International Journal of Engineering and Applied Sciences (IJEAS)
Vol.2, Issue 2(2010)13-22

COMPARISON OF SVC AND STATCOM IMPACTS ON WIND FARM STABILITY CONNECTED TO POWER SYSTEM

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Accepted Date: 10 September 2009

Abstract

This paper considers the impacts of the Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) on stability of the wind farms based on fixed speed induction generators (FSIG) which are connected to power system, after a severe disturbance occurrence. Because of asynchronous characteristic of fixed speed induction generators, the instability in wind farms based on FSIG is severally created by the extreme reactive power absorption by FISG after fault. This phenomenon is a result of rotor slip of FISG increase during the fault, and consequently, the consumption of reactive power is raised. The comparison is made between the performances of the wind farm equipped by SVC and STATCOM to improve the wind farm stability during and after fault. The simulation results show both of the devices can enhance the system stability during and after disturbance, especially when the network is weak. It is shown that the STATCOM have a much better performance as compared to SVC to improve wind farm stability, and provided better reactive power support to network.

Keywords: SVC, STATCOM, Stability, Wind Farm

1. Introduction

Nowadays wind as a significant proportion of non-pollutant energy for electric energy generation, is widely used. If a large wind farm, which electrically is far away from its connection point to power system, is not fed by adequate reactive power, it present major instability problem. The wind farm stability is one of indexes that prober think on it, and many researches about various methods of analyze and improve wind farm stability, has been performed [1-4]. In [2] the stability of FISG based on wind turbines is analyzed by the equal area early introduced for synchronous generators. However, due to the different characteristics of a synchronous generator among the FSIG, this method cannot be acceptable to analyze. The authors in [5] proposed a breaking resistor to absorb active power during fault to enhance the system stability, but the important problem for FSIG is providing of reactive power during and after fault and this technique is not effective. In [6] it is suggested to use FACTS devices such as SVC and STATCOM to improve the stability in wind farm. Generally, stability means the capability of power system to hold synchronism during occurrence of a severe transient disturbance such as fault in equipment and transmission line or loss of generation or lumped load.

This paper proposes the use of either the Static Var Compensator (SVC) or the Static Synchronous Compensator (STATCOM) to improve stability of wind farm that is connected to power system. Firstly, stability analysis of FSIG based on wind turbine is explained. Furthermore, the wind farm models based on FSIG, equipped with SVC and STATCOM, connected to power system are developed by MATLAB-SIMULINK. Then the impacts of SVC and STATCOM on power system during and after fault are investigated. Afterward the effect of ratings of these devices and the Short Circuit Ratio (SCR) of network on the system recovery is analyzed. Finally, as a conclusion, the performance of SVC and STATCOM is compared during disturbances.

2. Stability analysis of Fixed Speed Induction Generator Connected to Network

When the induction generator operates at normal steady state, it has a small slip and speed variation [6]. In no load condition when the slip is near to zero, the reactive power absorbed by machine is the lowest value. When the load and power generation is increased, the rotor slip and the reactive power absorption will also raise. In the wind farms the reactive power is mainly compensated per turbine level, i.e., when the power output is increased, a number of power factor capacitors (PFC) are gradually connected to induction generator terminal through mechanical switches. However, this system can only generate steady state compensation and cannot be an effective compensating tool during transient conditions.

During normal operation, the electric torque is equal to the mechanical torque and the FSIG is in steady state condition. When a system fault happens, a sudden drop in the AC voltage is created and it causes the FSIGs electrical torque reduction. The mechanical and electrical torqueses become unbalanced Due to the fixed mechanical torque in this condition, and it causes the rotor to accelerate so the rotor slip increases to a new slip. When the system fault cleared, the AC voltage will return to pre fault value (if the system configuration is not changed from pre fault to post fault). Because the rotor slip cannot change instantaneously due to mechanical restrictions, a large amount of reactive power is absorbed by FSIG and the electric torque will be greater than the mechanical torque. It causes to de-accelerate rotor and to decrease slip. The deceleration of the FSIG and reduction of rotor slip lead to reduction of reactive power absorbed by the FSIG and it cause AC voltage to increase. Finally, the reactive power and electrical torque come back to their steady state conditions and the system is stable. If the fault is not isolated on suitable time, the rotor slip may increase extensively and the system will be unstable.

