IMPROVEMENT OF VOLTAGE STABILITY IN VARIABLE SPEED WIND ENERGY CONVERSION SYSTEMS USING STATCOM

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ABSTRACT-In this paper voltage stability in Grid connected variable speed wind energy conversion systems using statcom is proposed. Grid connected Variable Speed Wind Turbines (VSWT) may cause voltage stability problems which results in islanding of the generator from the grid. Voltage stability is a major issue to achieve the uninterrupted operation of wind farms equipped with VSWTs. In this paper the design of a Static Synchronous Compensator (STATCOM) based on Cascaded H-Bridge (CHB) – Multi Level Converter (MLC) is proposed. The dynamic behavior of 5 level and 7 level CMC based STATCOM is validated by simulation with MATLAB/SIMULINK simulation techniques. A detailed analysis of the operating characteristics of the various inverter topologies are compared in the paper. To analyze the performance of the STATCOM connected in shunt with the transmission line, an induction generator based wind farm has been considered. The complete digital simulation of the STATCOM incorporated into the power system is performed in the MATLAB/SIMULINK environment and the results are presented to validate the feasibility of the proposed topology.

KEYWORDS
Wind Farm, Induction Generator, Point of Common Coupling (PCC), Voltage Source Converter (VSC), Flexible AC Transmission Systems (FACTS), Pulse Width Modulated (PWM) inverter, Multilevel inverter.

I.INTRODUCTION

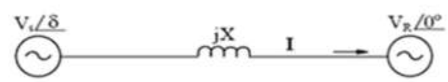
The increasing number of renewable energy sources and distributed generator requires a new strategy for operation and management of electric grid system. Today, wind energy generating system is connected into the power system to meet the consumers demand and to support the grid. However, the output power of wind generator is fluctuating and will affect operation of interconnected grid. The utility system cannot accept the new generation without the strict condition of voltage regulation due to real power fluctuation and reactive power generation/absorption. Thus addition of wind power into the grid system, affects the power quality. However, in practice the wide use of a nonlinear load connected to power distribution system or inverter based application, causes significant power quality degradation in the grid connected system in the terms of current/voltage harmonic, power factor and resonance problem. As a result of a nonlinear nature of the load, the purity of waveform of supplies may lose. Thus the power quality issue is becoming an increasingly important to the electricity consumer at all level of usages

In the event of increasing grid disturbance, a battery energy storage system for wind energy generating system is generally required to compensate the fluctuation generated by wind turbine. A STATCOM based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial wind turbines. The proposed STATCOM control scheme for grid connected wind energy generation for power quality improvement has following objectives.

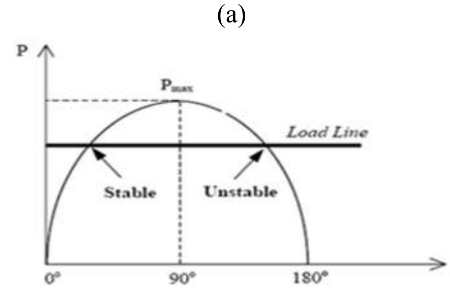
• Unity power factor at the source side.
• Reactive power support only from STATCOM to wind Generator and Load.
• Simple bang-bang controller for STATCOM to achieve fast dynamic response.

II.POWER FLOW CONTROL IN TRANSMISSION LINES

Active and reactive power in a transmission line depend on the voltage magnitudes and phase angles at the sending and receiving ends as well as line impedance.



(a)



(b)

Fig.1 (a) Equivalent Circuit Model (b) Power Angle Curve of a Lossless Line

To facilitate the understanding of the basic issues in power flow control using VSC-based FACTS controllers, the simple model shown in Fig 1(a) is used. The sending and receiving ends are connected by an equivalent reactance X, assuming that the resistance of high voltage transmission lines is very small. The receiving end is modeled as an infinite bus with a fixed angle of 0°.

