

# **Analysis and Modeling of Modular Multilevel Converter based Inverter for Grid Connected Wind Energy Conversion System**

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**ABSTRACT:** In Grid connected wind energy conversion system (WECS), electricity is generated and transfer to the load but because of reactive elements power loss occur. To resolve this problem a new topology modular multilevel converter (MMC) represent an attractive alternative against traditional two-level voltage source converter as the interphase between renewables and the ac grid. Here in this paper PWM based MMC topology is used to design a Multilevel Inverter having FACTS capability. MMCs feature lower losses, improved voltage quality, scalability and redundancy. In this paper, a pulse width modulation is used in MMC topology to control the parameter in desired form. The proposed grid-interconnection of a wind energy conversion system (WECS) is modelled to compensate reactive power and balance the active power by improving the power factor (PF) through Pulse Width Modulated MMC topology. In this research work 11 level inverter is designed through this MMC topology and this Inverter is working as Inverter as well as D-STATCOM device. The WECS is realized through the cascaded connection of a wind turbine, a permanent magnet synchronous generator (PMSG), along with a control strategy able to perform both maximum power point tracking and arbitrary reactive power injection. The approach is validated and analysed using MATLAB/Simulink software.

**KEYWORDS:** Pulse Width Modulation (PWM) Distribution static synchronous compensator (D-STATCOM), Power Factor (PF), Power Quality (PQ), Modular multilevel converter (MMC), multilevel inverter (MLI), wind energy conversion System (WECS), Distributed Generator (DG).

## **I. INTRODUCTION**

The small-scale windmill system is applied as generators into distribution systems and this system is also called distributed generators (DGs). If this system is properly integrated, two main advantages are observed. First, this concept increase the efficiency of the system by avoiding transmitting power over long distances. Second, emissions are reduced since most DGs are based on renewable sources like wind and solar. The DGs are became challenges and as well as revolution for the power industry, And also for the recent energy trends. The power rating less than 100kW Wind-based DGs with a usually referred to as small-scale wind energy conversion systems (SS-WECS). In this windmill the power quality and efficiency issues arising from unmanaged power flow have been the major problem in power systems. The phase difference occur between generated voltage and the grid system. And this include harmonics, low power factor, voltage collapse, and oscillations. Recently the role of power electronics in distribution systems has greatly increased. The Power electronic devices are usually used to convert the nonconventional energy to the suitable energy for power distribution lines (grid) by manipulating voltage, current, and frequency at a desired level. The back-to-back converter is normally used to connect the generator to the grid. SS-WECS are connected to the ac grid via a power electronics devices that is typically based on a voltage-source converter (VSC) topology. The main purpose of this power electronics device is to convert the variable-frequency power produced by the SS-WECS into grid-frequency power. And main objectives are (i) Improvement of power factor Power. And (ii) perform the maximum power point tracking (MPPT) function to extract the maximum available power from the SS-WECS. The main motive

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to introduce MMC topology as VSC in the market for High Voltage Direct Current (HVDC) applications [2]. The concept of MMC (i) provides lower losses compared to a two-level equivalent VSC, (ii) features an increased output voltage quality, requiring smaller or no

Harmonic filters; (iii) provides a design aspect to design a multilevel inverter having FACTS capabilities. (iv) Inverter based on MMC topology can perform as inverter as well D-STATCOM as per the requirements of DGs. (v) it reduces the voltage stress on the devices. While this topology has been already proposed for the large scale of wind power plants interconnection. [5] its application to the interconnection of SS- WECS is still being explored. In [8], an inverter based on the MMC topology was used to compensate reactive power by adjusting the power factor at desired level into a single-phase ac grid. The control strategy discussed in the paper is Pulse width modulation (PWM) which is able to perform the MMC topology to compensate the reactive

Power and improve the power quality and also can perform as Inverter as well as D-STATCOM .The Pulse width Modulated MMC topology can also perform MPPT function for the SS-WECS, and simultaneously transfer the generated power into the grid with desired power quality. Section II describes the various work has been done for WECS. Section III describes the various components involved in the realization of a proposed system .And the modeling of the proposed multilevel inverter, followed by the considered control approach in Section IV. In Section V, the control schemes are validated via detailed MATLAB/SIMULINK simulations results. Finally, the conclusions and future aspects of Section VI close the paper.

