IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

# Stability and Reactive Power Compensation Techniques in Wind Farm

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## Abstract

Wind energy's presence in the electric power system has dramatically grown over the past decade and will continue to grow worldwide as many countries have planned future developments. Large number of wind turbines are being installed and connected to power systems. In some of the countries the penetration of wind power is significant high so as to affect the power quality, system operation and control and power system stability. In this paper an attempt is made to predict the reactive power burden of the wind farm based on conventional fixed speed induction generator during wind variation and fault condition. PSCAD/EMTDC based large scale wind farm model is developed where STATCOM is introduced as an active voltage and reactive power supporter to increase the power system stability. STATCOM unit injects reactive power to mitigate power quality problems and to get stable grid operation.

**Keywords**: Squirrel Cage Induction Generator (SCIG), PSCAD, Wind Turbine Generator (WTG), Static Synchronous Compensator (STATCOM).

## Introduction

Windmills have been used for at least 3000 years, mainly for grinding grain or pumping water, while in sailing ships the wind has been an essential source of power for even longer. From as early as the thirteenth century, horizontal-axis windmills were an integral part of the rural economy and only fell into disuse with the advent of cheap fossil-fuelled engines and then the spread of rural electrification. To use wind energy efficiently and to concentrate the visual impact of modem wind turbines, the regions with a good wind climate, a tendency to group turbines in wind farms can be observed. These wind farms are connected to high voltage transmission grids and thus directly influence the dynamic behaviour of the electrical power system. One of the major concerns related to high level wind power penetration is the impact on power system stability. To facilitate the investigation of the impact of a wind farm on the dynamics of the power system to which it is connected, an adequate model is required. In order to avoid the necessity of developing a detailed model of a wind farm with tens or hundreds of wind turbines and their interconnections, aggregated wind farm models are needed [1].From each generating station the probability of the total generating capacity not exceeding a given power level. This gives a measure of the reliability of the system [2].

If the network is weak this situation will cause a voltage collapse to occur in the transmission system. The process can be dynamically supported by a STATCOM to improve voltage stability and to improve recovery from network faults and mitigate voltage flicker [3].All induction generators are assumed to operate at 0.85 leading power factor for the entire operation range because the operation of wind farm at 0.95 leading, unity power factor does not survive after disturbance and the situation is better during disturbance at 0.95 lagging power factor [4].

The power pollution is caused due to the variation of frequency, voltage, wave shape, asymmetry, transients, impulses, non-sinusoids etc. This pollution is unavoidable as the wind parameters are continuously changing [5].The short circuit level of the grid network is very high than the wind power penetration into the network [6].Use of more intelligent controller for STATCOM and its interface to large power systems addressing various issues such as security, stability, and voltage profile improvement and power quality [7].It was found that STATCOM considerably improves the stability during and after disturbances especially when network is weak [8].FACTS devices provide an effective means of dynamic voltage control of wind farm, dynamic power control of the transmission lines, improving power oscillations damping and transient stability [9].

This paper investigates the use of a STATCOM to improve the power quality in terms of reactive power supporter during wind variation and to mitigate the voltage dip during the grid fault of a wind farm equipped with Squirrel Cage Induction Generator (SCIG).

## Squirrel Cage Induction Generator

Induction generators are gaining the popularity due to its simplicity and no synchronization problem.

However the major drawback of this machine is its additional reactive burden on the system, where it is connected. In number if countries asynchronous generators are used for conversion of energy in installation of renewable power especially wind power. The induction generator has the very same construction as induction motor with some possible improvements in efficiency. There is an important operating difference; the rotor speed is advanced with respect to stator magnetic field rotation. The rotor is being driven at a speed more than synchronously rotating magnetic field. The rotor conductors are now being cut by the rotating flux in a direction opposite to that during motoring mode. This shows that rotor generated EMF, rotor current and hence its stator components change their signs. As the speed during induction generator operation is not synchronous, it is also called an asynchronous generator. Variation in "δ" changes both active power and reactive power flow at the SEIG terminals there by simultaneously changing both terminal voltage and frequency of the SEIG [10].

The use of STATCOM shall be considered for stability improvement as well as improvement of power quality taking considering techno economic aspects [11].

