Simulation Model of a Three Phase Multilevel Inverter for a Grid Connected Photovoltaic System

Ruchi Mishra
Electrical Engineering Dept.
Rama University, Kanpur
tripathiruchi20@gmail.com

Gaurav Mishra
Electrical Engineering Dept.
M.P.E.C., Kanpur
gaurav7859@gmail.com

Abstract: **This paper presents a novel approach for the connection of renewable energy sources to the utility grid. Due to the increasing power capability of the available generation systems, a three-level three-phase neutral-point-clamped voltage-source inverter is selected as the heart of the interfacing system. Solar Energy is one of the favorable renewable energy resources and the multilevel inverter has been proven to be one of the important enabling technologies in photovoltaic (PV) utilization. The inverter is capable of producing multilevel of output voltage from the dc supply voltage. With multilevel inverters harmonic content gets reduced and with more levels the output approaches the sine wave. The voltage stress also gets reduced. This work presents simulation of three phase multilevel inverter for standalone applications. Multilevel voltage source inverters offer several advantages compared to their conventional counterparts. By synthesizing the AC output terminal voltage from several levels of voltages, staircase waveforms can be produced, which approach the sinusoidal waveform with low harmonic distortion, thus reducing filter requirements. The need of several sources on the DC side of the converter makes multilevel technology attractive for photovoltaic applications.**

Keywords: Photovoltaic Technology, Multilevel Inverters, Simulation models of Photovoltaic Systems & Simulation models of Multilevel Inverter

I. INTRODUCTION

In this paper, new trends in power-electronic technology for the integration of renewable energy sources and energy-storage systems are presented. The power-conditioning systems used in grid-connected photovoltaic (PV) generation plants. The continuously decreasing prices for the PV modules lead to the increasing importance of cost reduction of the specific PV converters. Energy storage in an electricity generation and supply system enables the decoupling of electricity generation from demand.

For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations. A multilevel converter not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel converter system for a high power application.[3]

II. PHOTOVOLTAICS TECHNOLOGY

The wide spread use of PV generation is however mainly hampered by economic factors. Efforts are being made worldwide to reduce the cost/watt through various technological innovations. The advantages of photovoltaic technologies are as follows:

1. Absence of moving part
2. Ability to function unattended for long periods
3. Long effective life and high reliability

Figure 1 shows the basic PV cell structure. Metallic contacts are provided on both sides of the junction to collect electrical current induced by the impinging photons. A thin conducting mesh of silver fibers on the top surface collects the current and lets the light through.

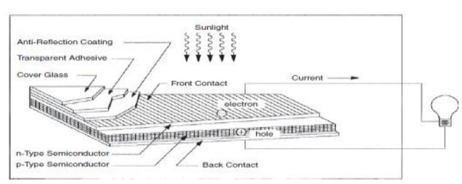
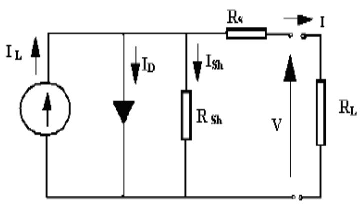


Fig. 1 Basic structure of a generic silicon PV cell

A. Equivalent electrical circuit of PV Cell

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in Figure 2. The current *I* at the output terminals is equal to the light-generated current *IL*, less the diode current I_D and the shunt-leakage current I_{sh} **.** The series resistance R_s represents the internal resistance to the current flow, and depends on the p-n junction depth, impurities, and contact resistance. The shunt resistance R_{sh} is inversely related to the leakage current to the ground. In an ideal PV cell $R_s = 0$ and $R_{sh} = \infty$



.

Fig. 2 PV cell equivalent electrical circuit

The open-circuit voltage V_{oc} of the cell is obtained when the load current is zero and is given by the following:[2]

$$V_{oc} = (I_L - I_D)\, R_{sh}$$

The diode current is given by the classical diode current expression:

$$I_D = I_o[\exp\left(\frac{qV_{oc}}{AKT}\right) - 1]$$

Where,
I_o is the saturation current of the diode (A),
q is electron charge (1.6×10^{-19} C),
A is curve-fitting constant,
K is Boltzmann constant (1.38×10^{-23} J/°K),
T is temperature on absolute scale °K.
Thus, the load current is given by the expression:

$$I = I_L - I_D - I_{sh}$$

$$I = I_L - I_o\left[\exp\left(\frac{qV_{oc}}{AKT}\right) - 1\right] - \frac{V_{oc}}{R_{sh}}$$

The last term is the leakage current to the ground. In practical cells, it is negligible compared to I_L and I_o and is generally ignored.