## II. BACKGROUND

There are many of research paper are published on the integration of renewable energy power systems. An idea of designing multilevel inverter based on pulse width modulated modular multilevel converter topology is described in [1]. The basics of wind energy conversion system and its implementation as the Distributed generation is detailed in [2]. The D-STATCOM theory with grid connected wind energy conversion system is implemented through simulation Modell in [3]. The concept of a multilevel Inverter having FACTS capability comes from [4] and [6], in this paper the multilevel inverter is presented that can work as inverter as well as D-STATCOM to compensated reactive power by improving power factor. In [5] the hybrid topology modular multilevel is introduce by author for high voltage dc (HVDC), and this topology is implemented here in large wind turbine in WECS .In [11], a complete list of the most important multilevel inverters was reviewed. In [7]-[8] the voltage profile correction is done by implementing D-STATCOM under unbalanced voltage condition in grid connected wind energy conversion system. The different modulation methods such as sinusoidal pulse width modulation (PWM), selective harmonic elimination, and optimized harmonic stepped waveform technique and space vector modulation (SVM) were discussed and SVM implementation is done as controller in wind energy conversion system. in [9]. In [10] the PWM control strategy is detailed for PMSG based wind turbine for WECS. [12] Presented a novel topology for standalone wind forms under HVDC power transmission. In [13] a multilevel inverter application for renewable grid connected system is described. The multilevel inverter with the single phase D-STATCOM are well elaborated [14] and [15]. Here the authors are presented a system to improve the power quality without any additional cost in distributed generation (DG) system.

## III. PROPOSED SYSTEM

### (i) Small-scale wind energy conversion system

The schematic of Fig. 1 illustrates the power stage of the SS-WECS and the power electronics interphase considered in this paper. It includes a wind turbine which basically PMSG/PMSM, because here permanent magnet synchronous motor is used to generate power from the speed of wind which rotate the wind turbine. A voltage-source rectifier (VSR). And dc link realized through a capacitor, an MMC topology based inverter is implemented and an LC-filter in series with a coupling transformer that connects to the three-phase ac grid.

### (ii). Proposed Hybrid MMC

The proposed modular multilevel converter based multilevel inverter is placed between wind turbine and grid .This multilevel inverter is equipped with D-STATCOM in order to regulate the reactive power of the local distribution lines

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and place between turbine and grid same as wind energy inverter (WEI) without any additional cost .Here the MMC topology is controlled by PWM controller which is based on PI controller and this system is implemented in WECS to improve power factor and enhance the power quality as well as eliminate the power loss ,which make this system efficient and useful for grid connected renewable energy sources .This modular multilevel converter based topology can perform as inverter with Facts capabilities.

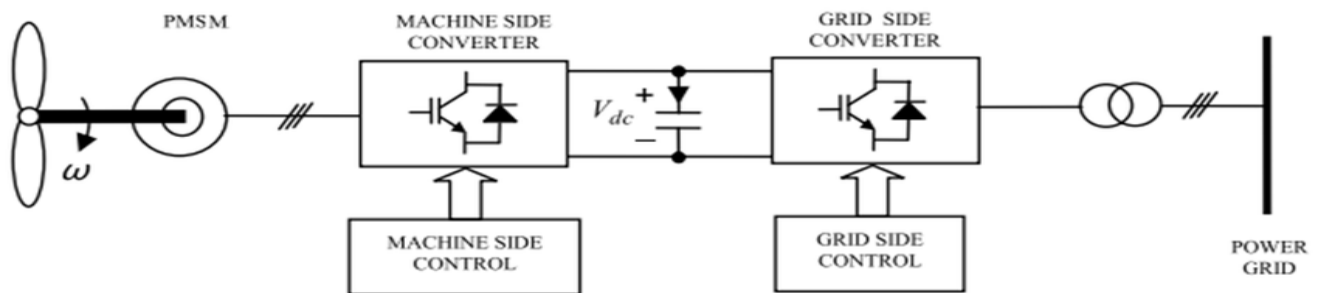


Fig .1 Small Scale Wind Energy Conversion System (WECS).

