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Control and Design of an 11-Level MMI Connected through a Wind Energy Source System

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ABSTRACT: In this paper, a brand new single-phase wind energy system (WES) with versatile AC transmission is conferred. The planned 11- level inverter is placed between the turbine and therefore the grid, same as an everyday inverter, and is in a position to manage active and reactive power transferred to the grid. This inverter is supplied with distribution static synchronous compensators choice so as to regulate the power factor (PF) of the native feeder lines. During this paper, a modular multilevel converter is employed because the desired topology to satisfy all the wants of a single-phase system like compatibility with IEEE standards, total harmonic distortion (THD), efficiency, and total price of the system. The planned management strategy regulates the active and reactive power victimization power angle and modulation index, severally. The perform of the planned electrical converter is to transfer active power to the grid furthermore as keeping the PF of the local power lines constant at a target PF notwithstanding the incoming active power from the turbine. The simulations for an 11-level inverter are tried using MATLAB/Simulink

KEYWORDS: Wind Energy System, Multi modular multilevel inverter, Performance, Harmonics

I.INTRODUCTION

The role of power electronics in distribution systems has greatly raised recently. the facility electronic devices ar typically accustomed convert the nonconventional styles of energy to the acceptable energy for power grids, in terms of voltage and frequency. In permanent magnet (PM) wind applications, a consecutive convertor is generally utilised to attach the generator to the grid. A rectifier equipped with a most power point tracker (MPPT), converts the output power of the turbine to a dc power. The dc power is then born-again to the specified ac power for power lines exploitation an inverter and a transformer. With recent developments in wind energy, utilizing smarter wind energy systems (WESs) has become a crucial issue. There ar lots of single-phase lines within the us, that power tiny farms or remote homes [1], [2]. Such customers have the potential to supply their needed energy employing a small-to-medium-size turbine. Increasing the amount of small-to-medium wind turbines can create many troubles for native utilities like harmonics or power issue (PF) problems. A high PF is usually fascinating in a very installation to decrease power losses and improve voltage regulation at the load. it's typically fascinating to regulate the PF of a system to close 1.0. once reactive components offer or absorb reactive power close to the load, the apparent power is reduced. In different words, this drawn by the load is reduced, that decreases the facility losses. Therefore, the voltage regulation is improved if the reactive power compensation is performed close to giant masses. historically, utilities ought to use condenser banks to compensate the PF problems, which can increase the entire price of the system. the trendy ways in which of dominant the PF of those power lines is to use tiny distribution static synchronous compensators (D-STATCOMs). The planned inverter during this paper is supplied with a D-STATCOM choice to regulate the reactive power of the native distribution lines and might be placed between the turbine and therefore the grid, same as an everyday Wei dynasty with none extra price.

The function of the planned electrical converter isn't solely to convert dc power returning from dc link to an appropriate ac power for the most grid, however additionally to repair the PF of the native grid at a target PF by injecting enough reactive power to the grid. within the planned management strategy, the ideas of the electrical converter and therefore

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the D-STATCOM are combined to create a brand new electrical converter, that possesses FACTS capability with no extra price. The planned management strategy permits the electrical converter to act as an electrical converter with D-STATCOM possibility once there is enough wind to produce active power, and to act as a D-STATCOM once there's no wind. The active power is controlled by adjusting the ability angle δ, that is that the angle between the voltages of the electrical converter and also the grid, and reactive power is regulated by the modulation index m. There ar an outsized range of publications on integration of renewable energy systems into power systems. a listing of complete publications on FACTS applications for grid integration of wind and solar power was given in [3]. In [4], new business wind energy converters with FACTS capabilities ar introduced with none elaborated data concerning the potency or the topology used for the converters. In [5], a whole list of the foremost vital structure inverters was reviewed. Also, totally different modulation ways like curving pulsewidth modulation (PWM), selective harmonic elimination, optimized harmonic stepped undulation technique, and area vector modulation were mentioned and compared. Among all structure topologies [6]–[9], the cascaded H-bridge structure device is extremely accepted for STATCOM applications for many reasons [10]–[12]. The most reason is that it's straightforward to get a high range of levels, which may facilitate to attach STATCOM on to medium voltage grids. The standard structure device (MMC) was introduced within the early 2000s [13], [14]. Reference [15] describes a MMC device for High voltage DC (HVDC) applications. This paper principally appearance at the most circuit parts. Also, it compares 2 differing types of MMC, as well as H-bridge and full-bridge sub modules. In [9] and [16], a brand new single-phase electrical converter victimisation hybrid clamped topology for renewable energy systems is given. The planned electrical converter is placed between the renewable energy supply and also the main grid. the most downside of the planned electrical converter is that the output current has important fluctuations that aren't compatible with IEEE standards. The authors believe that the matter is expounded to the snubber circuit design.

