International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 5 Issue 7, July-2016

Application of FACTS devices in wind farm

Amit[1], Ms Bhawna[2], Mrs Nancy[3]

[1]M. Tech Student, Dept. of EE, R.N College of Engineering, Gohana Road, Rohtak, Haryana.
[2] HOD, Dept. of ECE, R.N College of Engineering, Gohana Road, Rohtak, Haryana.

ABSTRACT

When wind farm is connected to a grid system some issues of voltage stability and reactive power posed . The study includes the implementation of FACTS devices as voltage restorer to maintain stable voltage and thereby protection IG-based wind farm interconnected power system from isolating during and after disturbances. This thesis analysis the application of FACTS devices in wind farm using squirrel cage induction generator. FACTS devices are used to enhance the voltage stability of wind farm using squirrel cage induction generator. FACTS devices used in the thesis are STATCOM and SVC . A comparison between these FACTS devices also done which is shown in results .When Wind farm is connected to a grid then problem of voltage dip occur due to variation in loads or other disturbances and this can be maintained to rated value using FACTS devices .A simulation model of 9MW wind farm interconnected to grid is carried out using the MATLAB SimPower System Toolbox.

I. INTRODUCTION

Electrical power is most widely used source of energy for industries, homes, work place. Electricity generation by means of non renewable sources (coal, oil, gas) causes enhanced green house effect, leading to the warming of the earth' atmosphere. The adverse effect of conventional systems have given rise to a shift in focus toward renewable energy sources such as hydro, wind, tidal wave, biomass, and so on.

Global wind power installations increased by 35,467 megawatts (MW) and 51,447 MW in 2013 and 2014, respectively. As of the end of 2014, worldwide, total cumulative installed capacity from wind power amounts to 369,553 MW and increased by 16% compared to the previous year (318,106 MW). The development of wind power in India began in the 1990s, and has significantly increased in the last few years.

The wind power penetration has increased dramatically in the past few years, hence it has become necessary to address problems associated with maintaining a stable electric power system that contains different sources of energy including hydro, thermal, coal, nuclear, wind, and solar. In the past, the total installed wind power capacity was a small fraction of the power system and continuous connection of the wind farm to the grid was not a major concern. With an increasing share derived from wind power sources, continuous connection of wind farms to the system has played an increasing role in enabling uninterrupted power supply to the load, even in the case of minor disturbances. The wind farm capacity is being continuously increased through the installation of more and larger wind turbines. Voltage stability and an efficient fault ride through capability are the basic requirements for higher penetration. Wind turbines have to be able to continue uninterrupted operation under transient voltage conditions to be in accordance with the grid codes [6]. Grid codes are certain standards set by regulating agencies. Wind power systems should meet these requirements for interconnection to the grid. Different grid code standards are established by different regulating bodies, but Nordic grid codes are becoming increasingly popular.

One of the major issues concerning a wind farm interconnection to a power grid concerns its dynamic stability on the power system [14]. Voltage instability problems occur in a power system that is not able to meet the reactive power demand during faults and heavy loading conditions. Stand alone systems are easier to model, analyze, and control than large power systems in simulation studies. A wind farm is usually spread over a wide area and has many wind generators, which produce different amounts of power as they are exposed to different wind patterns.

Power control is vital for transient and voltage stability during faults and is required to meet the connection requirements of the wind turbines to the grid which vary mostly with the short circuit capacity of the system considered. Reactive power is required to compensate for the additional reactive power demand of the generator and the matching transformers so that the wind power installation does not burden the system. LVRT is a recently introduced requirement that transmission operators demand from wind farms.

The two basic types of wind turbines used are

- Fixed speed wind turbine
- Variable speed wind turbine

Fixed speed wind turbine are mainly equipped with squirrel cage induction machine, which are also known as self excited machines. Self excited machines work within a limited wind speed range, which is one of their main drawbacks in comparison with variable speed wind turbines. They can be manufactured as one or two speed versions and they are suitable for low power ranges up to 2 MW. The majority of megawatt wind turbines are variable speed wind turbines equipped with a Doubly Fed Induction Machine (DFIG) that is coupled to power grid via a main transformer and supplied to the rotor from a frequency converter. The simulation studies have been carried out by using commercial simulation software such as a Matlab/ Simulink .The induction generator used in this thesis is squirrel cage induction generator that is fixed speed wind turbine.