For the receiving end side;

$$S_R = P_R + j\,Q_R \quad (1)$$

$$P_R = \frac{V_S V_R \sin\delta}{X} \quad (2)$$

$$Q_R = \frac{V_S V_R \cos(\cos\delta - V_R)}{X} \quad (3)$$

Similarly, for the sending end

$$P_S = \frac{V_S V_R \sin\delta}{X}$$

$$= P_{max} \sin\delta \quad (4)$$

$$Q_S = \frac{V_S\,(V_S - V_R \cos\delta)}{X} \quad (5)$$

The equations for sending and receiving end active power flows, P_S and P_R, are equal because the system is assumed to be a lossless system. As it can be seen in Fig 1(b), the maximum active power transfer occurs, for the given system, at a power or load angle δ equal to 90°. Maximum power occurs at a different angle if the transmission losses are included. The system is stable or unstable depending on whether the derivative dp/dδ is positive or negative. The steady state limit is reached when the derivative is zero. In practice, a transmission system is never allowed to operate close to its steady state limit, as certain margin must be left in power transfer in order for the system to be able to handle disturbances such as load changes, faults, and switching operations. Fig 1(b), the intersection between a load line representing sending end mechanical (wind turbine) power and the electric load demand line defines the steady state value of δ , a small increase in mechanical power at the sending end increases the angle.

For an angle above 90°, increased demand results in less power transfer, which accelerates the generator, and further increases the angle, making the system unstable; on the left side intersection, however, the increased angle δ increases the electric power to match the increased mechanical power. In determining an appropriate margin for the load angle, the concepts of dynamic or small signal stability and transient or large signal stability are often used. Typical power transfers correspond to power angles below 30°; to ensure steady state rotor angle stability, the angles across the transmission system are usually kept below 45°. Eq (2) and Eq(4) shows that the real or active power transfer depends mainly on the power angle and inspection of Eq (3) and Eq(5) shows that the reactive power requirements of the sending and receiving ends are excessive at high angles and high power transfers. It is also possible to conclude that reactive power transfer depends mainly on voltage magnitudes, which flows from the highest voltage to the lowest voltage, while the direction of active power flows depends on the sign of the power angle. Eq (2) to Eq (5) show that the power flow in the transmission line depends on the transmission line reactance, the magnitudes of sending and receiving end voltages and the phase angle between the voltages.

The ability to control power rapidly, within appropriately defined boundaries, can increase transient and dynamic stability, as well as the damping of the system. For a given power flow, a change of X also changes the angle between the two ends. Regulating the magnitudes of sending and receiving ends voltages, V_S and V_R can also control power flow in a transmission line. However, these values are subject to tight control due to load requirements that limit the voltage variations to a range between 0.95 and 1.05p.u. And hence cannot influence the power flows in a desired range. Hence, the regulation of voltage magnitude has much more influence over the reactive power flow than the active power flow. Of the FACTS controllers, the STATCOM has the ability to increase/decrease the terminal voltage magnitude and, consequently, to increase/decrease power flows in the transmission line [4]. FACTS controllers can be used to control steady state active and reactive power flow, but it should be also noted that these fast controllers could have pronounced, positive impact on transient and dynamic conditions in a power system if designed properly. The STATCOM has the ability to control reactive power absorption/generation, and since its time response is very fast, sometimes even less than one cycle, it can be used to effectively prevent the problem of voltage stability in VSWTs.

III.WIND TURBINE MODEL

The dynamic stability of induction generators directly connected to a grid as shown in Fig 2 depends on the characteristic of the generator, the grid configuration and the characteristic of the disturbance.

