PERFORMANCE ANALYSIS OF GRID INTEGRATED PHOTO-VOLTAIC SYSTEMS USING MARX MULTILEVEL INVERTER IN DIFFERENT ENVIRONMENTAL CONDITIONS

L. M. KRISHNA[1], J. N. CHANDRA SEKHAR[2], M. NARESH[3], P. SAMUEL[4]

In this paper is to performance the analysis of grid integrated the solar photovoltaic system by using Marx multilevel inverter in different environmental conditions. In multilevel inverters, there are three basic types of topologies used, commonly diode clamped inverter (neutral point clamped), capacitor clamped (flying capacitor) and cascaded H-bridge inverter. Among this all inverters, the Marx multilevel inverter gives better performance of low voltage and current THD. The number of voltage levels is arbitrarily chosen in Marx multilevel inverter, without using of transformer the output voltage of the inverter can reach high level. In addition, due to the step characteristic, the output voltage can be almost sinusoidal which results decrease the size and cost of the filter. The control modulation method for the grid integration of Marx multilevel inverter has been chosen and implemented. Finally, the topologies are implemented using MATLAB.

Keywords: Total harmonic distortion (THD), Direct Current (DC), Phase locked loop (PLL), proportional integral (PI) controller, pulse width modulation (PWM), phase disposition Modulation (PDM) method

1. Introduction

Nowadays the demand of renewable energy resources is increasing day by day. The renewable energy resources are available abundantly in nature, based on the availability the efficient renewable energy resource is solar energy, photovoltaic power is generated from different levels of solar radiation and temperature [1]-[3]. To extract maximum power from PV system, the Perturbation and Observation (P&O) method is used. The PV system is connected to the boost converter for getting stepped up voltage from the solar panels. The generated

[1] Student, Dept. of Electrical Engineering, MNNIT Allahabad, INDIA. e-mail: mohakrishnalingam@gmail.com
[2] Assistant Professor, Dept. of Electrical and Electronics Engineering, SVUCE, Tirupati, INDIA. e-mail: chandu.jinka@gmail.com
[3] Research Scholar, Dept. of Electrical Engineering, MNNIT Allahabad, INDIA. e-mail: naresh219.m@gmail.com
[4] Associate Professor, Dept. of Electrical Engineering, MNNIT Allahabad, INDIA. e-mail: paul@mnnit.ac.in

switching pulses from the P&O MPPT technique is given to the boost converter [4]. After survey of different multilevel inverter like diode-clamped inverter (neutral-point clamped), capacitor-clamped (flying capacitor), and cascaded multilevel inverter [5]. The Marx multilevel inverter is seen as the most suitable topology for the integration of the renewable energy, which comes from photovoltaic modules i.e. the Marx multilevel inverter can integrate DC energy source as it is conferred with many desirability's. Besides this, to mitigate the swing in the output of renewable energy sources mainly photo voltaic energy, it is necessary to incorporate diverse energy storages into system. Furthermore, with the provision of choosing the DC sources whimsically, it is advantageous to achieve the increased levels of output voltage and output power. The Marx multilevel inverter is suitable for the grid integration requirements because it is current THD was low [6]-[7] and it gives most suitable output voltage. The grid synchronization was implemented by using phase-locked loop (PLL) [7], the controlling pulses for inverter are produced using phase disposition technique by tuning of PI controller. For validation of total grid integrated system, simulation results are presented in this paper. Section- 5 contains grid synchronizing technique of single-phase inverter, the closed loop control of Marx Multilevel inverter. This control technique mainly concentrates on synchronizing the grid voltage with inverter voltage by tuning the PI Controller values. Section-6 contains detailed explanation about the simulation results. Next sections consist of overall conclusion of the paper and finally references taken for this paper are included. In Fig.1.the block diagram represents the grid connected Marx multilevel inverter with varying of different levels of temperature and irradiance of solar module, for the extraction of maximum power from solar module the MPPT i.e. Perturbation and Observation (P&O) method was used, the output of photovoltaic system is connected by a DC-DC Boost converter, the pulses for converter are generated from the MPPT method. The output of boost converter was connected to the input of Marx Multilevel inverter, the output of Marx Multilevel inverter was connected to grid without using the transformer because inverter output voltage was stepped up to two times the input voltage of inverter. The control signals for Marx Multilevel inverter are generated using PLL, the inputs of PLL given from sensing the grid voltage and current, the output of PLL i.e. sin wave is compared by reference current and voltage. The generated error signal was given to the PI controller. The generation pulse width modulation is comparison with the output of the PI controller and triangular wave [7] given to the Marx Multilevel inverter. The generated pulses given to the Marx Multilevel inverter by comparison of the output of PI controller and triangular wave. Finally, power flow is observed from both grid side and inverter side.