Objectives

The objectives of thesis are:

- Implementation and comparison of FACTS devices like STATCOM and SVC for the voltage stability issue for IG-based wind farm connected to a grid and load.
- The steady state behaviour of an interconnected IG based wind farm with STATCOM and SVC is studied.

LITERATURE REVIEW

Mousa Marzband et al [1] The paper aims modeling and simulating a wind turbine and its induction generator (WTIG) system as an electricity source in the power networks. System simulation has been done using the facilities offered by MATLAB/SIMULINK software. At first, equivalent models of various parts of a wind turbine generation system (WTGS) with fixed speed wind turbine (FSWT) are presented, and then an equivalent model of a wind turbine that operates in a grid connected mode is achieved by integrating these sub-models. The proposed equivalent models provide high accuracy for representing the dynamic response of wind power generation systems (WPGS) and can be used for power system simulations. Likewise, the analysis of the reactive power management of a WTGS consisting of FSWTs is carried out by using a static synchronous compensator (STATCOM). Regarding this matter, the rating calculation of the compensator for a FSWT is performed, and the effect of the network strength on the compensator rating is studied. Furthermore, the compatibility of FSWT with the mathematical models is evaluated by using simulation in MATLAB/SIMULINK environment.

Mr.M.Vimalraj et al [3] In this paper investigations on a fixed speed wind farm with squirrel cage induction generators directly connected to the grid in combination with a STATCOM under unbalanced grid voltage fault are given by means of theory and simulations. The stability of fixed speed wind turbines can be improved by a STATCOM, which is well known and documented in literature for balanced grid voltage dips. Under unbalanced grid voltage dips the negative sequence voltage causes additional generator torque oscillations. A STATCOM control structure with the capability to control the positive or negative sequence of the voltage is used. The simulation results clarify the effect of positive and negative sequence voltage compensation by a STATCOM on the operation of a fixed speed wind farm. The influence of different STATCOM control targets is investigated that lead to an increased network voltage stability and lower torque pulsations.

Miao-miao Cheng et al [5] Distributed power system has attracted great interest in terms of renewable energy use and new generation technology. Induction generator is one of the most widely used energy conversion means due to its low cost, robustness and simple control. This paper proposes a distributed system which is powered by squirrel cage induction generators (SCIG). Different from the synchronous generator, SCIG has to get exciting current from outer device at normal operation. Furthermore, voltage instability problem exists at the load change when it is excited with fixed capacitor bank. In order to solve this problem, this paper proposes a new technology named Static VAR Compensation Magnetic Energy Recovery Switch (SVC-MERS) for the induction generators. The SVC-MERS aims to stabilize the generator voltage by providing continues variable reactive power. The operation principle is further developed in order to get a broader operating range. It is confirmed by simulation results. Then, voltage control of induction generator is experimented and the SVC-MERS is proved to stabilize the generator voltage with quick response. Compared to the STATCOM, the SVC-MERS has advantage in line frequency switching and small dc-capacitor.

M. Molinas et al [7] The impact of the wind generation on the power systems is no longer negligible if high penetration levels are going to be reached. Significant barriers to interconnection are being perceived already with the severe requirements of the new emerged grid codes. Depending on the generator technologies, different solutions are found to support behavior in case of voltage sags. Voltage Source Static Var Compensator such as the STATCOM can be used to regulate voltage as shunt compensator with directly connected asynchronous wind generators. This paper has analyzed the extent to which the transient stability margin can be increased by the use of a STATCOM, first by simulations and then with an experimental verification on a setup of 7.5 kW. Measurement results confirm that the STATCOM provides a clear stability margin increase and with adequate rating it becomes possible to ride through severe faults.

