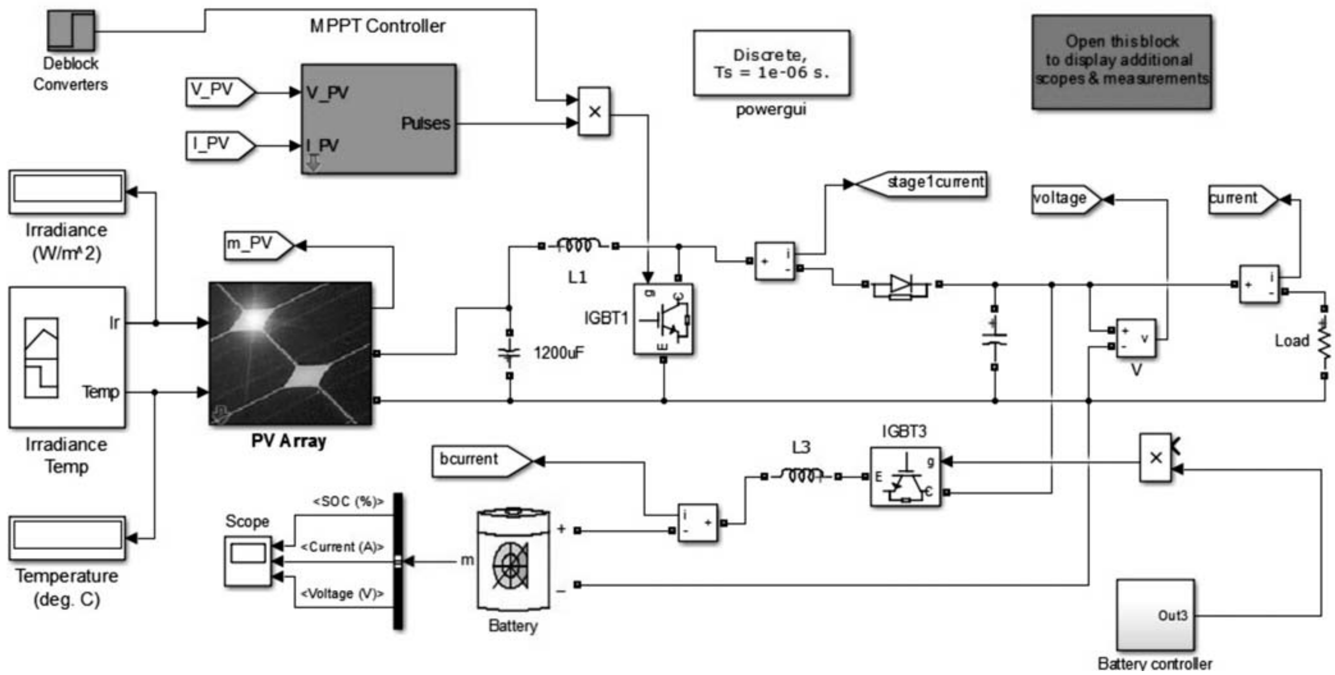

Figure 5: Simulation environment of the Photovoltaic System

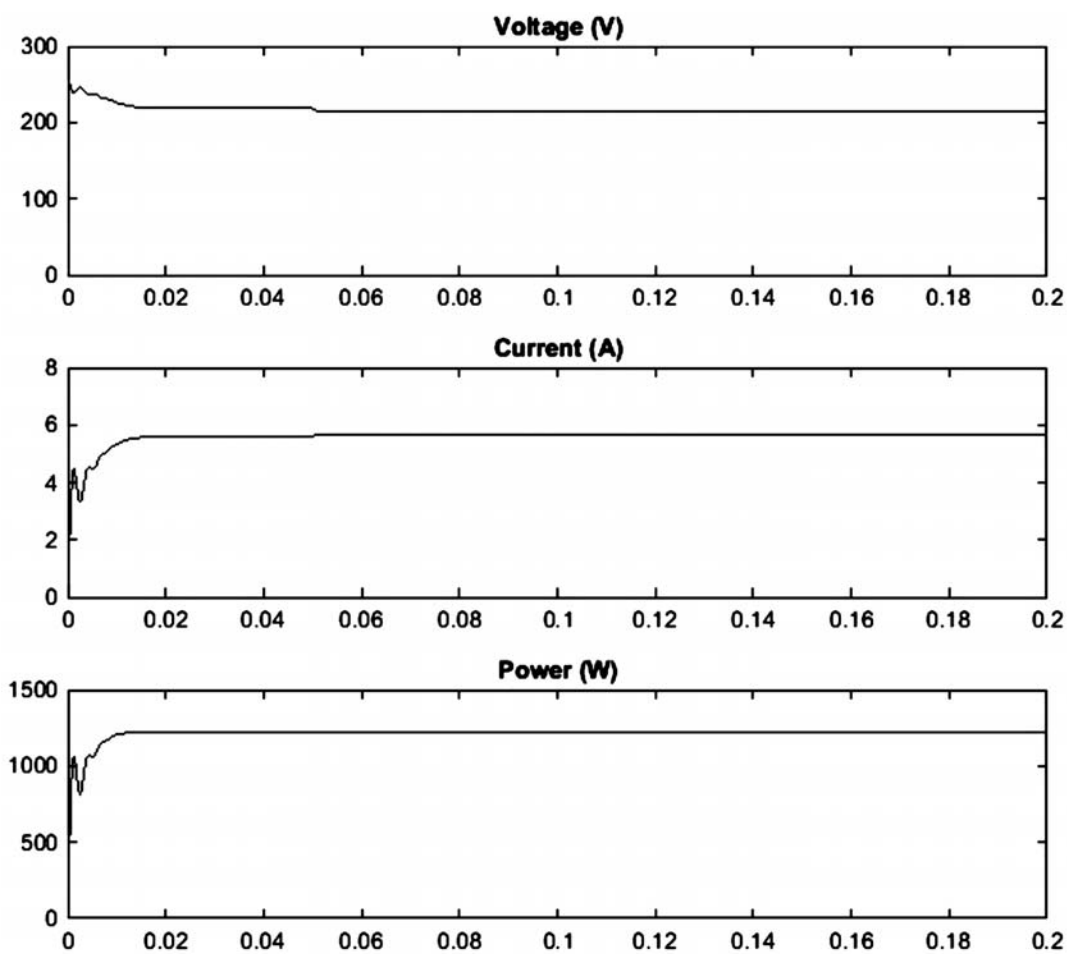

Figure 6: Solar Panel Output

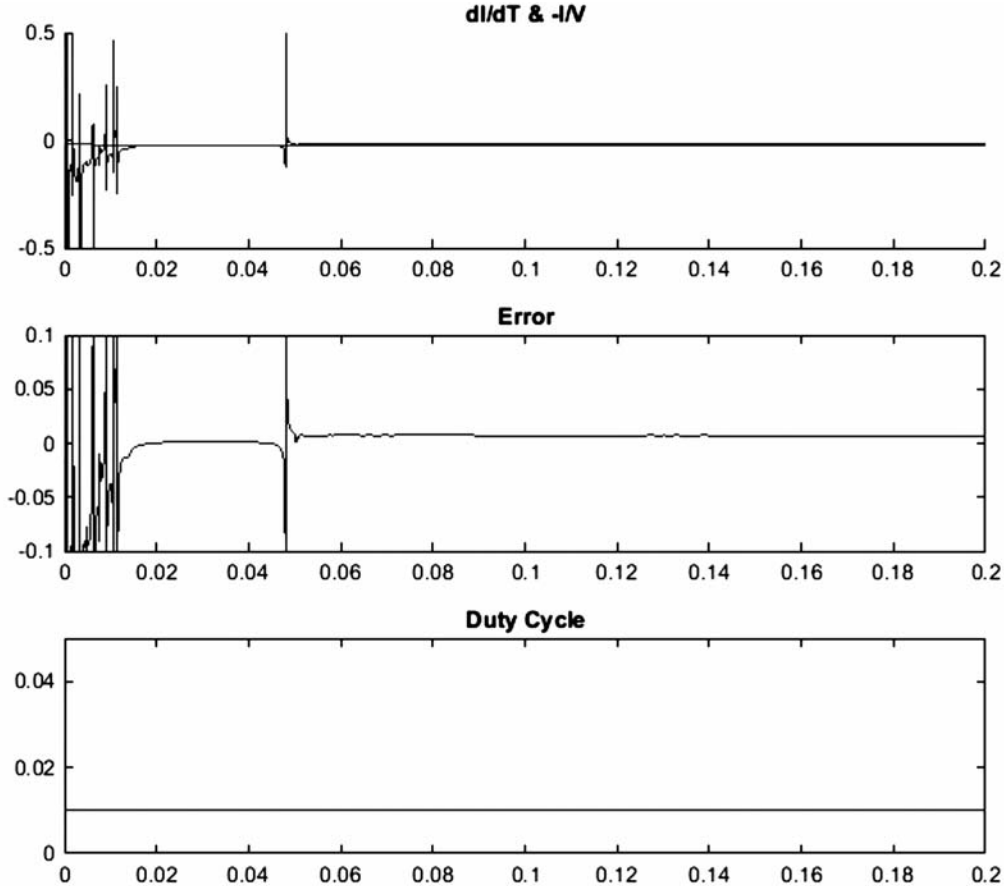