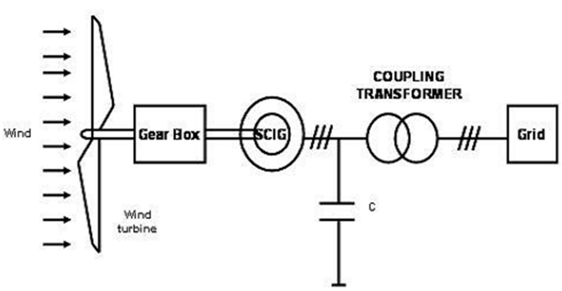


Fig.2 Grid connected VSWT

Wind farms with induction generators generate real power and consume reactive power. The over speed of the induction generator resulted from transient currents drawn by the induction generator from the electrical power system can exceed the stability limit resulting collapse of the system and islanding operation. Voltage fluctuations during normal operations can be mitigated and voltage instability during grid faults can be prevented by using dynamic reactive compensation. The most commonly used dynamic reactive compensators are the thyristor-based Static Var Compensator (SVC) [4] and the voltage source converter (VSC) based Static Synchronous Compensator (STATCOM) [5], [6]. Compared to the SVC, the STATCOM is able to provide faster and smoother dynamic voltage control because of its rapid and continuous response characteristics. Therefore, it is more suitable for voltage flicker mitigation at the connection point of the wind farm [7]. In order to evaluate the improvement of the stability conditions that a STATCOM can produce in the system with a wind farm connected to a weak grid, power system simulation have been performed in MATLAB/ SIMULINK. A sketch of the power system that has been studied is outlined as drive train model as shown in Fig 3.

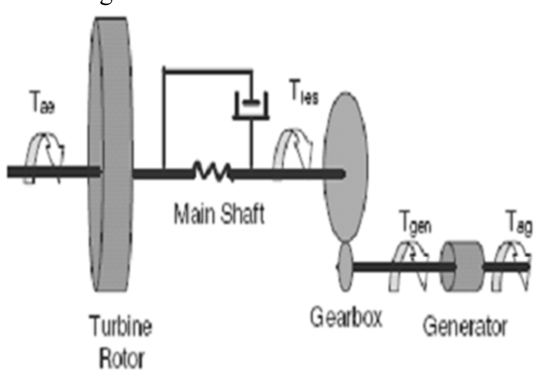


Fig.3 Drive Train Model

In this model it is known that a wind turbine with squirrel-cage induction generator has a relatively soft coupling between the turbine rotor and the induction generator rotor this means that a two mass representation of the shaft would be recommended. One mass is representing the turbine and another representing the generator rotor. In case of non-representation of the shaft by two-mass model, that is, the shaft is represented by a lumped-mass model, the result would give an oversimplified representation of the wind turbine shaft system, but the behavior of the frequency deviation follows the expected average frequency curve. Considering that the study will compare cases with or without the STATCOM a simpler representation of the shaft has been used in the study, which means, a single mass representation.

IV.STATCOM TOPOLOGY

The STATCOM is based on a solid – state voltage source implemented with an inverter and connected in parallel to the power system through a coupling reactor. A STATCOM consists of an inverter and a DC capacitor as shown in Fig 4. With this arrangement, this device can supply both leading and lagging Var s with a small energy storage device. The AC current is the result of interaction of the converter output voltage with the AC system and can have any phase relationship with respect to the voltage. It is always a combination of two controlled switches and one uncontrolled switch conducting and vice versa.

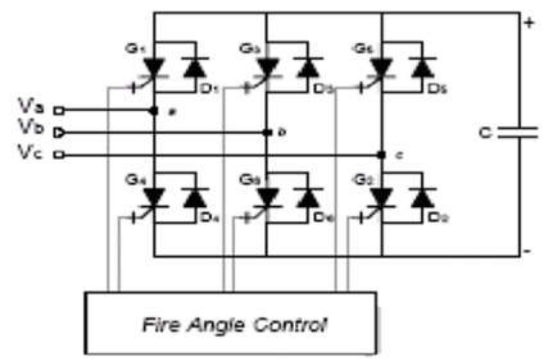


Fig.4 STATCOM Inverter

The amount of exchanged real power is typically small in steady state; hence, the firing angle is also small. The real power that is being exchanged by the transmission system must be supplied or absorbed at its DC terminals by the DC energy storage. In contrast, the reactive power exchange is internally generated or absorbed by the voltage-sourced converter, without the DC energy storage device playing any part in it. If two sources $V_1$with a phase angle of δ and V_2 with a phase angle of 0 are connected together by means of an inductive link of impedance (R +jX) ohms as shown in Fig 6 and if the active power flowing into the source V_2 is constrained to be zero (because this represents the STATCOM situation) the power delivered by the source V1 (which will not be zero and it will be equal to the power absorbed by the resistance in the link) and the reactive power delivered to the link by the source V_2will be given by the following relations (Assuming ∝ is small and R << X).