Again by ignoring the ground leakage current, above equation with I give the open-circuit voltage as follows:

$$V_{oc} = \frac{AKT}{q} \ln\left(\frac{I_L}{I_D} + 1\right)$$

B. Current-Voltage and Power-Voltage curves

The figure 3 depicts the I-V curve of typical PV cell. This curve shows the variation of current and voltage when cell resistance varies from zero to infinity.

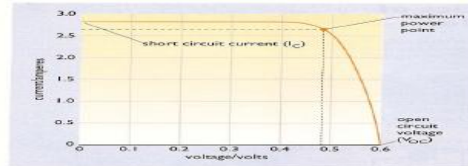


Fig. 3: I-V Curve of a typical silicon PV

In Figure 4, the power is plotted against the voltage which is P-V curve of the PV cell.

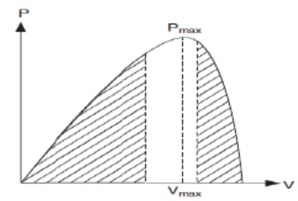


Fig. 4: P-V characteristic of the PV cell

Finally in order to measure the photovoltaic cells output power the following standard test conditions are established internationally. The irradiance level is 1000 W/m², with the reference air mass 1.5 solar spectral irradiance distributions and cell or module junction temperature of 25°C.

III. MULTILEVEL INVERTER

The elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple dc voltage sources.

A. Advantages and disadvantages

The attractive features of a multilevel converter can be briefly summarized as follows.

- Multilevel converters can generate the output voltages with very low distortion and also reduces the dv/dt stresses so electromagnetic compatibility (EMC) problems can be reduced.
- Multilevel converters produce smaller common mode voltage; therefore, the stress in the bearings of a motor connected to a multilevel motor drive can be reduced.
- Multilevel converters can draw input current with low distortion.

The disadvantage of multilevel converters is the greater number of power semiconductor switches needed. Although lower voltage rated switches can be utilized in a multilevel converter, each switch requires a related gate drive circuit. This may cause the overall system to be more expensive and complex.

a) Basic Multi-Level Inverter Structures

There are various types of structure as Cascaded H Bridge, Diode Clamped and Flying Capacitor structures.

i) Cascaded H-Bridges

A single-phase structure of an m-level cascaded inverter is illustrated in Figure 5. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0 and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches S_1, S_2,S_3 and S_4.

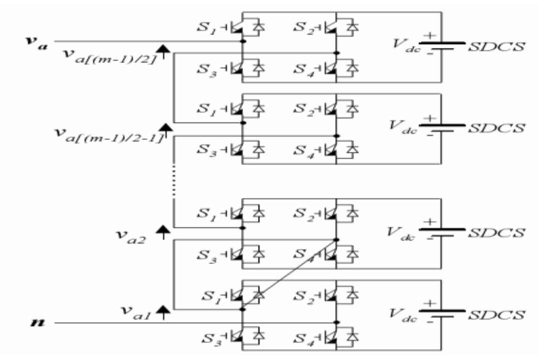


Fig. 5: Single-phase structure of a multilevel cascaded H-bridges inverter

Cascaded inverters are ideal for connecting renewable energy sources with an ac grid, because of the need for separate dc sources, which is the case in applications such as photovoltaic or fuel cells.

The main advantages and disadvantages of multilevel cascaded H-bridge converters are as follows:

The **advantages** are as follows:

- The number of possible output voltage levels is more than twice the number of dc sources (m = 2s + 1).
- Compared with the diode clamped and flying capacitors inverters, it requires the least number of components to achieve the same number of voltage levels.
- Soft switching techniques can be used to reduce switching losses and device stresses.

