IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 3, March 2015.
www.ijiset.com
ISSN 2348 – 7968

Multilevel Inverter Modulation Scheme for Grid Connected Wind Turbines

Katepogu Rajesh [1], G.Sathish Kumar[2] and A. Praveen Kumar[3]

[1] PG Scholar, Electrical and Electronics Engineering. AVR & SVR College of Engineering and Technology, Nannur, Kurnool, Andhra Pradesh, India

[2] Assistant professor of the Department, Electrical and Electronics Engineering. AVR & SVR College of Engineering and Technology, Nannur, Kurnool, Andhra Pradesh, India

[3] Head of the Department, Electrical and Electronics Engineering. AVR & SVR College of Engineering and Technology, Nannur, Kurnool, Andhra Pradesh, India

Abstract

The design of a multilevel D-STATCOM inverter for small to mid-size (10–20kW) permanent-magnet wind or solar installations. The proposed inverter can actively regulate the reactive power on individual feeder lines at a programmable output while providing the variable output power of the renewable energy source. The aim is to provide utilities with distributive control of VAR compensation and power factor correction on feeder lines. The designed inverter utilizes a 5-level hybrid-clamped multilevel voltage-source converter topology and uses the optimized harmonic stepped waveform technique for harmonic elimination. The topology allows for the separation of active and reactive power control and the ability to operate under any load conditions. The aim of the work is to design a new type of inverter with FACTS capabilities to provide utilities with more knowledge about the distribution systems, specifically on end points. MMC has a modular design based on identical converter cells which make it a suitable choice for high-level applications. Wind turbine installation and purchase are handled under three different payment scenarios paid in full up front, paid through a second mortgage, or paid as part of a first mortgage. The simulations are obtained by MATLAB/SIMULINK.

Keywords—Multi-level Inverter, Modular Multi-level Converter (MMC), STATCOM.

1. Introduction

Renewable energy sources (RESs) have experienced a rapid growth in the last decade due to technological improvements, which have progressively reduced their costs and increased their efficiency at the same time [1]. Moreover, the need to depend less on fossil fuels and to reduce emissions of greenhouse gases, requires an increase of the electricity produced by RESs. This can be accomplished mainly by resorting to wind and photovoltaic generation, which, however, introduces several problems in electric systems management due to the inherent nature of these kinds of RESs [2]. In fact, they are both characterized by poorly predictable energy production profiles, together with highly variable rates. As a consequence, the electric system cannot manage these intermittent power sources beyond certain limits, resulting in RES generation curtailments and, hence, in RES penetration levels lower than expected.

A power electronic device is one that consists of a number of semiconductor components that is used to perform a specific function in a system. The most important is the capability to control and manage the flow of electrical power. Using power electronics has made it possible to connect AC or DC sources with different voltage or frequency levels to each other. Among all power quality concerns, controlling the active and reactive power transferring to or from the grid requires major attention. Traditionally, capacitor banks have been used to control the reactive power on a power grid, but with deployment of power electronics in power systems, STATCOMs were born and received more and more attention during recent years. The aim of this work is to combine the two concepts of inverters and D-STATCOMs into a so-called D-STATCOM inverter in order to enjoy the benefits of an inverter with DSTATCOM capability without any additional cost.

Renewable energy systems offer several advantages over conventional energy sources such as natural gas or coal. They are clean sources of energy that can be found in most regions without emitting any greenhouse gases. Renewable energy is abundant and free, and generally not affected by political instability. The main disadvantage of renewable energy sources is that they are mostly located in remote areas and far away from large loads. In addition, the use of renewable energy sources is limited by the fact that they are not always available. Power electronic-based flexible AC transmission System (FACTS) devices have been developed in order to provide more knowledge and control on power systems.

