Implementation of an 11 level inverter with FACTS capability for Distribution Energy Systems

Jerila J, Mr. Almond D Souza

ME Scholar, Dept. of Electrical Engineering, St. Xavier's Catholic College of Engineering, Tamil Nadu, India
Asst. Professor, Dept. of Electrical Engineering, St. Xavier's Catholic College of Engineering, Tamil Nadu, India

---***---

Abstract - *This paper introduces a new single phase multilevel inverter which has FACTS capability (Flexible AC Transmission system) so that the use of FACTS devices can be reduced. This new single phase multilevel inverter is placed between the wind plant and the distribution system to regulate the active power and reactive power to the grid. This designed inverter itself acts as a FACTS device to regulate the power factor of the feeder lines. This proposed inverter will eliminate the use of capacitor banks and FACTS devices and it itself provides reactive power compensation and can be used for small wind applications. Thus it reduces the cost of the system and increases the penetration of renewable energy system into the distribution system. In this paper a new single phase half bridge eleven level inverter is designed to meet all the IEEE standards. This proposed eleven level inverter regulates the active and reactive power to the grid and is cost effective. This implemented eleven level inverter is designed and its simulation are done in MATLAB/Simulink.*

Key Words: Multilevel Inverter, eleven level, cascaded, wind, sinusoidal pulse width modulation ,FACTS devices, capacitor banks

1. INTRODUCTION

The power electronics plays a major role in our day to day life. There is not even a device running in our homes without power converter devices encrypted in them. Thus the use of power converter devices is greatly increased. These power converter devices can be used for converting any non conventional source of energy in to voltage and frequency which is suitable for the distribution system. In case of wind applications a back to back converter is used for connecting the generator to the grid. The wind plant consists of a rectifier and MPPT(Maximum Power Point Tracking). Here the rectifier equipped with MPPT converts the ac output power of the wind turbine into dc. Now an inverter can be used which is used for converting the dc output into ac suitable for the grid.

Now a days the need for using wind energy inverter with greater efficiency has become a great deal. For a lossless and a high efficiency system .high power factor is necessary. A high power factor decreases the power losses and increases the voltage regulation to the load. The work of the reactive power elements is to supply or absorb the reactive power so that the harmonics and losses are reduced. This also reduces the apparent power. If the reactive power compensation is performed then voltage regulation can be improved.

For small wind applications normally permanent magnet synchronous motors are used. The doubly fed induction generators can also be used for large wind applications. The permanent magnet synchronous motor works on the principle of magnetic locking. The output of the generator is given to the wind turbine. Here it is connected to the rectifier with MPPT.

Traditionally capacitor banks are used to compensate the power factor and to provide reactive power compensation .But these capacitor banks increase the cost of the system. Also FACTS devices like DSTATCOM (Distribution Static Synchronous Compensators) are used for reactive power compensation. These devices are placed in parallel with the distribution system and operates as a source or sink of reactive power. These FACTS devices increases the cost of the system. So we opt for the new wind energy inverter with FACTS capability for being cost effective and to meet IEEE standards.

2. PROPOSED SYSTEM

For use in distribution energy systems an 11 level inverter is introduced. This inverter which is a combination of inverter and DSTATCOM is placed between the wind turbine and the grid. This inverter regulates the active power and the reactive power to the grid and is cost effective.

MODE 1

- When there is wind ,the active power is generated from the turbine so inverter + DSTATCOM mode

- In this mode, the device is works as a regular inverter to transfer active power from the renewable energy source to the grid as well as it works as a normal DSTATCOM to regulate the reactive power of the grid in order to control the PF of the grid.
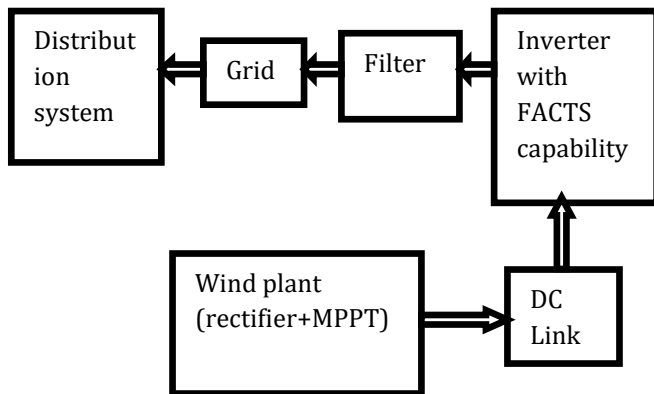
Fig -1: Block diagram of proposed method

MODE 2

- When there is no wind ie., the wind speed is zero or too low to generate active power it acts in DSTATCOM mode. In this case, the inverter acts as a DSTATCOM to control the reactive power in order to maintain the power factor of the grid. Thus to regulate the PF of the distribution feeder lines the use of additional capacitor banks or external STATCOMs is eliminated by this option.

