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Active and Reactive Power control of a 15-level Inverter with FACTS Capability for Distributed Energy Systems

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***Abstract*-In this paper, a new single-phase wind energy inverter (WEI) with flexible Ac transmission system (FACTS) capability is presented. The proposed inverter is placed between the wind turbine and the grid, same as a regular WEI, and is able to regulate active and reactive power transferred to the grid. This inverter is equipped with distribution static synchronous compensators option in order to control the power factor (PF) of the local feeder lines. Using the proposed inverter for small-to medium- size wind applications will eliminate the use of capacitor banks as well as FACTS devices to control the PF of the distribution lines. The goal of this paper is to introduce new ways to increase the penetration of renewable energy systems into the distribution systems. I Considered a single phase voltage sources in the series RLC Branch at the grid side, similarly a single-phase asynchronous Machine are placed at Load side, the d-stastcom and Pv cell are placed in between AC Voltage source and wind turbine. In this paper modular multilevel converter is utilized to meet all the requirements of IEEE standards the total harmonics distortion (THD), Active and Reactive of the system are calculated. The proposed 15-level inverter is a single-phase wind energy inverter is placed between the wind turbine and the grid, The function of inverter can manage active and reactive power transfer to the grid and wind turbine, as well as keeping Pf constant at wind turbine. Active and Reactive power from the grid, Turbine and inverter side was calculated, and also calculated line voltage of wind turbine and Inverter. The simulation Results of a 15-level inverter have been done in MATLAB/Simulink.**

Keywords: Modular multilevel converter (MMC), multilevel inverter (MLI), Wind energy inverter (WEI)

I. INTRODUCTION

Power electronics is the major field in electrical and electronics engineering which are used in semiconductor devices to convert power from the source to the corresponding load requirement. The load may be differs according to its applications i.e. DC or AC, single and three phase and also depends upon its isolation. Mainly used power source are AC and DC source, batteries, solar panel, generators and also for commercial uses. Single and three phase are having line frequency about 50 or 60 HZ. Power converters are used here to convert the power from source to the form required by the load. The commonly used power converters are AC-DC converter, a DC-DC converter, a DC-AC inverter or an AC-AC converter depending on the application.

II. CASCADED H BRIDGE MULTILEVEL INVERTER

INVERTER

An electrical device that converts DC to AC current is called Inverter. In home inverter is used for back up process. It is also used in aircraft for converting direct current to alternative current. In general, AC power is commonly used in applications like radio, radar, motor etc.

MULTILEVEL INVERTER

Now a days the industrial needs are raised to have high power in their applications. But still some appliances power requirement is medium or low to run their operation. By using high power in all industries load is good for only some motors which requires high power. But it will damage the other loads. Because applications that run on medium power source requires only medium voltage. Hence multi level inverter has introduced in 1975 to have both high and medium.

DC-AC INVERTER

The basic need of multilevel inverter is to have high power output from medium voltage. Some of the medium voltage sources are batteries, super capacitors, solar panel are medium voltage source. These inverters consist of number of switches. These switches angle arrangement in an inverter is the most important while designing.
Multilevel inverters are three types.
1) Diode clamped multilevel inverter
2) Flying capacitors multilevel inverter
3) Cascaded H- bridge multilevel inverter

The five level multilevel inverter of diode clamped uses diode, switches, and one capacitor is used. So that the output voltage is half of the supply voltage DC. The 9 level inverter consists of elements like diodes, capacitors and switches. In this inverter the output voltage is more than five level inverter.

