

Hardware Implementation of Grid connected Solar PV inverter

Asheesh Dhaneria
Research And Development Department
Electrical Research And Development Association
Vadodara, India
asheesh.dhaneria@erda.org

Hardik Khambhadiya
Research And Development Department
Electrical Research And Development Association
Vadodara, India
asheesh.dhaneria@erda.org

Abstract—Grid connected solar inverter converts the DC electrical power from solar PV panel into the AC power suitable for injection into the utility grid. This paper discusses various control modules used for the developed grid tied solar inverter. The developed grid tied solar inverter uses a boost converter to regulate the DC power from solar PV panels and converts the output of the boost converter into AC using a single phase DC to AC converter. The system ensures Maximum Power Point Tracking operation of the inverter using the Perturb and Observe method. Unity power factor operation is chosen to utilize the full inverter capacity. Cascaded second order generalized integrator method is implemented in the programming to solve the problem of DC offset in the phase locked loop output. Cascaded second order generalized integrator method used for grid synchronization shows better DC rejection capability than second order generalized integrator. At the end of the paper, hardware results of the developed 5 kW rating solar inverter are presented. Hardware results have shown that the developed solar inverter is able to supply the harvested energy from the solar PV to the grid for all irradiance levels.

Keywords—Grid tied solar inverter, renewable, Phase locked loop, DC voltage control, current control, maximum power point tracking

I. INTRODUCTION

Grid connected solar photovoltaic (PV) system is one of the distributed energy resource which converts DC power produced by solar PV into AC power in a form suitable for pumping into the grid. The main purpose of the grid connected solar PV system is to transfer maximum solar array energy into grid with unity power factor. The grid tied solar inverter consists of a DC to DC converter which helps in extracting the maximum power from the solar PV panels when it's switching device is fired suitably. The output of the DC to DC converter is connected to the DC to AC converter called as inverter. These inverters are connected to the existing electric utility ac grid, therefore the voltage cannot be controlled.

In this paper, reactive power is controlled to zero which means that the phase shift between the grid voltage and inverter output current is also zero. Therefore, only active power is pumped into the grid. The grid tied solar inverter is implemented using simple basic control algorithms: Maximum Power Point Tracking (MPPT) control, DC voltage control, grid synchronization control and current controller. This paper discusses the above listed control blocks in detail.

The topology of the solar inverter developed is Dual stage single phase type. The rating of the developed inverter is 5 kW.

II. TOPOLOGY: SINGLE PHASE DUAL STAGE INVERTER

Acknowledgement: Ministry of New and Renewable Energy, New Delhi for funding the project

The topology of the grid tied solar inverter is Single phase dual stage type and is shown in figure 1. The solar PV array is connected to the DC to DC converter. The DC to DC converter is of boost type. The IGBT of the boost converter is used for achieving MPPT control. A DC link capacitor is connected in parallel to the boost converter. This helps in reducing the ripple in the DC output voltage of the boost converter. The output terminals of the boost converter is connected to the DC to AC converter having H-bridge configuration. This configuration is selected for its simple design and its ability to send and receive both real and reactive power. This is possible because of the presence of diodes in the IGBT which provides alternative path for the load current during the OFF condition of power switches. This inverter is followed by LCL filter which helps in reducing the harmonic content in grid current. This filter also provides sufficient attenuation for the switching frequency harmonics and also allow a low impedance path for the fundamental component. LCL filter also ensures better decoupling between the filter and the grid impedance. This reduces the dependence of the filter on grid impedance. However, the designer needs to take into account various constraints like resonance phenomenon, current ripple through inductor, attenuation of current harmonics at switching frequency, reactive power absorption by capacitor etc. The output of the LCL filter is connected to the utility grid.

III. CONTROL BLOCKS

The developed grid tied solar inverter utilizes following control algorithms for its operation: MPPT control, DC voltage control, grid synchronization control and current controller. Each of these control modules are discussed below [1]:

A. MPPT control

The IGBT of DC to DC converter is switched in accordance with the MPPT control algorithm. This algorithm ensures operation of solar PV panel for maximum power generation irrespective of irradiance value. Perturb and Observe (P&O) algorithm is used to implement MPPT. This algorithm is simple to apply and uses solar PV voltage and current for its implementation. The tracker operates by periodically incrementing or decrementing the solar array voltage. If a given perturbation leads to an increase (decrease) in the solar PV output power, then the subsequent perturbation is generated in the same (opposite) direction [2]. Once the MPP is found the system keeps on oscillating at this point.

