International Journal of Engineering and Applied Sciences (IJEAS)
Vol.2, Issue 4(2010)38-54

INVESTIGATION AND COMPARISON OF USING SVC, STATCOM AND DBR's IMPACT ON WIND FARM INTEGRATION

M. Sedighizadeh[1] and M. M. Hosseini[2]
1-Faculty of Engineering and Technology, Imam Khomeini International University, Ghazvin, 34194, Iran, Email: m_sedighi@sbu.ac.ir
2-Faculty of Engineering, Islamic Azad University, Saveh Branch, Saveh.,Iran

Received Date: 01 June 2010; Accepted Date: 28 July 2010

Abstract

This research studies stability of wind farms based on Fixed Speed Induction Generators (FSIG). It also investigates the effects of using SVC, STATCOM or DBR (Dynamic Resistance Braking) on wind farms stability. Because of the asynchronous operation nature, system instability of wind farms based on FSIG is largely caused by the reactive power absorption by FSIG due to the large rotor slip during fault. In this paper, a model of wind farm based on FSIG, equipped with SVC, STATCOM or DBR is developed in MATLAB/SIMULINK and then results of system simulation with these devices are compared. Finally for additional investigations and comparisons about the impact of these devices on wind farm stability, some studies are conducted on the system in different conditions and with various variables like: nominal power of the used devices, the X/R ratio of transmission line, nominal power of wind farm, wind speed and short circuit power of the network. Results of the simulation illustrate that, these devices considerably improve wind farm stability. However after considering all aspects and simulation results, In comparison with SVC and DBR, due to its dynamic performance and better reactive power support, STATCOM is the best choice for increasing stability of network connected wind farms.

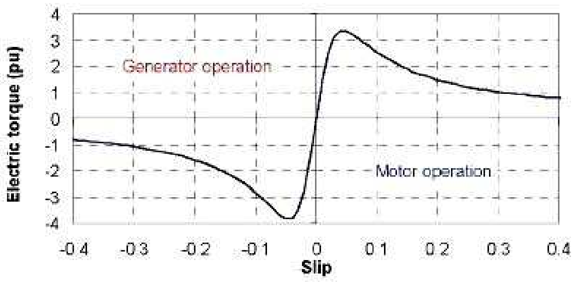
Keywords: Stability, Wind Farms, DBR, STATCOM, SVC

1. Introduction

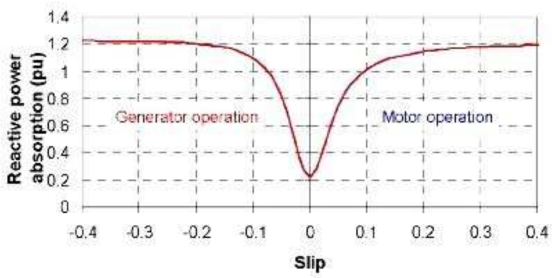
Considering the limitation of energy resources of fossil fuels and their daily increasing price and also the problem of pollutions caused by these resources, the usage of renewable energies in electrical energy generation has found a great importance [1]. It has been years that using wind energy which is one of the renewable energies, as a clean and free resource in electrical energy generation is seriously followed in industrial countries, but in recent year's role of the sparse systems of generation has considerably increased. According to forecasts 10% of the whole world electricity would be obtained by wind energy till 2020 and the annual development will be 10% to 40% till 2040. Nowadays one of the significant fields of study about sparse generation systems is their stability issue when they are connected to network. As wind farms increase in size, the ratio of the grid short circuit level at the connection point to wind generating capacity (known as the short circuit ratio, SCR) is reduced. Most of the existing wind farms use the fixed speed induction generator. These generators absorb significant amounts of reactive power from the grid in order to magnetize their stator. The connection of a large wind farm will normally be subject to a connection agreement between the wind farm owner and the network operator. The connection agreement sets out specific technical requirements to be fulfilled by the wind farm e.g. Fault ride through capability [2]. Previous research has revealed that faults which occur on the transmission line can lead to generator over-speed and instability of the network voltage, if the SCR is too low [3]. After the fault is cleared, large amounts of reactive power are required by the generator. If this is not available, the machine will speed out of control and has to be disconnected from the power system. While the loss of a small capacity wind farm may be acceptable, large wind farms are subject to Grid Code requirements and must be able to ride through disturbances. Studies have shown that by controlling the terminal voltage at the wind farm installation, transient and steady-state stability can be improved. In [4] and [5, 6] stability of FSIG based wind farms, using equal area criterion of synchronous generators is studied. However, the operation of a FSIG is different to that of a synchronous generator due to the nature of its asynchronous operation. Thus the effectiveness of using the equal area criterion for studying system stability with FSIG is in doubt. The research was limited to a few case studies and has not comprehensively looked at the effect of nominal power of the used devices, the X/R ratio of transmission line, nominal power of wind farm, wind speed and short circuit power of the network on wind farm stability. In this paper stability of FSIG based wind farm is investigated using the torque-slip and reactive power-slip characteristics. An instance of these wind farms connected to network and equipped with SVC, STATCOM or DBR is developed using MATLAB/SIMULINK. A detailed investigation is conducted on the impact of SVC/STATCOM/DBR on system recovery after a network fault. Furthermore, the influence of nominal power of the SVC/STATCOM/DBR, the X/R ratio of transmission line, nominal power of wind farm, wind speed and short circuit power of the network on wind farm stability is studied. Finally the performance of SVC and STATCOM and DBR is compared during disturbances on the wind farm connected network.