Another important issue related to the FSWTs equipped with squirrel-cage induction generators is the fault ride-through capability. When connected to a weak power grid and during a grid fault, the over-speeding of the wind turbines can cause voltage instability. As a result, utilities typically disconnect the wind turbines immediately from the grid when such a contingency occurs. With the rapid increase in penetration of wind power in power grids, tripping of many wind turbines in a large wind farm during grid faults may begin to influence the overall power system stability [12].Grid connected wind turbines often produce active power with significant fluctuations due to wind speed variations, the wind gradient and the tower shadow effect. The output power variations can cause fluctuations of the voltage at the connection point. Because of the power quality requirements from the utilities, flicker emission may become a major limiting factor for integrating wind turbines, especially the fixed-speed wind turbines (FSWTs), into weak power grids where the wind power penetration levels are high [12].With the development of wind turbine technology, large scale wind farms of hundreds of MW level being developed in many countries. These modern wind farms are usually connected to the power grid. The global annual installation capacity is increased with the rate of 30 % in recent years [13].

Although there is a growing interest in the usage of doubly fed induction generators, squirrel-cage rotor type induction generators are still in use due to their simplicity, robustness, low cost and low maintenance, which can be very advantageous for small and medium size wind farms Moreover, in Europe there are large wind power plants composed by squirrel-cage rotor [14].A Squirrel cage induction generator may be directly connected to grid. The frequency of grid determines the air gap flux speed $\omega s$, the synchronous speed. The rotor speed $\omega r$ of induction machine is made slightly higher synchronous speed to operate the machine as induction generator. The features SCIG driven wind farms are simple, cheap and no synchronization required.

The SCIG in this WTG concept can only operate within a narrow range of the rotational speed slightly above the synchronous speed. Because of these very small rotational speed variations, this type of WTG is considered to operate at fixed speed.Grid connected wind turbine generator based on SCIG gave the following results for active power (P), reactive power requirement (Q) and reactive power supplied by grid (O) when simulated using PSCAD/EMTDC environment. Simulated results are obtained for mean wind speed (*Wms*) variations.

The wind farms equipped with FSWTs are composed of a large number of wind turbines with directly grid connected SCIGs. A gearbox is used to connect the low-speed wind turbine rotor shaft and the high-speed induction generator rotor shaft. The Squirrel Cage Induction Generator (SCIG) in this WTG concept can only operate within a narrow range of the rotational speed, slightly above the synchronous speed. Because of these very small rotational speed variations, this type of WTG is considered to operate at fixed speed.

## Static Synchronous Compensator

The Static Synchronous Compensator (STATCOM) is a shunt connected reactive compensation equipment which is capable of generating and/or absorbing reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. The STATCOM provides operating characteristics similar to a rotating synchronous compensator without the mechanical inertia, due to the STATCOM employ solid state power switching devices it provides rapid controllability of the three phase voltages, both in magnitude and phase angle. STATCOM consists of controllable PWM voltage source converter. The STATCOM is a shunt FACTS device. It consists of VSC connected in shunt to a bus through a coupling transform. The objective of the STATCOM is to provide fast and smooth voltage regulation at the point of common coupling. In this paper, the VSC is modelled as a six-pulse PWM-IGBT converter with a dc-link capacitor. The static compensators are devices with the ability to both generate and absorb reactive and active

ISSN: 2277-9655
Impact Factor: 1.852

power, but the most common applications are in reactive power exchange between the AC system and the compensator. The Static Synchronous Compensator (STATCOM) based on six-pulse Voltage Source Inverter (VSI). The compensator control is achieved by small variations in the switching angle of the semiconductor devices, so that the fundamental component of the voltage produced by the inverter is forced to lag or lead the AC system voltage by a few degrees. This causes active power to flow into or out of the inverter, modifying the value of the DC capacitor voltage, and consequently the magnitude of the inverter terminal voltage and the resultant reactive power. If the developed voltage is higher than system voltage the STATCOM will supply reactive power like a rotating synchronous compensator and improve the voltage and conversely if lower it will remove reactive power. It is necessary to extend the application of STATCOM for SEIG of higher ratings operated in large wind farms interfaced to grid feeding linear and nonlinear loads.

## Simulation Model for Wind Farm

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, different power system simulations have been performed in EMTDC/PSCAD digital simulator.

**Case A:** As shown in figure No.1. Wind farm with squirrel cage induction generators is connected to two buses radial system is modelled. The simulation results indicated active and reactive power of flow of Squirrel Cage Induction generator as shown in Table No. 1.Table.2.show Reactive power requirement for SCIG. Fig.3.show Active power generated by Generator during Fault and Fig. 4 show Reactive power requirement of Generator during Fault.