B. DC voltage control

Actual capacitor voltage is filtered through a low pass filter and compared with the capacitor reference voltage. This error is fed to a PI controller to generate the magnitude of the reference current that should be injected into the grid to maintain the capacitor voltage tracking the reference value generated by MPPT block.

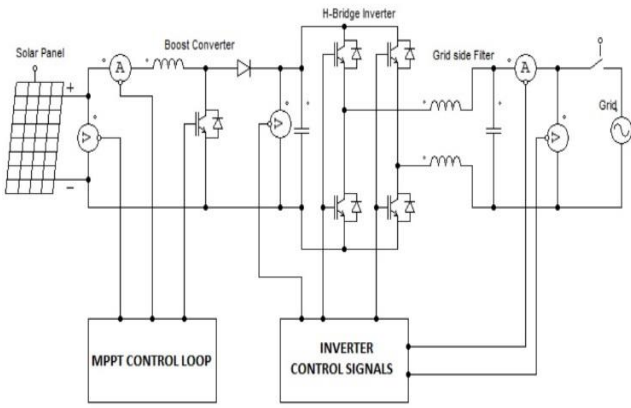


Fig. 1. Topology of single phase dual stage grid tied solar inverter

C. Grid Synchronization

Phase locked loop (PLL) technique is used for grid synchronization. Figure A shows the general structure of single phase PLL using Second Order Generalized Integrator (SOGI) where v' and qv' are the two sine wave output signal with a phase shift of 90° and v' signal is having the same phase and magnitude as the fundamental signal v (sensor output) [3].

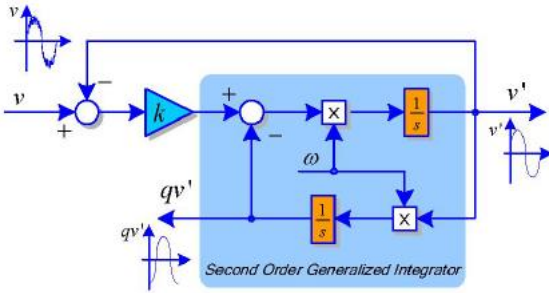


Fig. 2. General structure of a single-phase PLL

Figure B shows the hardware result for SOGI output. It indicates a dc shift in the output signal, qv' whereas the second signal, v' is free from dc offset. DC offset occurs on the input signal (v) due to sensor calibration, ADC conversion issue etc.

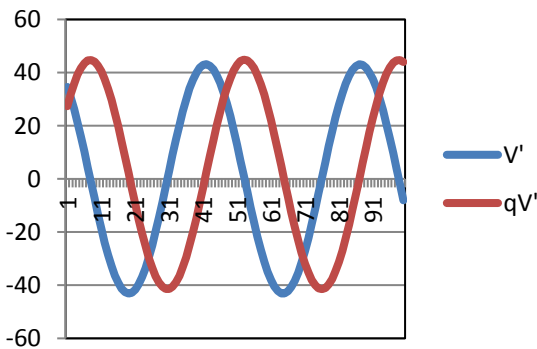


Fig. 3. Hardware result for output of SOGI

In cascaded SOGI (c-SOGI), two SOGIs are connected in cascaded, in which first one removes dc offset and second one creates two orthogonal signals for PLL algorithm [4]. The output v' of the first SOGI is fed as input to the second SOGI connected in cascaded to the first one. Figure C depicts the structure of c-SOGI. Figure D shows the output of the c-SOGI in which both the output signals – V and qV are free from DC offset.

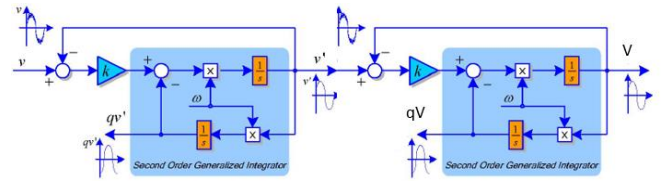


Fig. 4. Structure of c-SOGI

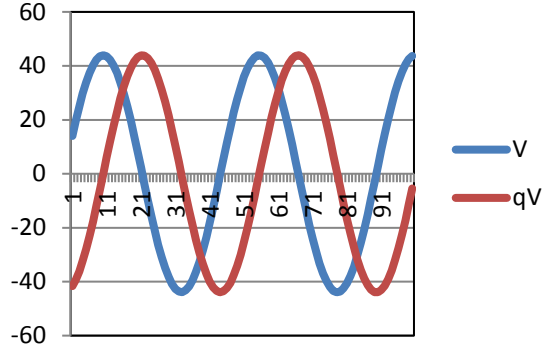


Fig. 5. Hardware result for output of c-SOGI

These results indicate that with the incorporation of cascaded-SOGI, the DC offset get rejected.