This system shown in Fig.1 consist wind turbine with PMSM motor as generator and power electronic converters to get desired output. As shown above figure two power electronic converter is used both source side as well as load side.

MMC concept is increasing attention recently. Several papers were published on the structure, control, and application of this topology [5], [14], but none has suggested the use of that for inverter + D-STATCOM application. The MMC topology consists of several half-bridge (HB) submodules (SMs) per each phase, which are connected in series. An  $n$ -level single phase MMC consists of a series connection of  $2(n-1)$  basic submodule and two buffer inductors .Each submodule having two semiconductor switches here in our MMC topology we are going to use MOSFET switch instead of IGBTs switches these switches are operate in complementary mode and one capacitor is also involve. The unique structure of MMC Make it an ideal and useful system for medium-to-high-voltage application like wind energy conversion system. Only one Dc source is required in this topology. That is a key point for MMC requires large capacitors for the wind applications, because of this cost of the system get increased. This problem is compensated by the lack of need for any snubber circuit. The main advantage of the MMC topology are: modular design based on identical converter cells, Fig. 2 shows the circuit configuration of a single-phase MMC and its structure of with Sub Modules (SMs)

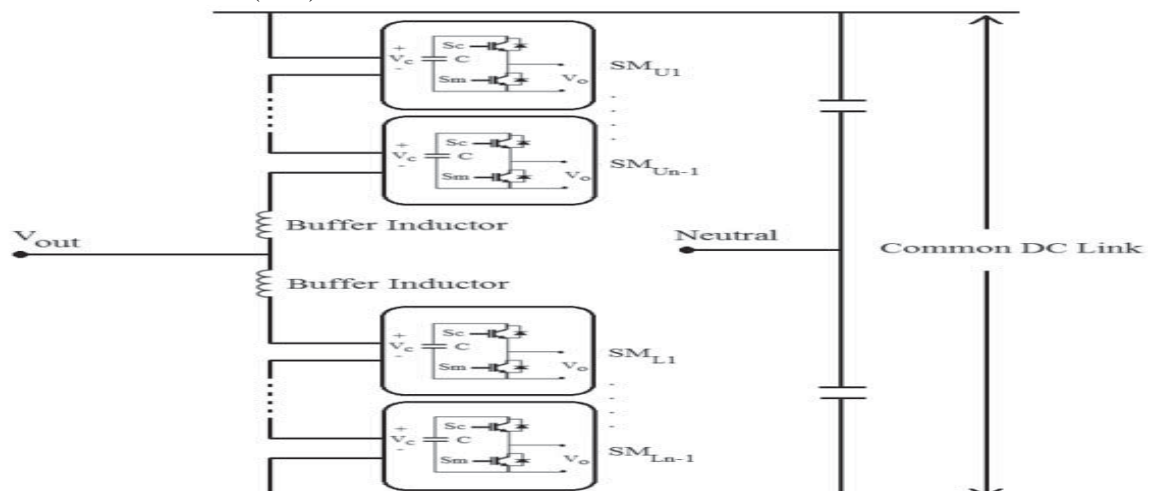


Fig.2 Structure of a single-phase MMC inverter structure.

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This Fig.2 shows the basic circuit configuration of MMC topology n level MMC structure consists of 2(n-1) submodules and two buffer inductors. Each modules having two semiconductor switches.

Consisting of two power switches and a floating capacitor.  $V_o$  is the output voltage of each module which is equal either  $V_c$  or equal to zero, depending on the switching states. The buffer inductors here used to the control the current in each phase arm and limit the fault currents. In MMC operation, each SM can be considered as a two pole switch. If  $S_{ui}$ , which is defined as the status of the  $i$  th submodule in the upper arm, is equal to unity, then the output of the  $i$  th SM is equal to the corresponding capacitor

Voltage; otherwise it is zero. Similarly, if  $S_{li}$  which is defined as the status of the  $i$  th submodule in the lower arm, is equal to unity, then the output of the  $i$  th 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  $i$  th upper or lower SM is ON; otherwise it is OFF. Therefore, the upper and lower arm voltages of the MMC are as follows:

$$V_{upperArm} = \text{sum.of } S_{ui} * V_{ci} \text{ (from } i=1 \text{ to } n-1) + V_{11} \quad (i)$$

$$V_{lowerArm} = \text{sum.of } S_{li} * V_{ci} \text{ (from } i=1 \text{ to } n-1) + V_{12} \quad (ii)$$