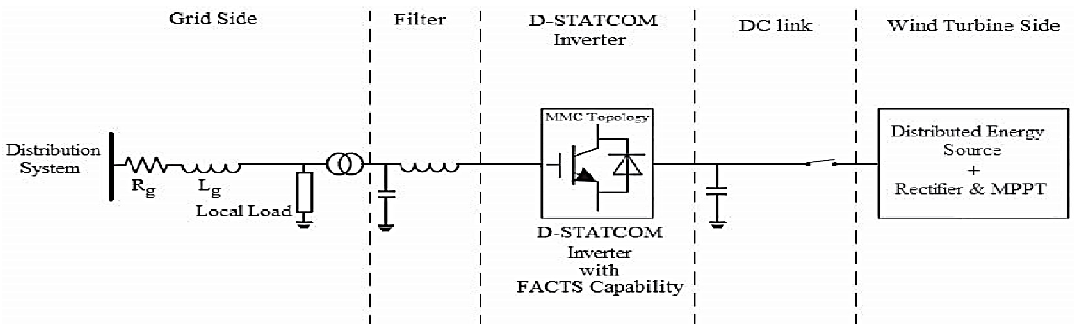

Figure 1 Equialent model of considered system

II.CONTROL OF WIND ENERGY SYSTEM

The intentions of the machine (SCIG_w) side converter are to achieve optimum torque for MPT for SCIG_w and to provide the required magnetizing current to the SCIG_w.

A. Speed-Control Loop for MPT:

In the proposed algorithm, the rotor position (θ_rw) of SCIGw besides the wind speed are sensed. The rotor speed (ω_rw) of SCIGw is dogged from its rotor position (θ_rw). The tip speed ratio (λ_w) for a wind turbine of radius (r_w) and gear ratio (η_w) at a wind speed of v_wis well-defined as [3]

$$\lambda_w = \frac{\omega_{rw} r_w}{\eta_w v_w} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Intended for MPT in the wind-turbine-generator system, the $SCIG_w$ought operate at the optimum tip speed ratio (λ_w^*)

Thus the situation rotor speed (w_{rw}^*) for MPT iscreated using equation (1) as

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$$\lambda_w^* = \frac{\omega *_{rw} r_w}{\eta_w v_w} \ldots\ldots\ldots\ldots\ldots(2)$$

The flow chart diagram for the anticipated MPT system is given in Fig.2

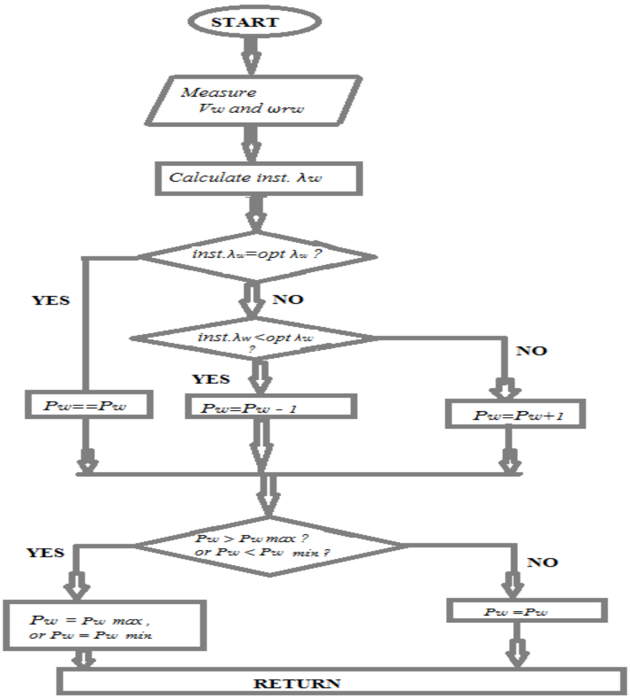

Fig.2. Flow chart diagram of MPT technique.