Yongning Chi et al [9] In some regional grids in China, wind power penetration will increase rapidly because of the abundant wind resources in those areas and the government policy impetus. However, the power system security and stability may be affected due to the higher wind power penetration. Because majority of the wind farms with higher installed capacity intends to be connected into the transmission network of 220kV voltage level, their impacts are becoming more widespread. In the grid impact studies of wind power integration, voltage stability is the mostly concerned problem that will affect the operation and security of wind farms and power grid. In this paper, the detailed wind turbines steady-state model and dynamic model are used to explore the wind power integration impact on voltage stability of the power system; the load flow calculation (P-V curve and V-Q curve) and dynamic contingency study are conducted; the different impacts on voltage stability of integrating wind farms based on different wind turbines technologies are illustrated and the following conclusions are presented.

Wind turbines equipped with simple induction generator are not provided with reactive power regulation capability. Voltage stability deterioration is mainly due to the large amount of reactive power absorbed by the wind turbine generators during the continuous operation and system contingencies. Wind turbines equipped with doubly fed induction generator (DFIG) controlled by the PWM converters are provided with reactive power regulation capability; can absorb or supply reactive power during normal operation. The adverse affect on local network voltage stability is mitigated so that more wind power installed capacity can be incorporated into the grid. The transient voltage stability characteristics of wind turbines with DFIG are better than wind turbines with induction generator because of the voltage control capability of the DFIG based wind turbines; The DFIG based wind turbines have a better voltage recovery performance than the IG based wind turbines with same rating.

Juan Shi and Ian Furness et al [31] This paper provides a comparative study on the lo voltage ride-through (LVRT) capacity of wind energy conversion systems (WECSs) under Fixed Speed Induction Generator (FSIG), FSIG with FACTS (Flexible AC Transmission) devices such as Static Synchronous Compensator (STATCOM) or Static Var Compensator (SVC), and Doubly Fed Induction Generator (DFIG). The dynamic operations of the WECSs during grid side voltage sag and various balanced and unbalanced faults are investigated. The simulation results in MATLAB/SimPowerSystems show that a FSIG based wind farm does not have the LVRT capacity due to insufficient reactive power support during disturbances. FACTS devices such as STATCOM or SVC can improve the LVRT capacity of FSIG based WECSs, with STATCOM providing better Var compensating capacity than SVC. DFIG based WECSs has better LVRT capacity and voltage stability due to its real and reactive power control ability. As a result, DFIG based WECS can provide better stability performance to enable the WECS to ride-through severe balanced and unbalanced faults

N. Galán et al [32] In this article the dynamic behavior of a wind farm with reactive compensation is analyzed using a FACTS device (STATCOM). The wind generator system includes the models of the wind, turbine and squirrel-cage induction generator speed gear system. A STATCOM is used to minimize the effects of the wind speed variation. Two controllers are analyzed in the STATCOM; one PI lineal type and the other is a non-lineal robust type known as Super-Twisting, to regulate the voltage magnitude in the connection node.

WIND ENERGY IN THE POWER SYSTEM

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern wind turbines, can be used to generate electricity. The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

Wind is a continuously varying source of energy and so is the active power generated by the wind turbine. If a WT is connected to a weak grid (which has low short circuit power), the terminal voltage also fluctuates, producing flicker, harmonics and inter harmonics due to the presence of power electronics.

For a set of connected wind turbines forming a wind farm, there exist certain grid codes or specific requirements with which each wind turbine must conform with in order to be allowed to be connected to the grid [9]. Most wind power systems are based in remote rural locations and are therefore prone to voltage sags, faults, and unbalances. These unbalanced grid voltages can cause many problems such as torque pulsations, unbalanced currents and reactive power pulsations [10]. When wind farms are connected to a strong grid, that is closer to a stiff source, voltage and frequency can be quickly re-established after a disturbance with the support of the power grid itself. To wait for the voltage to re-establish after the fault has been cleared in the case of a weak grid interconnection is not reliable because there is always a risk of voltage instability initiated by the disturbance. Hence, reactive power and voltage support that can be provided by mechanically switched capacitors, SVC or STATCOM is needed to help improve the short term voltage stability and reinforce the power network. This is also true for wind farms with all fixed speed wind turbines with no dynamic control or reactive power compensation.