Figure 7: MPPT Controller

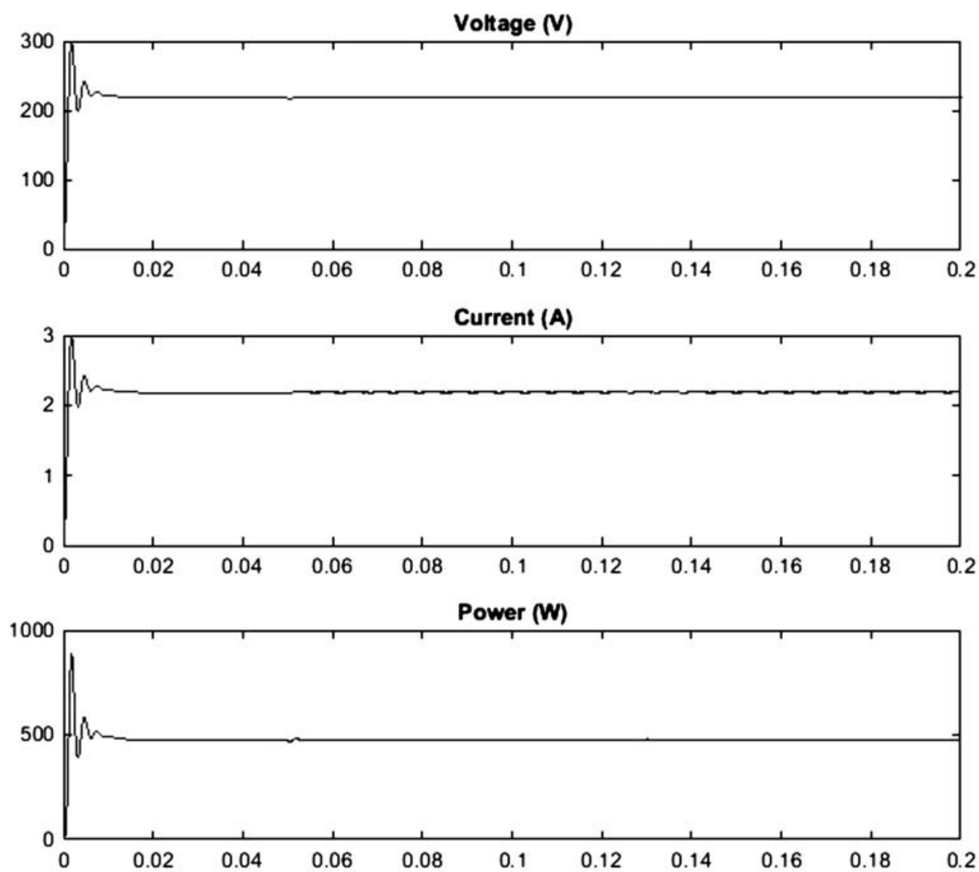

Figure 8: Inverter input Load Output

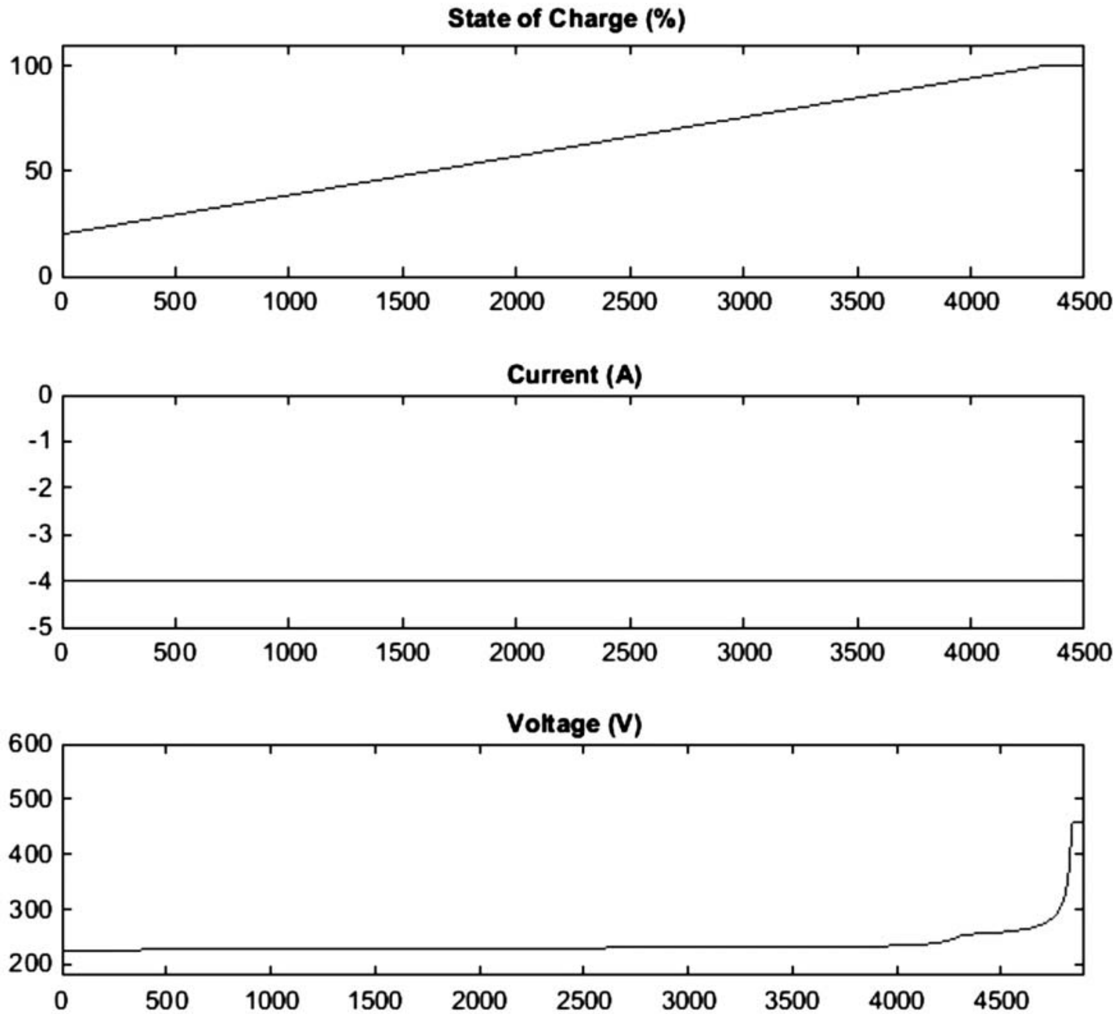

Figure 9: Battery Output

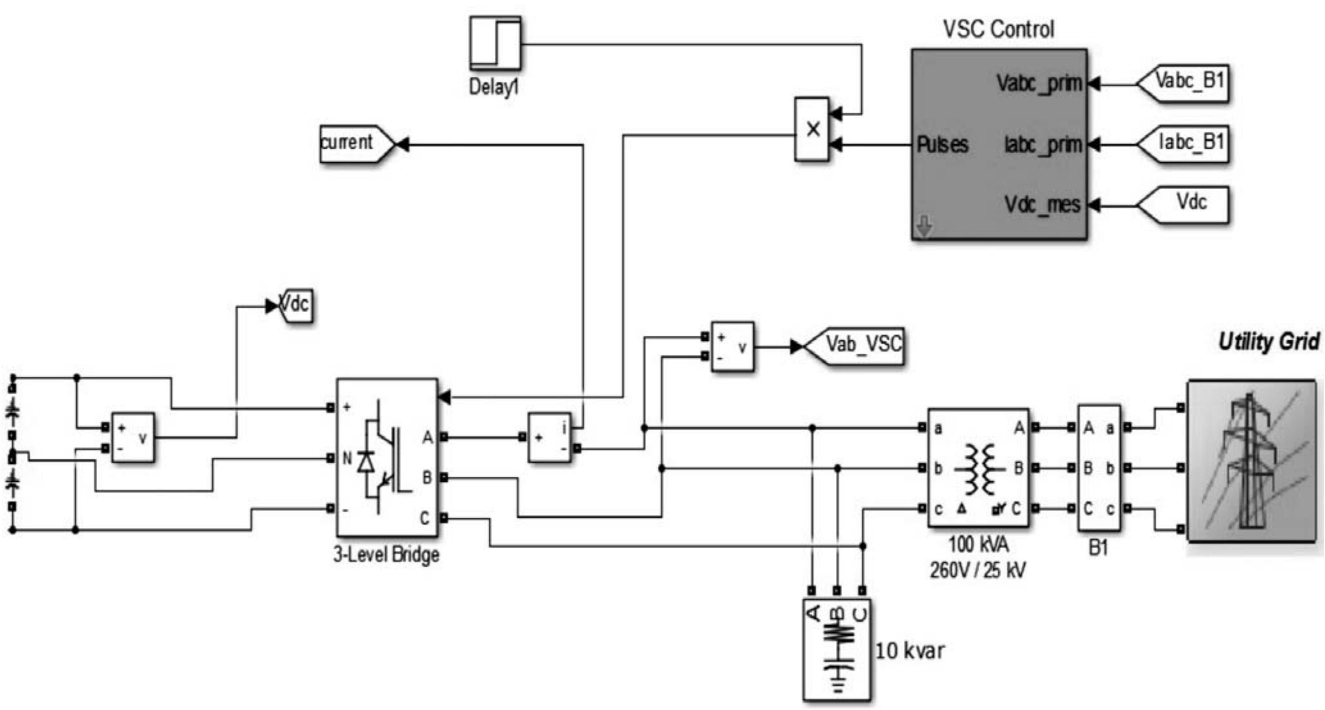

Figure 10: Simulation environment of the three phase inverter system

Three Phase Inverter and Grid Synchronization

The system was simulated for a condition where it had to operate in mode 4. The solar panel produces power which is storing in the battery and also being sent to the grid.The inverter tries to synchronize to the grid after a delay time of ~0.2s. After the grid synchronization, the solar panel is connected to the inverter and power starts flowing into the battery and the grid. The simulation environment for the invertor system is shown in Fig 6. The output line voltage of the inverter is given in fig 7 and the DC link voltage tracking is shown in Fig 8.