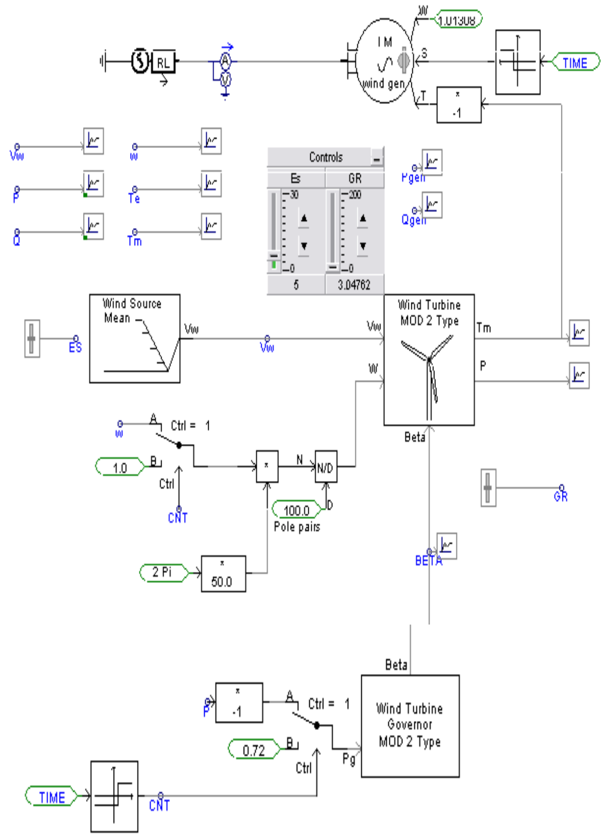


**Fig.1. Wind farm model**

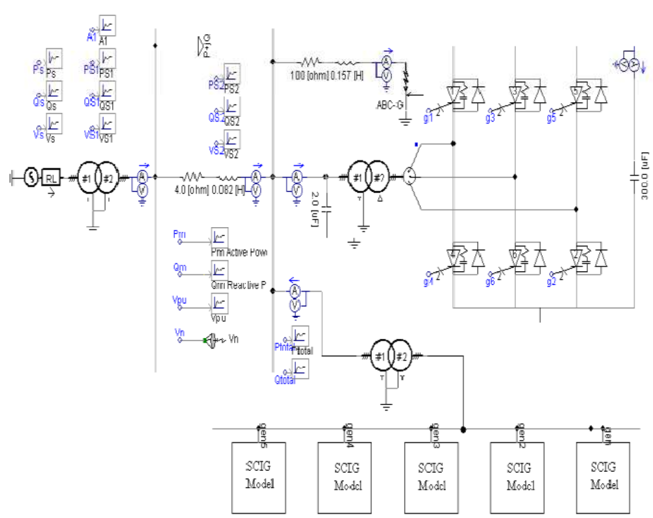


**Fig.2. Modelling of induction generator**

**Table.1. Active, reactive power flow of SCIGs.**

| Wind variation | Source Power flow | | Wind Farm Power Flow | |
|---|---|---|---|---|
| (m/sec) | Active (MW) | Reactive (MVAR) | Active (MW) | Reactive (MVAR) |
| 8 | 140 | 135 | 31.32 | -25.76 |
| 9 | 134 | 135 | 37.07 | -26.75 |
| 10 | 130 | 135 | 41.08 | -27.51 |
| 11 | 127.5 | 137 | 43.24 | -27.95 |
| 12 | 126 | 138 | 43.76 | -28.06 |
| 13 | 127.5 | 136 | 42.785 | -27.84 |
| 14 | 130 | 135 | 40.63 | -27.41 |
| 15 | 132 | 135 | 37.64 | -26.84 |
| 16 | 140 | 135 | 34.128 | -26.23 |
| 17 | 141 | 135 | 30.35 | -25.62 |

**Table.2. Reactive power requirement for SCIG**

| Wind variation | Source Power flow | | Wind Farm Power Flow | |
|---|---|---|---|---|
| (m/sec) | Active *PG1* (MW) | Reactive *QG1* (MVAR) | Active (MW) | Reactive (MVAR) |
| 8 | 182.5 | 43.0 | 30.45 | -38.83 |
| 9 | 176.5 | 44.0 | 36.15 | -39.42 |
| 10 | 172.5 | 44.0 | 40.28 | -39.9 |
| 11 | 168.5 | 44.5 | 42.39 | -40.14 |
| 12 | 167.5 | 44.5 | 42.9 | -40.14 |
| 13 | 172.0 | 44.5 | 41.78 | -40.09 |
| 14 | 172.5 | 45.0 | 39.54 | -39.717 |
| 15 | 175.0 | 44.0 | 36.57 | -39.47 |
| 16 | 178.5 | 43.0 | 33.2 | -39.04 |
| 17 | 182.5 | 42.5 | 29.18 | -38.78 |