Variable-Speed Wind Turbine

For a variable-speed wind turbine the generator is controlled by power electronic equipment,which makes it possible to control the rotor speed. In this way the power fluctuations caused by wind variations can be more or less absorbed by changing the rotor speed and thus power variations originating from the wind conversion and the drive train can be reduced. Hence, the power quality impact caused by the wind turbine can be improved compared to a fixed-speed turbine.

Wind Farm

When many wind turbines are added to the system, the grid becomes weaker as these types of generators require additional control equipment since they do not have any self recovery capability like the conventional generators. This requires a thorough study of the normal and dynamic performance of the wind turbines during and after a disturbance. Before integrating large amounts of wind power with the conventional generating units, a comprehensive analysis of the power system stability and reliability issues has to be studied. A simulation study is the best known method to understand the system dynamics for operation under normal conditions and during contingencies. Smaller wind farms are easier to model and study while larger wind farms require more effort and complex modeling.

Wind Turbine Performance With Faults On The System

Generators are the major components in the power system that reacts to system disturbances. The reaction of the conventional synchronous generators to all kinds of grid disturbances has been studied extensively; however wind turbines are generally not equipped with synchronous generators. Wind turbine generators interact differently with the grid when there are faults on the system. The grid voltage has to be controlled inevitably, irrespective of the capabilities with which a wind farm's generators might be equipped.

The most popular type of wind turbines installed today are variable speed wind turbines that feature improved power quality and speed control and reduced mechanical stresses. Under the same circumstances, the power generated by variable speed wind turbines is greater than that generated by the fixed speed wind turbines [17]. The LVRT requires that a WT does not trip even if the voltage drops to 0.15 per unit for about 0.625 seconds. If due to a fault, the voltage drops below this value, the wind turbine can be tripped until the system restores and the wind turbine can be resynchronized. A WT can take a maximum of 2.375 seconds to restore to about 0.9 per unit voltage after the fault has been cleared. These rules are more stringent for some grids which are derived based on grid reliability requirement.

This thesis focuses mainly on understand the behavior of the wind generators, the voltage profile and the reactive power in the system, to various system disturbances and supporting voltage and wind farm reactive power using FACT devices. Several studies have been performed to understand the transient behavior of the wind turbines during and after fault in the presence of different compensation techniques.

FACTS DEVICES

The rapid development of power electronics technology provides exciting opportunities to develop new power system equipment for better utilization of existing systems. Since 1990, a number of devices under the term FACTS (flexible AC transmission systems) technology have been proposed and implemented. A flexible alternating current transmission system (FACTS) is a system composed of static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability of the network, voltage regulation, and enhancement of transient stability and mitigation of system oscillations. Mechanical switching has to be supplemented by rapid response power electronics.

FACTS employ high speed Thyristors for switching in or out transmission line components such as capacitors, reactors or phase shifting transformers for desirable performance of systems. The FACTS technology is not a single high power controller, but rather a collection of controllers, which can be applied individually or in coordination with others to control one or more of system parameters depending on requirements. Subsequently, devices like thyristor controlled series compensator (TCSC), static compensator (STATCOM), static VAR compensator (SVC), static synchronous series compensator (SSSC), unified power flow controller (UPFC) were proposed and installed under the generic name of flexible AC transmission systems (FACTS) controllers..