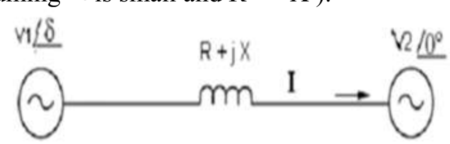


Fig 5 Equivalent Circuit Model

Active power delivered by V_1,

$$P=\left(\frac{V_1^2}{R}\right)\delta^2\ W \quad (6)$$

Reactive power delivered by V_2

$$Q=\frac{V_1V_2}{R}\delta\text{var} \quad (7)$$

Also,

$$Q=\frac{V_1(V_2-V_1)}{X}\text{ var} \quad (8)$$

Where the powers are for one phase and voltages have phase values. These relations can be used up to about 20 degrees for δ .Active Power drawn from the source V1is independent of sign of phase angle (only V_1 can supply losses in R because of the zero active power constraint at V_2) whereas the reactive power delivered by $V_2$is directly proportional to the phase angle. In the STATCOM context, the source $V_1$is the power system voltage at the bus where the STATCOM is connected, V_2 is the AC voltage generated by the inverter in the STATCOM, R is the total loss resistance in the link comprising the winding losses in the link inductor, interface magnetic, the inverter switches and snubber etc. It is also possible to derive the following useful relationships in this context. The phase angle of $V_1$with respect to V_2,

$$\delta=\frac{R}{X}\frac{(V_2-V_1)}{V_1} \quad (9)$$

This shows that the relative phase angle is linearly related to the voltage magnitude difference (for small differences) and hence the reactive power delivered by V_2 is proportional to the voltage magnitude difference. Thus Q is proportional to δ or equivalently to (V_2-V_1). In the STATCOM, the required AC voltage source V_2 is generated by inverting the DC voltage, which is assumed available across the capacitor in the DC side. But if the active power which goes into the inverter from the mains is kept zero, the initially charged capacitor will soon discharge down to zero due to active power losses in the inverter which the D.C. side will have to supply. The DC side voltage will remain constant (or at least controlled) if the power drawn from mains is just enough to supply all the losses which take place everywhere due to the flow of demanded reactive current. The DC side capacitor voltage is,

$$V_{dc}=\left(\frac{V_1}{k}\right)\left(1-\frac{X}{R}\right)\delta \quad (10)$$

where V1is the rms phase voltage of AC mains, k is a constant, which also absorbs the modulation index of PWM process in the Inverter.VSC transforms, through appropriate switching sequence, DC voltage at its DC terminals into an AC voltage of controllable frequency, magnitude and phase angle at its terminals.

V.STATCOM CONTROL STRATEGY

Fig.6 shows the block diagram of phase angle control scheme implemented in STATCOM. A STATCOM is configured to keep the reactive power delivered by the source at a zero value as long as the reactive demand is within the STATCOM rating [9]. The control of STATCOM reactive power is by pure α control. The source side voltages and currents are sensed and the reactive power is calculated by analog/pulse circuitry. This calculated value is compared with the desired value (usually zero) and the error is processed in a Proportional-Integral Controller [10]. The error output decides the phase shift needed in the inverter output in order to develop the required DC bus voltage such that the inverter output voltage magnitude will be sufficient to make the Inverter deliver the var required by the load. The inverter is gated by a fixed PWM pattern optimized for eliminating chosen harmonics (usually fifth, seventh, eleventh etc; triple harmonics need not be eliminated since they do not result in current flows in a three wire system).