3. Introduction of STATCOM and SVC

The SVC and STATCOM can provide dynamic reactive power compensating and it in turns leads to an increase in network voltage during and after fault. This raises the electric torque generated by the FSIG, prevents from accelerating of rotor, and finally improves the system stability. The STATCOM is one of the FACTS devices that is connected to the system and compensates the reactive power. In this device, capacitive or inductive current can be controlled independent of the AC bus voltage. If voltage of the system is reduced suddenly, STATCOM can support the decreased voltage by injection of capacitive reactive power. STATCOM comprises two main sections that are seen in Figure 1 as the voltage supply converter (VSC) and coupling transformer. The STATCOM DC voltage is usually kept to a fixed value In order to make it operate sufficiently. The STATCOM is operating in two inductive and capacitive modes. When the voltage of converter is upon the transmission line voltage, the STATCOM is considered as a capacitive reactance and it performs in capacitive mode. In similar way when system voltage is upon the converter voltage, system is observing an inductive reactance in conjunction of its terminal, and STATCOM operates in inductive mode. In inductive mode, current direction is toward STATCOM, and in capacitive mode, current direction is from STATCOM toward system. This two performance modes enables STATCOM to prepare inductive and capacitive compensating for one system.

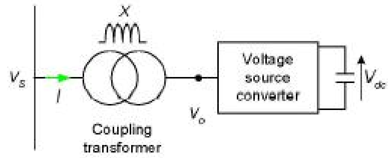


Fig. 1 STATCOM Configuration

Other kinds of FACTS devices that connected to system in parallel are SVC. An SVC consists of a combination of fixed capacitors or reactors, thyristor switched capacitors (TSC), and thyristor controlled reactors (TCR), connected in parallel with the electrical system. The TSC splits up a capacitor bank into sufficiently small capacitance steps and switches these steps on and off individually, using anti-parallel connected thyristors as switching elements. TCR controls the fundamental-frequency current component through the reactor by delaying the closing of the thyristor switches with respect to the natural zero crossing of the current. Equivalent circuit of SVC connected to HV bus is shown in Figure 2. In addition, SVC can be seen as the adjustable suseptance and its maximum reactive current is proportional to the network voltage.

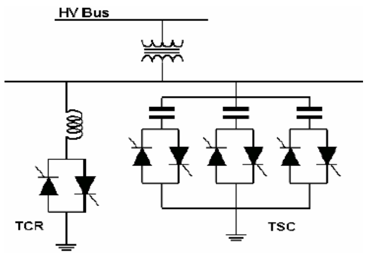


Fig. 2 Static Var Compensator (SVC)

4. Simulated System

The wind farm equipped by SVC and STATCOM was simulated through MATLAB-SIMULINK toolbox. The system that has been shown in Figure 3, comprise one wind farm 9 MW, that consists of 6 wind turbine with 1.5 MW or 3 pair Wind turbine with 1.5 MW. The generators are fix speed squirrel cage induction generators that are equipped with pitch angle control. The farm transmits power to a 120 kV network via a 25-kilometer transmission line. The system parameters are shown in the table 1 and 2. For each wind turbine a PFC capacitor rated at 400 KVar is connected to the terminal of the generator to compensate a part of absorbed reactive power by squirrel cage induction generator.

Table 1: Model base values	
V_{base}	120 kv
P_{base}	9 MW
F_{base}	60 Hz

Table 2: 9 MW induction wind turbine model parameters	
Stator resistance (Rs)	0.004843 pu
Rotor resistance (Rr)	0.004377 pu
Magnetizing inductance (Lm)	6.77 pu
Reactive power of SVC & STATCOM	3Mvar

SVC and STATCOM, that are connected to 25kv bus supplies the rest of needful reactive power. Capacity of each SVC and STATCOM is three MVar. The system equipped by

STATCOM and SVC are shown in figures 4 and 5 respectively. The power network comprises a 120kv generator with 60 HZ frequency. The generator has a $X_1/R_1 = 10$ ratio and short circuit ratio 2500 MVA, that connects via a 120/25 kV Y/Δ 47 MVA transformer .It is connected to 25kv bus via a 25 km transmission line.