2. System Stability of FSIG Based on Wind Farms

The typical steady-state torque-slip and absorbed reactive power-slip curves for a FSIG, whose parameters are given in Appendix, are shown in Fig. l (a) and (b) respectively [6]. As shown in Fig. l (a), during normal steady-state operation the machine operates at a small slip and the speed variation is small. According to Fig. 1(b), at rotor slip of 0 which refers to no load operation, the generator has the lowest reactive power absorption. When the load (power generation) increased, the rotor slip will also increase and so as the reactive power absorption. When the rotor slip reaches a certain level, around +0.15 in this example, the increase of reactive power absorption with the increase of rotor slip becomes insignificant. In a practical system, reactive power compensation is usually provided by a number of power factor correction (PFC) capacitors which are switched in gradually using mechanical switches when the power output is increased. However, such a system can only provide steady-state compensation and their responses during transient condition are inadequate [7], [8].



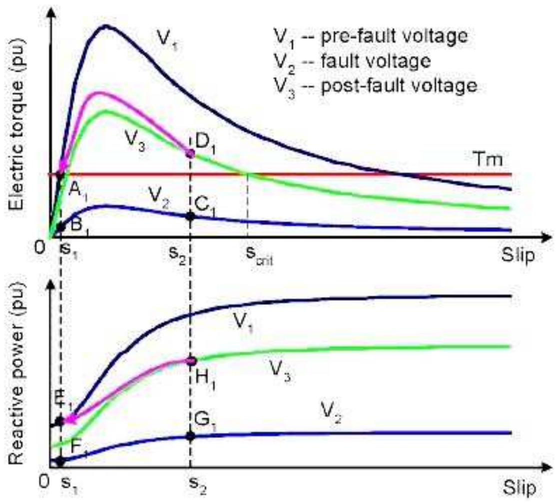
(a) Machine electric torque vs. slip



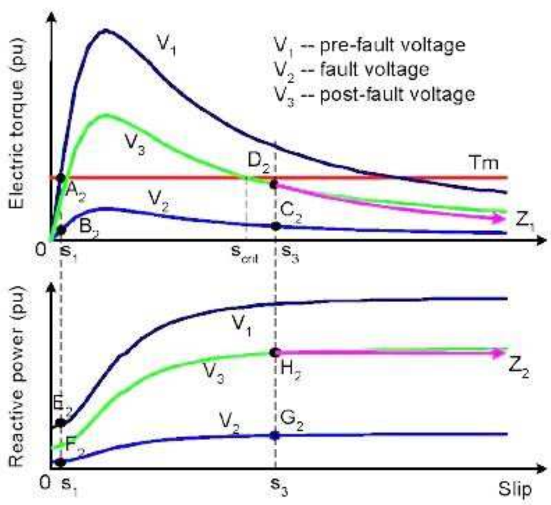
(b) Machine reactive power absorption vs. slip