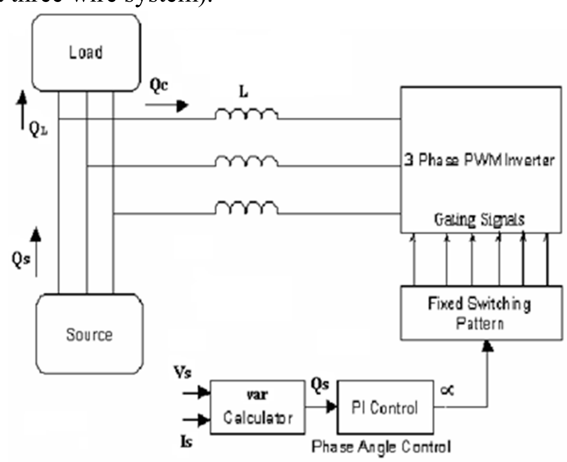


Fig.6 STATCOM with Phase Angle Control Scheme

The PWM technique is commonly employed to generate high quality output waveforms by relatively low power converter used in wind power applications [13].With this technique, the output of each converter pole is switched several times during a fundamental cycle between the positive and negative terminals of the DC source.PWM requires a considerable increase in the number of switch operations, thereby it generally increases the switching losses of the converter.

VI.TEST SYSTEM AND COMMENTS ON RESULTS

In order to evaluate the improvement of the stability conditions that a STATCOM can produce in the system with a wind farm connected to a weak grid, power system simulation is performed in MATLAB/ SIMULINK as shown in Fig 7.A 220 KW wind farm consisting of single Squirrel Cage

Induction Generator (SCIG) driven by Fixed Speed Wind Turbine (VSWT) is connected to a power grid through a step-up transformer T1and a power line. The Wind Turbine Generator (WTG) with a rated power capacity of 220kWis considered here. A STATCOM is shunt connected at the 22kV bus (the high voltage terminal of the transformer T1) to provide dynamic reactive compensation.

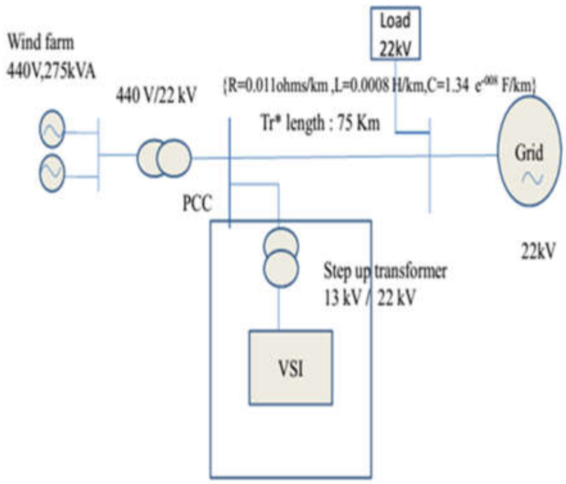


Fig.7 Single Line Diagram of the Test System

To reduce the size of the STATCOM, a fixed capacitor bank is used to supply about 10 Mvar reactive powers at the nominal voltage condition. The parameters of the system components are as follows. SCIG: rated power = 220 kW, rated stator voltage = 440 V, stator resistance = 0.0079 pu, rotor resistance = 0.025 pu, stator leakage inductance = 0.07939 pu, rotor leakage inductance = 0.4 pu, magnetizing inductance =4.4 pu; Transformer T1: turns ratio = 440 V/22 kV, equivalent leakage reactance = 0.06 pu; Transformer T2: turns ratio = 22 kV/13 kV.

In order to evaluate the improvement of the stability conditions that a STATCOM can produce in the system with a wind farm connected with induction generators, different power system simulations have been performed in MATLAB/ SIMULINK model as shown in the simulation results are as shown from Fig 8-Fig 13.