D. Current control

In grid connected solar inverter, the output of the inverter must have higher value than the grid voltage. Since grid voltage is not under control, the only way to control the power fed to the grid is to control the current fed to the grid. Digital PI current controller is used for grid current control algorithm. To ensure that the controlled signals do not saturate, an anti-windup is introduced in the PI path.

IV. HARDWARE RESULTS

Hardware model for 5 kW grid connected solar PV inverter was developed as shown in figure 6 and figure 7. This hardware setup was tested for its functionality at different irradiance by using PV simulator.



Fig. 6. 5 kW grid tied solar inverter panel

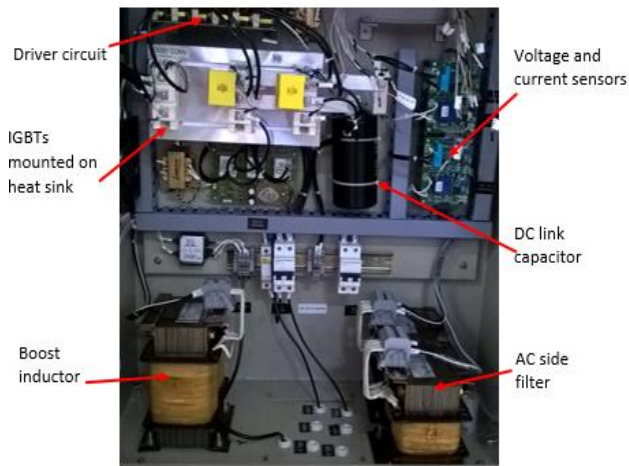


Fig. 7. Hardware setup of 5 kW grid tied solar inverter

Solar PV simulator having following setup for PV panel rating was used for experimentation:

$$V_{mpp} = 35 \text{ V}$$

$$I_{mpp} = 9.0 \text{ A}$$

$$P_{max} = 315 \text{ W}$$

Number of PV panels in a string = 8

Number of strings = 2

Total PV panel power rating = 5.04 kW

The experimental results captured on power meter are as shown below.