Fig. 1. Steady state characteristics of FSIG

Using the torque-slip and reactive power-slip curves, system stability of FSIG can be analyzed [9]. Fig. 2 (a) and (b) show the stable and unstable conditions respectively. As shown in Fig. 2(a), during normal operation the FSIG operates at points A1 and E1 with an AC voltage of V1 and a rotor slip of S1. At this point the electric torque is equal to the mechanical torque and the FSIG is operating at steady state. When a system fault occurs, it will cause a sudden drop in the AC voltage, falling from V1 to V2. This in turn causes the FSIG's electrical torque to fall from point A1 to point B1 and reactive power to fall from point E1 to F1. As the mechanical torque is much greater than the electric torque, the FSIG will begin to accelerate to a rotor slip of S2. This results in the electric torque and reactive power characteristics moving to points C1 and G1 respectively. When the system fault isolated, the AC voltage will start to recover. With the FSIG still operating at a slip of S2, it absorbs a large amount of reactive power. This causes the AC voltage to recover to a lower level of V3. The operating points now move to points D1 and H1. As the electric torque is now greater than the mechanical torque, the rotor de-accelerates and the slip begins to decrease. The deceleration of the FSIG and decline of rotor slip means a reduction in reactive power absorbed by the FSIG. This reduction in reactive power absorbed in turns leads to a rise in AC voltage. As the AC voltage approaches V1 from V3, the electric torque and reactive power characteristics will return to their steady state conditions (points A1 and E1 respectively) thus, the system is stable.



(a) Stable operation



(b) Unstable operation

Fig. 2. Investigation of System stability with FSIG

If the fault were not cleared until the rotor slip reaches S3 as shown in Fig. 2 (b) the operating points would move to D2 and H2 from C2 and G2 respectively. However, the electric torque now is still less than the mechanical torque and the rotor slip continued to increase. As the FSIG continues to accelerate, both electrical torque and reactive power will move towards points Z1, and Z2. Thus the system is unstable and the wind farm will have to be disconnected from the grid.

According to these observations, we need a criterion which can evaluate all characteristics of system, to compare stability of variant systems equipped with generators and different devices. This criterion is Critical Clearing Time (CCT). CCT is the longest time that fault remains on network before it becomes unstable. According to this description the longer CCT is an index for more stability.

3.SVC, STATCOM and DBR Model

Fig. 3 shows the single line diagram of SVC and its controller diagram block in MATLAB/SIMULINK software. It consists of a number of (TSC) and a (TCR). The number of branches is selected with practical considerations such as: operational voltage levels, maximum output reactive power, nominal current of thyristor, bus configuration and installation expenses. Inductive limits can also develop to any nominal amounts, using extra TCR branch.

