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How to Improve Stability by Using Facts Controller

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Abstract:-In recent years generation of electricity using wind power has received considerable attention worldwide. Induction machines are mostly used as generators in wind power based generations. Since induction machines have a stability problem as they draw very large reactive currents during fault condition, reactive power compensation can be provided to improve stability. This paper deals with stability improvement of a Transmission system embedded with wind farms by using power electronics based Flexible AC Transmission Systems (FACTS) reactive power compensator controller. The dynamic behavior of the example Transmission system, during an external three-phase fault and under various types of wind speed changes, is investigated. The study is carried out by three-phase, non-linear, dynamic simulation of distribution system component models. Simulation results are presented for different cases such as with and without FACTS and also for different modes of operation of FACTS controller. The effect of constant wind speed and linear change in wind speed on stability is also analyzed. The simulation analysis of stability of Transmitted system with wind farm is performed using MATLAB/SIMULINK.

I. INTRODUCTION

The rapid development of distributed generation (DG) technology is gradually reshaping the conventional power systems in a number of countries. Wind power is among the most actively developing distributed generation. Grid-connected wind capacity is undergoing the fastest rate of growth of any form of electricity generation, achieving global annual growth rates on the order of 20 - 30% [1]. The presence of wind power generation is likely to influence the operation of the existing power system networks, especially the power system stability [2]-[3]. After the clearance of a short-circuit fault in the external network, the grid connected wind turbine should restore its normal operation without disconnection caused by inrush current and dipped voltage [4]. The protective disconnection of a large amount of wind power may cause an important loss of generation that may threaten the power system stability. Further, dynamic changes of wind speed make amount of power injected to a network highly variable. Depending on intensity and rate of changes, difficulties with Frequency, voltage regulation and stability, could make a direct impact to quality level of delivered electrical energy [5]. In this context, from stability viewpoint, connection of wind turbine generator with dispersed generation of electricity, calls for a detailed technical analysis. Majority of the wind power based DG technologies employ induction generators instead of synchronous generators, for the technical advantages of induction machines like: reduced size, increased robustness, lower cost, and increased electromechanical damping. Wind turbine induction generator (WTIG) can be viewed as a consumer of reactive power. Its reactive power consumption depends on active power production. Further, induction generators draw very large reactive currents during fault occurrence [6]. Following the fault conditions, the voltage recovery may become impossible, and consequently the wind farm may experiences voltage collapse at its terminals. One way to prevent this from happening is by providing reactive power compensation which would help in preventing the voltage collapse at the terminals of wind farms, which would lead to improving the stability of the wind farm. Conventionally, shunt capacitor banks are connected at the generator terminals to compensate its reactive power consumption. To minimize reactive power exchange between wind power plant and distribution network, dynamic compensation of reactive power can be employed [7]-[8]. Further, the normal operation restoration after the clearance of an external system fault can be improved with dynamic reactive compensation. Without the dynamic compensation, it is possible that at some locations only a small number of wind turbines could be connected due to weak voltage conditions. This would not only leave assessed wind potential unused, but it could also prohibit installation of larger number of wind turbines jeopardizing the economics of the whole project. Recent development of power electronics introduces the use of flexible ac transmission system (FACTS) controllers in power systems [9]. Shunt FACTS devices play an important role in controlling the reactive power flow in the power network, which in turn affects the system voltage fluctuation and transient stability. The STATCOM is one of the important FACTS devices and can be used for dynamic reactive power compensation of power systems to provide voltage support and stability improvement [10]. in this work the effect of a STATCOM in improving the stability performance of the distributed network with WTIG is studied. In order to overcome negative dynamic impacts caused by WTIGs, a STATCOM is used at the point of WTIGs and distribution network connection. The study is based on the three phase non-linear dynamic simulation, utilizing the SimPowerSystem block set for use with MATLAB/SIMULINK [11]. Simulation results are presented to show the improved stability performance of a distributed network embedded with WTIGs under severe disturbances with the use of a STATCOM. Further the effects different types of wind speed and different control mode of operation of STATCOM on distribution system are presented

II. TRANSMISSION SYSTEM COMPONENTS MODELS

Transmission systems are inherently unbalanced due to the asymmetrical line spacing and imbalance of customer load. In view of this, single phase models can not be used for accurate studies on the operation of transmitted systems. Therefore in this work all network components are represented by the three-phase models. Wind turbine types Three types based on the generating system and the way in which the aerodynamic Efficiency of the rotor is limited during high wind speeds Generating systems types:

1. Squirrel cage induction generator
2. Doubly fed (wound rotor) induction generator
3. Direct drive synchronous generator

1. Squirrel cage induction generator

- Conventional, directly grid coupled squirrel cage induction generator.
- The slip, and hence the rotor speed of a squirrel cage induction generator varies with the amount of power generated.
- These rotor speed variations are, however, very small, approximately 1 to 2 per cent.
- Therefore, this wind turbine type is normally referred to as a *constant speed or fixed speed turbine.*
- Can run at two different (but constant) speeds by changing the number of pole pairs of the stator winding.
- A squirrel cage induction generator always consumes reactive power. In most cases, this is undesirable, particularly in case of large turbines and weak grids.
- Reactive power consumption of the squirrel cage induction generator is nearly always partly or fully compensated by capacitors in order to achieve a power factor close to one.

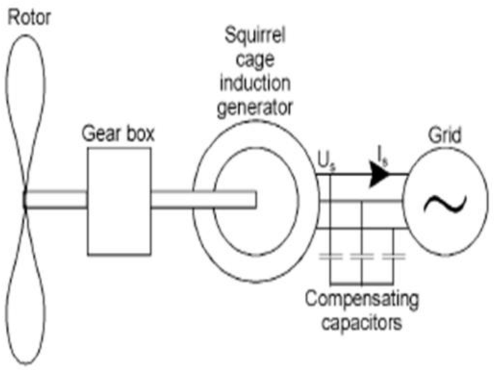
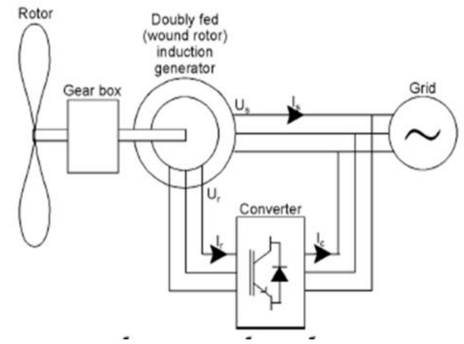


Fig. 1 Doubly Fed Induction Generator

- To allow variable speed operation, the mechanical rotor speed and the electrical frequency of the grid must be decoupled.
- In the doubly fed induction generator, a back-to-back voltage source converter feeds the three phase rotor winding.
- In this way, the mechanical and electrical rotor frequencies are decoupled and the electrical stator and rotor frequency can be matched, independently of the mechanical rotor speed.
- In the direct drive synchronous generator, the generator is completely decoupled from the grid by a power electronics converter



III. MODELING

Blade element impulse method: knowledge of aerodynamics and the simulation of a wind speed field including the spatial correlation between its individual elements, rather than the simulation of a single point wind speed. Requires detailed knowledge of the wind turbine blade geometry Quasistatic rotor model: an algebraic relationship between the wind speed and the mechanical power extracted from the wind. Used in power system studies Constant speed wind turbine model

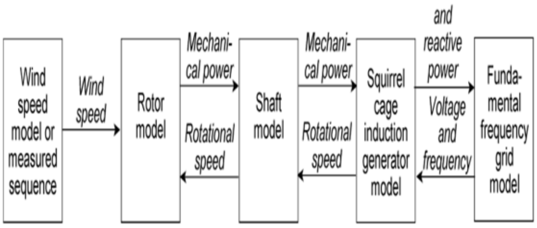
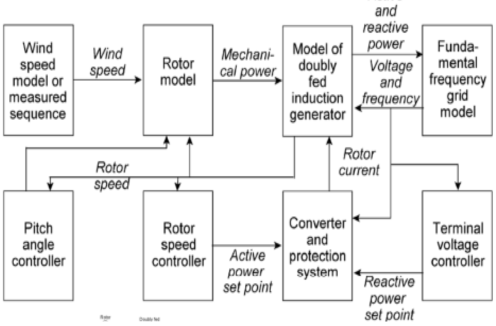


Fig 2 Variable speed wind turbine model (DFIG)



IV. WIND TURBINE INDUCTION GENERATOR (WTIG)

The block diagram of wind turbine the induction generator (WTIG) is shown in Fig. 1. The stator winding is connected directly to the 60 HZ grid and the rotor is driven by a variable-pitch wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. In order to generate power the induction generator speed must be slightly above the synchronous speed.