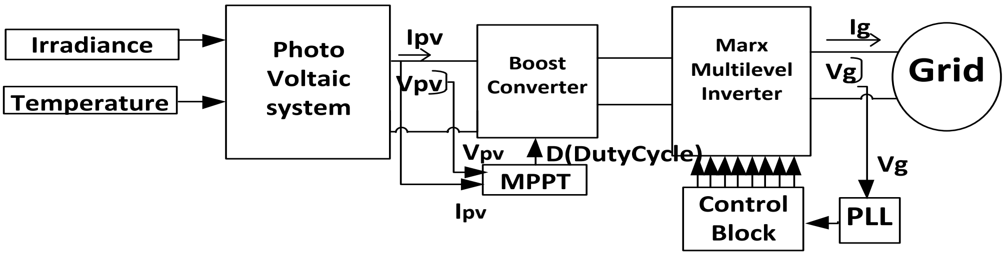


Fig. 1. Block diagram of Grid integration of Marx multilevel inverter

2. Modeling and Analysis of Photo Voltaic System

A. Modeling of PV Cell and Array

The photovoltaic system equivalent circuit was shown in Fig.2. An ideal structure of solar cell not only consists of diode and also having one series and shunt resistance. Where the series resistance is Rs and shunt resistance Rsh. Practically the value of Rs is very small compare to the shunt resistance Rsh [2].

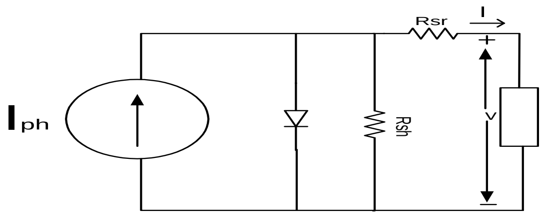


Fig.2. Equivalent Circuit Model of PV Cell

A solar cell is basically a current source the current produced by solar cell was represented by the euqtion.1.

$$I = I_{ph} - I_0 \left[\exp - \left(\frac{q(V + IR_{sh})}{nkt} \right) - 1 \right] - \frac{V + IR_{sh}}{R_{sh}} \tag{1}$$

Where q is the electronic charge (q = 1.602 × 10−19 C), k is the Boltzmann constant (k = 1.3806503 × 10−23 J/K), n is the ideality factor or the ideal constant of the diode,T is the temperature of the cell in Kelvin, I0 is the diode saturation current or cell reverse saturation current, Rsris the series equivalent resistance, Rsh represents the shunt resistance.

B. Maximum power point tracking

In this paper perturbation and observation method is implemented for tracing maximum power from solar PV array.

The MPPT is implemented for extracting of maximum power from solar panel at different levels of solar irradiance and temperature. Among from all MPPT techniques, Perturbation and observation method was used because it is simple, easy to understand and fast approaching [4]. Fig. 3 represents P&O algorithm for maximum power point technique.

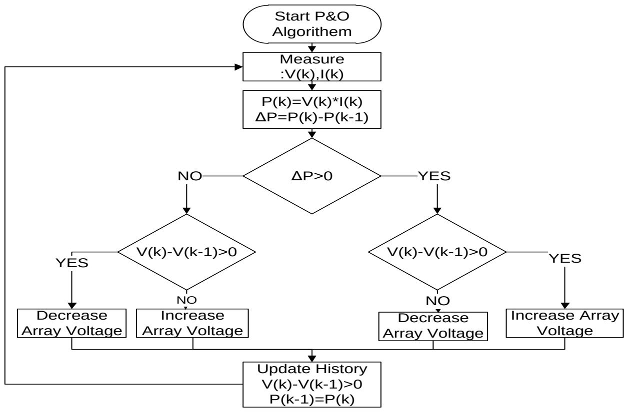


Fig. 3. P&O Algorithm of MPPT

3. DC-DC Boost Converter

The boost converter is represented in Fig. 4. It consists of one voltage source (Vdc), inductor (L), switch (SW), diode (D), capacitor (C) and load (R). The output voltage Vo= Vdc/(1-d) [4], where duty cycle (D) and Vdc is the input voltage. In this paper pulse generated from MPPT technique given to the switch of boost converter

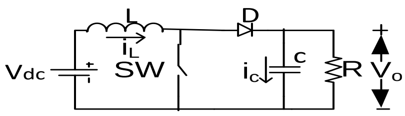
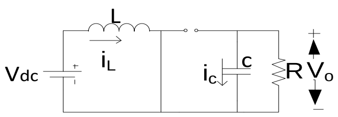
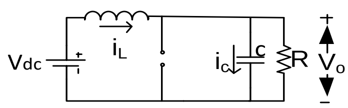


Fig. 4. DC-DC Boost Converter

When Switch (SW) is ON, the equivalent circuit as follows



When Switch is ON



When Switch is OFF

The output voltage across Boost Converter is $V_0 = 0$ V. When Switch (SW) is OFF, the output voltage across Boost Converter is $v_0 = V_{dc}$.

4. Marx multilevel inverter

The Marx inverter consists of ten power electronic switches (commonly implemented with an insulated gate bipolar transistor, or IGBT). As shown in

Fig.10, the top bridge connects to the positive terminal and Bottom Bridge connects the negative terminal. The switching pattern and topology vary depending on the application. In most applications, the single-phase inverters are controlled in current-regulated pulse width modulation (PWM) mode [8]-[9]. This modulation technique uses phase disposition technique used for generation of pulses to the switches. The operation of Marx multilevel inverter is described here. During positive half cycle of output voltage, the inverter circuit shown in Fig. 5 works in half bridge mode (Fig. 6a).