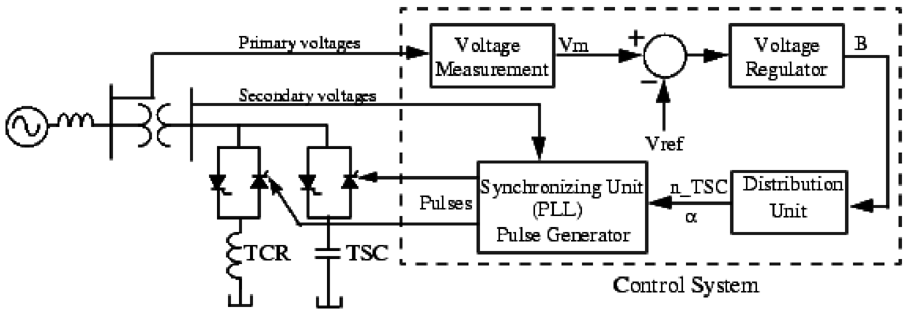


Fig.3. single line diagram of SVC and its controller diagram block

Its control system is consisted of below parts: Measurement system which measures positive-sequence voltage, voltage regulator which uses voltage error(difference between measured voltage and reference voltage) to estimate required susceptance for voltage regulation or reactive power control, dispatch unit which specifies required TCS capacity and required fire angle for TCR, synchronizing system which uses a phase-locked loop system for coordination between secondary voltage with pulse generator, to create proper pulse for thyristors. SVC voltage-current characteristic is shown in Fig. 4.

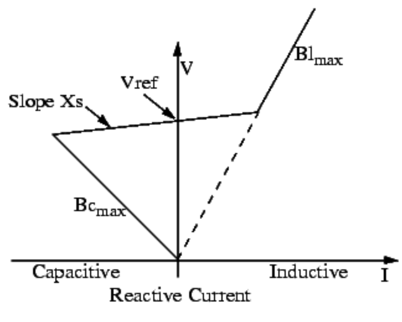


Fig.4. V-I characteristics of SVC

Fig. 5 shows the single line diagram of STATCOM and its controller diagram block in MATLAB/SIMULINK software.

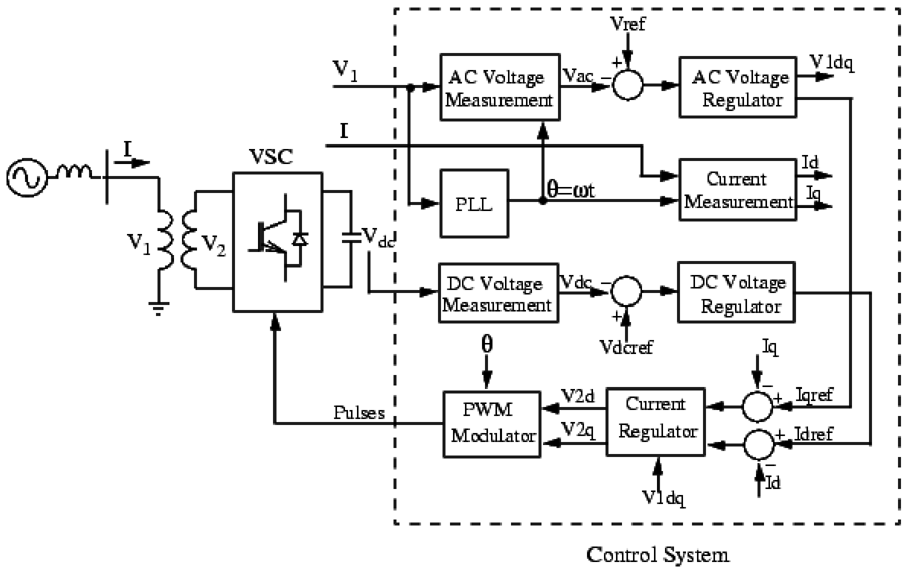


Fig. 5. single line diagram of STATCOM and its controller diagram block

The its control system is consisted of these parts: PLL part generates a sinusoidal voltage like V1, which is used in computing q and d axes components, voltage and current measurement system that measures q and d axis components in AC side to control DC voltage, AC voltage regulator generates reference current of q axe (Iqref) and DC voltage regulator generates reference current of d axe (Idref), current regulator specifies steps and level of voltage generation. PWM generates necessary pulses for VSC.