Traditionally, capacitor banks have been used to control the reactive power on a power grid, but with deployment of power electronics in power systems, STATCOMs were born and received more and more attention during recent years. The aim of this work is to combine the two concepts of inverters and D-STATCOMs into a so-called D-STATCOM inverter in order to enjoy the benefits of an inverter with DSTATCOM capability without any additional cost. A multilevel D-STATCOM inverter is a power electronic device that is placed between a renewable energy source and a distribution grid not only to provide active power, but to control reactive power on the system. Multi-level converters have several advantages compared to the conventional two level converters. They have the capability to perform at a lower switching frequency, they have lower total harmonic distortion (THD), and they have less dv/dt across switches and therefore less voltage stress on the devices [2-6]. The proposed D-STATCOM inverter in this paper could replace existing inverters used for renewable energy systems, specifically for small- to mid-sized wind applications.

2.PROPOSED D-STATCOM INVERTER

At this time, the modular multilevel converter (MMC) is the newest topology for large scale commercial applications [7-8]. Fig. 1 shows the configuration of the MMC topology. The structure of this topology is based on several modules in which each module consists of a floating capacitor and two switches. This topology is an ideal choice for FACTS applications if the capacitor voltages are kept balanced. It requires only one DC source which is proper for renewable energy inverters, it is easy to design for higher levels, and it can deliver active and reactive power regardless of the load characteristics. MMC has a modular design based on identical converter cells [9-11] which make it a suitable choice for high-level applications. The main drawback of this topology is that it requires large capacitors in comparison with similar topologies which may affect the total cost of the inverter. However, this problem can be alleviated by the lack of need for any snubber circuits. Each leg of an n-level MMC inverter consists of several basic sub modules (SMs) and two inductors which are in series. This lowers dv/dt and therefore the voltage stress across the switches.

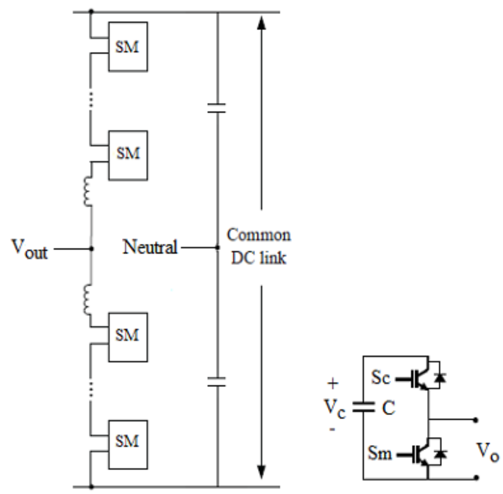

Fig.1. Configuration of the MMC topology and its sub-module

3.PROPOSED CONTROL STRATEGY

This inverter is designed to control the flow of active and reactive power between the wind turbine and the grid. It is able to provide utilities with distributive control of VAR compensation and power factor (PF) on feeder lines. To enhance the reactive power control of the proposed inverter, it is equipped with the additional D-STATCOM option. This option permits the inverter to deliver reactive power fully independent from the wind speed. When the wind speed is too low to generate active power, the inverter acts as a source of reactive power to control the PF of the grid, like a D-STATCOM. The inverter is able to control the active and reactive power regardless of the input active power required by the DC link. Generally, there are two modes of operation for D-STATCOM inverter when it is connected to the grid: 1) when active power is gained from the wind turbine, which is called inverter mode, 2) when no active power is gained from the wind turbine, which is called D-STATCOM mode. The active and reactive power flow of the D-STATCOM is governed by:

$$P_S = \frac{mE_S E_L}{X}\sin\delta \qquad \& \qquad Q_s = \frac{mE_s E_L \cos\delta - E_L^2}{X} \tag{1}$$

Where Es, E_L, δ, m and X are the voltage of the STATCOM, voltage of the line, power angle, modulation index, and inductance between the inverter and the grid, respectively. The steady state operation of the D-STATCOM inverter is controlled by adjusting m and δ, so that it provides the desired amount of active power and reactive compensation. The modulation index is used to control the active power while the power angle is used to control the reactive power transferring between the wind turbine and the grid. Fig. 2 shows the proposed control system.

The control system consists of three separate parts. The first part is to define the modulation index which is done by comparing the actual reactive power on the grid with the required reactive power considering the target power factor (PF). The second part is to define the power angle which is done by comparing the DC link voltage with a reference voltage defined by the specifications of the inverter. The defined values of modulation index and power angle are applied to the reference sinusoidal signal which is required to generate the PWM signals. The third part of the control system is to select the required SMs to generate the proper gate signals. Generally, the controller measures the SMs' capacitor voltages and sorts them in descending order. The suitable switching pattern will be chosen based on the direction of the current flowing through the switches.