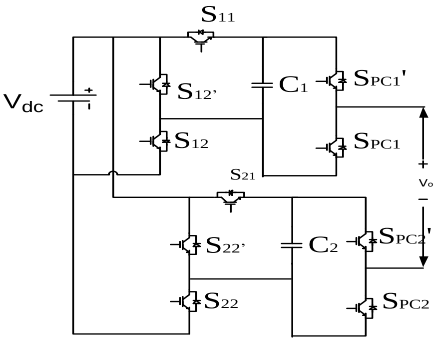
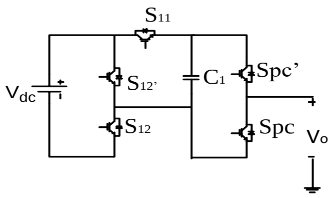
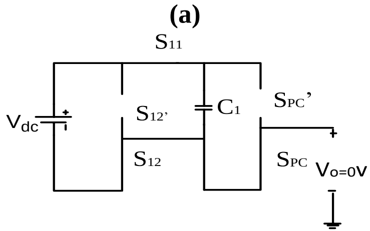


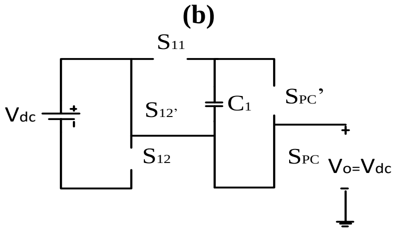
Fig. 5. Marx Multilevel Inverter



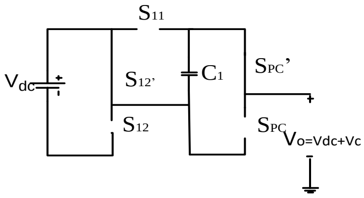
(a)



(b)



(c)



(d)

Fig. 6. Operation of single phase five level Marx multilevel inverter during positive half cycle (a) Three phase Marx Multilevel inverter (b) equivalent circuit when inverter produces V0 = 0 (c) equivalent circuit when inverter produces V0 = Vdc (d) equivalent circuit when inverter produces V0 = Vdc + Vc

In Fig. 6a, when S11, S12 and Spc are ON, the equivalent circuit obtained is shown in Fig. 6b. The output voltage across inverter Vo = 0.

When S12' and Spc are ON, the equivalent circuit obtained is shown in Fig. 6c. The output voltage across inverter Vo = Vdc.

When S12' and Spc' are ON, the equivalent circuit obtained is shown in Fig. 6d. The output voltage across inverter Vo = Vdc + Vc.

Similar operation occurs during the negative half cycle of inverter output voltage.

5. Grid Synchronization Techniques for Single Phase System

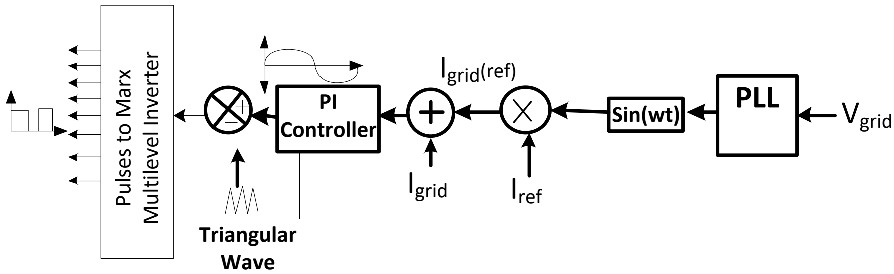


Fig. 7. Closed loop control of Marx Multilevel Inverter

Vgrid taken from the grid side and it is given to the PLL, PLL gives the sin(wt), the sinusoidal wave is multiplied by Iref current which gives Igrid(ref). By the addition of Igrid current with Igrid(ref) an error signal is produced. This error signal is given to the PI controller. The PI controller tuned with values of Kp = 0.005 and Kd = 0.034 will produce reference signal. For the production of pulses to the Marx multilevel inverter, this reference signal is compared with triangular wave using phase disposition method. This ensures that grid current (Igrid) is in phase with grid voltage (V grid) and always at nearly unity power factor.

6. Simulation Results

Results are explained in three cases each case having a constant temperature with three different irradiances are taken as a inputs of solar panel and observed all the outputs (solar current, solar voltage, closed loop reference current and power from grid side and inverter side, boost converter output and Marx inverter output), finally all outputs all examined inductively in different environmental conditions.

1. ***Waveforms when temperature at 20^0Cand irradiance at 600 W/m^2, 800 W/ m^2, 1000 W/ m^2***

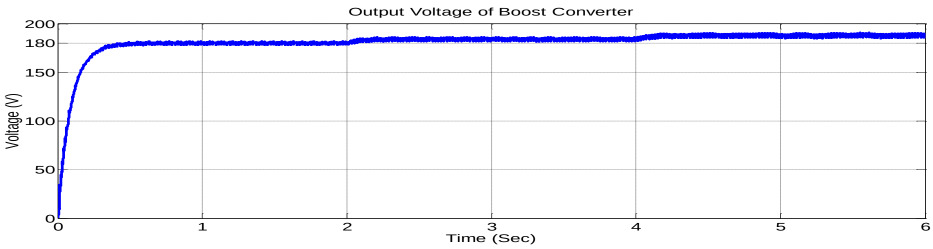


Fig. 8 Output Voltage Generated by boost Converter when temperature at 200C and irradiance at 600 W/m2, 800 W/ m2, 1000 W/ m2