III.FIFTYTEEN LEVEL CASCADED H-BRIDGE MULTI STRUCTURE DIODE CLAMPED MULTILEVEL INVERTER

The diode clamped multilevel inverter provides multiple voltage level by the use of diode through the capacitor bank which are connected in series. The stress of the electrical devices is reduced by transferring limited level of voltage in diode. The input DC voltage is the half of the maximum output voltage. This is the disadvantage of the diode clamped multilevel inverter. This drawbacks can be overcomes by increasing the diode, switches and capacitors. The high efficiency is provided by this type of inverter due to the fundamental frequency for all switching devices. It is the easy method for the back to back power transfer topology. The five level multilevel inverter of diode clamped uses diode, switches, and one capacitor is used. So that the output voltage is half of the supply voltage DC. The 9 level inverter consists of elements like diodes, capacitors and switches. In this inverter the output voltage is more than five level inverter.

FLYING CAPACITORS MULTILEVEL INVERTER:

The concept of multi inverter with flying capacitor use capacitors. It is connected in series with the switching cell of capacitor clamped. The capacitor will transfer little amount of voltage to electrical devices. The switching state of this inverter is same as the diode clamped multilevel inverter. The output voltage is determined by half of the input DC voltage. This is the disadvantage of multi-level inverter with flying capacitor. It balance the switching redundancy of the flying capacitor. It also controls active and reactive power which flows in a circuit. Switching losses occurs due to high frequency switching. Here switches and capacitors only used.

CASCADED H-BRIDGE MULTILEVEL INVERTER:

In H-Bridge cascaded multi level inverter less number of switches are used and the inverter use capacitor and switches for the designing process. This method in multi level inverter includes power conversion cells that are connected in series and power is scaled. The combined capacitors and switches make H-Bridge. Each H-Bridge inverter supplied with separate DC supply. H-Bridge inverter consists of cells where each cell consists of zero voltage, positive DC voltage and negative DC voltage. Compared with other type multi level inverter like diode clamped and flying capacitor, H-Bridge has the advantage of having fewer components.

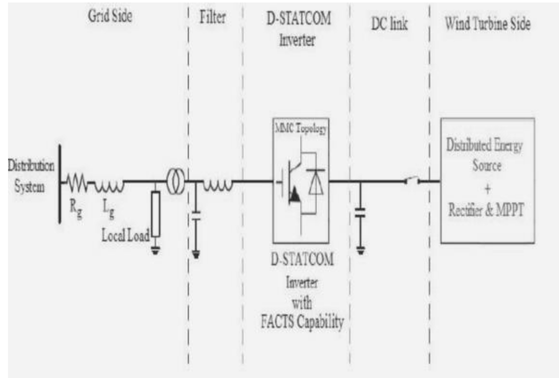

Fig. 1. Complete configuration of the proposed inverter with FACTS capability.

In this paper, the proposed WEI utilizes MMC topology, which has been introduced recently for HVDC applications. Replacing conventional inverters with this inverter will eliminate the need to use a separate capacitor bank or a STATCOM device to fix the PF of the local distribution grids. Obviously, depending on the size of the power system, multiple inverters might be used in order to reach the desired PF. The unique work in this paper is the use of MMC topology for single phase voltage-source inverter, which meets the IEEE standard 519 requirements, and is able to control the PF of the grid regardless of the wind speed Fig. 1 shows the complete grid connected mode configuration of the proposed inverter. The dc link of the inverter is connected to the wind turbine through a rectifier using MPPT and its output terminal is connected to the utility grid through a series-connected second-order filter and loads and the Ac Synchrocus machine.

MODULAR MULTILEVEL CONVERTER

MMC has gained increasing been recently. A number of papers were published on the structure, control, and application of this topology, but none has suggested the use of that for inverter + DSTATCOM application. This topology consists of several half-bridge (HB) sub modules (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 SMs and two buffer inductors. Each SM possesses two semiconductor switches, which operate in complementary mode, and one capacitor. The exclusive structure of MMC becomes it an ideal candidate for medium-to-high-voltage applications such as wind energy applications. Moreover, this topology needs only one dc source, which is a key point for wind applications. MMC requires large capacitors which may increase the cost of the systems; however, this problem is offset by the lack of need for any snubber circuit. Figure 2: Structure of a single-phase MMC inverter structure. The main benefits of the MMC topology are: modular design based on identical converter cells, simple voltage scaling by a series connection of cells, simple