B. Reference q-axis SCIG$_w$ Stator-Current Generation

The situation rotor speed of $SCIG_w$is compared with $(\omega_{rw})$to calculate the rotor-speed error (ω_{rwer}) at the n^{th} samplinginstant as[24]

$\omega_{rwer(n)} = \omega^*_{rw(n)} - \omega^*_{rw(n)}$(3)

The above-mentioned error is fed to the speed proportional integral (PI) controller. At the n^{th}sampling instant, the productivity of the speed PI controller with proportional gain $K_{p\omega}$and integral gain $K_{i\omega}$gives the reference q-axis $SCIG_w$stator current (I^*_{qsw}).

C. Reference d-axis SCIG$_w$ Stator-Current Generation

The reference d-axis $SCIG_w$ stator current (I^*_{dsw}) is resolutefrom the rotor flux set point ($\varphi^*{}_{drw}$) at the n^{th} samplinginstant as [23]

$I^*_{dsw(n)} = \frac{\varphi^*_{drw}}{L_{mw}}$ (4)

Where $L_{mw}$is the magnetizing inductance of $SCIG_w$

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D. Generation of PWM Signal for machine side converter:

For generation of three-phase reference $SCIG_w$ stator currents (i^*_{swa}, i^*_{swb}, and i^*_{swc}), the transformation angle $\theta_{rotorflux\,w}$ is[25]

$$\theta_{rotor\ flux\ w} = \theta_{slip\ w} + \left(\frac{pw}{2}\right)\theta_{rw} \qquad (5)$$

The references for d-q components of $SCIG_w$ stator currents are converted as

$$i^*_{swa} = I^*_{dsw}\sin(\theta_{rotor\ flux\ w}) + I^*_{qsw}\cos(\theta_{rotor\ flux\ w}) \qquad (6)$$

$$i^*_{swb} = I^*_{dsw}\sin(\theta_{rotor\ flux\ w} - {}^{2\pi}/_{3}) + I^*_{qsw}\cos(\theta_{rotor\ flux\ w} - {}^{2\pi}/_{3}) \qquad (7)$$

$$i^*_{swc} = I^*_{dsw}\sin(\theta_{rotor\ flux\ w} + {}^{2\pi}/_{3}) + I^*_{qsw}\cos(\theta_{rotor\ flux\ w} + {}^{2\pi}/_{3}) \qquad (8)$$

The three-phase reference $SCIG_w$ stator currents (i^*_{swa}, i^*_{swb}, and i^*_{swb}) are then compared with the sensed $SCIG_w$ stator currents (i_{swa}, i_{swb} and i_{swc}) to total the SCIG*w* stator current errors, and these current errors are amplified with gain (K = 5) and the amplified signals are related with a fixed frequency (10 kHz) triangular carrier wave of unity amplitude to cause gating signals for the IGBTs of the machine-side VSC. The sampling time of the controller is taken as 50 μs, as this time is sufficient for completion of calculations in a typical DSP controller. The total control mechanism of machine side converter is shown in Fig.3.

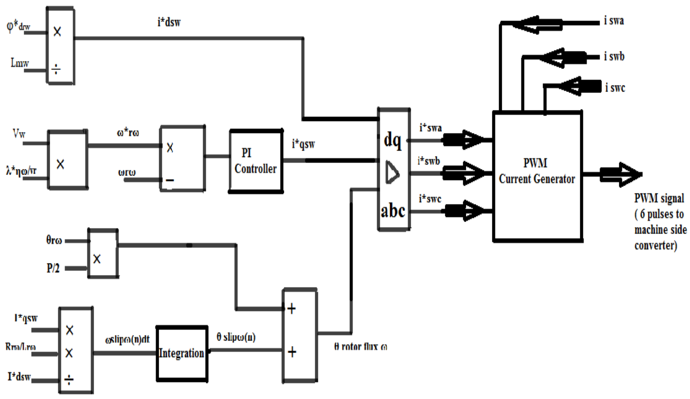

Figure 3 Control of Machine side converter

III. MODULAR MULTILEVEL CONVERTER

MMC has gained increasing attention recently. A number of papers were published on the structure, control, and application of this topology [21], [22], but none has suggested the use of that for inverter + D-STATCOM application. This topology consists of several half-bridge (HB) submodules (SMs) per each phase, which are connected in series. An *n*-level singlephase 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