Where  $V_{11}$  and  $V_{12}$  are the voltages of the upper and lower buffer inductors,  $n$  is the number of voltage levels, As Here  $n=11$  and  $V_{ci}$  is the voltage of the  $i$  th SMs capacitor in upper arm or lower arm. A single-phase 11-level MMC inverter consists of 20 SMs which translates to 40 power switches, 20 capacitors, and 2 buffer inductors. The dc and ac voltages of the 11-level MMC are described by

Here putting  $n=11$  in equation (i) and (ii) and adding them, then we get VDC as follow -:

$$V_{DC} = V_{upperArm} + V_{lowerArm}$$

$$V_{DC} = \{ \text{sum.of } S_{ui} * V_{ci} \text{ (from } i=1 \text{ to } 10) + \text{sum.of } S_{li} * V_{ci} \text{ (from } i=1 \text{ to } 10) \} + (V_{11} + V_{12}) \quad (iii)$$

And finally the output will be -:

$$V_{out} = (V_{DC} / 2) - V_{upperArm} \quad (iv)$$

$$V_{out} = (V_{DC} / 2) + V_{lowerArm} \quad (v)$$

The operation mechanism of the MMC sub modules SMs is shown in Fig.7 where out configuration is presented.

### (iii). PROPOSED CONTROL STRATEGY

The proposed controller perform of main function to control the active and reactive power. This PWM controllers Simulink model presented in Fig .3, in which the basic operation is performed by managing the two mode operation that means this controller can work like a D-STATCOM +Inverter when there is wind is blowing and it will controlling to behave as D-STATCOM when there is no wind available for wind energy conversion system. In this control strategy, active and reactive power transferred to load is controlled by adjusting the  $\delta$  and level of Inverter. Amplitude of the inverter voltage is regulated by modified by adjusting the modulation index.  $m$  and the angle  $\delta$  by adding a delay to the firing signals which concludes, Following active power and reactive power equations as (vi) and (vii) respectively.

$$P_S = -mE_s E_L \sin \delta / X$$

(vi)-active power.

$$Q_S = -mE_s E_L \cos \delta - E^2 / X$$

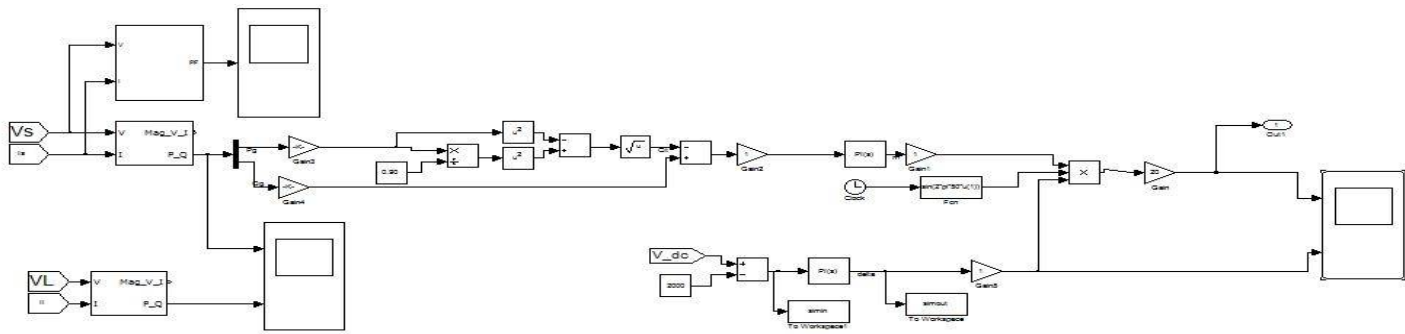
(vii)-reactive power.

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These equations are used for power factor correction of the transmission line in power grid system/and also decrease the THD of the output voltage. This control strategy is basically PI controller that helps a system to work like a multilevel inverter as well as D-CTATCOM device. The modelling of control method is shown in Fig. 3 which controls the parameter to desired output.