There are two type of compensation

1. series compensation
2. shunt compensation

Here we are using shunt compensation Static synchronous compensator (STATCOM) and static VAR compensator (SVC)

Static Synchronous Compensator

STATCOM systems essentially consist of a DC voltage source behind self commutated inverters using insulated gate bipolar transistor (IGBT), gate turn-off (GTO), or gate commutated turn-off (GCT) thyristors and an interconnecting transformer. The voltage source inverter set connects to the power system via a multi-winding or two winding inverter transformer, depending upon the application. The figure here shows the basic STATCOM configuration. An inductor representing the leakage reactance of the transformer connects the two voltage sources. The output voltage phase of the thyristor-based inverter, Vi is controlled in the same way as the system voltage, Vs

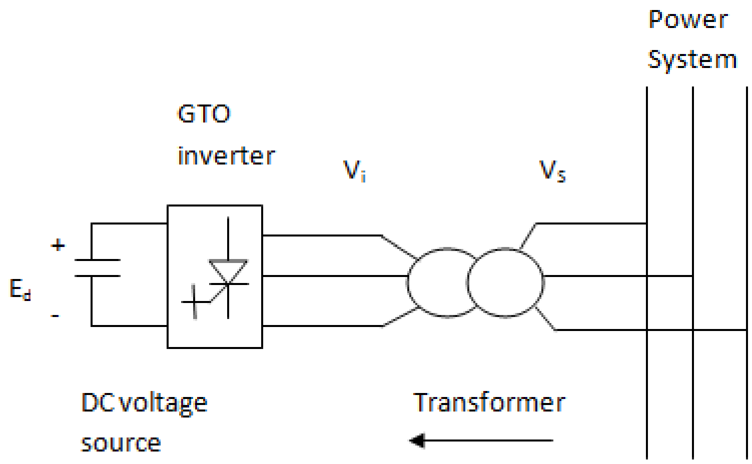

Fig.1 Basic arrangement of SATCOM in circuit

The STATCOM is a static var generator whose output can be varied so as to maintain or control certain specific parameters of the electric power system. The STATCOM is capable of generating continuously variable inductive or capacitive shunt compensation at a level up its maximum MVA rating. It is a power electronic component that can be applied to the dynamic control of the reactive power and the grid voltage. The STATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive power compensation to reduce the amount of voltage fluctuations. The reactive output power of the compensator is varied to control the voltage at given transmission network terminals, thus maintaining the desired power flows during possible system disturbances and contingencies.

Principle of voltage regulation using STATCOM

Basic operating principle of a STATCOM is similar to that of synchronous machine. The synchronous machine will provide lagging current when under excited and leading current when over excited. STATCOM can generate and absorb reactive power similar to that of synchronous machine and it can also exchange real power if provided with an external device DC source.

- Exchange of reactive power:- If the output voltage of the voltage source converter is greater than the system voltage then the SATCOM will act as capacitor and generate reactive power(i.e.. provide lagging current to the system)

- Exchange of real power: - As the switching devices are not loss less there is a need for the DC capacitor to provide the required real power to the switches. Hence there is a need for real power exchange with an AC system to make the capacitor voltage constant in case of direct voltage control. There is also a real power exchange with the AC system if STATCOM is provided with an external DC source to regulate the voltage in case of very low voltage in the distribution system or in case of faults.

It can be seen that if ES > Et then current I q flows from the counter to ac system through reactance and converter generates capacitive reactive power for ac system. On the other hand, if ES < Et then current I q flows from ac system to the converter and converter absorbs inductive reactive power from ac system. Finally, if ES = Et then there is no exchange of reactive power.