2.1 MODULAR MULTILEVEL CONVERTER

Recently increased attention is gained by the Modular Multilevel Converter (MMC). The proposed multilevel inverter topology consists of several half bridge (HB) sub modules (SMs) per each phase, which are connected in series. A series connection of $2(n-1)$ basic SMs and two buffer inductors are present in an n level single phase MMC. Two semiconductor switches, which operate in complementary mode, and one capacitor are present in each sub module. It has become an ideal candidate for medium to high voltage applications such as wind energy applications because of the exclusive structure of the MMC. The key point for wind applications is that this topology needs only one dc source. MMC requires large capacitors which may increase the cost of the systems but this problem is an offset by the lack of need for any snubber circuit.

The main advantages of the MMC topology are identical converter cells with modular design, series connection of cells with simple voltage scaling, realization of redundancy is simple, and possibility of a common dc bus. Fig. 2 shows the circuit configuration of a single phase MMC and the structure of each SMs consisting of two power switches and a floating capacitor.

Depending on the switching states the output voltage of each SM (v_0) is either equal to its capacitor voltage (v_c) or zero.

The current control in each phase arm and the limitation of the fault currents is provided by the buffer inductors. Each SM can be considered as a two pole switch to describe the operation of MMC.

If S_{ui}, which is defined as the status of the ith sub module in the upper arm, is equal to unity, then the output of the ith SM is equal to the corresponding capacitor voltage; otherwise it is zero. Likewise, if S_{li} which is defined as the status of the ith sub module in the lower arm, is equal to unity, then the output of the ith lower SM is equal to the corresponding capacitor voltage; otherwise it is zero. Generally, when S_{ui} or S_{li} is equal to unity, the ith upper or lower SM is ON.
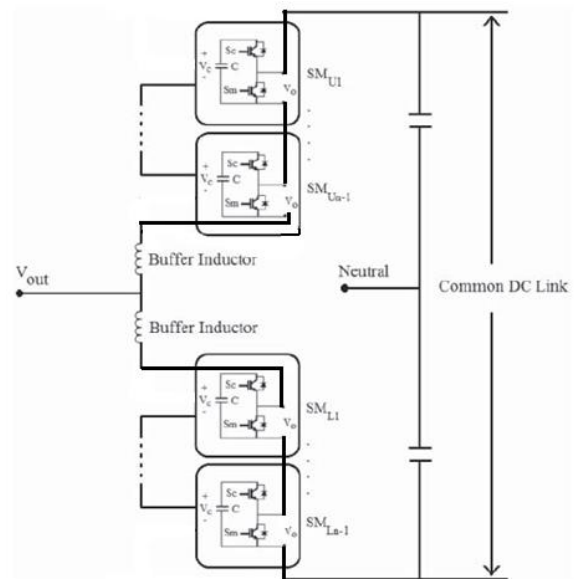

Fig-2: Structure of a single-phase MMC inverter structure

The upper and lower arm voltages of the MMC are given as:

$$v_{upperArm} = \sum_{i=1}^{n-1} (S_{ui} \, v_{ci}) + v_{11}$$

$$v_{lowerarm} = \sum_{i=1}^{n-1} (S_{li} \, v_{ci}) + v_{12}$$

where v_{11} and v_{12} represents the voltages of the upper and lower buffer inductors, n gives the number of voltage levels, and the voltage of the ith capacitor of the SMs in upper arm or lower arm is given by v_{ci}.

$$v_{DC} = v_{upperArm} + v_{lowerarm}$$
$$= \sum_{i=1}^{10} (S_{ui} \, v_{ci}) + \sum_{i=1}^{10} (S_{ui} \, v_{ci}) + (v_{11} + v_{12})$$
$$v_{out} = \frac{v_{DC}}{2} - v_{upperArm} = -\frac{v_{DC}}{2} + v_{lowerArm}$$