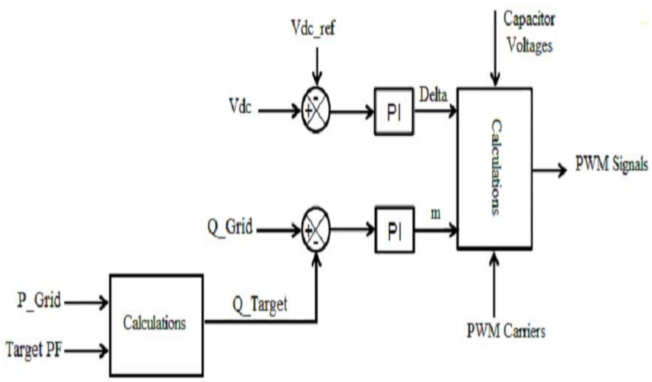

Fig.2. the proposed controller system

To maintain the SM capacitor voltages balanced, a carrier-based PWM (CPWM) method is used to control the voltages of the capacitors [12-13]. For a 5-level MMC inverter, this technique requires four in-phase carriers that are displaced with respect to the zero-axis. The output voltage level is determined by comparing a sinusoidal signal reference with these four carriers. In a 5-level inverter, at each instant four SMs should be chosen based on their capacitor voltages considering the direction of the current. Depending on the output voltage level, if the current is positive, the SM capacitors are being charged, and therefore a number of SMs with lowest capacitor voltage should be chosen. Likewise, if the current is negative, the SM capacitors are being discharged, and therefore a number of SMs with highest capacitor voltage should be chosen. Generally, when the output voltage of a SM is equal to zero, it is called *off* and when the out voltage of a SM is equal to its capacitor voltage, it is called *on*. The number of required SMs for each voltage level is as follows: for voltage level 1, in which $v_0 = -\frac{V_{dc}}{2}$, all the four upper SMs should be on and all the lower SMs should be off. For voltage level 2, in which $v_0 = -\frac{V_{dc}}{4}$, three upper SMs and one lower SM should be on and the other SMs should be off. For voltage level 3, in which $v_0 = 0$, two upper and two lower SMs should be on and the others should be Off. For voltage level 4, in which $v_0 = \frac{V_{dc}}{4}$, one upper SM and three lower SMs should be on and the other SMs should be off. For voltage level 5, in which $v_0 = \frac{V_{dc}}{2}$, all the upper SMs should be off and all the four lower SMs should be on. Considering this algorithm, the voltages of the capacitors are maintained balanced and the proper gate signals can be chosen.

4. ABOUT WIND SYSTEM

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern wind turbines, can be used to generate electricity. The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

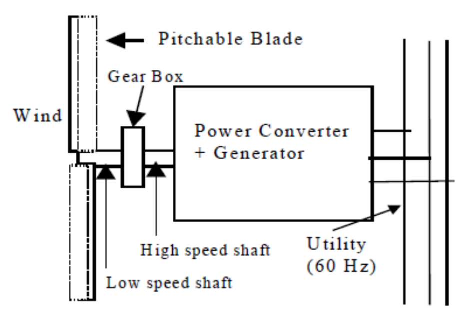

Fig.3 wind energy system

Distributed generation (or DG) generally refers to small scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include, but are not limited to synchronous generators, induction generators, reciprocating engines, micro turbines (combustion turbines that run on high energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, solar photovoltaic's, and wind turbines. Globally, the long-term technical potential of wind energy is believed to be five times total current global energy production, or 40 times current electricity demand. This could require wind turbines to be installed over large areas, particularly in areas of higher wind resources. Offshore resources experience average wind speeds of ~90% greater than that of land, so offshore resources could contribute substantially more energy.