**Case B:** As shown in figure No.2. Large scale wind farm with squirrel cage induction generators is connected to a two bus radial system with STATCOM is modelled. The simulation results indicated the active power, reactive power and phase angle variations, are regulated by means of STATCOM which injects reactive power to the system as shown in Table No. 3. Load flow study is carried out to compare the expected calculation results and simulation results for the wind variation. Fig. 5.shows Reactive power generated by STATCOM during Fault.Fig.6 shows Voltage sag at Bus 2 during Fault.Fig.7. shows Voltage sag mitigation at Bus 2 by STATCOM

**Table.3. Reactive power compensation by STATCOM**

| Sr. No. | Wind Speed | SCIG Power flow | | Phase angle | |
|---|---|---|---|---|---|
| | | Active power | Reactive power | Bus1 | Bus2 |
| | | (MW) | (Mvar) | (deg) | (deg) |
| 1 | 8 | 30.45 | -38.83 | -2.38 | -11.95 |
| 2 | 9 | 36.15 | -39.42 | -2.29 | -11.56 |
| 3 | 10 | 40.28 | -39.9 | -2.24 | -10.67 |
| 4 | 11 | 42.39 | -40.14 | -2.21 | -10.55 |
| 5 | 12 | 42.9 | -40.14 | -2.2 | -10.3 |
| 6 | 13 | 41.78 | -40.09 | -2.22 | -10.42 |
| 7 | 14 | 39.54 | -39.717 | -2.25 | -10.7 |
| 8 | 15 | 36.57 | -39.47 | -2.29 | -11.13 |
| 9 | 16 | 33.2 | -39.04 | -2.34 | -11.57 |
| 10 | 17 | 29.18 | -38.78 | -2.39 | -12.06 |

Continue------

| Source power flow | | STACOM power flow | | Bus voltages | |
|---|---|---|---|---|---|
| Active power | Reactive power | Active power | Reactive power | Bus1 | Bus2 |
| (MW) | (Mvar) | (MW) | (Mvar) | (Volts) | (Volts) |
| 182.5 | 43 | 2.6 | -122.2 | 113.63 | 116.5 |
| 176.5 | 44 | 2.62 | -120.7 | 113.87 | 116.47 |
| 172.5 | 44 | 2.71 | -119.97 | 113.6 | 116.34 |
| 168.5 | 44.5 | 2.51 | -119.45 | 113.91 | 116.22 |
| 167.5 | 44.5 | 2.26 | -119.25 | 113.89 | 116.48 |
| 172 | 44.5 | 2.54 | -119.51 | 113.76 | 116.5 |
| 172.5 | 45 | 2.69 | -120.08 | 113.59 | 116.37 |
| 175 | 44 | 2.771 | -120.64 | 113.60 | 116.44 |
| 178.5 | 43 | 2.723 | -121.52 | 113.69 | 116.63 |
| 182.5 | 42.5 | 2.74 | -122.61 | 113.62 | 116.66 |

Bus 1 is a slack bus where the known variables are $V1$ and $\delta 1$ and the unknown variables are $P1$ and $Q1$. Load connected to bus 1 is $PD1$ = 99 MW and $QD1$ = 60 Mvar. Bus 2 is PQ bus where the P2 and the Q2 are known and the $V2$ and $\delta 2$ are unknown variables. Load connected at bus 2 are having $PD2$ = 105 MW and $QD2$= 53 Mvar. Load flow study is carried out for 12 m/sec wind speed to obtained source power flow and STATCOM power flow for the validation of results given by simulation. Base voltage selected is 115KV i.e. 1 pu and Base MVA selected is 100 MVA.

Active and reactive power supplied (or accepted) by source at bus 1 are calculated as $PG1=P1+PD1$ and $QG1=Q1+QD1$ respectively. Active power flow at source by calculation and simulation results are 163.4 MW and 167.5 MW respectively whereas the reactive power flow by source at bus 1 by calculation and simulation results are 33.94 MVAR and 44.5 MVAR respectively. Case C: In this case large scale wind farm with squirrel cage induction generators is connected to a two bus radial system with STATCOM is modelled. Three phase fault is applied at bus 2. The result indicated the active power, reactive power, terminal voltage and phase angle variations, are regulated by the means of STATCOM which injects reactive power to the grid during fault to improve the voltage profile and stability of network. Load flow study is carried out to compare the expected results and simulation results for the wind variation.