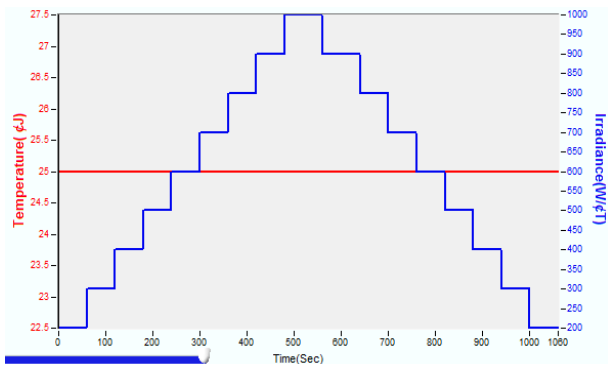


Fig. 8. Irradiance waveform fed from solar PV simulator

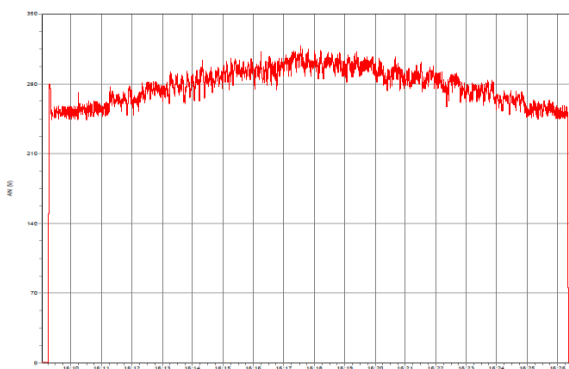


Fig. 9. Input DC voltage (V) from solar PV simulator

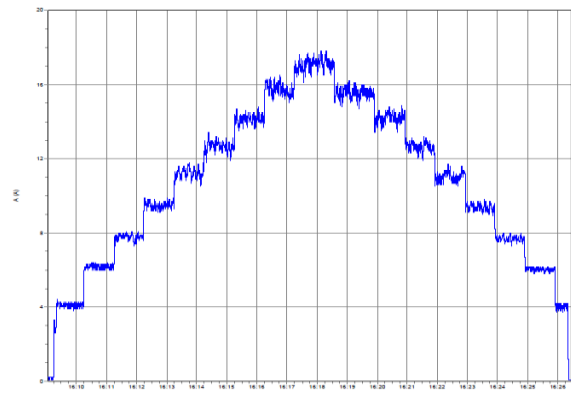


Fig. 10. DC input current (A) from solar PV simulator

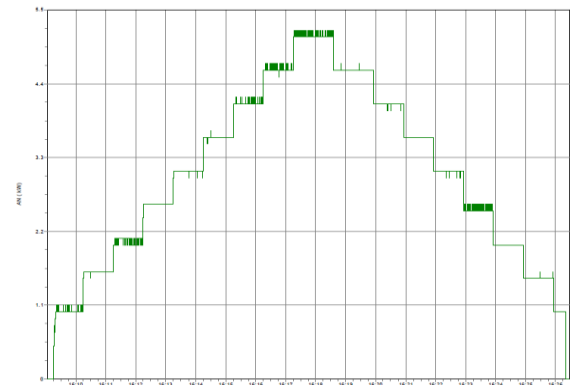


Fig. 11. DC input power (kW) from solar PV simulator

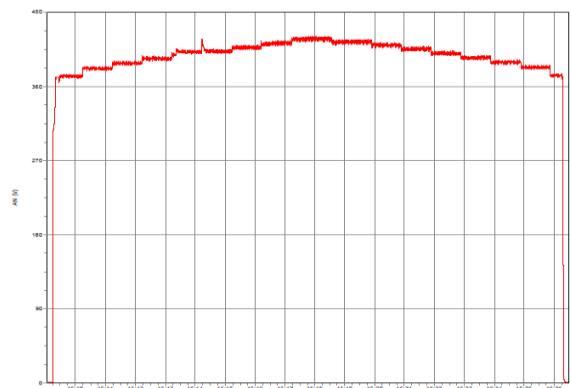


Fig. 12. DC link voltage (V) across the DC link capacitor

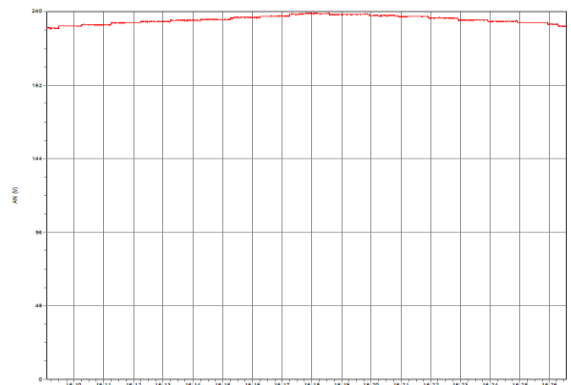


Fig. 13. rms value of solar inverter output ac voltage (V)

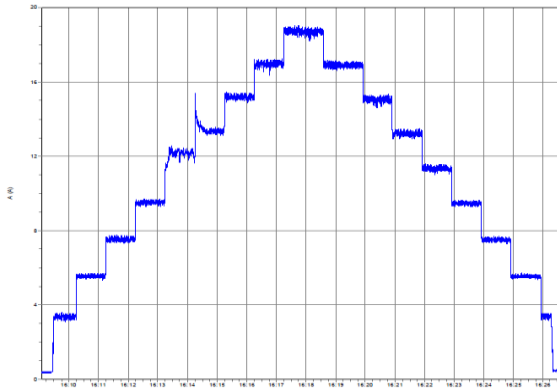


Fig. 14. rms value of solar inverter output ac current (A)

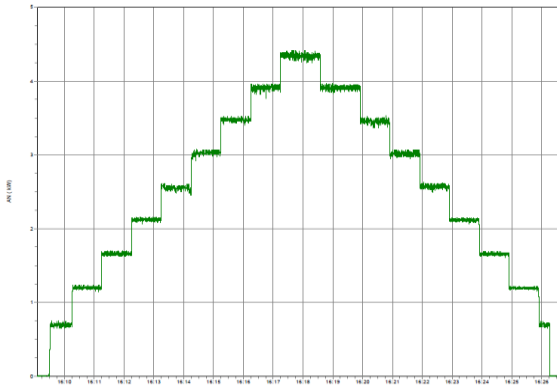


Fig. 15. AC output power from solar inverter (kW)

The solar inverter is tested for full range of irradiance variation from 200 W/m^2 to 1000 W/m^2 by varying the irradiance using a solar PV simulator. Figure 8 shows the irradiance waveform as set in the PV simulator. The PV panel power rating is set to 5.04 kW . The irradiance is increased from 200 W/m^2 to 1000 W/m^2 in steps of 100 W/m^2 with a time interval of 60 seconds stay at a particular irradiance and decreased from 1000 W/m^2 to 200 W/m^2 in the same fashion. The temperature is kept constant at 25°C .