5. MATLAB/SIMULINK RESULTS

A prototype sample is presented to verify using MATLAB/SIMULINK Platform to the practicability of the proposed converter. Here simulation is carried out in two different cases 1). Proposed MMC Topology Based DSTATCOM for Grid Connected System, 2). Proposed MMC Topology Based DSTATCOM for DG System with wind energy systems.

Case 1: Proposed MMC Topology Based DSTATCOM for Grid Connected System

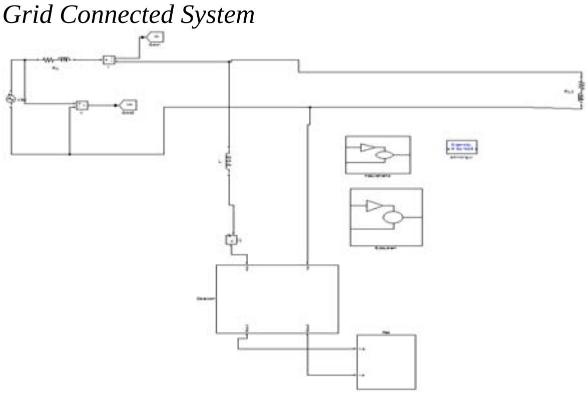

Fig.4 Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM for Grid Connected System

Fig.4 shows the Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM for Grid Connected System using Matlab/Simulink platform.

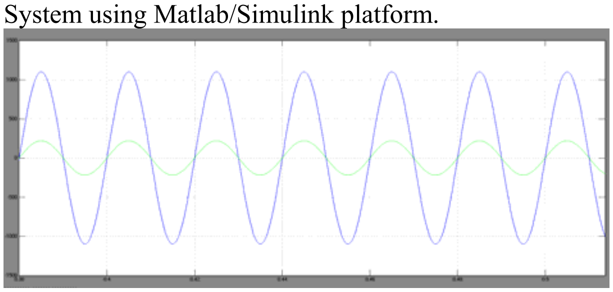

Fig.5 Source Side Voltage & Current – In Phase Condition

Fig.5 shows the Source Side Voltage & Current of Proposed MMC Topology Based DSTATCOM for Grid Connected System.

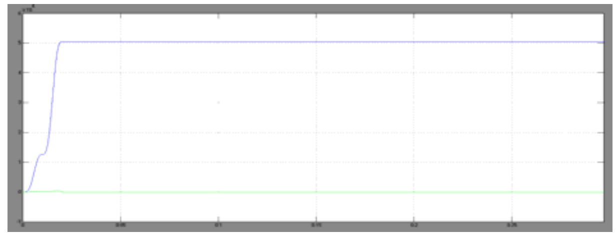

Fig.6 Active & Reactive Power

Fig.6 shows the Active & Reactive Power of Proposed MMC Topology Based DSTATCOM for Grid Connected System.

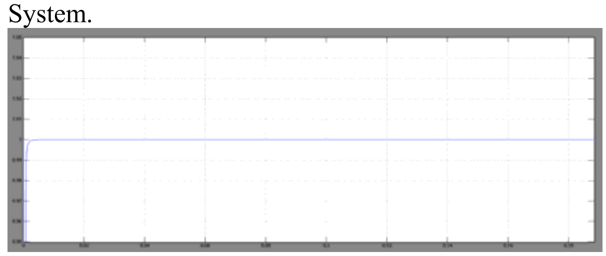

Fig.7 Power Factor

Fig.7 shows the Power Factor of Proposed MMC Topology Based DSTATCOM for Grid Connected System.

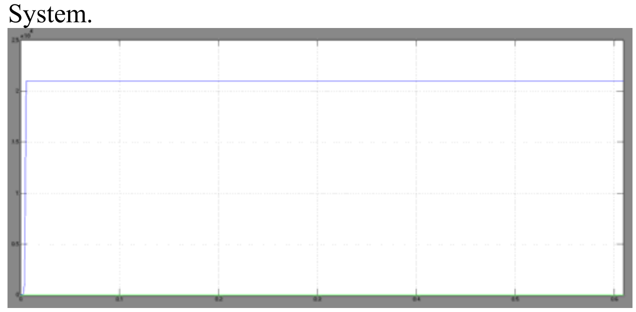

Fig.8 DSTATCOM Injected Active & Reactive Power

Fig.8 shows the DSTATCOM Injected Active & Reactive Power of Proposed MMC Topology Based DSTATCOM for Grid Connected System.