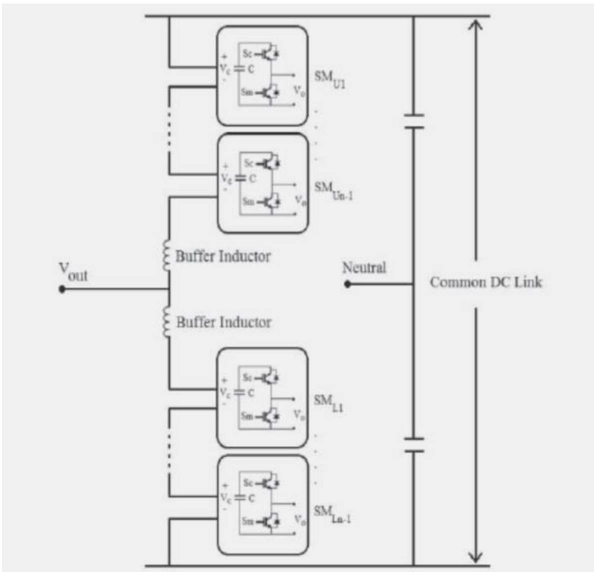

Figure 2: Structure of a single-phase MMC inverter structure.

Applications such as wind energy applications. Moreover, this topology needs only one dc source, which is a key point for wind applications. MMC requires large capacitors which may Increase the cost of the systems; however, this problem is offset by the lack of need for any snubber circuit. The main benefits of the MMC topology are: modular design based on identical converter cells, simple voltage scaling by a series connection of cells, simple realization of redundancy, and possibility of a common dc bus. Fig. 2shows the circuit configuration of a single-phase MMC and the structure of its SMs consisting of two power switches and a floating capacitor. The output voltage of each SM (*vo)* is either equal to its capacitor voltage (*vc)* or zero, depending on the switching states. The buffer inductors must provide current control in each phase arm and limit the fault currents.

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:

$$V_{UpperArm} = \sum_{i=1}^{n-1} (s_{ui} v_{ci}) + v_{11} \qquad (1)$$

$$V_{UpperArm} = \sum_{i=1}^{n-1} (s_{li} v_{ci}) + v_{12} \qquad (2)$$

where *v*11 and *v*12 are the voltages of the upper and lower buffer inductors, *n* is the number of voltage levels, and *v*ci is the voltage of the *i* th SMs capacitor in upper arm or lower arm. A single-phase 15-levelMMC inverter consists of 20 SMs which translates to 40 power switches, 20 capacitors, and 2 buffer inductors. The dc and ac voltages of the 15-level MMC are described by

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

$$= \sum_{i=1}^{10} (S_{ui} V_{ci}) + \sum_{i=1}^{10} (S_{ui} V_{ci}) + (V_{11} + V_{12}) \qquad (3)$$

$$V_{out} = \frac{V_{DC}}{2} - V_{UpperArm} = -\frac{V_{DC}}{2} + V_{lowerArm} \qquad (4)$$

PROPOSED CONTROL STRATEGY

The proposed controller consists of three major functions. The first function is to control the active and reactive power

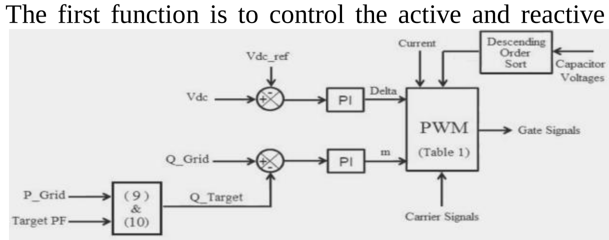

Fig 3 Schematic of the Proposed Controller System.