In an 11 level MMC inverter, there are ten upper and ten lower SMs where each SM has a capacitor. For instance, in voltage level 1 of Table 1, all the upper SMs should be OFF and all the lower SMs should be ON, which means the fact that the main switches S_m of all upper SMs and the auxiliary switches (S_c) of all lower SMs have to be ON and all the other switches have to be OFF. In this case, the input dc voltage is given only to the ten lower capacitors present bin the sub

module, so that the output voltage is $v_{DC}/2$. The most critical issue is to control MMC by maintaining the voltage balance across all the capacitors. Therefore, the SM voltages are measured and sorted in descending order during each cycle. If the current flowing through the switches is positive, capacitors are being charged, with the lowest voltages selected from $n_{upperarm}$ and $n_{lowerarm}$ which shows the number of SMs in upper arm and lower arm, respectively. As a result, ten capacitors with lowest voltages are chosen to be charged. Likewise, if the current flowing through the switches is negative, so that capacitors are being discharged with highest voltages are selected from $n_{upperarm}$ and $n_{lowerarm}$ of the SMs in upper arm and lower arm, respectively. As a result, ten capacitors with highest voltages are chosen to be discharged. Consequently, the voltages of the SMs' capacitors are balanced.

Table-1: Operating Regions for an 11-Level MMC Inverter

Voltage level	Status	$n_{upperarm}$	$n_{lowerarm}$	V_{out}
1	$v_r{>}{=}v_{c1}.v_{c2}.v_{c3}.v_{c4},v_{c5},v_{c6},v_{c7},v_{c8},v_{c9},v_{c10}$	0	10	$5V_{dc}/10$
2	$v_r{<}v_{c1};v_r{>}{=}v_{c2},v_{c3}.v_{c4},v_{c5},v_{c6},v_{c7},v_{c8},v_{c9},v_{c10}$	1	9	$4V_{dc}/10$
3	$v_r{<}v_{c1}.v_{c2};$ $v_r{>}{=}v_{c3}.v_{c4},v_{c5},v_{c6},v_{c7},v_{c8},v_{c9},v_{c10}$	2	8	$3V_{dc}/10$
4	$v_r{<}v_{c1}.v_{c2},v_{c3};$ $v_r{>}{=}v_{c4},v_{c5},v_{c6},v_{c7},v_{c8},v_{c9},v_{c10}$	3	7	$2V_{dc}/10$
5	$v_r{<}v_{c1}.v_{c2},v_{c3},v_{c4};$ $v_r{>}{=}v_{c5},v_{c6},v_{c7},v_{c8},v_{c9},v_{c10}$	4	6	$V_{dc}/10$
6	$v_r{<}v_{c1}.v_{c2},v_{c3},v_{c4},v_{c5};v_r{>}{=}v_{c6},v_{c7},v_{c8},v_{c9},v_{c10}$	5	5	0
7	$v_r{<}v_{c1}.v_{c2},v_{c3},v_{c4},v_{c5},v_{c6};$ $v_r{>}{=}v_{c7},v_{c8},v_{c9},v_{c10}$	6	4	$-V_{dc}/10$
8	$v_r{<}v_{c1}.v_{c2},v_{c3},v_{c4},v_{c5},v_{c6},v_{c7};$ $v_r{>}{=}v_{c8},v_{c9},v_{c10}$	7	3	$-2V_{dc}/10$
9	$v_r{<}v_{c1}.v_{c2},v_{c3},v_{c4},v_{c5},v_{c6},v_{c7},v_{c8};$ $v_r{>}{=}v_{c9},v_{c10}$	8	2	$-3V_{dc}/10$
10	$v_r{<}v_{c1}.v_{c2},v_{c3},v_{c4},v_{c5},v_{c6},v_{c7},v_{c8},v_{c9};$ $v_r{>}{=}v_{c10}$	9	1	$-4V_{dc}/10$
11	$v_r{<}v_{c1}.v_{c2},v_{c3}.v_{c4},v_{c5},v_{c6},v_{c7},v_{c8},v_{c9},v_{c10}$	10	0	$-5V_{dc}/10$

3. MATHEMATICAL MODELING FOR SINGLE PHASE CASCADED 11 LEVEL INVERTER

Average value of the output voltage,

$$V_{avg} = 10/T \int_{T/2}^{T} Vo(t)\,dt = 2.5Vs$$

RMS value of the output voltage

$$V_{rms} = \left[10/T \int_{T/2}^{T} \left(\frac{Vs}{2}\right)^2 dt\right]^{1/2} = 1.118\,Vs^2$$