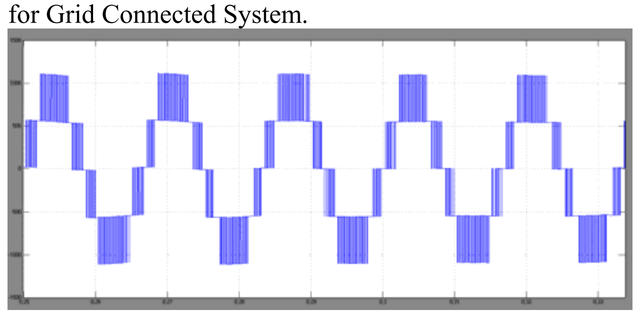

Fig.9 Five level Output Voltage

Fig.9 shows the Five Level Output Voltage of Proposed MMC Topology Based DSTATCOM for Grid Connected System.

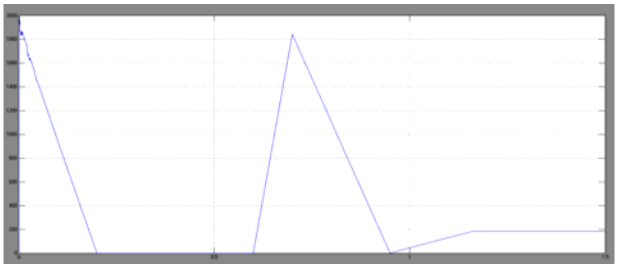

Fig.10 Wind Energy Power

Fig.10 shows the Wind Energy Power of Proposed MMC Topology Based DSTATCOM for Grid Connected System.

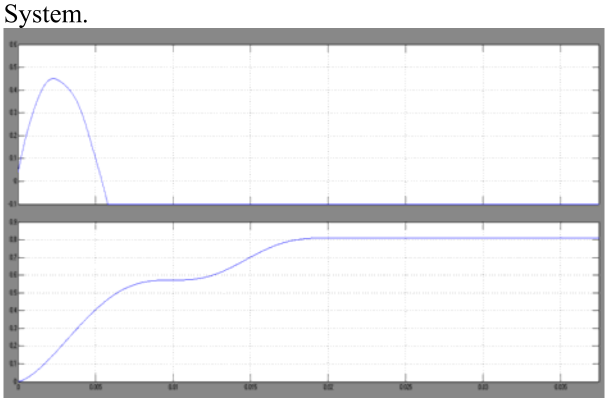

Fig.11 Delta & MI

Fig.11 shows the Delta & MI of Proposed MMC Topology Based DSTATCOM for Grid Connected System.

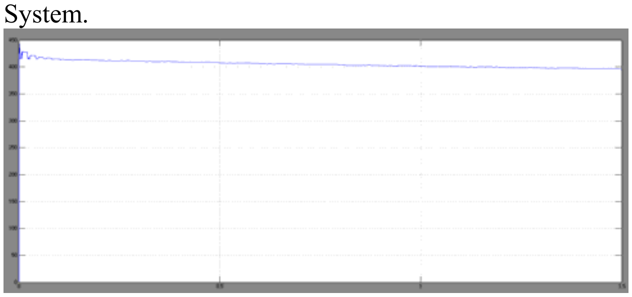

Fig.12 DC Link Voltage

Fig.12 shows the DC Link Voltage of Proposed MMC Topology Based DSTATCOM for Grid Connected System.

Case 2: Proposed MMC Topology Based DSTATCOM for DG System with wind energy systems.

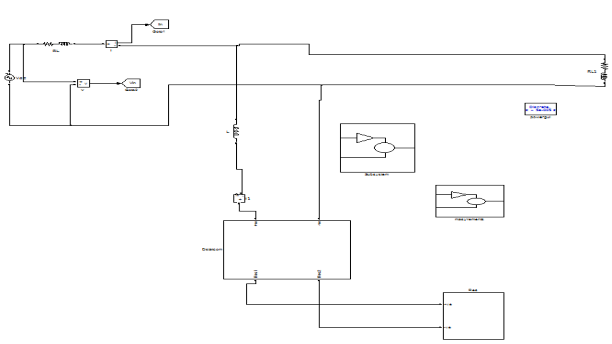

Fig.13Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM for DG Connected System

Fig.13 shows the Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM for DG Connected System with PV Source using Matlab/Simulink platform.