Transferred to the power lines, the second function is to keep the voltages of the SMs' capacitors balanced, and the third function is to generate desired PWM signals. Fig. 2 shows the complete proposed controller system. The aim of the designed inverter is to transfer active power coming from the wind turbine as well as to provide utilities with distributive control of volt-ampere reactive (VAR) compensation and PF correction of feeder lines. The application of the proposed inverter requires active and reactive power to be controlled fully independent, so that if wind is blowing, the device should be working as a normal inverter plus being able to fix the PF of the local grid at a target PF (D-STATCOM option), and if there is no wind, the device should be only operating as a D-STATCOM (or capacitor bank) to regulate PF of the local grid. This translates to two modes of operation: 1) when wind is blowing and active power is coming from the wind turbine: the inverter plus D-STATCOM mode. In this mode, the device is working as a regular inverter to transfer active power from the renewable energy source to the grid as well as working as a normal D-STATCOM to regulate the reactive power of the grid in order to control the PF of the grid and 2) when wind speed is zero or too low to generate active power: the D-STATCOM mode. In this case, the inverter is acting only as a source of reactive power to control the PF of the grid, as a D-STATCOM. This option eliminates the use of additional capacitor banks or external STATCOMs to regulate the PF of the distribution feeder lines. Obviously, the device is capable of outputting up to its rated maximum real power and/or reactive power, and will always output all real power generated by the wind turbine to the grid. The amount of reactive power, up to the design maximum, is dependent only on what the utility asks the device to produce.

Generally, (5) and (6) dictate the power flow between a STATCOM device and power lines

$$P_s = -\frac{E_S E_L}{X}\sin\delta \qquad (5)$$

$$Q_S = -E_S E_L \cos\delta - E_L^2 \qquad (6)$$

Where *X* is the inductance between the STATCOM (here as inverter) and the grid which is normally considered as output filter inductance added to the transmission line inductance. The root mean square (RMS) voltage of the STATCOM (= inverter) is given as *Es* and is considered to be out of phase by an angle of δ to the RMS line voltage *E*1. In the proposed control strategy, active and reactive power transferred between the inverter and the distribution grid is controlled by selecting both the voltage level of the inverter and the angle δ between the voltages of inverter and grid, respectively. The amplitude of the inverter voltage is regulated by changing the modulation index *m* and the angle δ by adding a delay to the firing signals which concludes.

$$P_S = -\frac{mE_S E_L}{X}\sin\delta \qquad (7)$$

$$Q_S = -\frac{mE_S E_L \cos\delta - E_L^2}{X} \qquad (8)$$

In this paper, *m* is the key factor to control the reactive power compensation and its main task is to make the PF of the grid equal to the target PF. δ is the control parameter to adjust the active power control between the inverter and the grid. Several assumptions should be considered for the proposed controllers which are as: 1) the load on the feeder line should be considered fixed for a small window of time and there is no change in the load during a cycle of the grid frequency; 2) the feeder line can be accurately modeled as a constant *P*, *Q* load. This means that the power produced by a wind turbine will displace other power on the feeder line and not add to it; and 3) although making a change in *m* or δ has effect on both (7) and (8), it is assumed that a change in the modulation index will predominantly affect *Q*, while a change in delta will predominantly affect *P*. Any effect on *Q* from a small change in delta is thus ignored. This results in controlling *P* and *Q* independently. Equation (9) shows the relation between the target reactive power and the target PF

$$P_G = \left(\sqrt{P_G^2 + Q_T^2}\right) \times PF_T \qquad (9)$$

where *PG* is the amount of active power on the grid, *QT* is the target amount of reactive power, and PFT is the target PF desired by the utility. So, *QT* can be calculated as

$$Q_T = \sqrt{\left(\frac{P_G}{PF_T}\right)^2 - P_G^2} \qquad (10)$$

Using (9) and (10), the target reactive power for the grid is Determined and is compared with the actual value of the reactive power of the grid. Using a PI compensator will determine the desired value for the modulation index. The power angle is also determined by comparing the actual dc voltage of the inverter with a reference value. A PI compensator determines the desired value for the power angle.