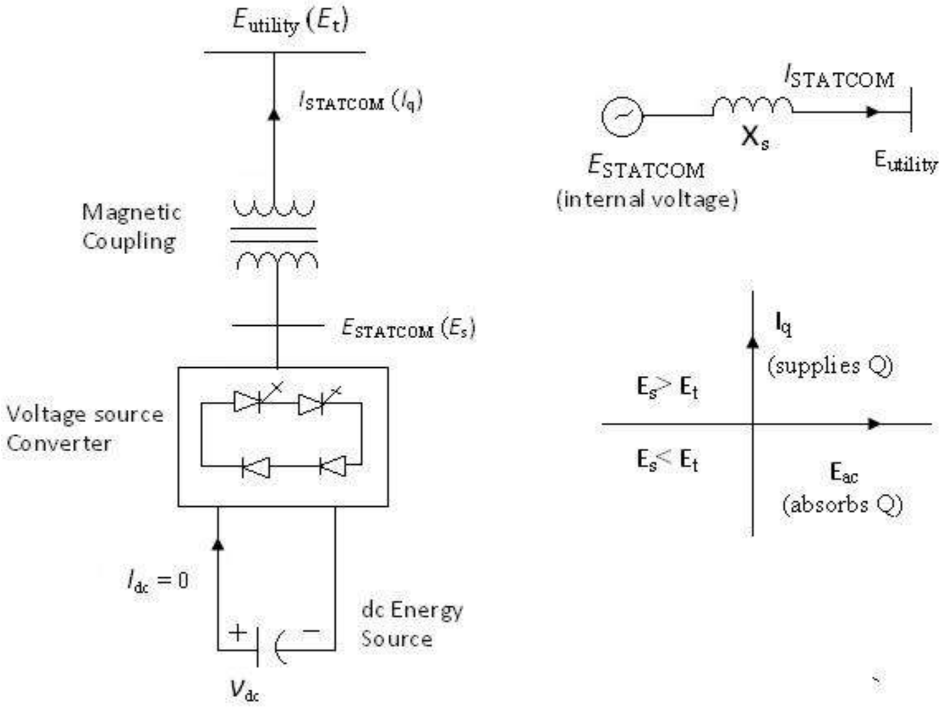

Fig. 2: Block diagram of STATCOM and working principle

Static Var Compensator

A static VAR compensator is a set of electrical devices for providing fast-acting reactive power on high- voltage electricity transmission networks . SVCs are part of the Flexible AC transmission system device family, regulating voltage, power factor, harmonics and stabilizing the system. Unlike a synchronous condenser which is a rotating electrical machine, a static VAR compensator has no significant moving parts (other than internal switchgear). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensor or switched capacitor banks. The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

In industrial applications, SVCs are typically placed near high and rapidly varying loads, such as arc furnace, where they can smooth flicker voltage. A shunt connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage). This is a general term for a Thyristor Controlled Reactor (TCR) or Thyristor Switched Reactor (TSR) and/or Thyristor Switched Capacitor (TSC) .The term, "SVC" has been used for shunt connected compensators, which are based on thyristors without gate turn-off capability.

RESULTS

To evaluate the voltage support provided by a STATCOM and SVC which is connected to a grid. A simulation model of 9 MW Wind farm interconnected grid is carried out using the MATLAB SimPower System Toolbox. Figure 5.1 shows the test system that includes a wind farm contain 3 pair of 1.5 MW and a total of 9 MW connected to 33KV distribution system export power to 132KV grid through 30km 33KV feeder. The power system is studied to evaluate the system performance under different transient conditions such as a single phase fault, a sudden load change. The values and ratings of system components are presented in the Appendix. The system voltage rating is 33 kV. A load1 of 20MW and 10Mvar connected at bus 1 and load2 of 4 MW and 2MVAR is connected at bus2 is between wind farm and grid. The total demanded reactive power is therefore mostly generated capacitor bank connected to wind generator. The active power of the load is shared by the WTs and the grid. As per the previous analysis, a STATCOM, an active voltage supporter, is connected to the load bus and the mechanically switched capacitors (MSC) will also be connected to the same bus.

The source of reactive power is always connected as close to the point where it is required and this is the main motivation for connecting the STATCOM and SVC at the load bus. Also, mechanically switched capacitors are relatively inexpensive and are used for slow changes in the reactive power but ideally reactive power requirement changes continuously and hence a controller is required to adjust the reactive power level.