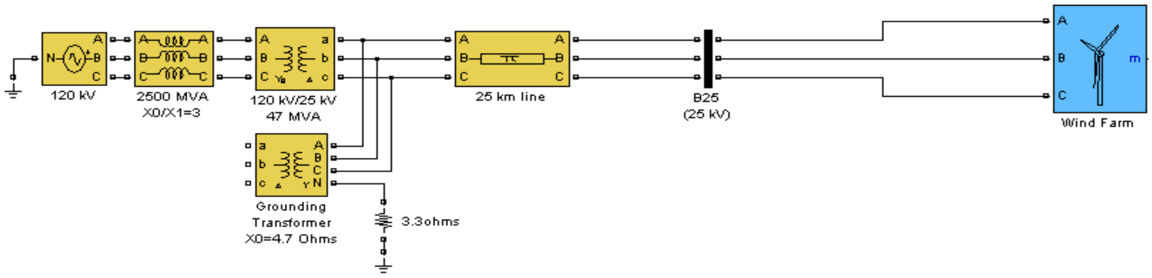


Fig. 3 Simulated System

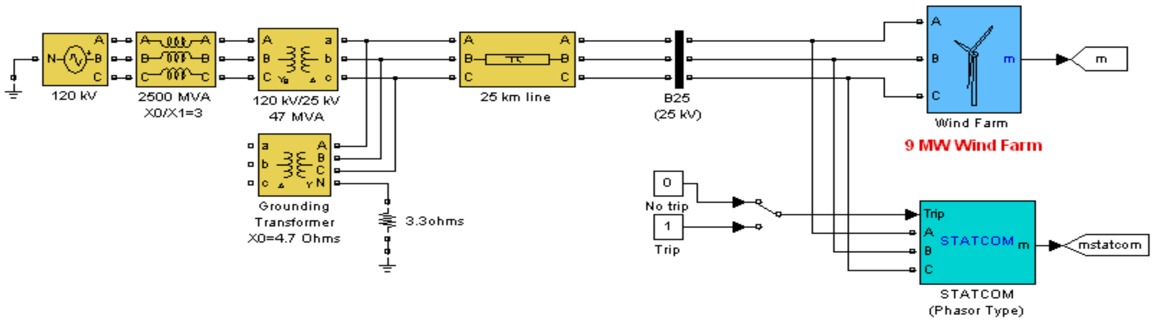


Fig. 4 System Equipped by STATCOM

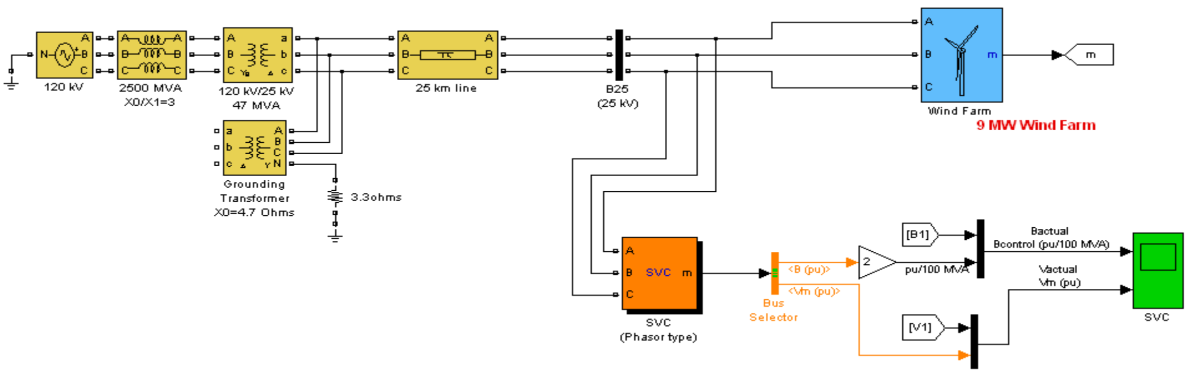
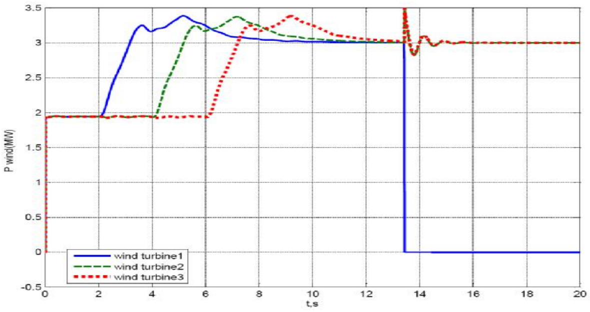