The disadvantage is that the separate dc sources are required for each of the H-bridges. This will limit its application to products that already have multiple SDCSs readily available.

ii) Diode-Clamped Inverter

The diode-clamped inverter provides multiple voltage levels through connection of the phases to a series bank of capacitors. According to the original invention, the concept can be extended to any number of levels by increasing the number of capacitors. Due to capacitor voltage balancing issues, the diode-clamped inverter implementation has been mostly limited to the three-level. [17]

The **major advantages** of the diode-clamped inverter can be summarized as follows:

- When the number of levels is high enough, the harmonics content is low enough to avoid the need for filters.
- Inverter efficiency is high because all devices are switched at the fundamental frequency.
- The control method is simple.

The **major disadvantages** of the diode-clamped inverter can be summarized as follows:

- Excessive clamping diodes are required when the number of level is high.
- It is difficult to control the real power flow of the individual converter systems.

Figure 6 shows the topology of the three-level diode-clamped inverter.

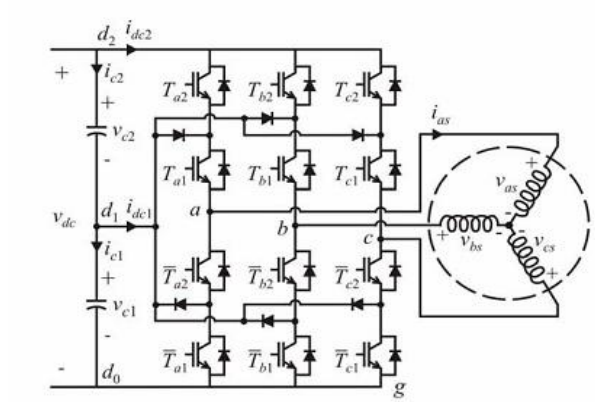


Fig. 6: 3 level Diode clamped inverter topology

iii) Flying capacitor structure

Another fundamental multilevel topology, the flying capacitor, involves series connection of capacitor clamped switching cells. This topology has several unique and attractive features when compared to the diode-clamped inverter. One feature is that added clamping diodes are not needed.

Furthermore, the flying capacitor inverter has switching redundancy within the phase which can be used to balance the flying capacitors so that only one dc source is needed.[18]

The **major advantages** of the flying capacitors inverter can be summarized as follows:

- Large amounts frequency storage capacitors can provide capabilities during power outages.
- These inverters provide switch combinations redundancy for balancing different voltage levels.
- Like the diode clamp inverter with more level, the harmonic content is low enough to avoid the need for filters.
- Both real and reactive power flow can be controlled.

The **major disadvantages** of the flying capacitors inverter can be summarized as follows:

- An excessive number of storage capacitors is required when the number of levels is high.
- The inverter control can be very complicated, and the switching frequency and switching losses are high for real power transmission.

Figure 7 shows the three-level flying capacitor inverter.

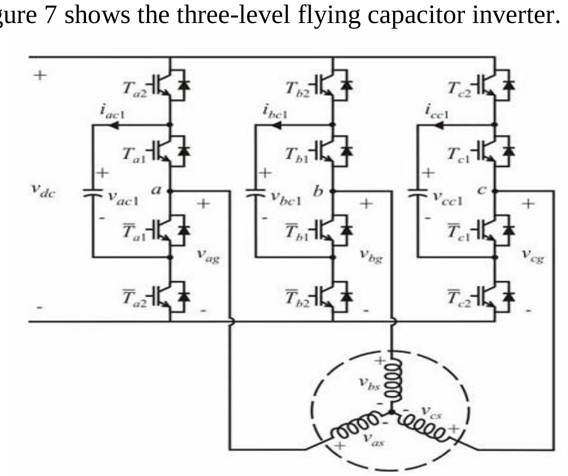


Fig. 7: Three level flying capacitor topology

IV. MATLAB SIMULATION MODELS

The simulation models of the three phase three level inverter, photo voltaic system & grid have been developed using MATLAB and its Sim Power System BLOCKSET in SIMULINK. Simulation results are obtained using synchronous reference frame control technique for voltage source inverter with (a) constant irradiation of solar and (b) with variable solar irradiation, on its DC side.