Table 1 Parameters used for the simulation

Parameter	**Value**
L_{Line}	15mh
R_{Line}	1ohm
L_{Filter}	5mh
Transformer primary voltage	1200v
Transformer secondary voltage	600v
Switching frequency	2KHZ
Load active power	50KW
Load reactive power	34.8 KVAR
Target PF	0.90
DC link Voltage	2000v

The goal is to assess the behavior of the control system in the worst conditions. Table 1shows the values of the parameters used for the simulation.
Before *t* = 6 s, there is no wind to power the wind turbine; therefore, the dc link is open-circuited.

Single-phase H-Bridge 15-level inverter with FACTS Capability for Distributed Energy System

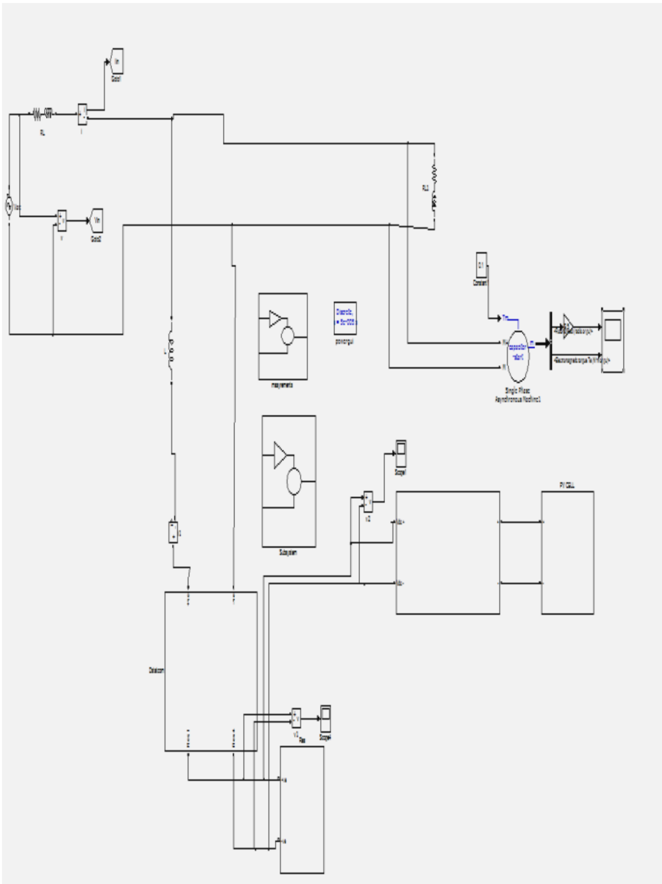

Fig 4 Simulation Diagram of 15-Level Inverter