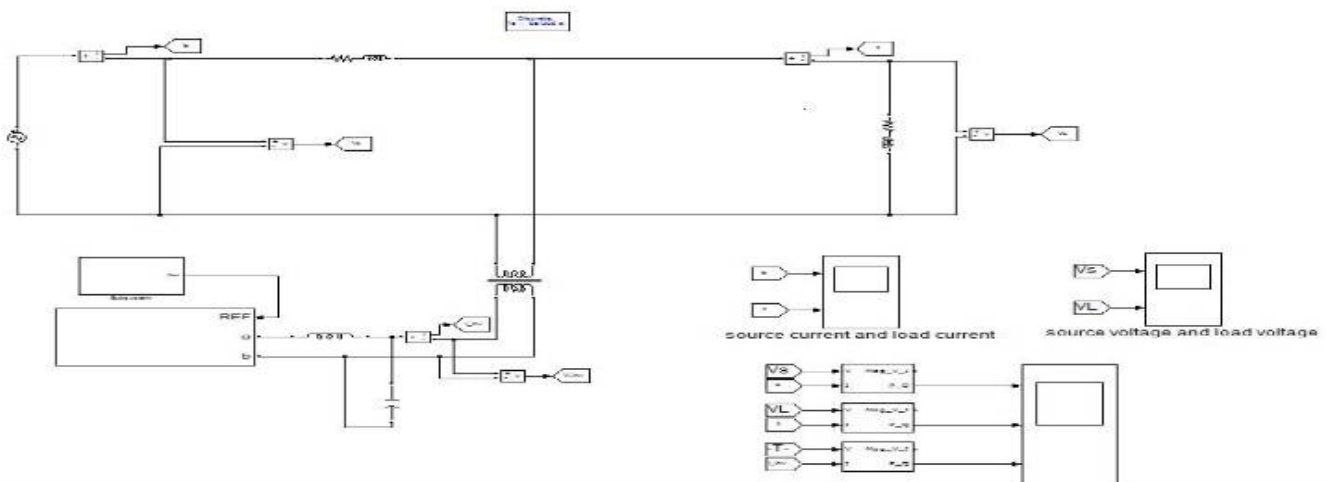


**Fig.3** Shows Simulink model of the proposed controller system.

This system in Fig.3 effectively controls the value of angle and modulation index which can improve the power factor and ultimately the real power gets boost and reactive power gets compensated by above system. Basic control mechanism used here is PI controller to control the parameter angle and modulation index.

## IV PROPOSED SYSTEM MODELLING

The modelling of 11-level MMC inverter is designed in MATLAB/Simulink. The simulation contains the fluctuation and severe ramping and de-ramping of the wind turbine. Simulation of the proposed system is shown in Fig.4. The MMC topology based inverter is shown in Fig.5. This system function is transferring active power from the wind turbine to the distribution grid as well as compensating the PF of the local distribution grid.



**Fig.4** Simulation model of proposed MLI in grid connected WECS.

This in Fig.4 system includes the WECS an MMC topology multilevel inverter and PWM controller. And parameter of the system is as according to TABLE.1 as shown below, in which value of inductor, resistance, and transformer voltage etc. are predefined.