Single line diagram of Wind Farm connected to Grid

A 9 MW wind farm is connected to Grid through a 30km line and Grid voltage 132KV is step down to 33KV using transformer of 62.5MVA rating . Two loads are connected at bus 1 and bus 2. Here we are checking the application of FACTS device STATCOM and SVC in voltage stability and its improvement during different load conditions

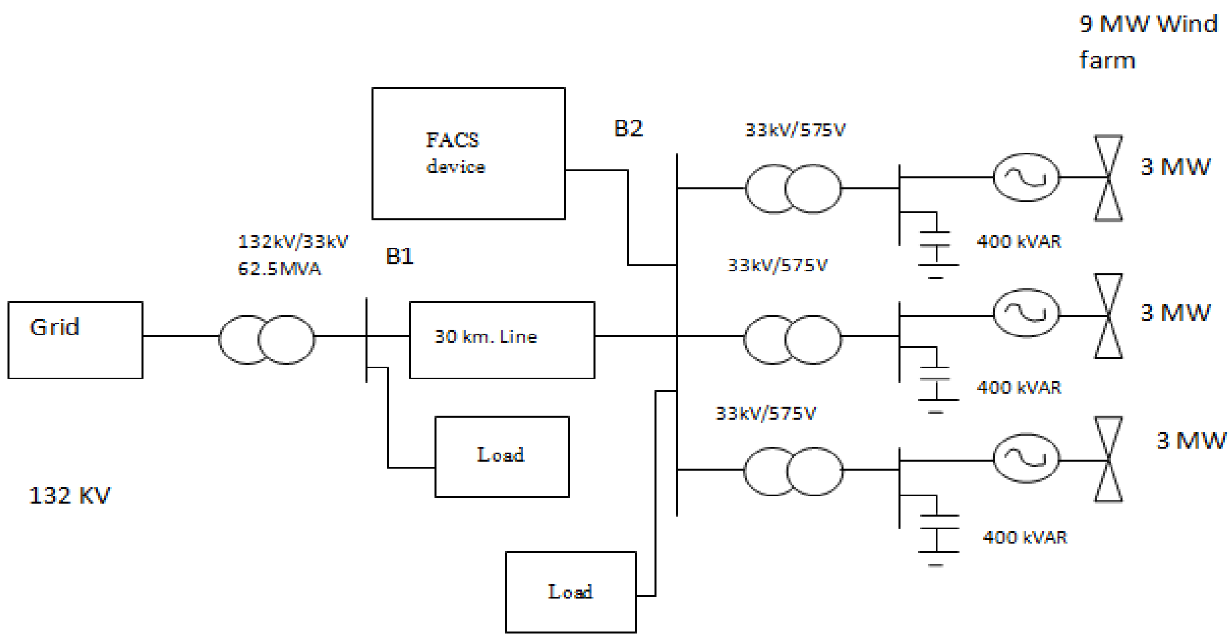

Fig.3: Single line diagram of Test System

SVC is used in system then Active and reactive power of wind plant in (pu) respectively are 3 .0 and 1.486. This can be compared with power of plant without FACTS device and reactive power demand of induction generator used in wind plant decrease as reactive power support is provided by SVC device

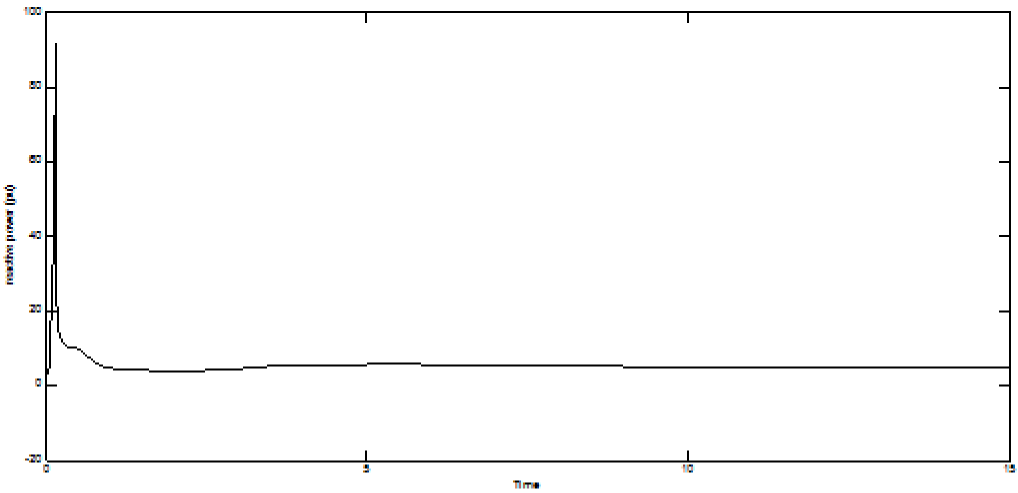

Fig.4: Reactive power with SVC

The reactive power provided by SVC of rating 6MVAR .This reactive power is improving voltages at bus 1 and bus 2 and Reactive power demand of induction generator also decrease as reactive support is now provided by SVC.