Figure 9 and figure 10 shows the hardware result for DC input voltage and current from solar PV simulator. It can be observed from these waveforms that the solar PV voltage remains almost constant while the solar PV current increases with the increase in the irradiance. Figure 11 shows the DC input power drawn from solar PV simulator. It can be seen that the solar PV panel is delivering DC power of 5.04 kW at the irradiance of 1000 W/m^2 which shows the proper functioning of the designed MPPT controller.

Figure 12 shows the hardware result for voltage waveform across the DC link capacitor put across the boost converter output. The DC link voltage varies in a margin of ± 25 volts around the set value of 400 volts for the full range of irradiance variation.

Figure 13 and figure 14 shows the hardware result for rms value of solar inverter output AC voltage and output AC current fed to the grid respectively. The rms value of ac output voltage remains almost constant despite the changes in the irradiance whereas the ac output current magnitude increases with the increase in the irradiance. The rms ac output voltage

remains almost fixed at 230 volt with maximum and minimum values of 239 volt and 229 volt respectively.

Figure 11 shows the hardware result for ac output power pumped to grid. The power pumped to grid is 4.3 kW at irradiance value of 1000 W/m^2 .

The grid current is regulated and is able to synchronize with the grid with the implementation of the MPPT and current control technique. The hardware results for the closed loop model at an irradiance of 200 W/m^2 and 1000 W/m^2 are shown in figure 16 and figure 17.

The slightly distorted ac output current is because of harmonics in the output current due to usage of semiconductor devices.

The experimental system parameters are given in Table 1.

TABLE I. EXPERIMENTAL SYSTEM PARAMETERS

Parameters	Values
Grid frequency	50 Hz
MPPT switching frequency	10 kHz
PWM switching frequency	20 kHz
Inverter nominal power	5 kW
Grid voltage	230 V

Figure 18 summarizes the results of the figure 11, 14 and 15. From this figure, it can be seen that the active power output of the solar inverter increases linearly with the solar irradiance. This active power is less than the power input from solar PV because of the losses that incur in the solar inverter. The power input from the solar PV varies in direct proportion to the irradiance as the MPPT controller adjust the duty cycle of the DC to DC converter switch in such a way that leads to maximum power for all the irradiance values. The efficiency of the grid connected solar inverter is calculated as 85 % for the irradiance range of 700 to 1000 W/m^2 .

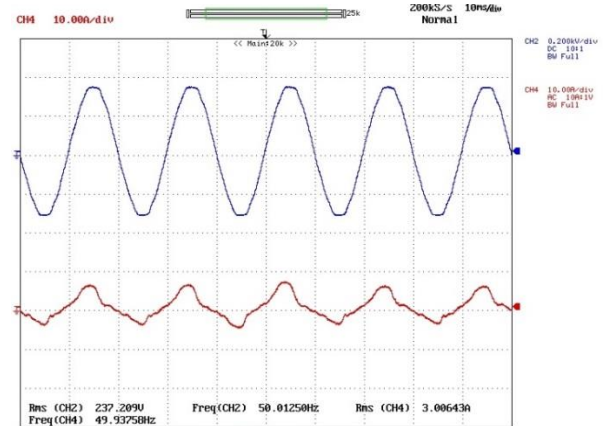


Fig. 16. Experimental results on the grid for solar irradiance of 200 W/m^2 , Blue – grid voltage 200 V/div; Red – current fed to grid 10 A/div

Switching frequency of the inverter switches is kept as 20 kHz. To avoid short circuit in one of the inverter leg a dead band of $1 \mu\text{s}$ is implemented. Switching frequency and dead band is shown in figure 19 and figure 20 respectively.