Fourier series of the output voltage is given as,

$$Vo\,(t) = \sum_{n=1,3,5}^{\infty} \frac{10Vs}{n\pi} * sin\,n\omega t$$

Fundamental voltage is given as,

$$V_1\,(t) = 10\frac{Vs}{\pi} sin\omega t$$

RMS value of the fundamental voltage

$$V_1 = 10Vs/\sqrt{2}*\pi = 2.25Vs$$

RMS value of other harmonics

$$V_{nrms} = 10Vs/\sqrt{2}n\pi = 2.25Vs/n$$

Total harmonic distortion is given as

$$THD = V_{harmonics}/V_{1rms}$$

$$THD = \frac{\sqrt{-4.8125\,Vs}}{2.25Vs} = -0.9746i$$

Distortion factor calculated is

DF $= 1/V1 \left[\sum_{n=3,5}^{\infty} \left(\frac{Vn}{n^2} \right)^2 \right]^{\frac{1}{2}}$

$= 3.2\%$

4. RESULT AND DISCUSSION

The 11-level inverter is implemented using MATLAB/Simulink (version 12.0a). The result was obtained were analyzed in this chapter.
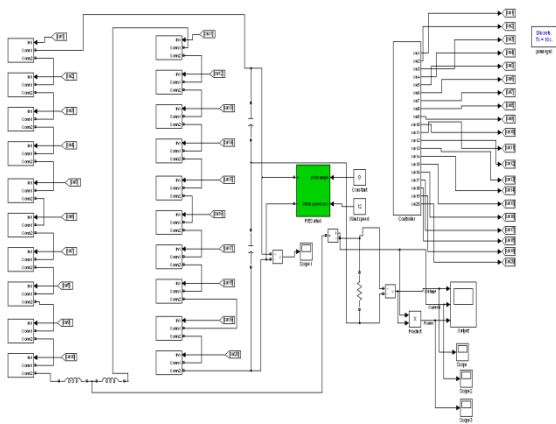
4.1. SIMULINK DIAGRAM

Fig-3: Simulink diagram of 11 level inverter

The figure 3 shows the simulink diagram of the implemented 11 level inverter. Here the input is given from the wind plant. The circuit consists of 20 sub modules.
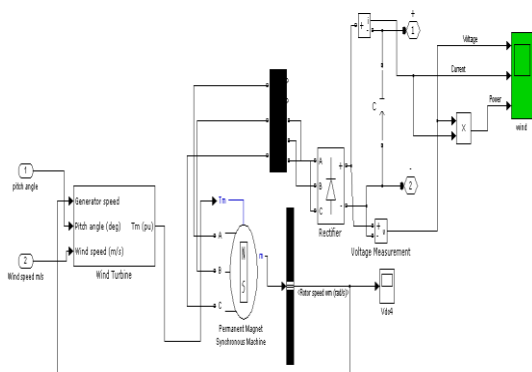
Fig-4: Simulink diagram of wind system

The above figure 4 shows the subsystem for the wind energy system which is given as input. The inputs to the wind turbine are pitch angle and wind speed. Here Permanent Magnet Synchronous Machine is used. The output of the wind generator is AC .It is converted into AC by using a

rectifier so that the output of the rectifier can be given to the inverter since its input is DC. The output from the rectifier is filtered and. then it is given to the inverter.
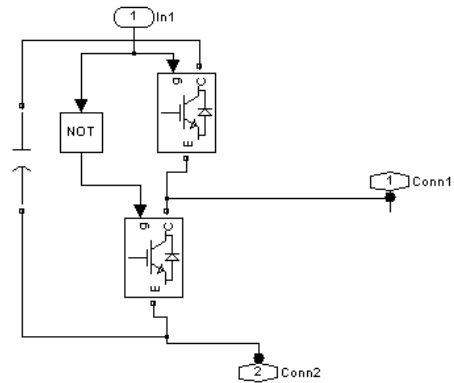

Fig-5: Simulink diagram of Sub module

The above figure 5 shows the simulink diagram of a single sub module of the 20 sub modules. Each sub module consists of 2 IGBT switches which operate in complementary action.
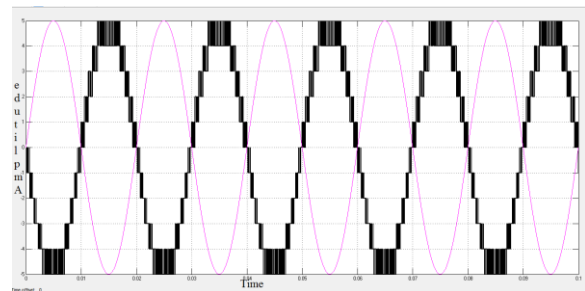