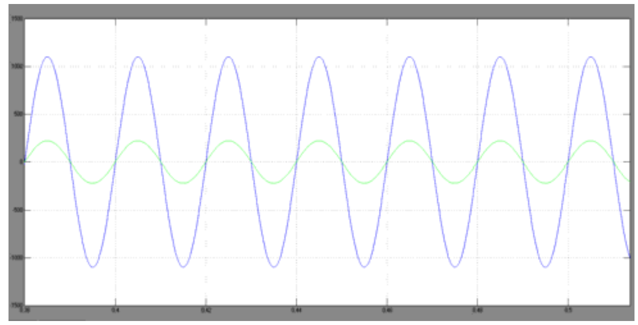

Fig.14 Source Side Voltage & Current – In Phase Condition

Fig.14 shows the Source Side Voltage & Current of Proposed MMC Topology Based DSTATCOM for DG Connected System.

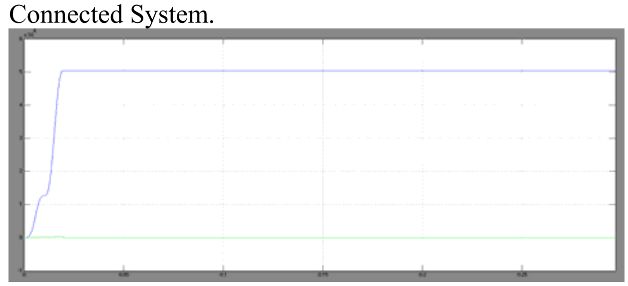

Fig.15 Active & Reactive Power

Fig.15 shows the Active & Reactive Power of Proposed MMC Topology Based DSTATCOM for DG Connected System.

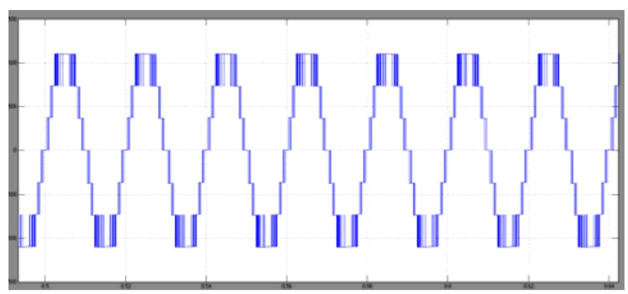

Fig.16 seven level Output Voltage

Fig.16 shows the seven Level Output Voltage of Proposed MMC Topology Based DSTATCOM for DG Connected System.

6. Conclusion:

By using this hybrid generation scheme instead of single sourced system, attains high power density, low voltage fluctuations, improve the grid stability, may increase the reliability, VAR compensation. The unique work of this research is to combine the two concepts of D-STATCOM and inverter using the most advanced multi-level topology to make a single unit called D-STATCOM inverter. In the current research a new D-STATCOM inverter using the most advanced multi-level topology called MMC is presented. In this paper, MMC is used as the voltage source converter (VSC) topology to make a D-STATCOM that is not only able to regulate reactive power, but is able to link to a wind turbine and regulate the active power transferred to the grid through system. The proposed device provides an inverter and D-STATCOM in a single unit without any additional cost. The goal is to increase the penetration of renewable energy systems, specifically wind to the distribution systems.