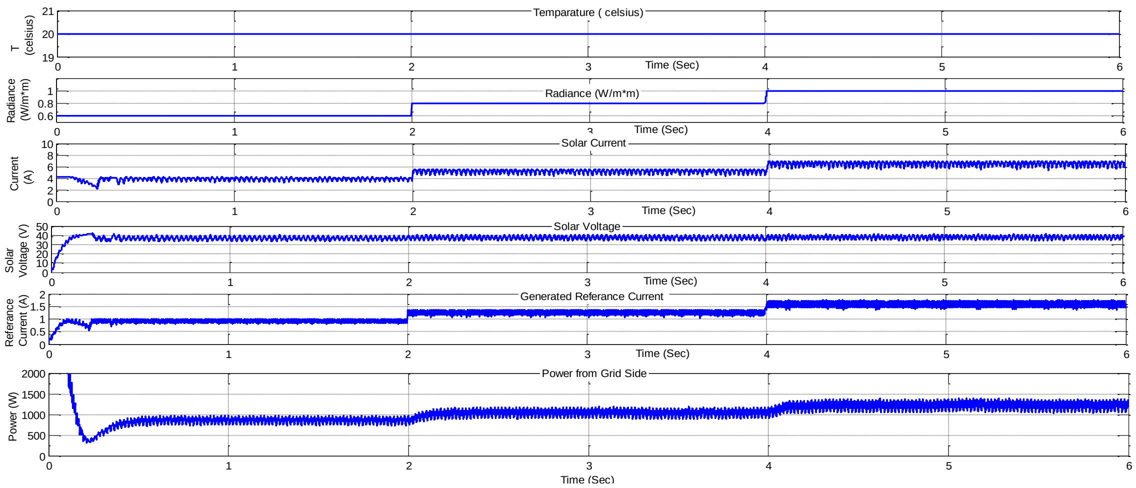


Fig.9 Temperature, irradiance, solar PV current, solar PV voltage, closed loop reference current and power from grid side when temperature at 200C and irradiance at 600 W/m2, 800 W/ m2, 1000 W/ m2

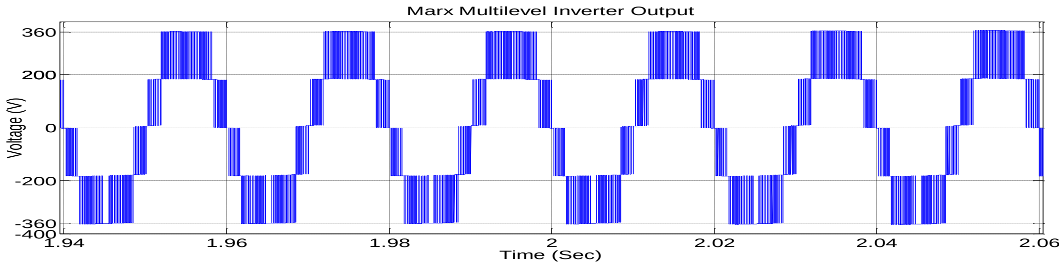


Fig. 10. Marx multilevel inverter maximized output voltage waveform when temperature at 200C and irradiance at 600 W/m2, 800 W/ m2, 1000 W/ m2

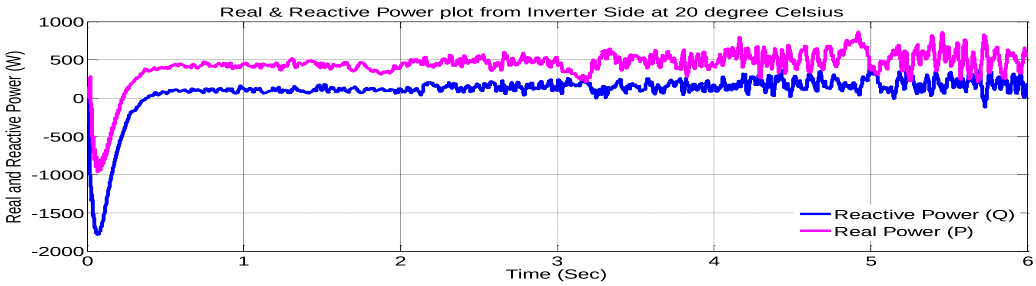


Fig.11. Real and reactive power change in inverter side when temperature at 200C and irradiance at 600 W/m2, 800 W/ m2, 1000 W/ m2

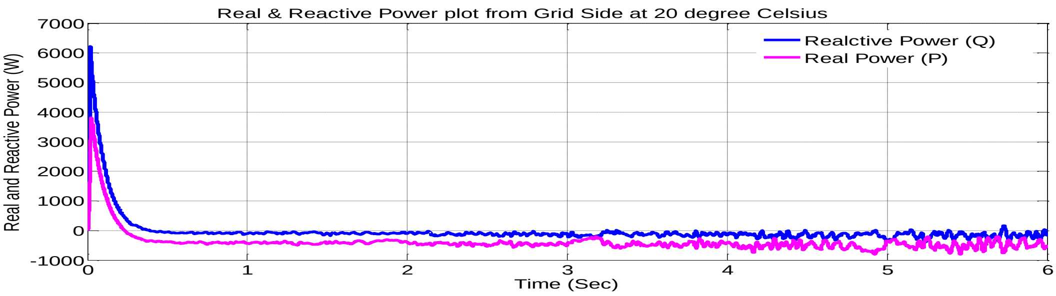


Fig.12. Real and reactive power change in grid side when temperature at 200C and irradiance at 600 W/m2, 800 W/ m2, 1000 W/ m2