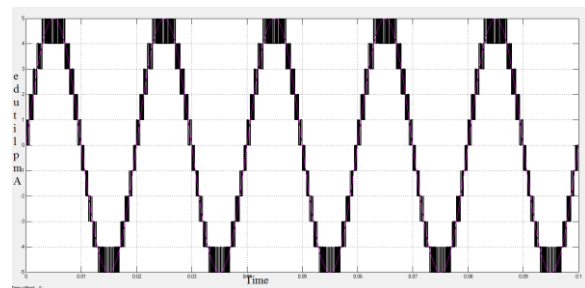**Fig-6:** Switching signal(upper)

Fig-7: Switching signal(lower)

Figure 6 shows the switching signal, which is used to trigger the sub modules in the upper arm. Figure 7 shows the switching signal, which is used to trigger the sub modules in the lower arm.
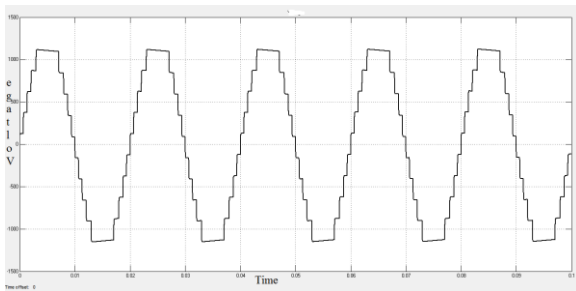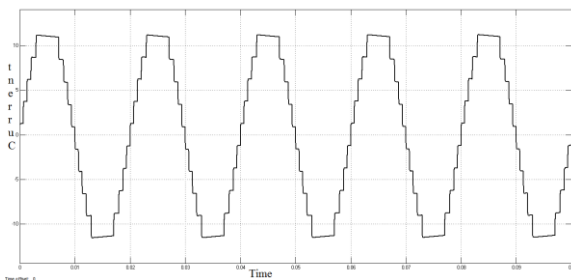
Fig -8: output voltage waveform

Fig -8: output current waveform

Figure 8 shows the output voltage waveform for constant source. Figure 9 shows the output current waveform for constant source.
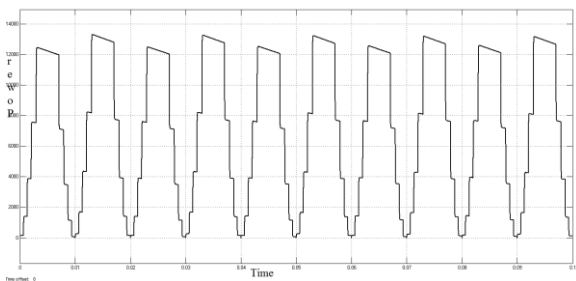

Fig -9: output power for constant source

5. CONCLUSIONS

A new concept of multilevel inverter with FACTS capability which can be used for small to medium power applications is introduced in this paper. This paper proposes a new multilevel inverter which is cost effective and lossless. This proposed inverter replaces the traditional wind energy inverter with DSTATCOMS and capacitor banks with power converter devices to regulate the power factor to the grid. Multiple inverter may be needed depending on the size of compensation to reach the desired pf. Thus new ways are introduced to provide control and support in distribution systems in which distributed renewable sources can be used. The results for an 11 level inverter are simulated in MATLAB/Simulink. The practical results of the proposed control strategy shows good response even in severe conditions. In future, this project can be extended to the level it can be implemented with reduced number of switches to minimize losses.

REFERENCES

[1] Adeleh Shahipour, Behrooz Vahidi, Javad Shokrolahi Moghani, "THD Minimization Applied Directly on the Phase Voltage of Multilevel Inverters by using ICA" Sci.Int.(Lahore),26(1),57-63,2014.

[2] Akash A. Chandekar, R.K.Dhatrak and Dr.Z.J..Khan, "Modeling and Simulation of Diode Clamp Multilevel Inverter Fed Three Phase Induction Motor for Cmv Analysis Using Filter" International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2, Issue 8, August 2013.

[3] Avinashverma, Ruchishivhare, Sanjeevgupta, "Total Harmonics Distortion Investigation in Multilevel Inverters" American Journal of Engineering Research (AJER), 2013.