CONCLUSION

Voltage instability problems occur in a power system that is not able to meet the reactive power demand during faults and heavy loading conditions. Dynamic compensation of reactive power is an effective measure of preserving power quality and voltage stability. When a wind farm is connected to a weak power grid, it is necessary to provide efficient power and voltage control during normal operating conditions and enhanced support during load changes. FACTS devices find application in Wind Farm consists of SCIG that operate at fixed wind speed connected to a Grid system. There is need to study the system during different loads condition and check the effect of FACTS devices such as STATCOM and SVC . An appropriately rating FACTS device can provide the necessary reactive power compensation when connected to a weak grid. Also, a higher rating STATCOM can be used for efficient voltage control and improved reliability in grid connected wind farm but its rating is limited due to economic. Simulation studies have shown that the additional voltage/var support provided by an external device such as a STATCOM and SVC can significantly improve the wind turbine's disturbances recovery by more quickly restoring voltage characteristics. The response of a wind farm to sudden load changes is improved by the use of a STATCOM and SVC in the system.

REFERENCES

[1]. A. S. A. Awad, M. M. A. Salama, Fellow, and Ramadan El Shatshat, " STATCOM modeling Impact on Wind Turbines Low Voltage Ride Through Capability".

[2]. Ł. Huchel, Mohamed hawky El Moursi, and H. H. Zeineldin, "A Parallel Capacitor Control Strategy for Enhanced FRT Capability of DFIG", IEEE TRANSACTIONS ON SUSTAINABLE ENERGY, VOL. 6, NO. 2, APRIL 2015.

[3]. Omar AL-Masari and Musa AL-Masari, "Influence of a Wind Farm on Power System Oscillatory Stability", International Journal of Inventive Engineering and Sciences (IJIES) ISSN: 2319–9598, Volume-2 Issue-9, August 2014.

[4]. Naimul Hasan, Ibraheem, and Shuaib Farooq, " Dynamic Performance Analysis of DFIG based Wind Farm with STATCOM and SVC", International Journal of Emerging Technology and Advanced Engineering , Volume 2, Issue 7, July 2012.

[5]. Miad Mohaghegh, Montazeri,and David Xu, "Coordination of DFIG and STATCOM in a Power System".

[6]. Mustafa Jawad Kadhim, and D.S.Chavan , "Stability Analysis of DFIG-based Wind Farms Using Different Bus Systems", International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-2, Issue-4, March 2013.

[7]. Dimitrios G.Giaourakis, Athanasios N.Safacas, and Savvas Tsotoulidis, "Dynamic Behaviour of 1.5 MW Doubly-Fed Induction Generator based Wind Energy Conversion System", 2012 International Symposium on Power Electronics, Electrical Drives, Automation and Motion.

[8]. S.M. Mohiuddin, and M.R.I. Sheikh, "Stabilization of Solar-Wind Hybrid Power System by Using SMES", International Journal of Electrical and Computer Engineering (IJECE) Vol. 4, No. 3, June 2014, pp. 351~358.

[9]. Mousa Marzband, Andreas Sumper and Mircea Chindris, " Modeling and Simulation of The Fixed Speed Wind Power Generation System for Grid Studies".

[10]. Morteza Rezaee, Ronald G. Harley and Hossein Heydari, "Designing an Efficient PI-based Voltage Control Method for Squirrel-Cage Induction Generators in Islanding/Weak Grid-Connection Conditions", power system conference (PSC).