2. *Waveforms when temperature at 25^{0}C and irradiance at 600 W/m^2, 800 W/ m^2, 1000 W/ m^2*

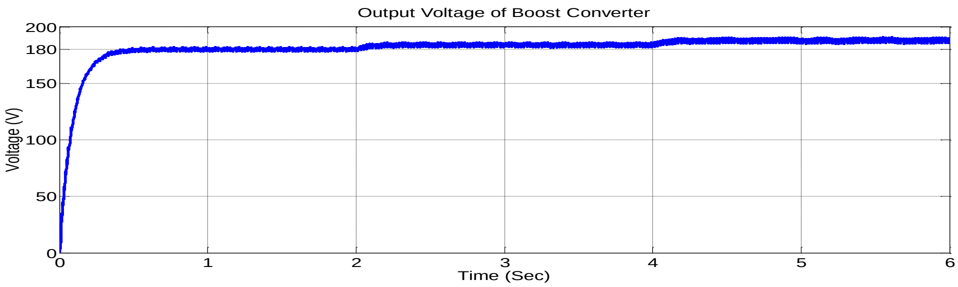


Fig. 13. Output Voltage Generated by boost Converter when temperature at 250C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

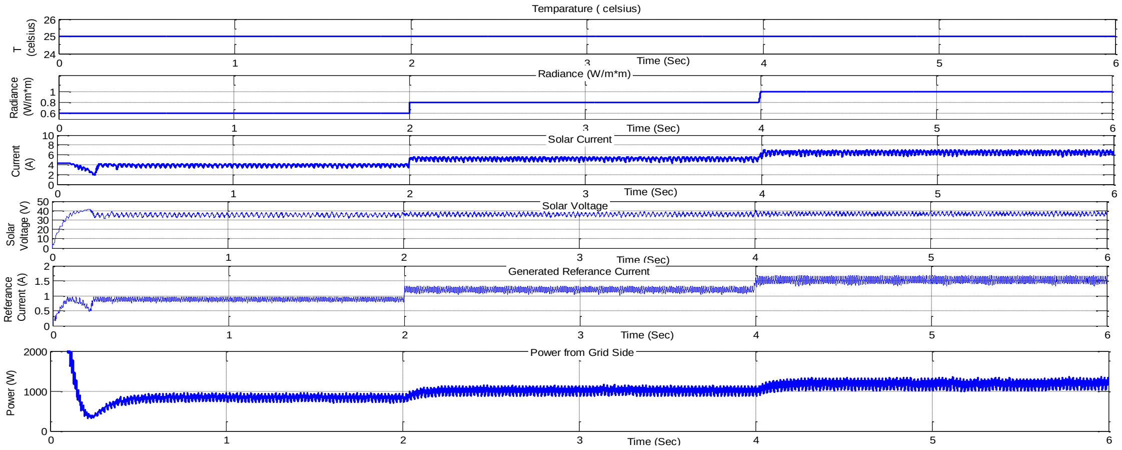


Fig.14. Temperature, irradiance, solar PV current, solar PV voltage, closed loop reference current and power from grid side when temperature at 250C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

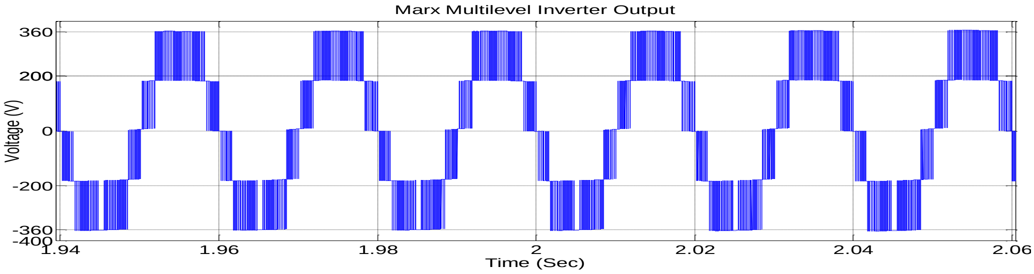


Fig. 15. Marx multilevel inverter maximized output voltage waveform when temperature at 250C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

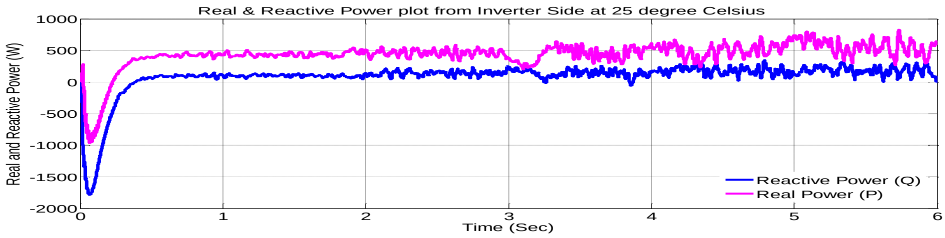


Fig.16. Real and reactive power change in inverter side when temperature at 250C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