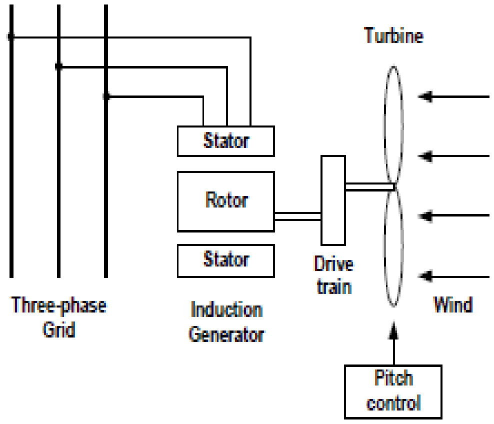


Fig.3 Block Diagram of Wind Turbine with Induction Generator

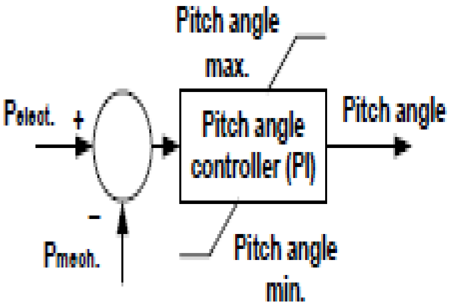


Fig. 4 Control System for Pitch Angle Control

The pitch angle controller regulates the wind turbine blade pitch angle β, according to the wind speed variations. Hence, the power output of WTIG depends on the characteristics of the pitch controller in addition to the turbine and generator characteristics. This control guarantees that, irrespective of the voltage, the power output of the WTIG for any wind speed will be equal to the designed value for that speed. This designed power output of the WTIG with wind speed is provided by the manufacturer in the form of a power curve. Hence, for a given wind speed, power output can be obtained from the power curve of the WTIG. A Proportional-Integral (PI) controller is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The pitch angle is kept constant at zero degree when the measured electric output power is under its nominal value. When it increases above its nominal value the PI controller increases the pitch angle to bring back the measured power to its nominal value. The pitch angle control system is illustrated in the Fig. 2. The pitch angle is controlled in order to limit the generator output power at its nominal value for winds exceeding the nominal speed. In order to generate power the IG speed must be slightly above the synchronous speed. Speed varies approximately between 1 pu at no load and 1.005 pu at full load. Each wind turbine has a protection system monitoring voltage, current and machine speed.

Wind turbine characteristic	Value
Rotor speed (constant speed)	17 RPM
Minimum rotor speed (variable speed)	9 RPM
Nominal rotor speed (variable speed)	18 RPM
Rotor diameter	75 m
Rotor swept area A_r	4418 m^2
Nominal power	2 MW
Nominal wind speed (constant speed)	15 m/s
Nominal wind speed (variable speed)	14 m/s
Gear box ratio (constant speed)	1:89
Gear box ratio (doubly fed)	1:100
Inertia constant H	2.5 s
Shaft stiffness (constant speed) K_s	0.3 p.u./el. rad.

Fig 5 Wind Turbine

Generator characteristic	Value
Number of poles p	4
Generator speed (constant speed)	1517 RPM
Generator speed (doubly fed)	900-1900 RPM
Mutual inductance L_m	3.0 p.u.
Stator leakage inductance $L_{s\sigma}$	0.10 p.u.
Rotor leakage inductance $L_{r\sigma}$	0.08 p.u.
Stator resistance R_s	0.01 p.u.
Rotor resistance R_r	0.01 p.u.
Compensating capacitor (constant speed)	0.5 p.u.
Inertia constant H	0.5 s

Fig 6 Induction Generator

V. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

The STATCOM is based on a solid state synchronous voltage source, which generates a balanced set of three sinusoidal voltages at the fundamental frequency, with rapidly controllable amplitude and phase angle. The STATCOM block used in the present study, models an IGBT-based STATCOM. However, as details of the inverter and harmonics are not represented in stability studies, a GTO-based model can also be used. Fig. 3 shows a single line diagram of the STATCOM and a simplified block diagram of its control system. The control system consists of:

- A phase-locked loop (PLL) to synchronize on the positive-sequence component of the three-phase primary voltage V1. The direct-axis and quadrature-axis components of the AC three-phase voltage and currents (labeled as Vd, Vq or Id, Iq on the diagram) are computed using the output of the PLL.
- The measurement systems measuring the d-axis and qaxis components of AC positive-sequence voltage and currents to be controlled and the DC voltage Vdc.
- The regulation loops, namely the AC voltage regulator and a DC voltage regulator. The output of the AC voltage regulator and DC voltage regulator are the reference current Iq ref and Id ref, for the current regulator.