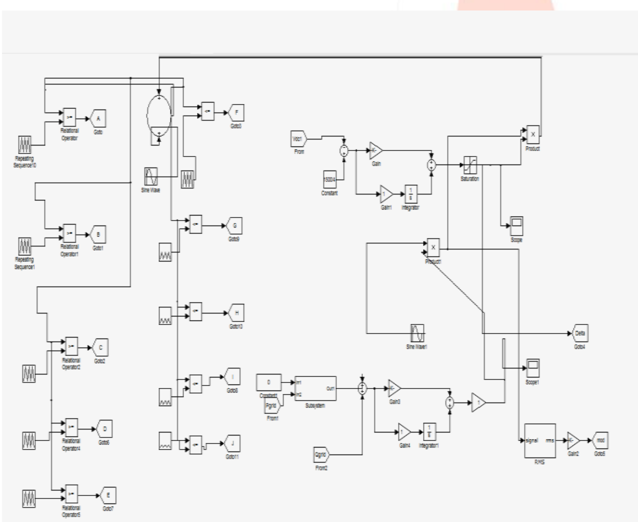

Fig 5.Schematic of the Proposed Controller system of 15-Level Inverter

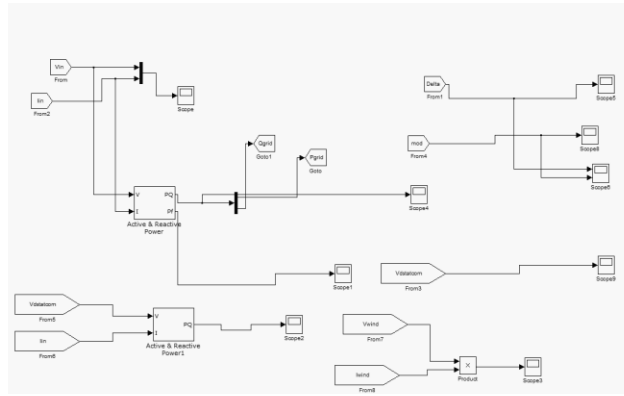

Fig 6 Simulation for All the Measurements of 15-Level Inverter

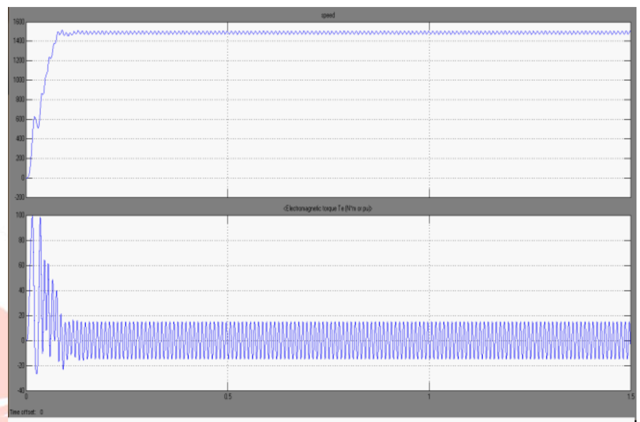

Fig 7 Speed and Electromagnetic Torque

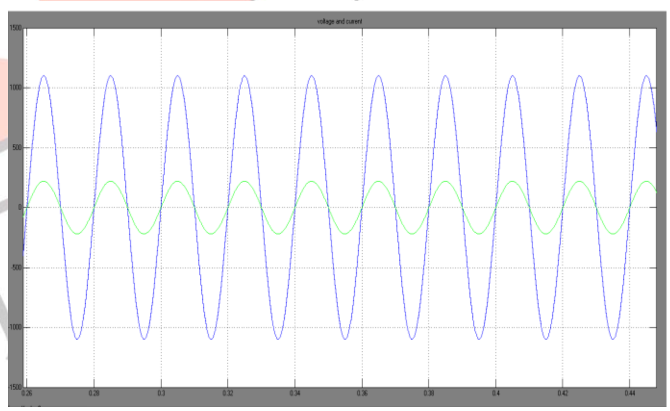

Fig 8 Simulation graph of the Line Voltage for 15-Level Inverter

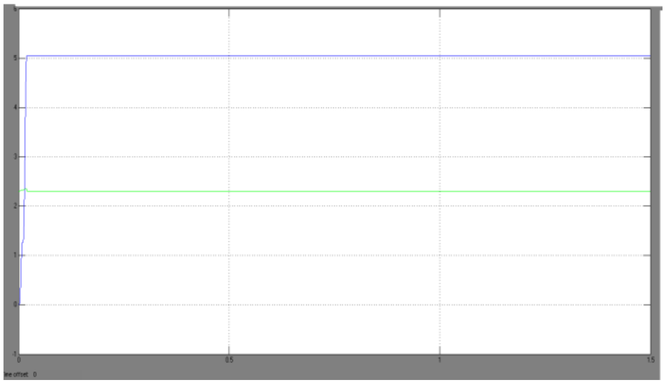

Fig 9 Simulated Active and Reactive Power of the Grid of 15-Level Inverter

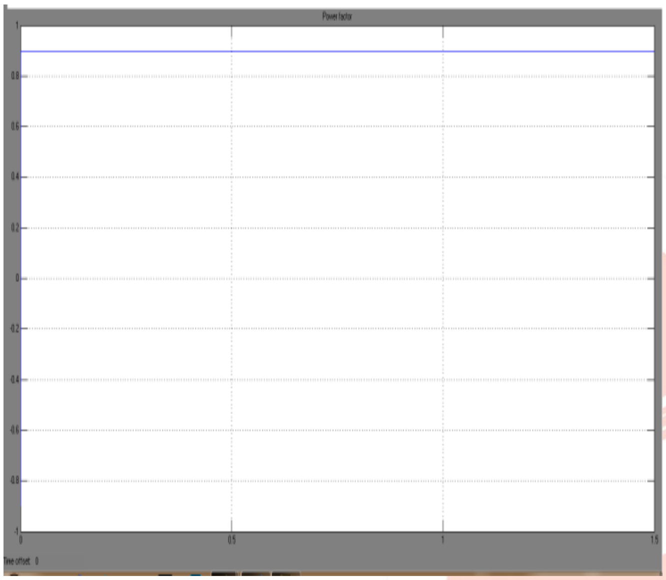

Fig 10 Power Factor of the Grid of 15-Level

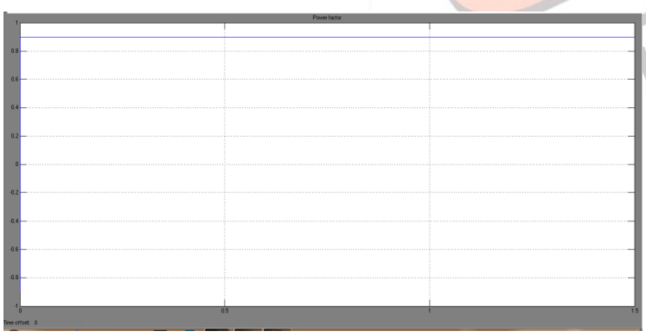

Fig 11 Active and Reactive Power of the Inverter of 15-Level Inverter

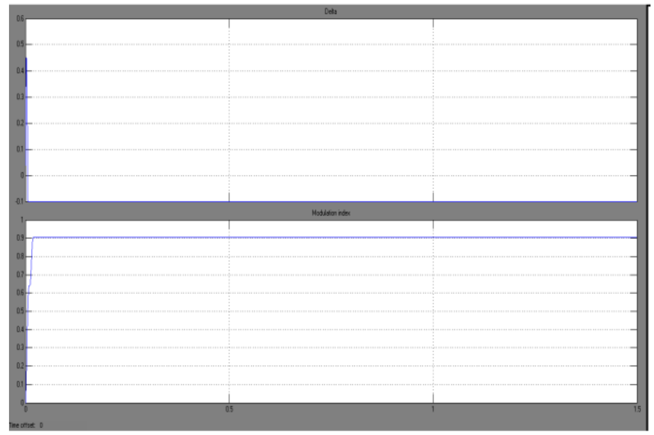