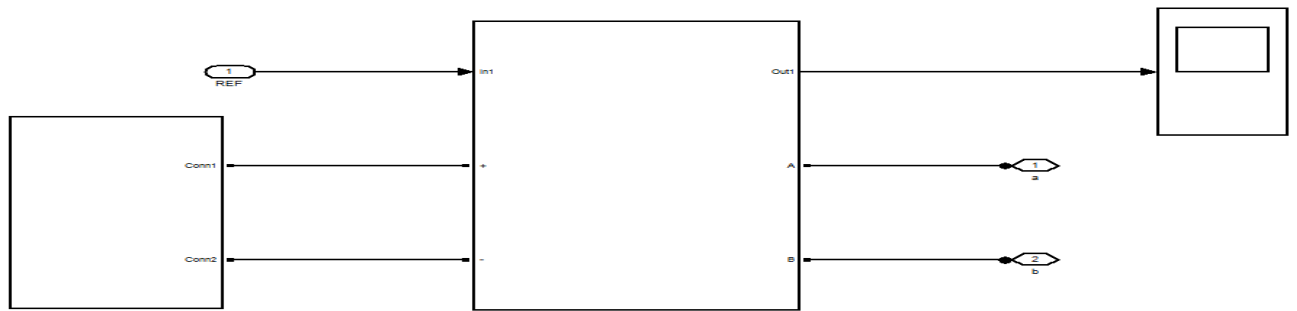
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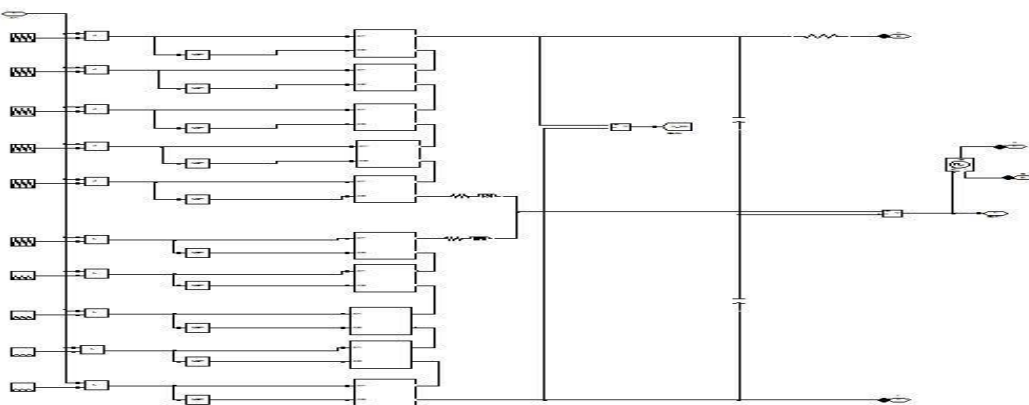
**TABLE 1- Parameter used for the simulation**

| PARAMETER                     | VALUE    |
|-------------------------------|----------|
| Lline                         | 15mH     |
| Rline                         | 1ohm     |
| Lfilter                       | 5mH      |
| Transformer primary voltage   | 600 V    |
| Transformer secondary voltage | 600 V    |
| Switching frequency           | 2kHz     |
| Load active Power             | 50kW     |
| Load reactive Power           | 34.8kVAR |
| Target PF                     | 0.94     |
| DC link Voltage               | 2000V    |



**Fig.5** Simulation schematic of MMC connected WECS.

This Fig.5 represents the combined structure of the wind sources and the multilevel inverter based on the MMC topology for better power quality in the distribution line. The output of the above model is shown in Fig. 10 given below in this research paper.



**Fig.6** Simulink structure of the MMC based Inverter.

Here in this Fig.6 submodules are connected together to form 11 level Inverter which is capable to improve power quality without externally connected STATCOM. Each submodule has two complementary switches to generate 11 level output of multilevel inverter.



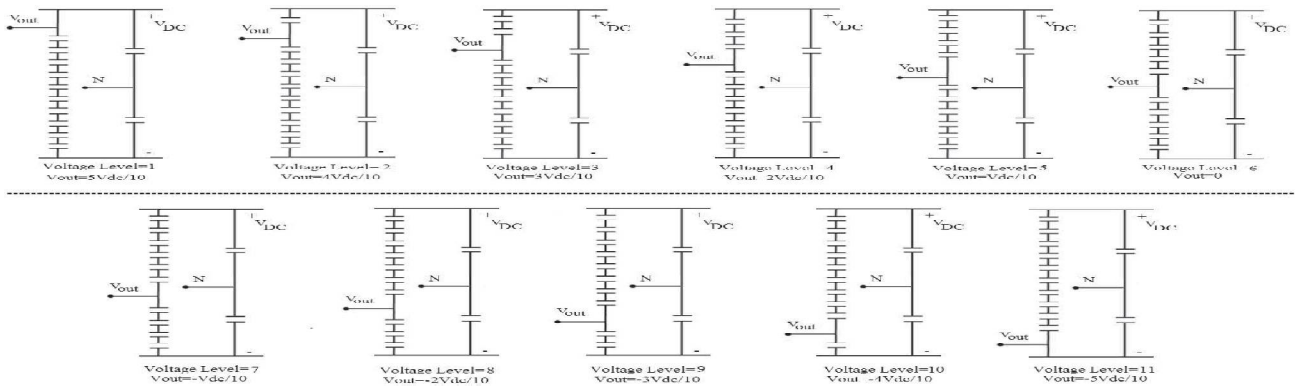


Fig. 7. Selection of SMs' capacitors for different voltage levels.