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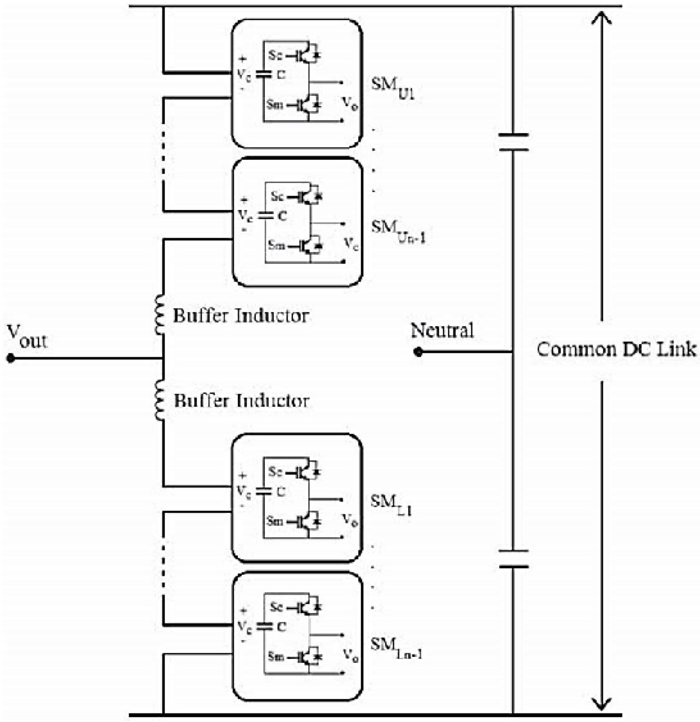
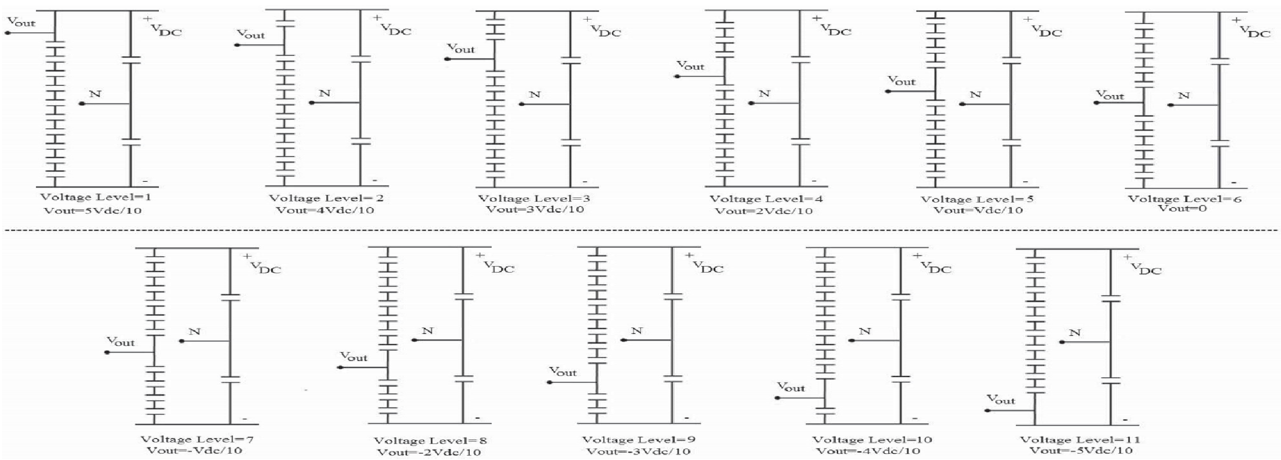


Fig. 4. Structure of a single-phase MMC inverter structure.

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. 4 shows 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 (v_o) is either equal to its capacitor voltage (v_c) or zero, depending on the switching states. The buffer inductors must provide current control in each phase arm and limit the fault currents. To describe the operation of MMC, each SM can be considered as a twopole switch. If S_{ui}, which is defined as the status of the *i*th submodule in the upper arm, is equal to



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unity, then the output of the i^{th} SM is equal to the corresponding capacitor voltage; otherwise it is zero. Likewise, 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.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 I, all the upper SMs should be OFF and all the lower SMs should be ON, which translates to the fact that the main switches Sm of all upper SMs and the auxiliary switches (Sc) 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 applied only to the ten lower capacitors, so that the output voltage is vDC/2. Fig. 5 illustrates the selection of capacitors for different voltage levels shown in Table I.