The complete working model in Matlab 2010(a)-7.10.0.0499 is shown in the figure given below:

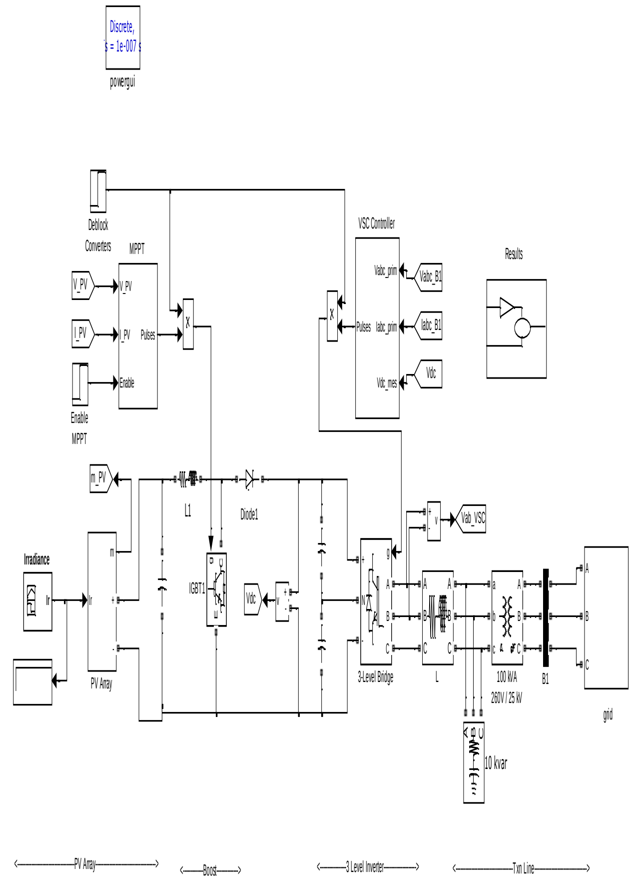


Fig. 8: Main model

In the above model PV array, boost converter, three level inverter and the transmission line is shown.

The figure 9 shown below shows the maximum power tracker in the model, MPPT decide the duty cycle for the converter.

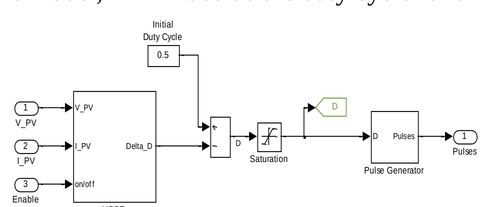


Fig. 9: Model of MPPT

The Simulink model of photo voltaic array is shown in figure 10.

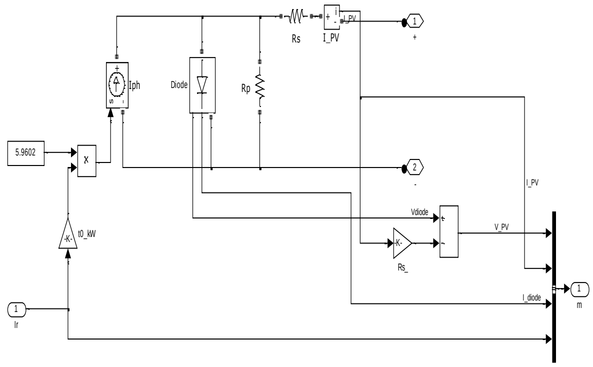


Fig. 10: PV array

The synchronous reference frame control technique for Voltage source controller is shown in figure 11.

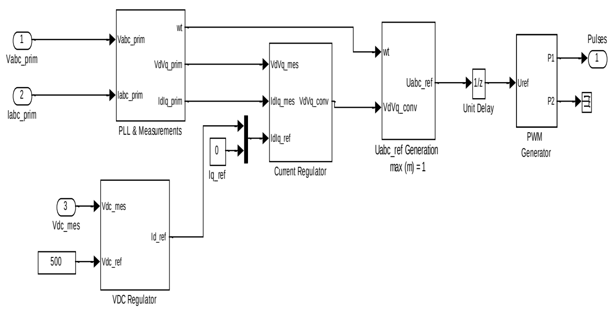


Fig. 11: VSC diagram

The simulation of V_{dc} regulator is shown in the model given below:

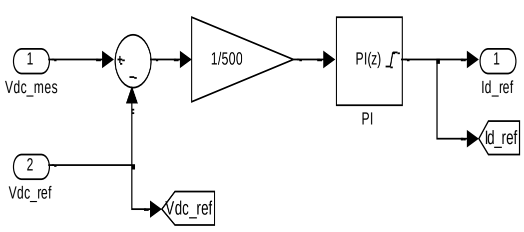


Fig. 12: V_{dc} controller

The reference voltage signal for generating the pulses is generated in V_{abc} reference generator diagram, which is shown in figure 13 below:

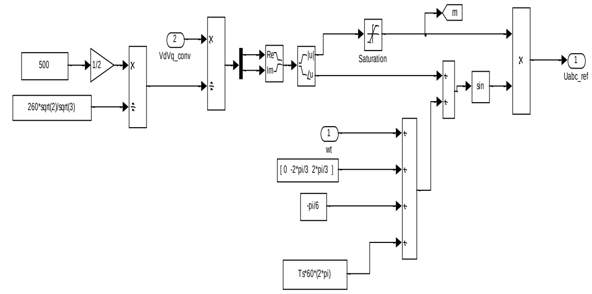


Fig. 13 : V_{abc} reference generator diagram

The Simulink model of grid is shown in figure 14 given below:

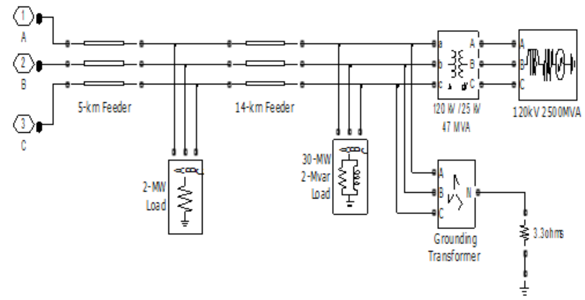


Fig.14: Grid Model

V. RESULTS AND DISCUSSION

The output voltage wave form of the three level voltage source inverter is shown in figure below.

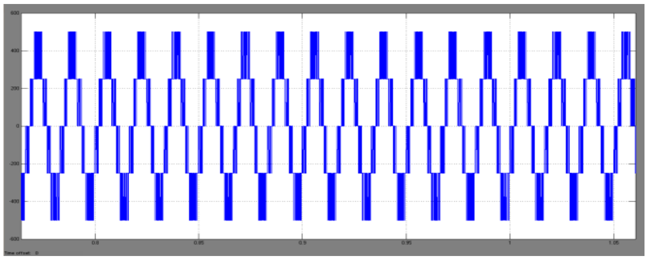


Fig. 15: Three level inverter output voltage

Figure 15 shows the variation of line voltage Vab with time. The output voltage is three level voltage waveform, the three levels are zero (0) voltage, 250V & 500V.

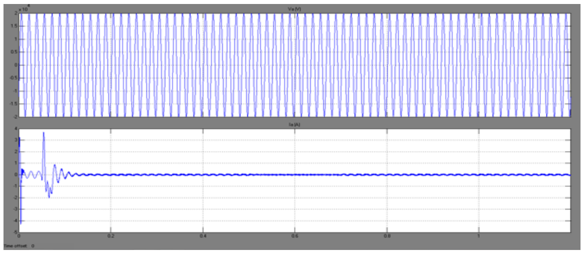


Fig. 16: Grid voltage and current waveform

Figure 16 shows the variation of grid voltage (top) and current (bottom). The voltage is 20kV peak to peak. After time t=0.1grid current becomes stable.

Figure 17 shows the variation of PV voltage, PV current and diode current. Due to variable solar intensity curve varies. The voltage and current decreases and after then stable state is achieved.

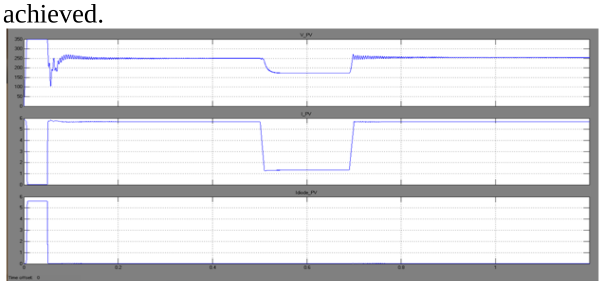


Fig.17: Photovoltaic Voltage, Current & Diode current

Figure 18 represents the variation of direct component of the reference current (I_d) and quadrature component of reference current (I_q) with respect to VSC.