- An inner current regulation loop consisting of a current regulator, which controls the magnitude and phase of the voltage generated by the PWM converter.

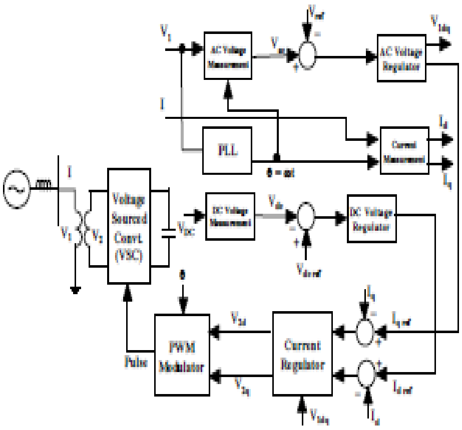


Fig. 7 single Line Diagram of Control System of STATCOM

VI. SIMULATION RESULTS

The dynamic behavior of the WTIGs during an external three-phase fault is analyzed and presented in this section. The active power generated by the WTIGs depends upon the wind speed. Two type of wind speed namely; constant wind speed and linear change of wind speed, are considered in the present study as shown in Fig. 5. Further, the reference voltage and the reference reactive power are set to 1 pu for both voltage controlled mode and VAr controlled mode.

Three cases are considered for all the types of wind speed changes:

Case-1: System without STATCOM.

Case-2: System with STATCOM, operating in the voltage control mode of operation.

Case-3: System with STATCOM, operating in the VAr/power factor control mode of operation.

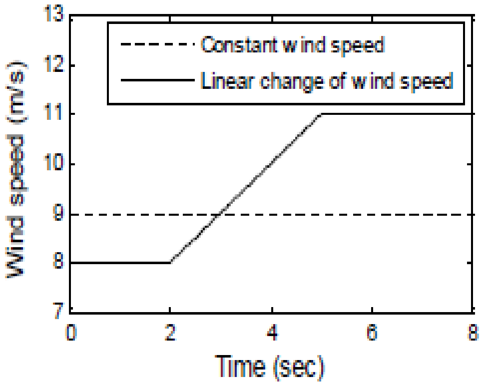


Fig. 8 Types of Wind Speed

A. Constant Wind Speed

A constant wind speed of 9 m/s is applied to the wind turbine. A three phase fault is applied at the bus no. 3, at t=2 sec. and cleared after 9 cycles. The original system is restored upon the fault clearance. Three cases as mentioned above are analyzed. Fig. 6 shows the response of WTIG terminal voltage for the above contingency. It can be seen from Fig. 6 that, as the fault is applied near to the WTIGs (bus-3), the WTIG terminal voltage drops drastically on the occurrence of the fault. The low voltage condition starts at t=2 sec, at which the fault is applied and lasts for 9 cycles i.e. the duration of the fault.