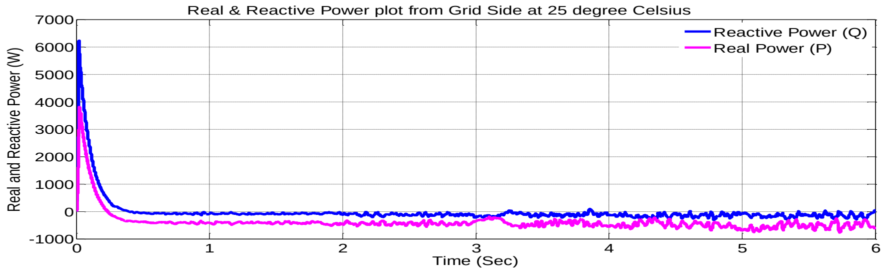


Fig.17 Real and reactive power change in grid side when temperature at 250C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

A. *Waveforms when temperature at 35^0C and irradiance at 600 W/m^2, 800 W/ m^2, 1000 W/ m^2*

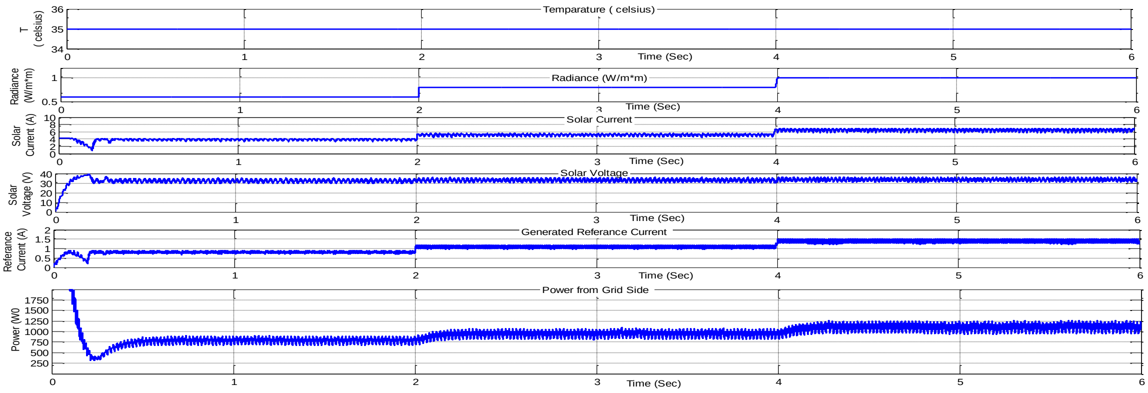


Fig.18. Temperature, irradiance, solar PV current, solar PV voltage, closed loop reference current and power from grid side when temperature at 350C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

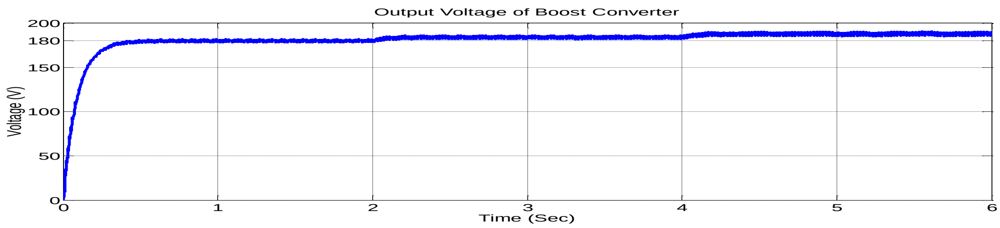


Fig. 19. Output Voltage Generated by boost Converter when temperature at 350C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

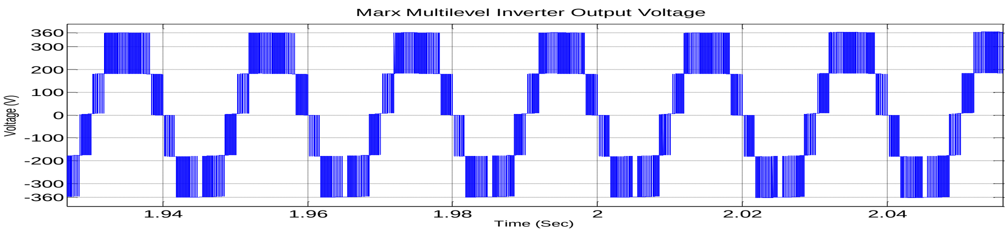


Fig. 20. Marx multilevel inverter maximized output voltage waveform when temperature at 350C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