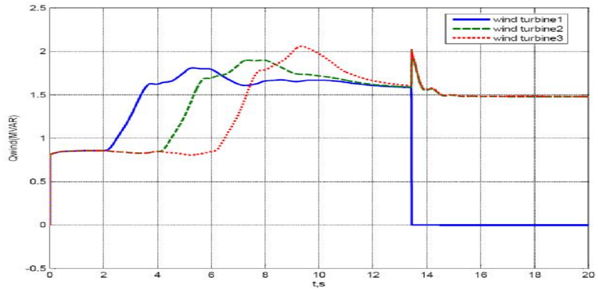
Fig. 5 System Equipped by SVC

6. Simulation Results

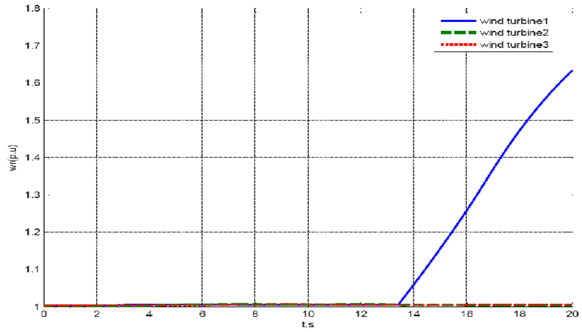
Firstly, system studies with only PFC and without fault were performed and the results are shown in figure 6. A 20 seconds simulation is considered.



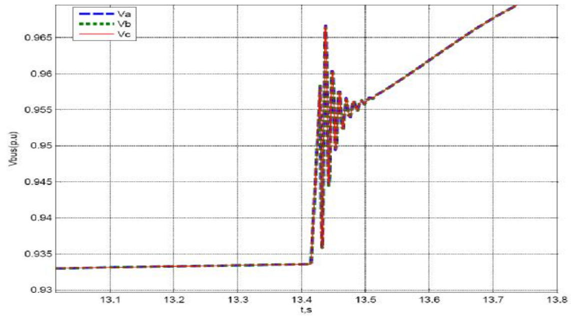
(a) Active power of three pair of wind turbine



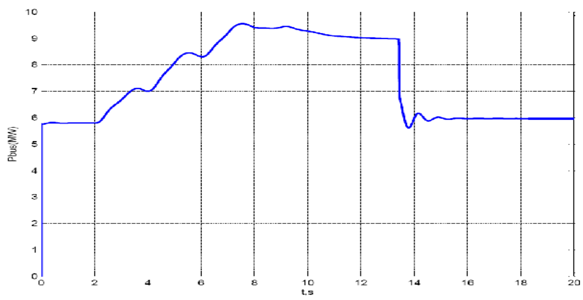
(b) Reactive power of three pair of wind turbine



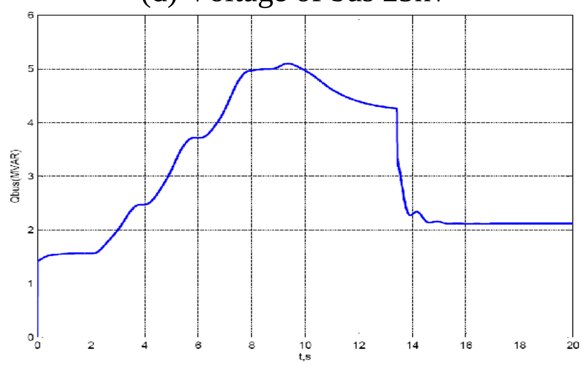
(c) Rotor speed of three pair of wind turbine