Fig 12 Simulated Delta and Modulation index of the 15-level Inverter

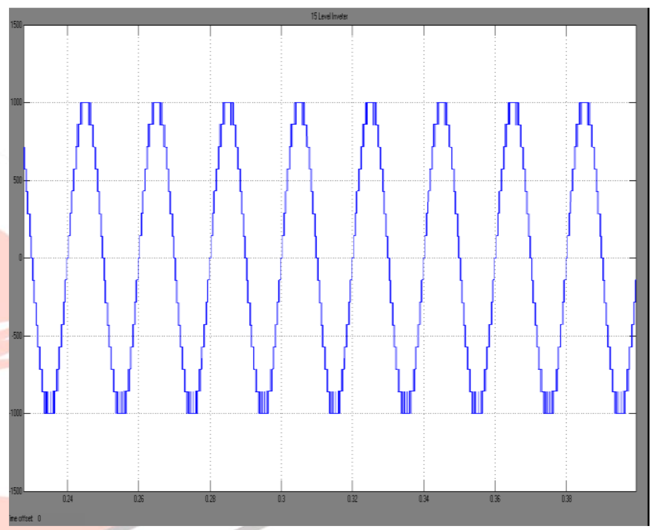

Fig 13 Simulated Output Voltage of 15-Level Inverter

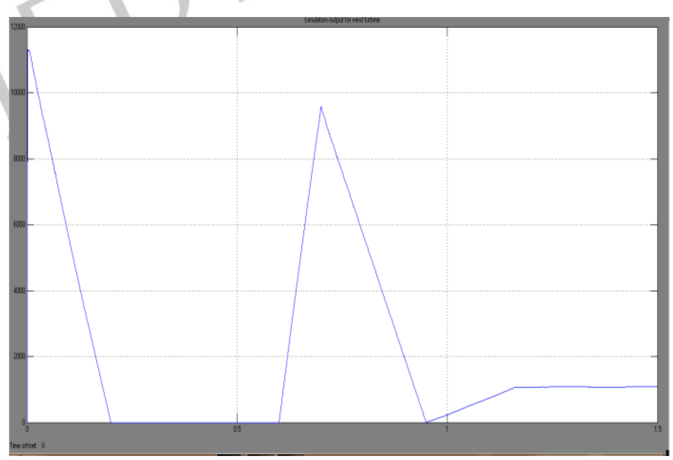

Fig 14 Simulated output active power from the wind turbine of 15-Level Inverter

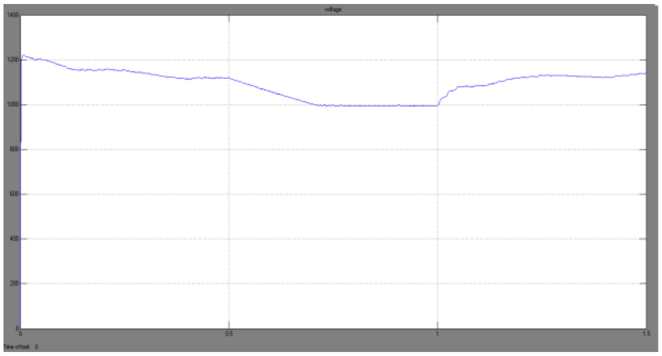

Fig 16 Simulated output Line Voltage of wind turbine for 15-Level Inverter

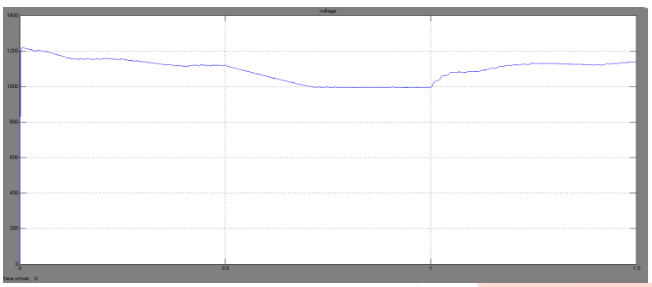

Fig 17 Simulated output Voltage of PV-cell in 15-level Inverter

CONCLUSION

In this paper, the concept of a new multilevel inverter with FACTS capability for small-to-mid-size wind turbine was preferred. The proposed system demonstrates the application of a new inverter with FACTS capability in a single unit without any additional cost. Replacing the Asynchronous machine and PV cell with the proposed inverter will eliminate the need of any external STATCOM devices to regulate the PFof the grid. Clearly, depending on the size of the compensation, multiple inverters may be needed to reach the desired PF. This shows a new way in which distributed renewable sources can be used to provide control and support in distribution systems. The proposed controller system adjusts the active power by changing the power angle (delta) and the reactive power is controllable by the modulation index *m*. The simulation results for an 15-level inverter are presented in MATLAB/Simulink.

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