TABLE I

OPERATING REGIONS FOR AN 11-LEVEL MMC INVERTER

Voltage level	Status	$n_{UpperArm}$	$n_{lowerArm}$	V_{out}
1	$v_r \geq v_{c1}, v_{c2}, v_{c3}, v_{c4}, v_{c5}, v_{c6}, v_{c7}, v_{c8}, v_{c9}, v_{c10}$	0	10	$5v_{dc}/10$
2	$v_r < v_{c1}$ $v_r \geq v_{c2}, v_{c3}, v_{c4}, v_{c5}, v_{c6}, v_{c7}, v_{c8}, v_{c9}, v_{c10}$	1	9	$4v_{dc}/10$
3	$v_r < v_{c1}, v_{c2}$ $v_r \geq v_{c3}, v_{c4}, v_{c5}, v_{c6}, v_{c7}, v_{c8}, v_{c9}, v_{c10}$	2	8	$3v_{dc}/10$
4	$v_r < v_{c1}, v_{c2}, v_{c3}$ $v_r \geq v_{c4}, v_{c5}, v_{c6}, v_{c7}, v_{c8}, v_{c9}, v_{c10}$	3	7	$2v_{dc}/10$
5	$v_r < v_{c1}, v_{c2}, v_{c3}, v_{c4}$ $v_r \geq v_{c5}, v_{c6}, v_{c7}, v_{c8}, v_{c9}, v_{c10}$	4	6	$v_{dc}/10$
6	$v_r < v_{c1}, v_{c2}, v_{c3}, v_{c4}, v_{c5}$ $v_r \geq v_{c6}, v_{c7}, v_{c8}, v_{c9}, v_{c10}$	5	5	0
7	$v_r < v_{c1}, v_{c2}, v_{c3}, v_{c4}, v_{c5}, v_{c6}$ $v_r \geq v_{c7}, v_{c8}, v_{c9}, v_{c10}$	6	4	$-v_{dc}/10$
8	$v_r < v_{c1}, v_{c2}, v_{c3}, v_{c4}, v_{c5}, v_{c6}, v_{c7}$ $v_r \geq v_{c8}, v_{c9}, v_{c10}$	7	3	$-2v_{dc}/10$
9	$v_r < v_{c1}, v_{c2}, v_{c3}, v_{c4}, v_{c5}, v_{c6}, v_{c7}, v_{c8}$ $v_r \geq v_{c9}, v_{c10}$	8	2	$-3v_{dc}/10$
10	$v_r < v_{c1}, v_{c2}, v_{c3}, v_{c4}, v_{c5}, v_{c6}, v_{c7}, v_{c8}, v_{c9}$ $v_r \geq v_{c10}$	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	$-5v_{dc}/10$

.

IV. CONTROL STRATEGY FOR INVERTER

The proposed controller consists of three major functions. The first function is to control the active and reactive power 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. 3 shows the complete proposed controller system.

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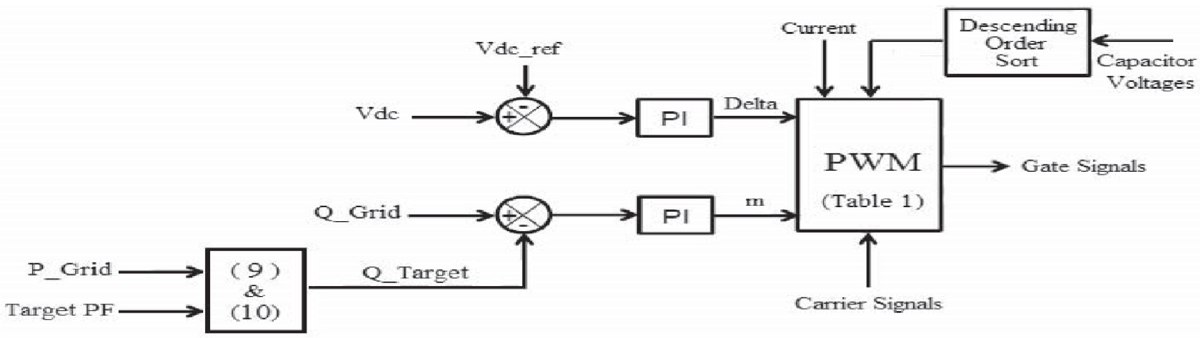

Figure 6 Control proposed

V. SIMULATION RESULTS

The design of an 11-level MMC inverter was carried out in MATLAB/Simulink.