(d) Voltage of bus 25kv



(e) Active power of bus 25kv



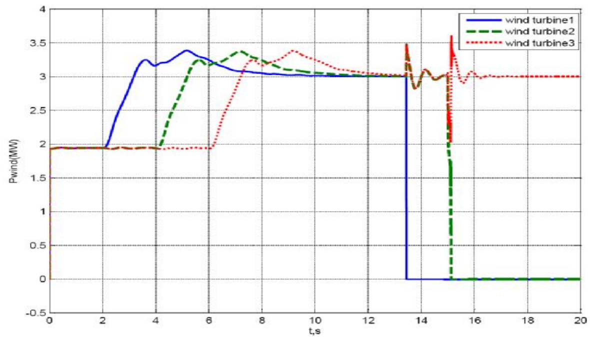
(f) Reactive Power of Bus 25kv

Fig. 6 simulation results with only PFC and without fault

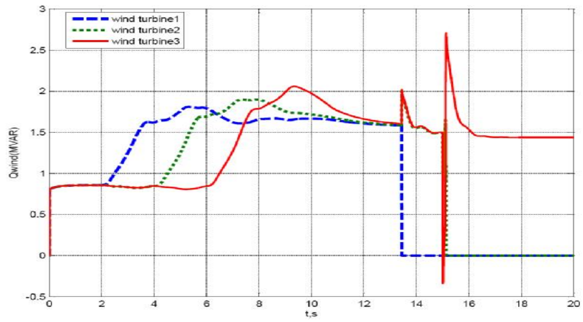
It is seen from Figure 6 that because of 7% voltage drop in bus 25kv at t = 13.43sec., as Fig (6-d), the first wind turbine, cannot absorb enough reactive power and due to reduction of electrical torque, this turbine lost its stability and it cause to rise in rotor speed as Fig (6-c). Then the first wind turbine is removed from network by protection system and its active and reactive power become zero as Fig (6-a) and (6-b).

The next simulation is carried out with only PFC and with a fault which is cleared after 0.1 sec.. The results are illustrated as Fig. 7. It is considered a line to line to ground fault in terminal of the second wind turbine on t= 15, and after 0.1 sec. (t = 15.1), fault is isolated as fig (8-d).

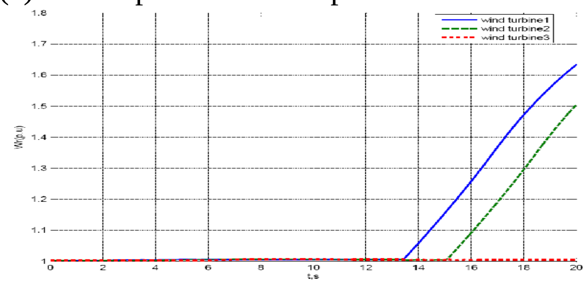
It is clear from Fig.7 that the first wind turbine is blocked because of weakness of electrical torque at t = 13.43 sec. then the occurrence of line to line to ground fault, on t = 15 sec. which is cleared on t=15.1 seconds, the second wind turbine will begin to accelerate as Fig (7-c). The second turbine is tripped by protection system as Fig (7-a) and (7-b), because of deficiency in reactive power and electrical torque in FSIG. Therefore, the third wind turbine is responsible for supplying active and reactive power and delivering them to 25 kV bus as Fig (7-e). It is shown in Fig (7-f) that after fault occurrence on t = 15 sec.. The reactive power is injected to the 25kv bus via 400kvar PFC capacitor, which is connected to terminal wind turbines. After fault clearance on t = 15.1 sec., reactive power injection decreases.



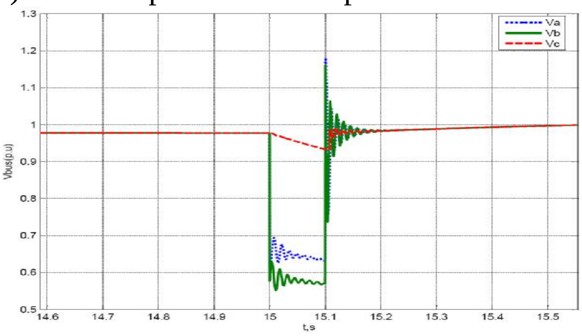
(a) Active power of three pair of wind turbine