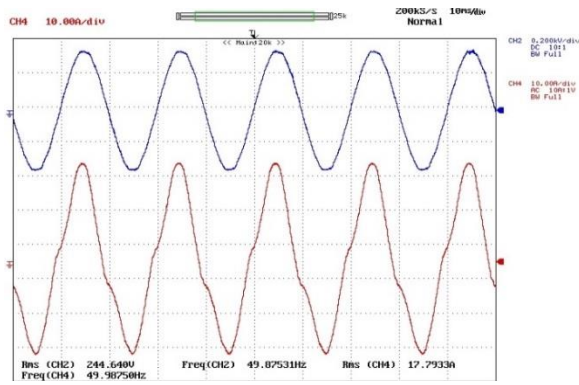


Fig. 17. Experimental results on the grid for solar irradiance of 1000 W/m², Blue – grid voltage 200 V/div; Red – current fed to grid 10 A/div

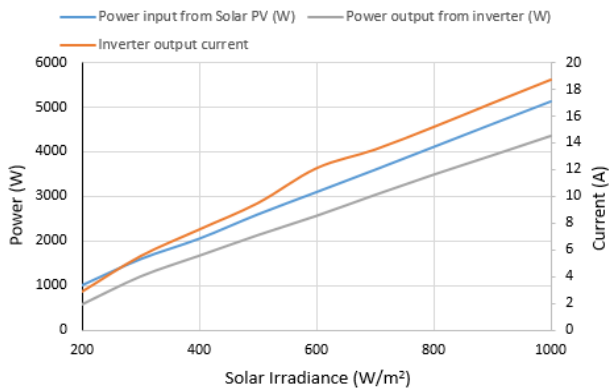


Fig. 18. Experimental result showing power input from Solar PV, power output from inverter and inverter output current as a function of solar irradiance

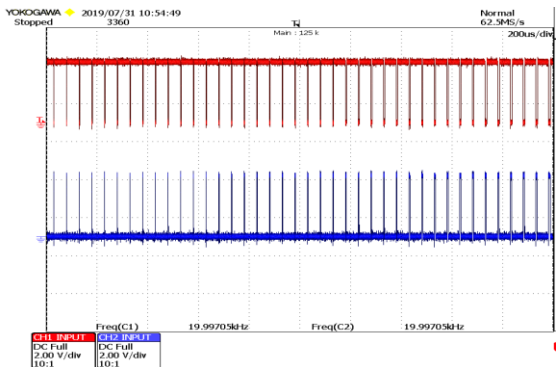


Fig. 19. Switching frequency (20 kHz) of the inverter switches

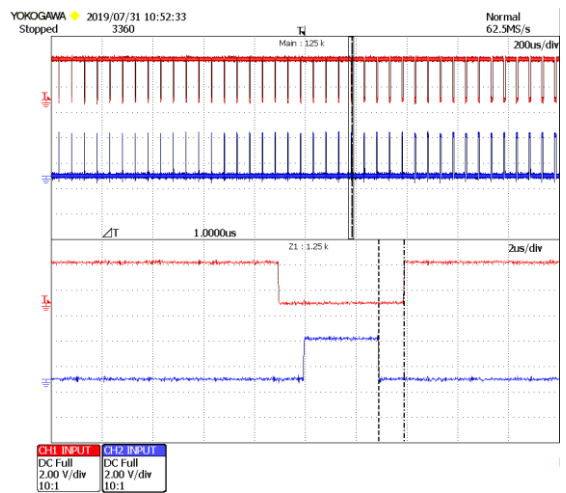


Fig. 20. waveform showing the dead band of 1 μ s.

V. CONCLUSION

In this paper, a single phase dual stage grid connected solar inverter is presented. All the control blocks of the inverter are explained. MPPT method has been implemented using P&O algorithm, grid synchronization using cascaded – SOGI and current control using digital PI control. Cascaded second order generalized integrator method used for grid synchronization shows better DC rejection capability than second order generalized integrator. Experimentation with the developed hardware model of the system demonstrated that the single phase dual stage grid connected solar inverter is able to pump the solar PV panel generation into the grid for all solar irradiance levels.

REFERENCES

- [1] Miss Sangita R. Nandurkar, Mrs. Mini Ranjeev, "Design and simulation of three phase inverter for grid connected photovoltaic system" Proceedings of Third Biennial National Conference, NCNTE – 2012, Feb 24-25, pp.80–83.
- [2] T. Tafticht and K. Agbossou, "Development of a MPPT method for photovoltaic systems," in Canadian Conf. Elect. Comput. Eng., 2004, pp. 1123–1126.
- [3] A. Kulkarni and V. John, "Design of a fast response time single-phase PLL and DC offset rejection capability", Applied Power Electronics Conference and Exposition (APEC), Mar. 2016.
- [4] M. Ciobotaru, R. Teoderescu, and F. Blaabjerg, "A new single-phase PLL structure based on second order generalized integrator," in Proc. 37th IEEE PESC, Jun. 2006.