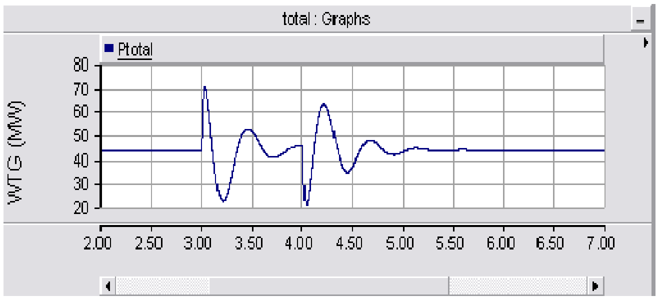


**Fig.3. Active power generated by WTG during Fault**

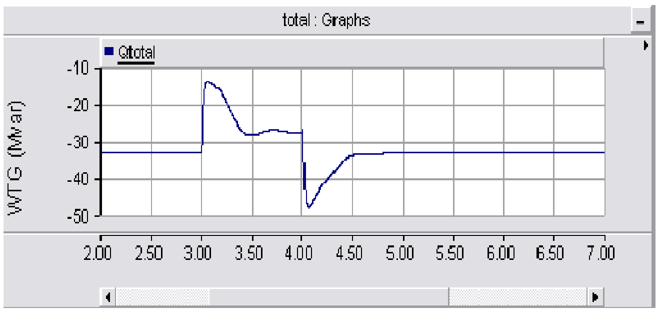


**Fig.4. Reactive power requirement of WTG during Fault**

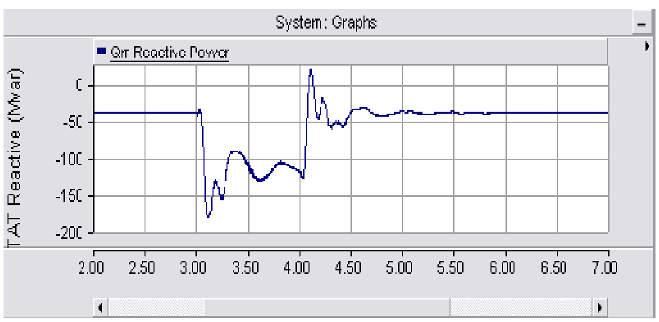


**Fig.5. Reactive power generated by STATCOM during Fault**

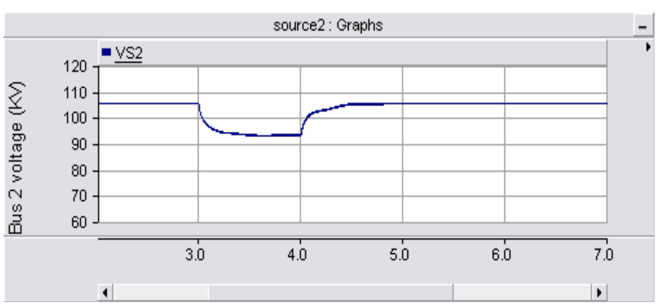


**Fig.6 Voltage sag at Bus 2 during Fault**

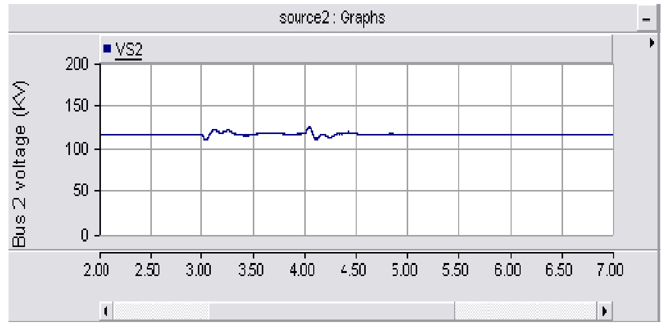


**Fig.7. Voltage sag mitigation at Bus 2 by STATCOM**

## Conclusion

This paper has investigated the application of STATCOM to wind farm equipped with Squirrel Cage Induction Generators to study reactive power supporter, during wind variation and three phase fault condition. A simulate on model for large scale wind farm is designed in PSCAD software to study the reactive power compensation and voltage sag mitigation using STATCOM. During case 1, the simulation results are obtained for active power generated and reactive power requirement of wind farm. The predicted active and reactive power flow based on equivalent induction generator parameters and simulation results are comparably good enough. During case 2, six pulse PWM based STATCOM is used to compensate the reactive power requirement of wind farm during wind variation. The study has demonstrated that STATCOM provides better reactive power support during dynamic behaviour of wind. Load flow analysis is used to validate the power flow results of active and reactive power with the simulation results obtained. During case 3, three phase balanced fault is created to obtain the voltage sag at bus 2. STATCOM is used to inject the reactive power to maintain voltage level. Fig 7 indicates the voltage profile at bus 2 during fault without STATCOM connected at PCC. Whereas From the simulation results, the designed wind farm with STATCOM responded well in mitigating voltage sag caused by three-phase balanced fault.

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