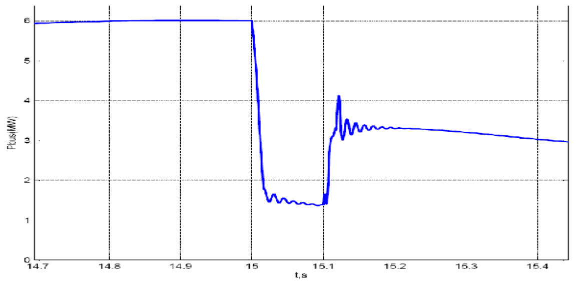
(b) Reactive power of three pair of wind turbine



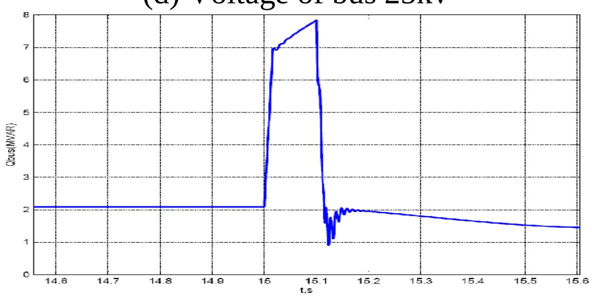
(c) Rotor speed of three pair of wind turbine



(d) Voltage of bus 25kv



(e) Active power of bus 25kv



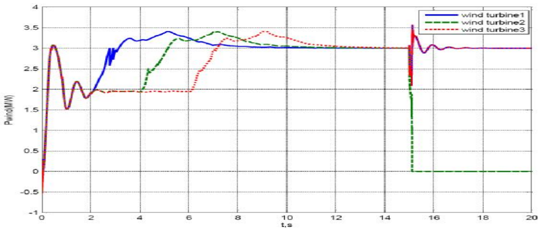
(f) Reactive Power of Bus 25kv

Fig. 7 simulation results with PFC only (fault applied at 15sec. and lasted for 0.1sec.)

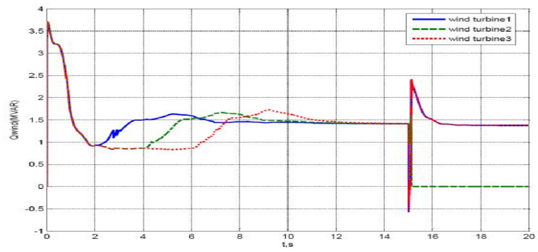
The simulation results of the same network configuration and an additional 3 MVar SVC and STATCOM, are illustrated in Fig. 8 and 9. It is clear from these figures that first wind turbine, that is removed by protection system on t=13.43 sec. in the previous simulation, can keep its stability and produce active and reactive power because of presence of SVC and STATCOM as shown in Figure (8-a) and (9-a). Second wind turbine cannot continue its service because of insufficiency capacity of SVC and STATCOM to supply necessary reactive power and it is tripped as Figure (8-c) and (9-c).

It is seen from Fig (8-e) and (9-e) that active power of 25 kv bus power decrease after fault occurrence on t =15, and this reduction continues until removal of fault on t = 15.1. However, active power reduction with presence of SVC is more than with presence of STATCOM. With a reduction in voltage profile, the reactive power generated by SVC is reduced. However, the maximum reactive current of STATCOM is only bounded by thyristors capability and is independent of network voltage. In addition, it is seen that after t = 15.1 sec., active power of bus increase until it reaches to its stable quantity (6MW) after several swings.

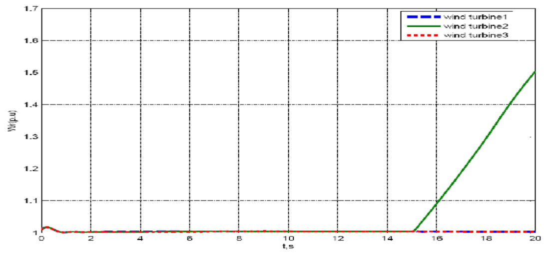
With increase in capacity of SVC from 3MVar to 4MVar and the capacity of STATCOM from 3MVar to 3.5 Mvar, the outage of the second wind turbine can be prevented. This phenomenon is shown in Figure 10, for a 3.5 MVar STATCOM.