References:

[1] J.T. Bialasiewicz, “Renewable energy systems with photovoltaic power generators: Operation and Modeling”, Ind. Electronics, IEEE Trans. on, vol. 55, pp. 2752-2758, 2008

[2] J. Rodriguez, J. S. Lai and F. Z. Peng, “Multilevel inverters: Survey of topologies, controls, and applications,” Industry Applications, IEEE Transactions on, vol. 49, no. 4, pp. 724-738, 2002

[3] F. Z. Peng, J. S. Lai, J. W. McKeever, J. VanCoevering, “A multilevel voltage-source inverter with separate DC sources for static var generation,” Industry Applications, IEEE Transactions on, vol. 32, no. 5, pp. 1130-1138, 1996

[4] L. M. Tolbert, F. Z. Peng, “Multilevel converters as a utility interface for renewable energy systems,” in Proceedings of 2000 IEEE Power Engineering Society Summer Meeting, pp. 1271-1274, 2000

[5] Kouro, S., Malinowski, M., Gopakumar, K., Pou, J., Franquelo, L.G., Bin Wu, Rodriguez, J., Pérez, M.A., Leon, J.I., “Recent advances and industrial applications of multilevel converters”, IEEE Electronics, IEEE Transaction on, vol. 57 , no. 8, pp. 2553–2580, 2010

[6] C. Tareila, P. Sotoodeh, R. D. Miller., “Design and control of a single-phase D-STATCOM inverter for wind application”, Power Electronics and Machines in Wind Application PEMWA 2012, Denver, Co, 2012

[7] M. Davies, M. Dommaschk, J. Dorn, J. Lang, D. Retzmann, and D. Soerangr, “HVDC PLUS basic and principle of operation,” Siemens AG Energy Sector, Erlandgen, Germany, 2009

[8] B. Gemmell, Siemens USA, J. Dorn, D. Retzmann, D. Soerangr, Siemens Germany, “Prospects of multilevel VSC technologies for power transmission,” in Proc. IEEE Transmission and Distribution Conference and Exposition, pp. 1-16, 2008

[9] R. Marquardt and A. Lesnicar, "New concept for high voltage – modular multilevel converter," Power Electronics Specialists Conference, Aachen, Germany, 2004

[10] A. Lesnicar and R. Marquardt, "An innovative modular multilevel converter topology suitable for a wide power range,” IEEE Power Tech Conference Proceedings, Bologna, Italy, 2003

[11] M. Saeedifard, R. Iravani, “Dynamic performance of a modular multilevel back-to-back HVDC system”, Power Delivery, IEEE Trans. On, vol. 25, no. 4, pp. 2093-2912, 2010.

[12] J. Kim, S. Sul, P. Enjeti., “ A carrier-based PWM method with optimal switching sequence for a multilevel four-leg voltage-source inverter” , Industry Applications, IEEE Transactions on, vol. 44, no. 4, pp.1239-1248, 2008

[13] J. Pou, J. Zaragoza, S. Ceballos, M. Saeedifard, D. Boroyevich, “A carrier-based PWM strategy with zero- sequence voltage injection.

K.Rajesh, currently pursuing M.Tech with POWER &INDUSTRIAL DRIVES specialization in AVR & SVR College of Engineering and technology, Nannur,Kurnool ,Andhra Pradesh ,India.Had Obtained B.Tech degree from DR.SGIET,Markapur,prakasam,Andhra Pradesh,India.

G.SATHISH KUMAR received his ***B.Tech D***egree in Electrical and Electronics Engineering ***JNT University*** in 2007.He then received his ***M.Tech*** in Power Electronics from ***JNTU University*** in 2010. He entered in to teaching field in 2010 as a Lecturer and latter promoted as Assistant Professor Presently he is working as ***Assistant Professor of the Department of EEE in AVR&SVR Engineering College*** , Nannur, Kurnool (AP,India). G.SATISH KUMAR has guided several B.Tech Projects M.Tech dissertations. He has published 5 research papers in National/International Journal/Conferences. He has also delivered special Lectures in various engineering colleges.

A.PRAVEEN KUMAR received his ***B.Tech D***egree in Electrical and Electronics Engineering ***JNT University*** .He then received his ***M.Tech*** Power systems from ***JNTU University***. He entered in to teaching field in 2002 as a Lecturer and latter promoted as Assistant Professor Presently he is working as ***Associate Professor & Head of the Department of EEE in AVR&SVR CoEngineering College,*** Nannur, Kurnool (AP,India).. A.PRAVEEN KUMAR has guided several B.Tech Projects M.Tech dissertations.