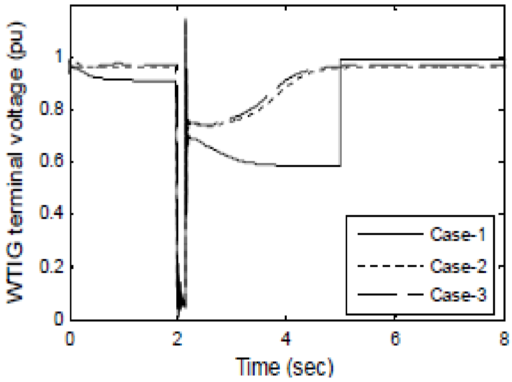


Fig. 9 WTIG Terminal voltage response for a 9 cycle 3 phase fault

For case of system without STATCOM (shown in Fig. 6, with legend Case-1), the WTIG terminal voltage drops to 0.69 pu immediately after the fault clearance. The AC Under voltage limit set by the protection system being equal to 0.75 pu, this low voltage condition results in tripping of WTIGs at t= 5 s, the tripping being been initiated by the AC Under voltage protection. For the system with STATCOM(shown in Fig. 6, with legends Case-2 & 3), because of reactive power support, the WTIG terminal voltage is slightly more than 0.75 pu immediately after the fault clearance, and is within the limit set by the protection system. So the system maintains stability and finally the WTIG terminal voltage recovers close to 1 pu for both the cases. Further, it can be seen from Fig. 7 that, for the case of STATCOM operating in VAr control mode (Case-3), the terminal voltage is slightly more than 1 pu as the controller tries to supply the rated reactive power. But, when the STATCOM is operating in voltage control mode (Case-2), the controller tries to maintain the terminal voltage constant at the set value of 1 pu and the STATCOM supplies that much reactive power as is required to maintain the terminal voltage constant. The response of the active power injected into the network is shown in Fig. 7. The active power injected to the distribution network reduces drastically during the duration of fault for all the cases. For the case of system without STATCOM (Case-1), because of the tripping of the WTIGs, the active power injected becomes zero after the fault clearance. But, for the cases of system with STATCOM (shown in Fig. 7, with legends Cases- 2 & 3), because of the reactive power support, the stability of the system is maintained and the WTIGs continue to supply the rated power to the distribution network after the fault clearance. Fig. 8 shows the variation of the reactive power supplied by the STATCOM for the above contingency, for all the cases. When the STATCOM is inactive (shown in Fig. 8, with legend, Case-1), the reactive power supplied by it is obviously zero.

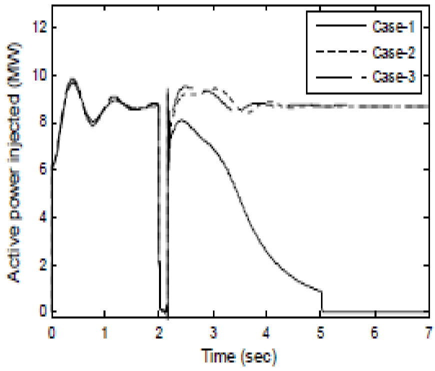


Fig. 10 Response of Active Power Injected To the Network for a 9 Cycle 3- Phase Fault

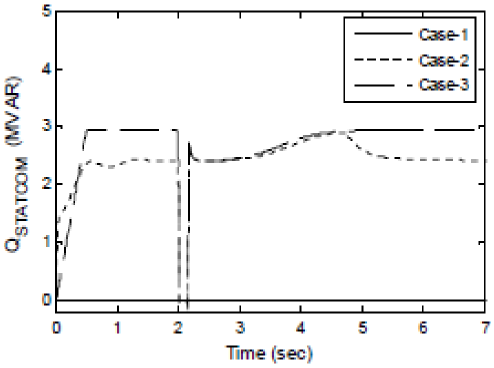


Fig. 11 Reactive Power Supplied By the STATCOM

It is also clear from Fig. 8 that, for the case of STATCOM operating in voltage control mode (shown in Fig. 8, with legends Case-2), the controller tries to maintain the terminal voltage constant at the set value of 1 pu and consequently the STATCOM supplies that much reactive power as is required to maintain the terminal voltage constant. In case of STATCOM operating in VAr control mode (shown in Fig. 8, with legends Case-3), as the reference reactive power is set to 1 pu, the controller tries to supply the rated reactive power. Hence the reactive power supplied for Case-3 is more than that of Case-2. The response of WTIG speed is shown in Fig. 9. The speed of the WTIGs increases at the occurrence of the fault at t=0.2 sec, for all the cases. For the case of system without STATCOM (Case-1), as explained earlier, the system looses stability and the speed of the WTIGs continues to increase. For the system with STATCOM (shown in Fig. 9, with legends Case-2 & 3), the stability of the system is maintained after the fault clearance. Further, it can be seen from Fig. 9 that the WTIG speed for Case-2 is slightly more than that for Case-3. This is due to the fact that, the reactive power supplied by the STATCOM is more in Case- 3, compared to the Case-2. In Case-2, the WTIGs draw the difference reactive power from the distribution network and hence the WTIGs are slightly overloaded compared to Case-3. To compare the performance of two modes of operation on transient stability improvement, the fault clearing time is increased by half a cycle and the same contingency is simulated. The response of WTIG speed is shown in Fig. 10. It can be seen from Fig. 10 that, when the STATCOM is operating in voltage control mode (shown in Fig. 10 with legend Case-2), the system looses stability due to the tripping of the WTIGs by the protection system. In case of STATCOM operating in VAr control mode (shown in Fig. 10 with legend Case-3), stability of the system is maintained. The difference between the reactive power requirement of the WTIGs and the reactive power supplied by the STATCOM is drawn from the distribution network. As explained earlier, the reactive power supplied by the STATCOM is more in Case-3, compared to the Case-2. In order to meet the reactive power requirement, the WTIGs are slightly overloaded in Case-2 compared to the Case-3. Hence, VAr control mode of operation of STATCOM improves the stability compared to the voltage control mode of operation.