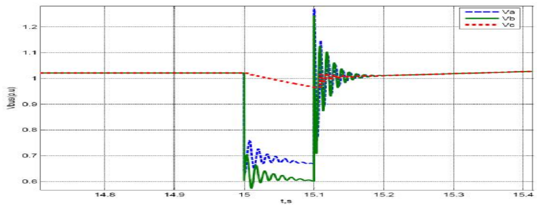
(a) Active power of three pair of wind turbine



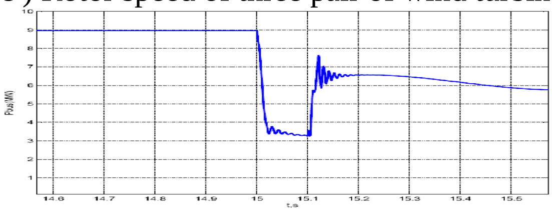
(b) Reactive power of three pair of wind turbine



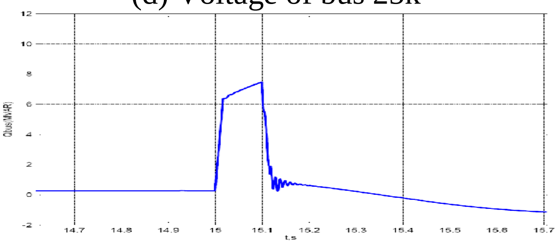
(c) Rotor speed of three pair of wind turbine



(d) Voltage of bus 25k



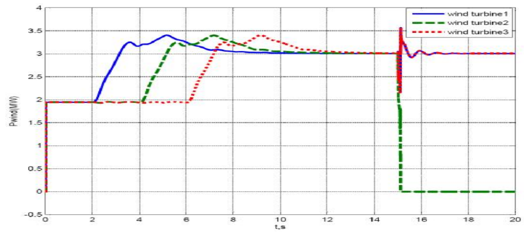
(e) Active power of bus 25k



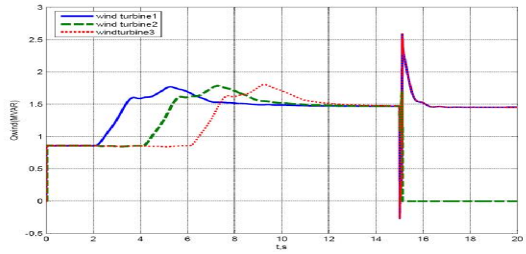
(f) Reactive Power of Bus 25kv

Fig. 8 simulation results with PFC and 3MVar SVC (fault applied at 15s and lasted for o.1s)

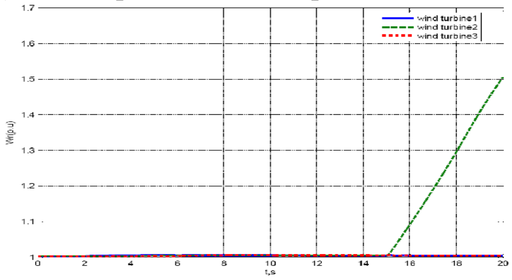
In figure 11, the impacts of network strength using the SVC and STATCON, on stability have been studied. This figure shows the variation of critical clearance time for system with PFC only, with SVC and with STATCOM for variations of network strength. In this study, both the SVC and the STATCOM have 3 MVar rating. It is clear, in the same short circuit ratio, that the STATCOM have further impact on the critical clearance time in contrast to the SVC.



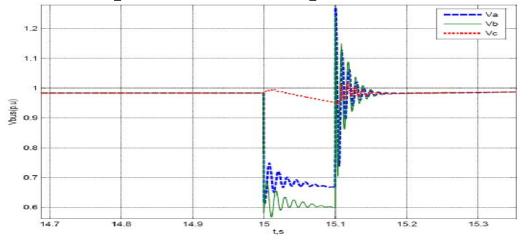
(a) Active power of three pair of wind turbine



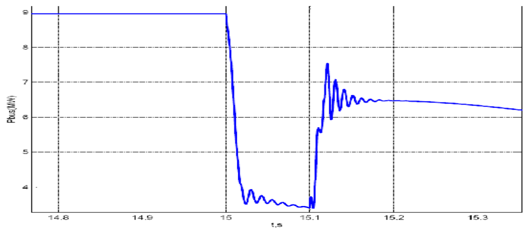
(b) Reactive power of three pair of wind turbine