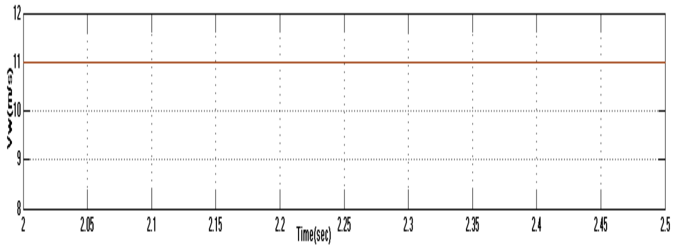

Figure 7 Wind velocity

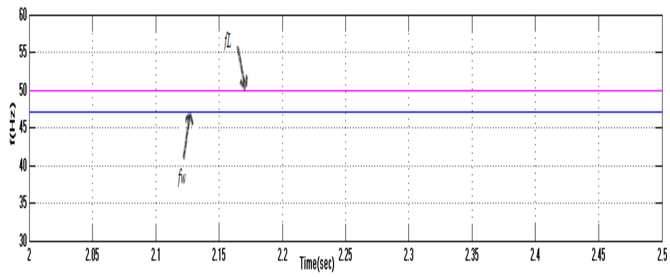

Figure 8 Generator frequency and Grid side frequency

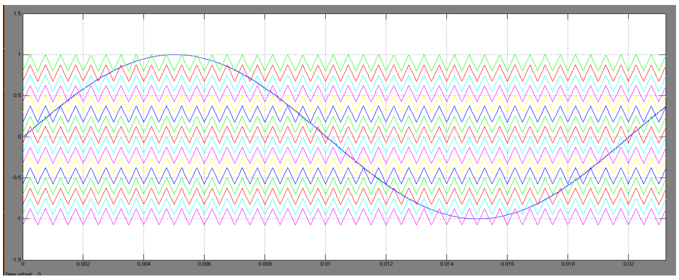

Figure 9 PWM signals (Both refernce wave and Carrier wave)

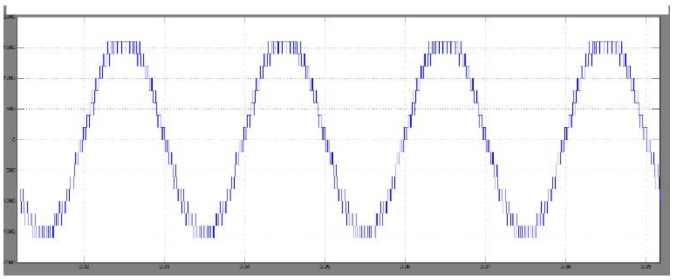

Figure 10 Inverter output voltage

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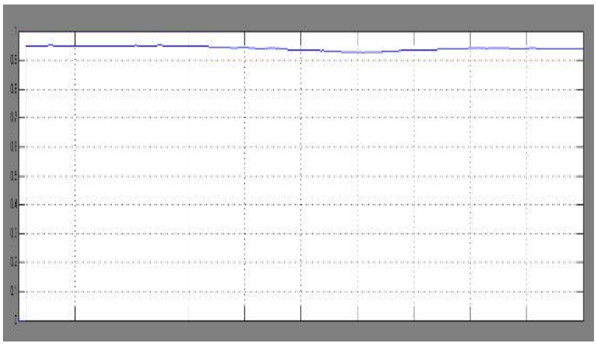

Figure11. Grid side voltage and current wave forms

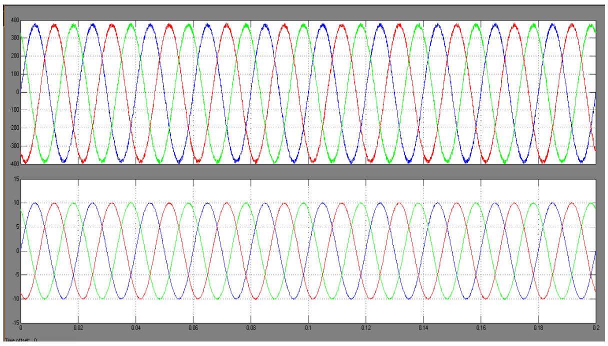

Figure 12. power facor

The above wave forms shows the results of the simulation performed. Figure 7 shows the constant wind velocity due to pitch angle control and the fig.8 shows the generator and grid frequencies maintain constant and fig.9 and fig.10 shows the reference and carrier signals used to generate the pulses and fig.11 and fig.12 shows the grid voltages ,currents and power factor.

VI. CONCLUSION

In this paper, the concept of a new multilevel inverter with FACTS capability for small-to-mid-size wind installations is presented. The proposed system demonstrates the application of a new inverter with FACTS capability in a single unit without any additional cost. Replacing the traditional renewable energy inverters with the proposed inverter will eliminate the need of any external STATCOM devices to regulate the PF of 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 simulation results for an 11-level inverter are presented in MATLAB/Simulink

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