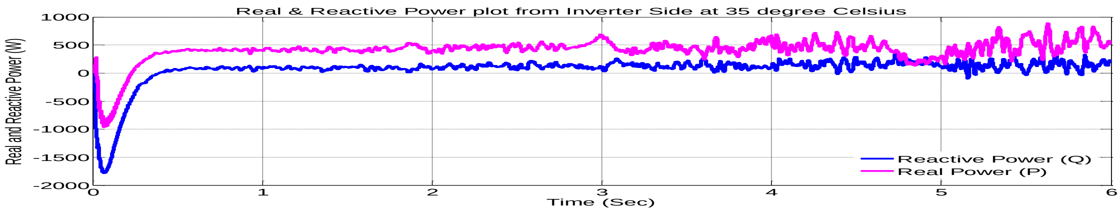


Fig. 21. Real and reactive power change in inverter side when temperature at 350C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

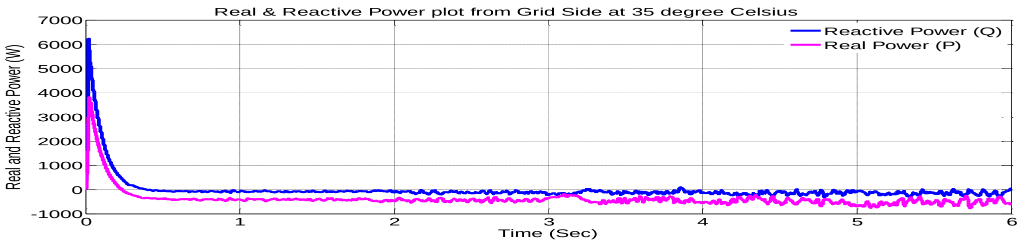


Fig.22. Real and reactive power change in grid side when temperature at 350C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

In all these cases after grid integration of Marx multi-level inverter the grid voltage and current are is in phase with each other (Fig. 23), whose power factor is nearly unity.

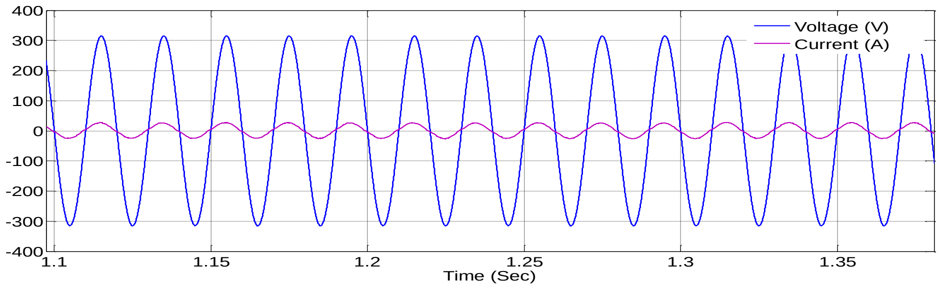


Fig. 23. Grid Voltage and current waveform when temperature at 350C and irradiance at 600 W/ m2, 800 W/ m2, 1000 W/ m2

In below these plots are plotted to observe the changes of PV current, PV Voltage, PV Power, Reference current and Grid side power of grid connected Marx multilevel inverter in various environmental conditions, the reference current is generated in the closed loop control of Marx inverter. Table 1 and Fig. 24 shows that variation of solar current with respect to temperature and irradiance.

Table.1.

Solar PV current changes w.r.to irradiance (R) and temperature

Solar PV current	R= 600 W/ m^2	R= 800 W/ m^2	R= 1000 W/ m^2
T=20^0 C	4A	5.2A	6.3A
T=25^0 C	4.1A	5.6A	6.7A
T=35^0 C	4.2A	5.8A	6.9A

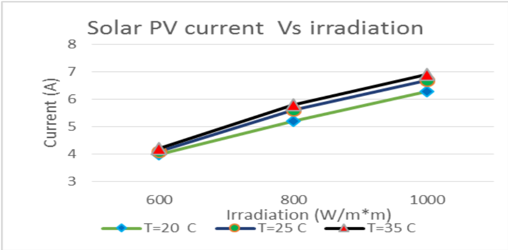


Fig.24 Solar PV current changes w.r.to irradiance and temperature

Table 2 and Fig. 25 show that variation of solar PV voltage with respect to temperature and irradiance.

Table.2.

Solar voltage (V) changes w.r.to irradiance (R) and temperature (T)

Solar PV voltage	R=600 W/ m^2	R=800 W/ m^2	R= 1000 W/ m^2
T=20^0 C	38.9V	39V	39.2V
T=25^0 C	32.9V	33.1V	33.3V
T=35^0 C	31.5V	31.6V	31.9V

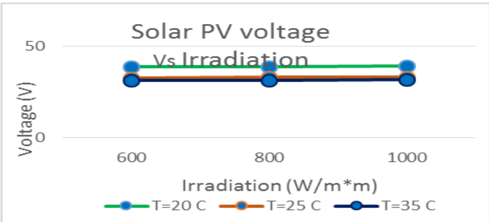


Fig.25. Solar voltage changes w.r.to irradiance and temperature

Table 3 and Fig.26. Show that variation of solar power with respect to temperature and irradiance.

Table.3.