4. CONCLUSION

The objective of the project was to design and simulate the performance of a photovoltaic system with Battery storage which would be connected to the grid.This system would allow the local grid to be primarily be powered by the local photovoltaic source with the help of the battery storage without having to depend a lot on the utility grid. This would enable the local grid to be more self-sufficient and be powered by renewable energy. The system was able to perform as expected and was able to deliver Photovoltaic DC power to the AC utility grid and was able to power the loads locally rather than drawing power from the grid. Although a basic and functional system was designed and simulated there is space for improvements in the design.

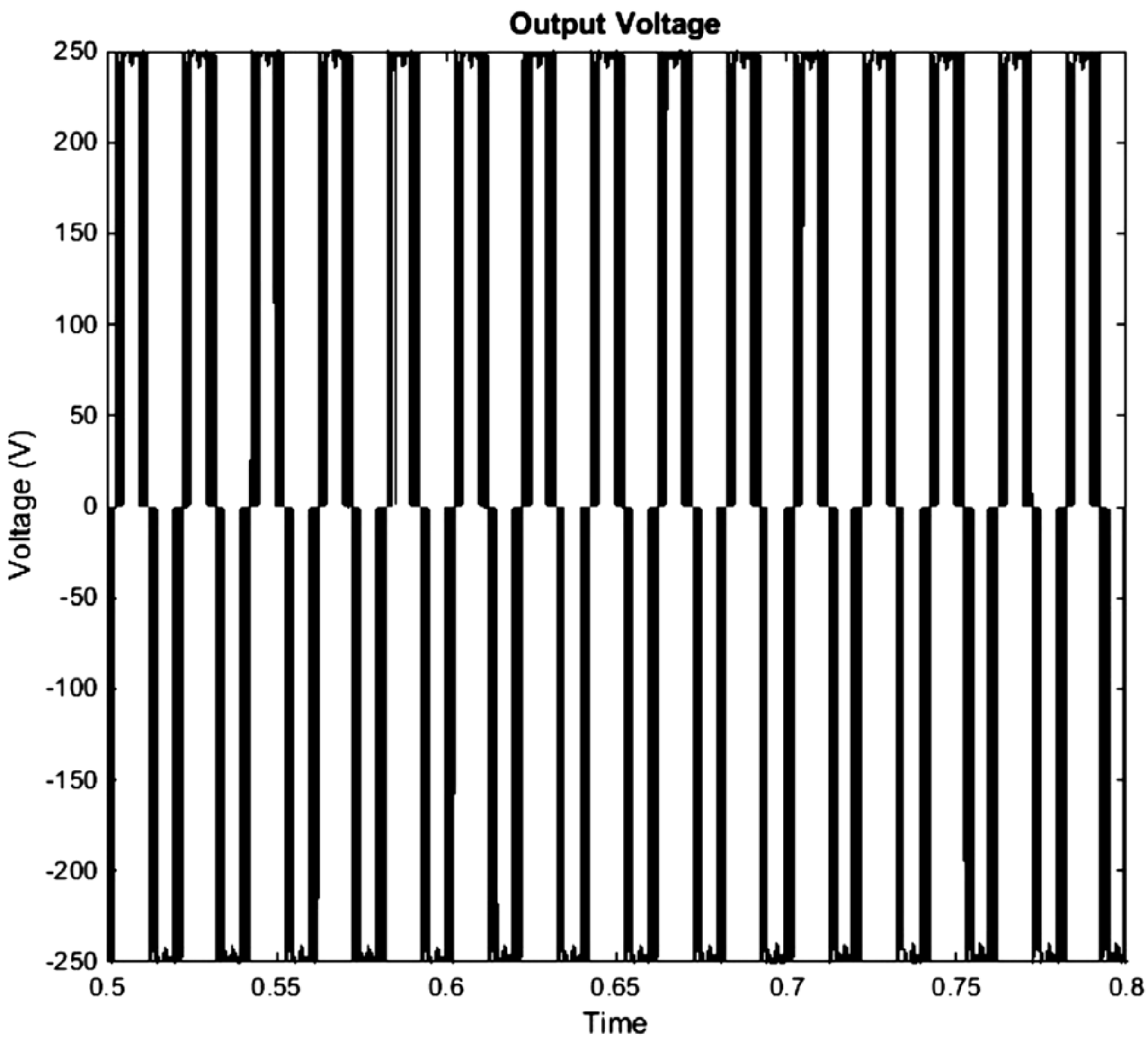

Figure 11: Line voltage output of the inverter

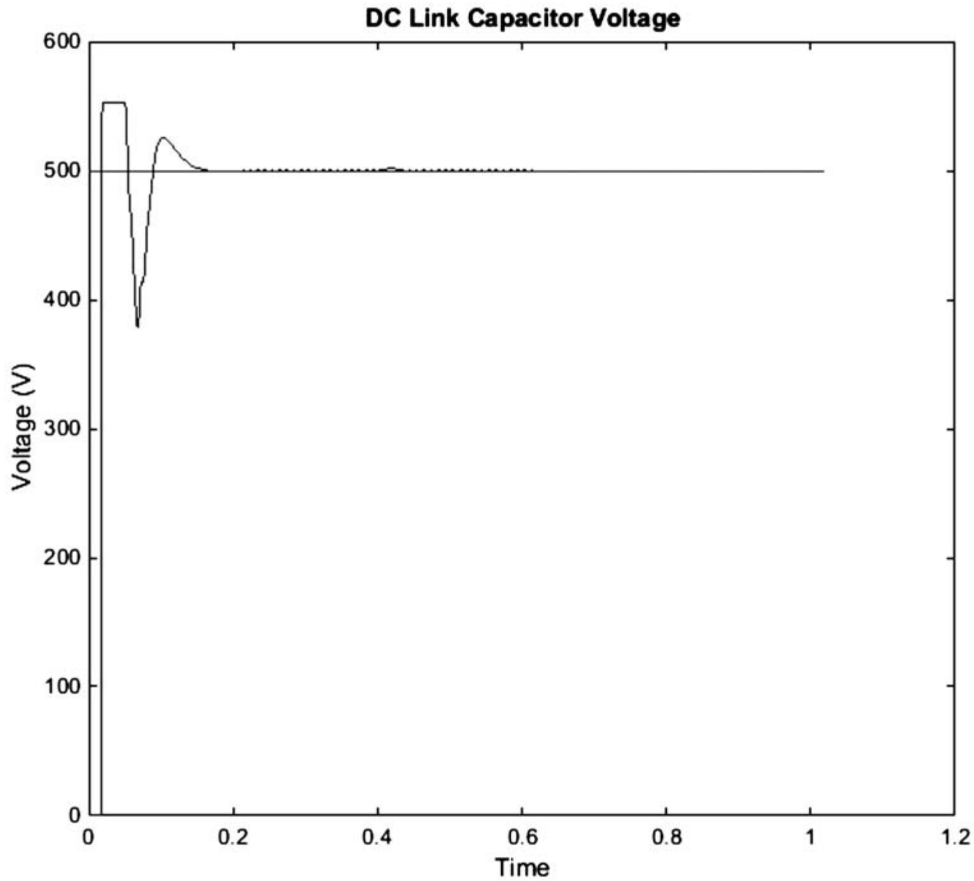

Figure 12: DC Link voltage tracking

5. REFERENCES

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