In this Fig.7 shown the basic working principle of the MMC topology multilevel inverter, by above configurations of circuit the output waveform is produces in multilevel .For in this paper the above figure illustrate the 11 level waveform generation through various combination of the MMC topology circuit to produce output power of the multilevel inverter.

## V. SIMULATION RESULT

The result of this proposed model of multilevel inverter power factor of out voltage should be near 1, and here the proposed system MATLAB/SIMULINK output waveform power factor is .94 shown in Fig. which very near to 1 . Also the various output like output voltage, output current at the source and load is shown in Fig. By using the MOSFET switches instead of IGBTs and less number of switches in the designing of MMC based topology, the efficiency of simulated system is high with reference to [6].The expected output for all the power quality issues is obtained using above strategy and after modelling of system in simulation software. The main motive above operation proposed system is to improve power factor that is obtain by pulse with modulated MMC based multilevel inverter with using any additional device .Fig.6 shows the t simulation structure MMC and its output a simulation model is shown in Fig.9. The simulation out of PMSG wind turbine is shown in Fig.8.The Simulink result of PWM including the Power Factor output is shown in Fig 10.And the measurement of Active and Reactive Power output waveform shown in Fig 11.

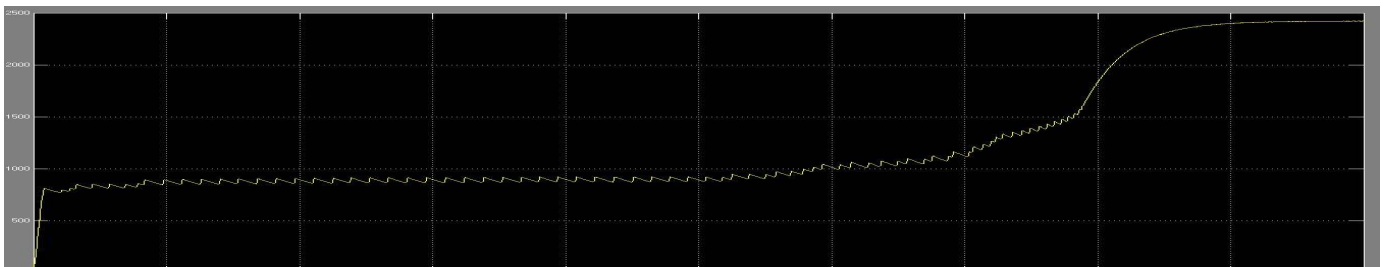
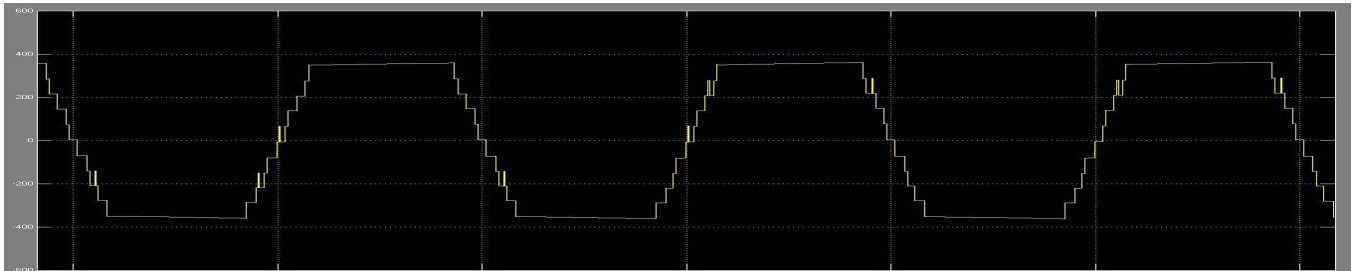