Solar PV power changes w.r.to irradiance (R) and temperature (T)

Solar PV power	irradiance = 600 W/ m^2	irradiance = 800 W/ m^2	irradiance == 1000 W/ m^2
T=20^0 C	150W	200W	250W
T=25^0 C	140W	190W	240W
T=35^0 C	130W	180W	230W

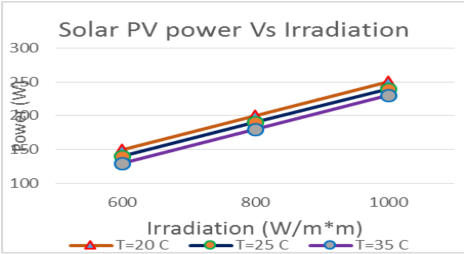


Fig.26. Solar PV power changes w.r.to irradiance and temperature

Table 5 and Fig.27 show that variation of grid side power (V grid (rms) * I grid (rms)) with respect to temperature and irradiance.

Table .5.

Grid side power (V grid (rms) * I grid (rms)) changes w.r.to irradiance and temperature

Grid side power	irradiance = 600 W/m^2	irradiance = 800 W/m^2	irradiance = 1000 W/m^2
T=20^0 C	980W	1180W	1380W
T=25^0 C	900W	1100W	1300W
T=35^0 C	860W	1060W	1260W

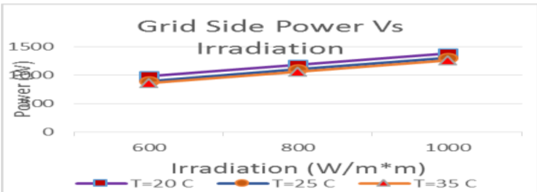


Fig.27. Grid side power changes w.r.to irradiance and temperature

7. Conclusion

This paper explains the grid integration of Photo Voltaic System using Marx multilevel inverter in different environmental conditions. The P&O MPPT method was used for switching pulse to the Boost Converter from PV panel and grid integration was done by using PLL with closed loop control strategy of Phase Disposition (PD) method. Methodology for designing the controller was developed by PI parameters, which are being obtained by tuning in MATLAB. Also, unity power factor between grid voltage and current has been achieved. Finally, the changes in PV current, PV Voltage, PV Power and Grid side power are observed in different environmental conditions, it is clear that the Marx multilevel inverter is suitable of the grid integration to extract maximum output from the PV system.

R E F E R E N C E S

[1] T. Esram and P. L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," in IEEE Transactions on Energy Conversion, vol. 22, no. 2, pp. 439-449, June 2007.

[2] P. I. Muoka, M. E. Haque, A. Gargoom and M. Negnevitsky, "Modeling, simulation and hardware implementation of a PV power plant in a distributed energy generation system," Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES, Washington, DC, 2013

[3] Subudhi and R. Pradhan, "A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems," in IEEE Transactions on Sustainable Energy, vol. 4, no. 1, pp. 89-98, Jan. 2013.

[4] Noman, K. E. Addoweesh and H. M. Mashaly, "Simulation and dSPACE hardware implementation of the MPPT techniques using buck boost converter," Electrical and Computer Engineering (CCECE), 2014 IEEE 27th Canadian Conference on, Toronto, ON, 2014.

[5] L.M.krishna J.N Chandra Sekhar, A.Srinivsulu and G.P.Ranga Reddy " Improved Dynamic Performance of a Multilevel Inverter fed Variable Speed Drive using ANFIS and Genetic Algorithms",Journal of Automation & Systems Engineering (JASE 2017)11-4 (2017): 324-336.

[6] P. Kant, A. Ahmad and P. Samuel, "Analysis and implementation of multicarrier modulation techniques for Marx multilevel inverter," Environment and Electrical Engineering (EEEIC), 2015 IEEE 15th International Conference on, Rome, 2015.

[7] L.M.krishna and P. Samuel, "Grid integration of PV system using Marx multilevel inverter," 2016 IEEE Uttar Pradesh Section International Conference on Electrical, Computer and Electronics Engineering (UPCON), Varanasi, India, 2016.

[8] J. I. Rodriguez and S. B. Leeb, "A Multilevel Inverter Topology for Inductively Coupled Power Transfer," in IEEE Transactions on Power Electronics, vol. 21, no. 6, pp. 1607-1617, Nov. 2006.

[9] João P. S. Catalão (editor) - Smart and Sustainable Power Systems: Operations, Planning, and Economics of Insular Electricity Grids, 2015, CRC Pres, ISBN 9781498712125

[10] J. M. Carrasco et al., "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey," in IEEE Transactions on Industrial Electronics, vol. 53, no. 4, pp. 1002-1016, June 2006.

[11] G. Chicco, F. Corona, R. Porumb, F. Spertino, Experimental indicators of current unbalance in building-integrated photovoltaic systems, IEEE Journal of Photovoltaics, Vol.4, Issue 3, May 2014, pp.924-934, DOI: 10.1109/ JPHOTOV.2014.2307491

[12] F. Zhang, J. Hui and L. Wu, "Design of single phase photovoltaic grid-connected inverter based on DSP&ARM," 2014 International Power Electronics and Application Conference and Exposition, Shanghai, 2014.

[13] O. Ceaki, R. Vatu, N. Golovanov, R. Porumb, G. Seritan, Analysis of the grid-connected PV plants behavior with FACTS influence, 49th International Universities Power Engineering Conference (UPEC), 2-5 Sept. 2014, Cluj-Napoca, Romania, DOI: 10.1109/UPEC.2014.6934822