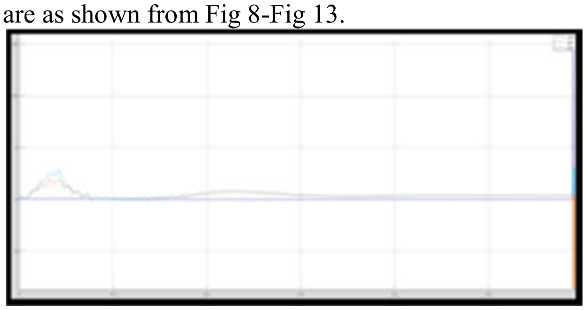


Fig.8: Active power with cascaded 5-level inverter STATCOM

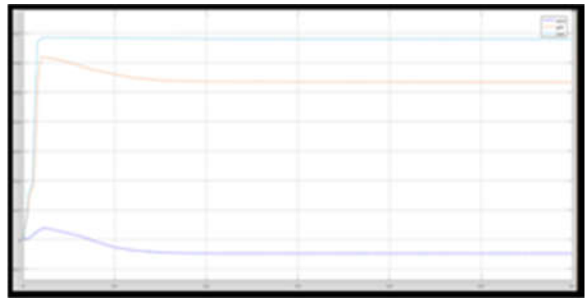


Fig.9: Active power with 7 level inverter STATCOM

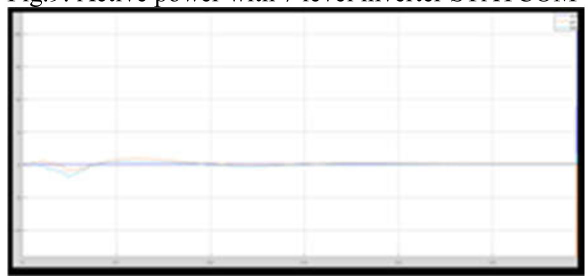


Fig.10: Reactive power with cascaded 5-level inverter STATCOM

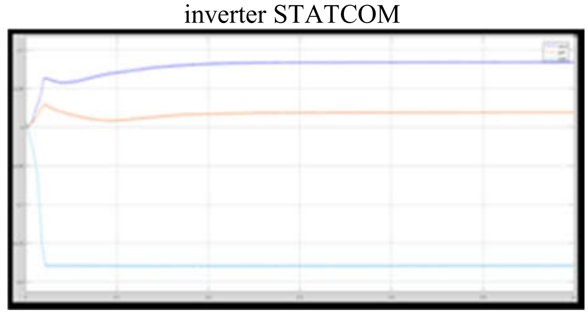


Fig.11: Reactive power with cascaded 7-level inverter STATCOM.

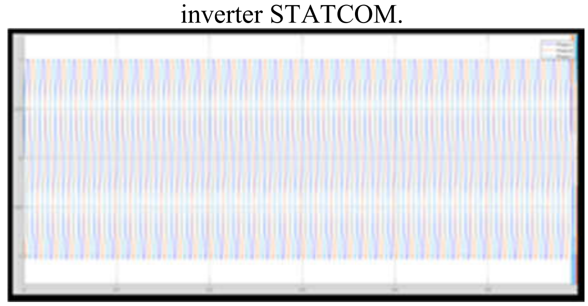


Fig.12: Load voltage with cascaded 5 level inverter STATCOM

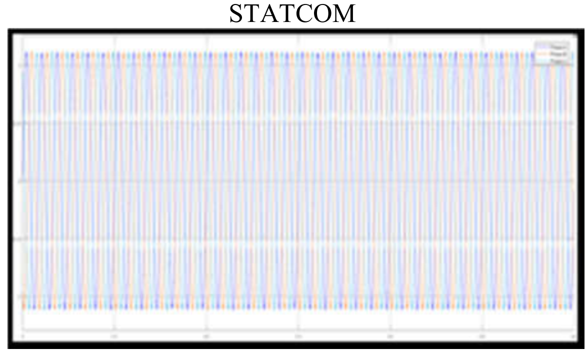


Fig.13: Load voltage with cascaded 7 level inverter STATCOM

VII.CONCLUSIONS

In this paper the transient stability limits of a variable speed wind farm with squirrel-cage induction generators. The squirrel-cage induction generators used in constant-speed turbines can lead to voltage and rotor instability. The study has demonstrated that an additional active voltage / reactive voltage support produced by a STATCOM can significantly improve the recovery of wind turbines from voltage collapse since this device can make a faster restoration of the voltage, improving the stability limit conditions of the induction generators. It is found in the simulation results that the STATCOM can provide a major increase in the transient stability margin of power systems that integrate wind generation.