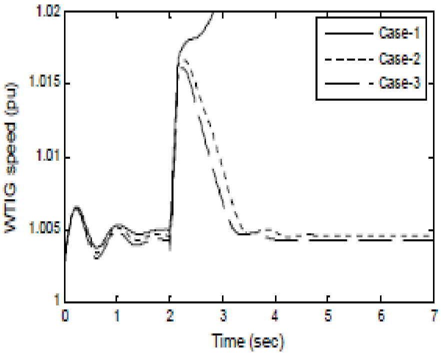


Fig. 12 Response of WTIG speed

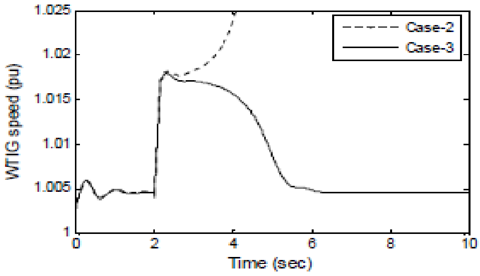


Fig. 13 Response of WTIG speed for different control modes of operation of STATCOM

B. Linear Change of Wind Speed

A linear change of wind speed as shown in Fig. 5 is applied to the wind turbine. This type of wind speed change enables the wind turbine to inject active power into a network from minimum to maximum value in a manner slow enough not to induce unwanted oscillations.

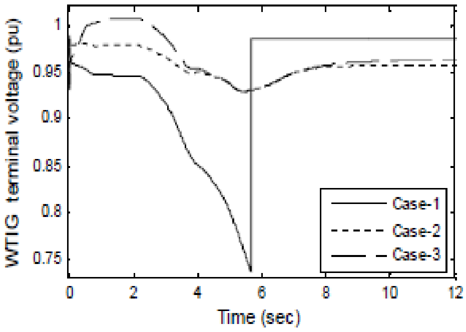


Fig. 14 Response of WTIG Terminal voltage for linear change of wind speed

As the maximum wind speed reaches 11 m/s, the active power injected to the network increases to 9.0 MW compared to constant wind speed (9 m/s) generation of 8.71 MW. The reactive power requirement of WTIG increases with the increase in the active power generation. Fig. 14 shows the response of the WTIG terminal voltage (without fault), for all the cases. For the case of system without STATCOM (shown in Fig. 11, with legends Case- 1), the WTIG terminal voltage drops below 0.75 pu, due to the insufficient reactive power compensation. This low voltage value is less than the AC Under voltage limit of 0.75 pu, set by the protection system. This low voltage condition results in tripping of WTIGs at t= 5 s, the tripping being been initiated by the AC Under voltage protection. Hence the stability of the system is lost for Case-1. For the system with STATCOM (shown in Fig. 11, with legends Case-2 & 3), the WTIG terminal voltage improves to 0.92 pu because of reactive power support. This is well within the limit set by the protection system. So the system stability is maintained and finally the WTIG terminal voltage recovers close to 0.95 pu for both the cases. Further, it can also be seen from Fig. 12 that, for the case of STATCOM operating in VAr control mode (Case-3), the terminal voltage is slightly more than that of STATCOM operating in voltage control mode (Case-2). As explained earlier, this is due to the fact that the reactive power supplied by the STATCOM is more in Case-3 than the Case-2. In Case-2, the WTIGs draw more reactive power from the distribution network and hence the WTIGs are slightly overloaded compared to Case-3. To compare the performance of two modes of operation on improving the stability, a three phase fault of 5 and half cycle duration is applied at the bus no. 3, at t=12 sec. The original system is restored upon the fault clearance. The response of the WTIG speed is shown in Fig. 12. In the prefault period, the WTIG speed settles to around 1.005 pu after the initial transients. The WTIG speed increases drastically at the occurrence of the fault at t=12 sec, for both the cases. It can be seen from Fig. 12 that, when the STATCOM is operating in voltage control mode (shown in Fig. 12 with legend Case-2), the system stability is lost due to the tripping of the WTIGs by the protection system. As explained earlier and shown in Fig. 11, the WTIG terminal voltage in Case-2 is slightly less than that of Case-3. Hence the WTIG terminal voltage drops to a lower value in Case-2 compared to Case-3, upon the occurrence of the fault. This low voltage condition results in tripping of the WTIGs for Case-2. The tripping is initiated by the AC Under voltage protection. In case of STATCOM operating in VAr control mode (shown in Fig. 12 with legend Case-3), stability of the system is maintained. This is due to the fact that, in Case-3 the pre-fault WTIG terminal voltage was comparatively higher, and upon the occurrence of the fault, drops to a value within the limit set by the protection system. Hence stability of the system is maintained in Case-3.