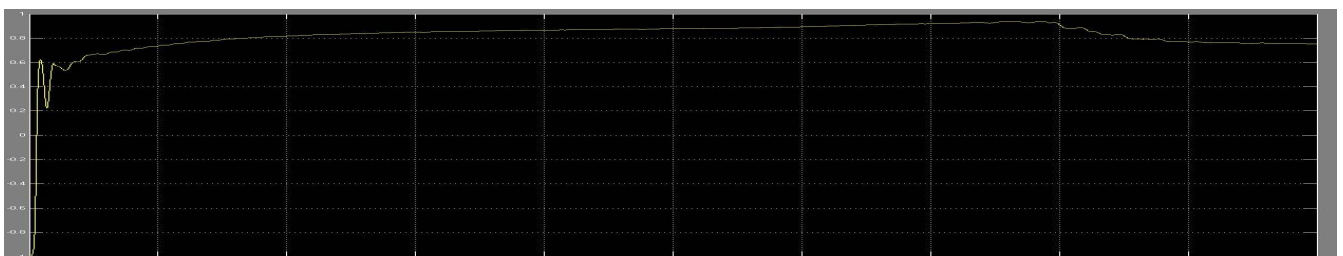
Fig.8 simulation o/p active power of wind turbine.

In this Fig.8 shown the PMSG wind turbine output is reaching to 2500 with respect to time.it initially fluctuate but after sometimes reaching towards the fixed value and at that time the power factor also gets fixed.



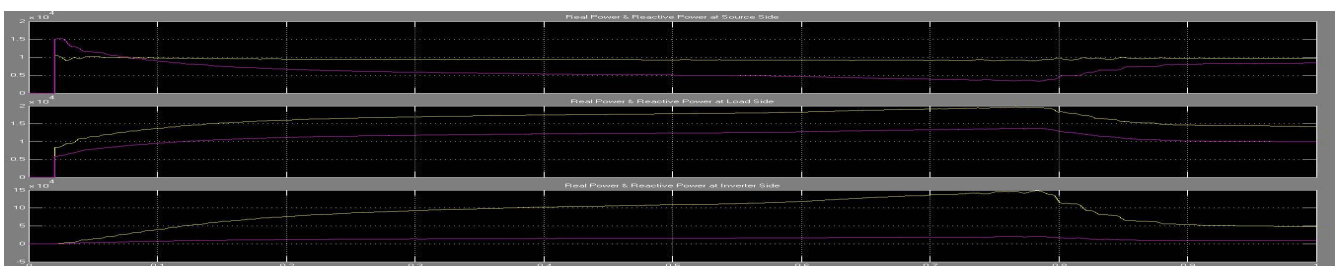
**Fig 9** Output of MMC topology based 11 level inverter.

This Fig.9 shows 11 levels of inverter out that completed 11 levels between +600V to -600V. And power factor of this voltage is controlled by PWM controllers as implemented is designed system.



**Fig 10** Power factor value 0.94 achieved in Simulink model.

The output waveform shown in this Fig.10 represents the power factor which is improved and reached at 0.94. And because of this power factor ultimately the reactive power is also compensated as desired.



**Fig 11** Real power and Reactive power near source side, load side and near inverter side.

This Fig. 11 output waveform represents improve power quality at the end of source side, load side and at end of the inverter. At each end the reactive power is compensated and real power get enhanced.

## VI. CONCLUSION AND FUTURE SCOPE

In this paper the Modular multilevel converter topology is used to design 11 level inverter having D-STATCOM feature and the proposed system has a PWM control strategy to suppress the reactive power and enhance the active power. In this grid connected system the inverter with FACTS capability in a single unit without any additional cost. Because this design will eliminate the need of external STATCOM devices to regulate the PF of grid. The presented topology is designed for Small Scale wind energy conversion system, and applicable for small to medium power applications. The controller used in system, adjusts the active power by adjusting the power angle and reactive power is controllable by modulation index. The MMC topology efficiently improve the power quality of grid connected windmill and very useful for standalone power grid or o remote coastal area to provide balanced power. And the transmission losses or reduced by increasing the power value near 1. Future scope of this project to increase the level of inverter by increasing the level of MMC topology without making a bulky DG system and reduce the harmonics.



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And in future artificial neural network (ANN) and Fuzzy logic control technique can be used to make an intelligent DG to improve power quality.

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