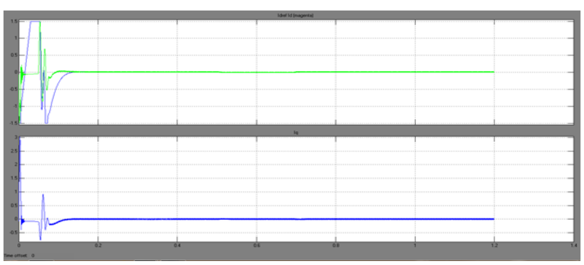


Fig.18: variation of I_d &I_q with respect to Vsc.

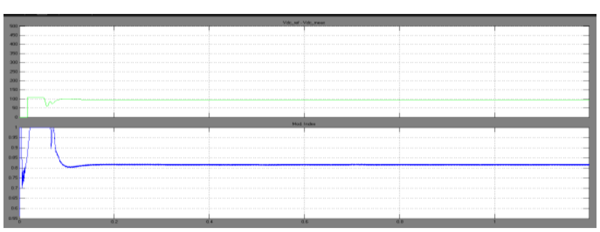


Fig. 19:{V_{dc}(ref)-V_{dc}(meas)} and modulation index

Figure 19 shows the variation of difference between reference DC voltage and the actual voltage or measured voltage. Under steady state condition the modulation index is 0.82.

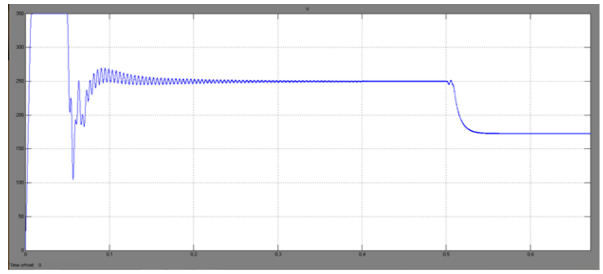


Fig. 20: Shows the dc voltage V_{dc}.

Figure 20 shows that the dc voltage applied to the multilevel inverter is 250V. At instant t = 0.05 sec when switching pulses are activated, the transient are present. After instant t=0.3 sec output voltage become stable. At instant 0.5 when I_r decreased the DC voltage now reduced to 175V.

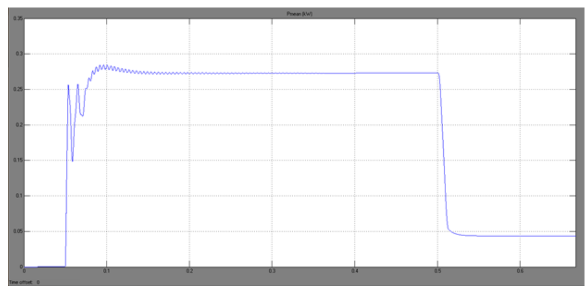


Figure 21: Power Curve

Figure 21 shows the power drawn in kW. From instant t=0.05 to t=0.5 the power is about 0.275 kW and after instant t=0.5 sec the power drawn is 0.05 kW.

I. CONCLUSION

Results shows that multilevel voltage source inverters offer several advantages compared to their conventional counterparts. By synthesizing the AC output terminal voltage from three levels of voltages, staircase waveform is produced, which approach the sinusoidal waveform with low harmonic distortion, thus reducing filter requirements. At MPPT power obtained is maximum and PV cell works at it's maximum efficiency. Practical MPPT characteristic follows the ideal characteristic. The need of several sources on the DC side of the converter makes multilevel technology attractive for photovoltaic applications.

REFERENCES

[1] P. Thirumuraugan, R. Preethi, "Closed loop control of multilevel inverter using SVPWM for grid connected photovoltaic system," in *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineerin*g, Vol.2, Issue 4, pp. 1561-1572, April 2013.

[2] Om. Prakash Mahela and Sheesh Ram Ola, "Modeling and control of grid connected photovoltaic system: A Review," in *International Journal of Electrical and Electronics Engineerin*g *Research*, Vol.3, Issue 1, pp.123-134, March 2013.