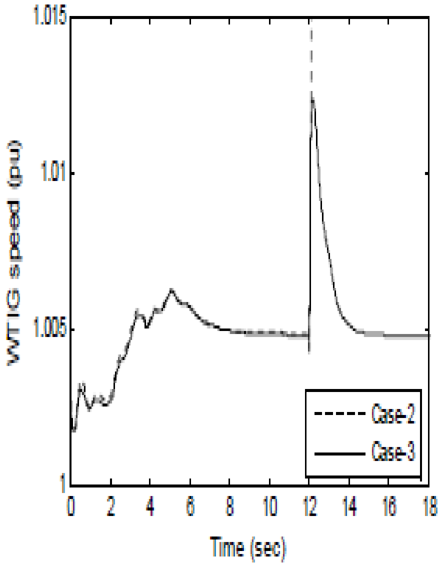


Fig. 15 Response of WTIG Speed for Different Control Modes of STATCOM

The response of the active power injected into the distribution network is shown in Fig. 13, for the same contingency and for both the cases. As the linear change of wind speed from 8 to 11 m/s is applied to the wind turbines, the active power injected to the distribution network increases with the increase in wind speed. After the initial transients the active power injected to the distribution network finally settles to its rated value of 9 MW. As the fault is applied at t=12 sec., near the WTIG bus (bus-3), the active power injected to the distribution network reduces drastically during the fault duration for both the cases. As explained earlier, the low voltage condition in Case-2 results in tripping of the WTIGs, upon the clearance of the fault. Hence, the active power injected to the distribution network becomes zero (shown in Fig. 13, with legends Case-2). In case of STATCOM operating in VAr control mode, due to the higher pre-fault WTIG terminal voltage, stability of the system is maintained upon the clearance of the fault (shown in Fig. 13 with legend Case-3).

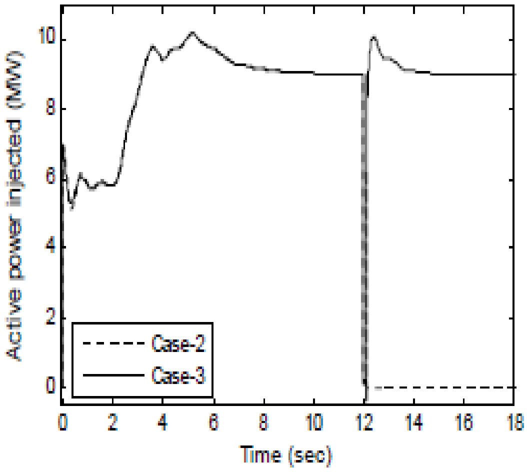


Fig. 16 Response of Active Power Injected To the Network for Different Control Mode of STATCOM

VII. CONCLUSION

This paper presented a study about the stability improvement of a distribution system embedded with wind farms. For dynamic reactive power compensation, a FACTS-based controller is employed. The dynamic behavior of the example distribution system, during an external three-phase fault and under various types of wind speed changes, is investigated. Simulation results show that the FACTS-based reactive power compensation prevents large deviations of bus voltage magnitude induced by reactive power drawn from distribution network by WTIGs. It is observed that, for the case of FACTS controller operating in voltage control mode, the controller tries to maintain the terminal voltage constant, at its preset reference value of 1 pu. Consequently the FACTS controller supplies that much reactive power as is required to maintain the voltage constant. For the case of FACTS controller operating in VAr control mode the controller tries to supply the preset reference reactive power of 1 pu and hence tries to supply the rated reactive power. As the reactive power supplied for VAr control mode is more than that of voltage control mode, the VAr control mode of operation of FACTS controller is more effective in improving the stability of the system compared to the voltage control mode of operation.

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