REFERENCES

[1]Pierre Bousseau, Floriane Fesquet, Régine Belhomme, SamuelNguefeu and Thanh Chau Thai, 2006, "Answers for the Grid Integration of Wind Farms—a Survey". WIND ENERGY; 9:13– 25.

[2] N.G.Hingorani andL.Gyugyi2000, Understanding FACTS: Conceptsand Technology of Flexible AC Transmission Systems", New York: IEEE Press, pp. 135-143.

[3]S.Sirisukprasert, A.Q.Huang, andJ.S.Lai, 2003, "Displaying, examination and con-trol of cascaded-multilevel converter – based STATCOM," in Proc .IEEE PES Gen .Meeting, vol.4, pp.2561– 2568.

[4] T. Sun, Z. Chen, and F. Blaabjerg, 2004, "Flicker relief of grid associated windturbines utilizing STATCOM," in Proc. second International Conference on Power Electronics, Machinesand Drives, Mar. 31-Apr. 2, vol. 1, pp. 175-180.

[5] Z. Saad-Saoud, M. L. Lisboa, J. B. Ekanayake, N. Jenkins, and G. Strbac, 1998., "Use of STATCOMs to wind ranches," IEE Proc – Generation, Transmission and Distribution, vol. 145, no. 5, pp. 511-516,

[6]C. Banos, M. Aten, P. Cartwright, and T. C Green, 2006, "Benefitsand control of STATCOM with energy storage in wind power generation," in Proc. eighth IEE International Conference onAC and DC Power Transmission, Mar. 28-31, pp. 230-235.

[7] T. Sun, Z. Chen, and F. Blaabjerg, Mar. 31-Apr. 2, 2004, "Flicker relief of grid associated wind turbines utilizing STATCOM," in Proc. second International Conference on Power Electronics, Machines and Drives, vol. 1, pp. 175-180.

[8]C. Chompoo-inwai, C. Yingvivatanapong, K. Methaprayoon, and W.J. Lee, "Reactive pay systems to enhance the ridethrough ability of wind turbine amid unsettling influence," IEEE Tas. Industry Applications, vol. 41, no. 3, pp. 666-672.

[9]Mohan, N.; Undeland, T. 2005.Robbins, W. Power Electronics. third release. New York: Wiley, pp. 16–30.

[10]P. C. Krause, 1992, Analysis of Electric Machinery, New York: Mc Graw-Hill, pp.133-163.

[11] V. Akhmatov, 2003, "Investigation of dynamic conduct of electric power systems with extensive measure of wind power," Ph.D. proposal, Technical University of Denmark, Kgs. Lyngby, Denmark.

[12]C. Chompoo-inwai, C. Yingvivatanapong, K. Methaprayoon, and W.- J. Lee,2005, "Reactive pay systems to enhance the ride-through ability of wind turbine amid aggravation," IEEE Tans. Industry Applications, vol. 41, no. 3, pp. 666-672.

[13]K.C. Divya, P.S. Nagendra Rao,2004, "Investigation of dynamic conduct of grid associated acceptance generator," IEEE Power Engineering Society General Meeting, vol.2, pp. 2200-2205.

[14]J.Rodriguez, J.- S. Lai, and F. Z. Peng, "Multilevel inverters: an overview of topologies, controls, and applications," IEEE Trans. on Industrial Electronics, vol. 49, no. 4, pp. 724– 738, 2002.

[15]http://www.academia.edu/20171609/PULSE_WIDTH_MODULATION_TECHNIQUES_FOR_INVERTERS