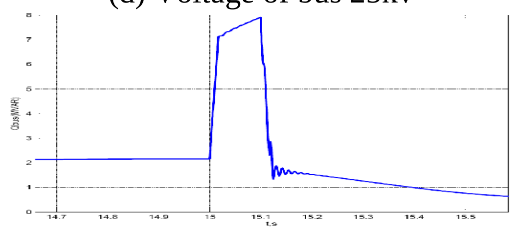
(c) Rotor speed of three pair of wind turbine



(d) Voltage of bus 25kv

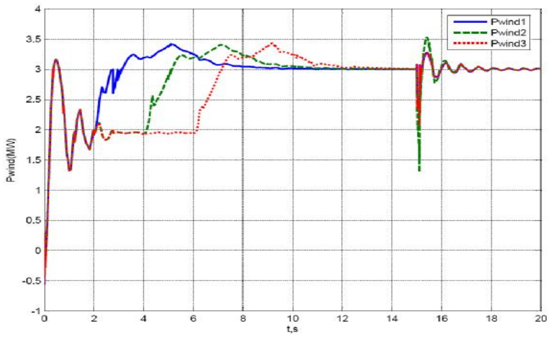


(e) Active power of bus 25kv

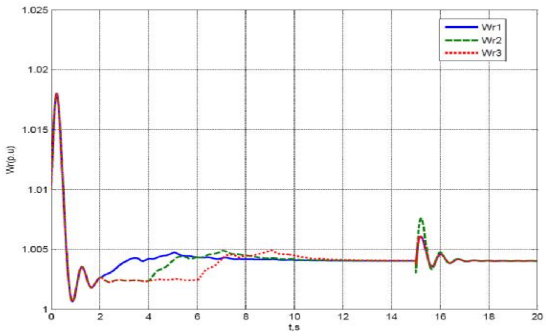


(f) Reactive Power of Bus 25kv

Fig.9 simulation results with PFC and 3MVar STATCOM (fault applied at 15 sec. and lasted for 0.1sec.)



(a) Active power of three pair of wind turbine



(b) Rotor speed of three pair of wind turbine

Fig.10 simulation results with PFC and 3.5MVar STATCOM (fault applied at 15s and lasted for o.1s)

The figure 12 shows the impact of variation of SVC and STSTCOM ratings on critical clearance time. It illustrates that with increasing of compensator capacity, the critical clearance time is raised and stability is enhanced.

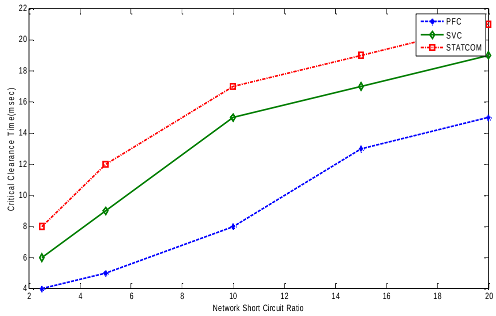


Fig. 11 Variation of critical clearance time with network SCR

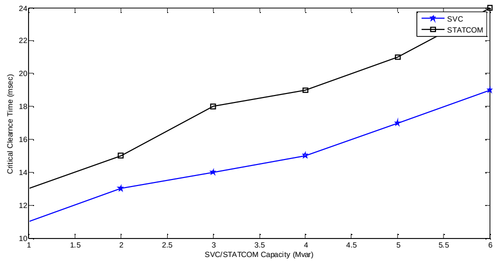


Fig. 12 Variation of critical clearance time with compensation device rating

7. Conclusions

The role of FACTS devices such as SVC and STATCOM in system performance improvement is specified. Stability improvement, power swings damping, voltage regulation, increase of power transmission and chiefly as a supplier of controllable reactive power to accelerate voltage recovery after fault occurrence, are considered as improvement factors. The simulation results show better wind farm stability performance of STSTCOM compensation compared to SVC compensation during fault occurrence.

Acknowledgment

The authors were supported in part by a Research grant from Shahid Beheshti University with no. s/603/27-87/4/27. The authors are indebted to the editor and referees for greatly improving the paper.

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