[3] Penugonda V.V.N.M. Kumar, P.M.Kishore and R.K.Nema, "Simulation of cascaded H- Bridge multilevel inverters for pv applications," in *International Conference on Global Scenario in Environment and Energy*," Vol.5, Issue 2, pp. 918-924, March 2013.

[4] Vishal Verma and Amritesh Kumar, "Power balanced cascaded multilevel inverter fed scalar controlled induction motor pump sourced from photovoltaic source," in *IEEE International Conf. on Power Electronics, Drives and Energy Systems*, December 2012.

[5] K Mathew, K Gopakumar, Jaison Mathew, Najath Abdul Azeez, Anubrata Dey, and L Umanand, "Multilevel octadecagonal space vector generation for induction motor drives by cascading asymmetric three level inverter" *IEEE Trans.*, pp. 1915-1920, February 2012.

[6] C. Bharatirajai , S. Ragfu and R. Palanisamy, "A New space vector pulse width modulation for reduction of common mode voltage in three level neutral point diode clamped multilevel inverter," in *IEEE Conf. on Advances in Engineering, Science and Management*, pp. 694 – 699, March 2012.

[7] Anubrata Dey and P.P. Raveevan, "A space-vector-based hysteresis current controller for a general n-level inverter-fed drive with nearly constant switching frequency control" *IEEE Trans. on Industrial Electronics*, Vol. 60, No. 5, pp. 1989 – 1998, May 2013.

[8] Bidyadhar Subudhi and Raseswari Pradhan, "A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems," *IEEE Trans on Sustainable Energy*, Vol.4, Issue 1, pp. 89 – 98, January 2013.

[9] K. Ravi and P. Rajendhar, "Single phase grid connected pv system employed by a novel modified H- Bridge inverter" *International Journal of Engineerin*g *Science and Advanced Technology*, Vol.2, Issue 5, pp. 1507-1514, October 2012.

[10] V. Fernao Pires , J.F. Martins and D. Foito, "A grid connected photovoltaic system with a multilevel inverter and Le-Blanc transformer," *International Journal of Renewable Energy Research*, Vol.2, Issue 1, pp. 84-91, February 2012.

[11] N. Shanmugavadivu and T. Annamalai, "Single phase seven level stand alone inverter for photovoltaic system," *Bonfring International Journal of Power System and Integrated Circuits*, Vol. 2, Issue 1, pp. 49-53, February 2012.

[12] Abir Chatterjee, Ali Keyhani and Dhruv Kapoor, "Identification of Photovoltaic Source Models," *IEEE Trans. on Energy Conversion*, Vol. 26, Issue 3, pp. 883-889, September 2011.

[13] Riad Kadri, Jean-Paul Gaubert and Gerard Champenois, "An improved maximum power point tracking for photovoltaic grid-connected inverter based on voltage-oriented control," *IEEE Trans.on Industrial Electronics*, Vol. 58, No. 1, January 2011.

[14] C. Bharatiraja and R.Latha, "Simplified structure – a mapped space vector pulse width modulation for three level neutral point diode clamped multilevel inverter," *Second International Conf. on Sustainable Energy and Intelligent System (SEISCON 2011)*, pp. 266-271, July 2011.

[15] M. A. Mahmud and R. Pota, "Dynamic stability of three phase grid connected photovoltaic system using zero dynamic design approach," *IEEE Trans. On Energy Conversion*, Vol. 19, No. 4, pp. 36-44, July 2011.

[16] Dr. Abu Tariq, Mohammed Asim and Mohd. Tariq, "Simulink based modeling, simulation and Performance Evaluation of an MPPT for maximum power generation on resistive load" *Second International Conf. on Environmental Science and Technology*, Vol.6, pp. 397-401, July 2011.

[17] Saad Mekhilef and Mohamad N. Abdul Kadir, "Novel vector control method for three-stage hybrid cascaded multilevel inverter," *IEEE Trans. on Industrial Electronics*, Vol. 58, No. 4, pp. 1339 1349, April 2011.

[18] Wuhua Li and Xiangning He, "Review of non-isolated high-step-up dc/dc converters in photovoltaic grid-connected applications," *IEEE Trans. on Industrial Electronics*, Vol. 58, No. 4, pp. 314-317, April 2011.