[4] B. Gemmell, Siemens USA; J. Dorn, D. Retzmann, D. Soerangr, Siemens Germany, "Prospects of Multilevel VSC Technologies for Power Transmission, IEE 2008.

[5] Brendan Peter McGrath, Donald Grahame Holmes and Thomas Lipo,"Optimized Space Vector Switching Sequences for Multilevel Inverters" IEEE Transactions On Power Electronics, Vol. 18, No. 6, November 2003.

[6] BurhanGultekin and MuammerErmis, "Cascaded Multilevel Converter Based Transmission STATCOM: System Design Methodology and Development of a 12 kV ±12MVAr Power-Stage" IEEE Transaction on Power System vol. 26, No.5, December 2013.

[7] Jang-Hwan Kim, Seung-Ki Sul and Prasad N. Enjeti, "A Carrier-Based PWM Method With Optimal Switching Sequence for a Multilevel Four-Leg Voltage-Source Inverter" IEEE Transactions on Industry Applications, Vol. 44, No. 4, July/August 2008.

[8] JosepPou, Jordi Zaragoza and Salvador Ceballos, "A Carrier-Based PWM Strategy with Zero-Sequence Voltage Injection for a Three-Level Neutral-Point-Clamped Converter" IEEE Transactions on Power Electronics, Vol. 27, No. 2, February 2012.

[9] José Rodríguez, Jih-Sheng Laiand Fang Zheng Peng, "Multilevel Inverters: A Survey of Topologies, Controls, and Applications" IEEE Transactions on Industrial Electronics, Vol. 49, No. 4, August 2002.

[10] Julymol Joseph, AryaPrakash, "Modified Cascaded Multilevel Inverter With GA To Reduce Line To Line Voltage THD" International Journal of Electrical Engineering & Technology (IJEET),Volume 5, Issue 12, December (2014), pp. 32-41.

[11] Kenichiro Sano and Masahiro Takasaki, "A Transformer less D-STATCOM Based on a Multivoltage Cascade

Converter Requiring No DC Sources"IEEE Transactions on Power Electronics, Vol. 27, No. 6, June 2012.

[12] K. Sneha, K.P. Swaroop, "A Cascaded Multilevel Converter with Reduced Components Applied To Induction Machine Drive"8th December 2013, Nagpur, India. ISBN: 978-93-82702-46-7.

[13] Leon M. Tolbert, Fang Z. Peng, "Multilevel Converters as a Utility Interface for Renewable Energy Systems" 0-7803-6420-1, 2000.

[14] Maryam Saeedifard and Reza Iravani, "Dynamic Performance of a Modular Multilevel Back-to-Back HVDC System" IEEE Transactions on Power Delivery, Vol. 25, No. 4, October 2010.

[15] N.B.Mohite, Prof. Y. R. Atre, "Neutral-Point Clamped Multilevel Inverter Based Transmission Statcom for Voltage Regulation" IOSR Journal of Electronics & Communication Engineering (IOSR-JECE) ISSN: 2278-2834, ISBN: 2278-8735, PP: 31-35.

[16] Rajiv K. Varma, Shah ArifurRahman, Mahendra, A.C., Ravi Seethapathy, and Tim Vanderheide, "Novel Nighttime Application of PV Solar Farms as STATCOM (PV-STATCOM)" IEEE 2012.

[17] Rajiv K. Varma and Shah ArifurRahmanVinay Sharma Tim Vanderheide, "Novel Control of a PV Solar System as Statcom (PV-Statcom) for Preventing Instability of Induction Motor Load" 25th IEEE Canadian Conference on Electrical and Computer Engineering (CCECE),2012.

[18] Samir Kouro, Mariusz Malinowski, K. Gopakumar, JosepPou, Leopoldo G. Franquelo, BinWu, "Recent Advances and Industrial Applications of Multilevel Converters" IEEE Transactions on Industrial Electronics, Vol. 57, No. 8, August 2010.

[19] Surya Suresh Kota and M. Vishnu Prasad Muddineni, "An Inverted Sine PWM Scheme for New Eleven Level Inverter Topology" International Journal of Advances in Engineering & Technology, Sept 2012.

[20] Z. Yang, C. Shen, L. Zhang, M. L. Crowand S. Atcitty, "Integration of a StatCom and Battery Energy Storage" IEEE Transactions on Power Systems, Vol. 16, No. 2, May 2001.