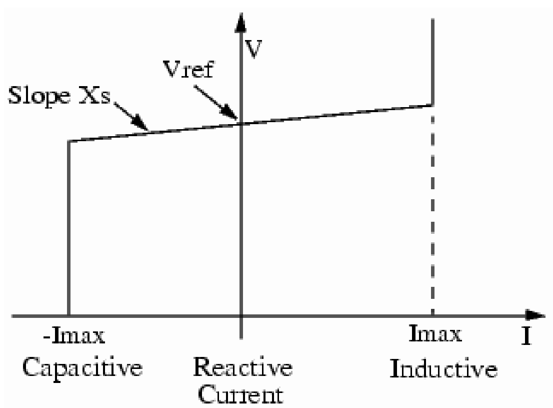


Fig. 6. V-I characteristics of STATCOM

Fig. 6 shows STATCOM V-I characteristics. Since SVC is based on nominal passive components, its maximum reactive current is proportional to the network voltage. While for STATCOM, its reactive current is determined by the voltage difference between the network and the converter voltages and therefore, its maximum reactive current is only limited by the converter capability and is independent of network voltage variation.

Fig. 7 shows DBR implementation in MATLAB/SIMULINK. Dynamic Resistance Braking (DBR) consists of a switch and a three phase resistance load which resistance load can have star or delta connection. Switch can be either based on thyristor or mechanical. To gain a precise operation, it's better to divide resistance bank in to several parts in order to enter them gradually in circuit if it's necessary.

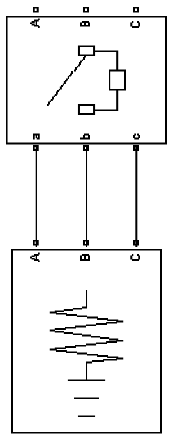


Fig. 7. DBR modeling

The most important purpose of using this device is consuming generator active power during fault and preventing generator from speeding up too much. Therefore control signal of this device can be generator speed, generator electrical torque and etc.

Due to its simple structure this device can be considered as the most economical device to keep system stable. In this paper a three phase breaker and resistance load is used to have simple design and control. As the fault occurs in network which its result is a great drop in voltage and generator speed increasing, wind farm is disconnected from network and it connects to DBR. DBR uses active power of wind farm and prevent generator from speeding up during fault. After fault clearing wind farm disconnects from DBR and connects to network again. Therefore system remains stable.

4.Case Studies

In this paper MATLAB/SIMULINK is used to investigate and simulate FSIG based wind farms equipped with SVC, STATCOM and DBR. Single line diagram of a typical system is shown in Fig.8 [9]. The 60 MW wind farm with an output voltage at 11kV is presented as a single lumped wind turbine model. Its induction generator parameters are shown in table 1. The farm is coupled to the 132 kV network through an 80 MVA transformer and connected to the grid via a double-circuit line. In order to provide the whole reactive power consumed by farm induction generator at rated output power of 60MW, a PFC capacitor rated at 30 MVar is used which fully compensates the reactive power absorbed by network. Throughout this study, the system short circuit level is fixed at 1200 MVA with an X1/ R1 ratio of 20 and the short circuit level of transmission line is fixed at 600 MVA with an X1/ R1 ratio of 10. For comparing system stability using each of these devices, it is assumed that a solid three-phase-to-ground fault occurs at the centre of one of the transmission lines at second 1 and after 155ms by opening the circuit breakers at the two ends of the line after a short circuit occurrence it is cleared. This will be half the strength of line.

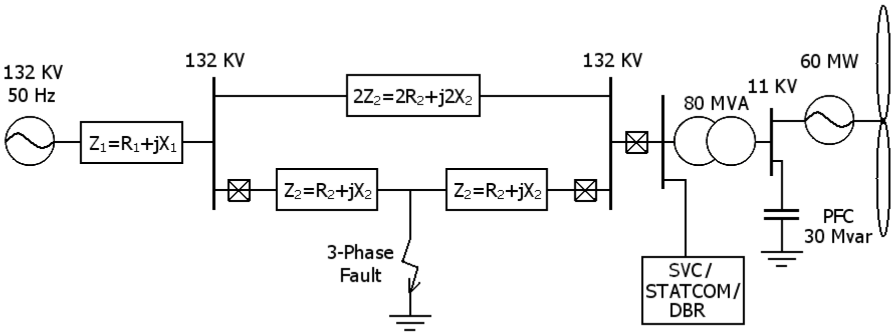
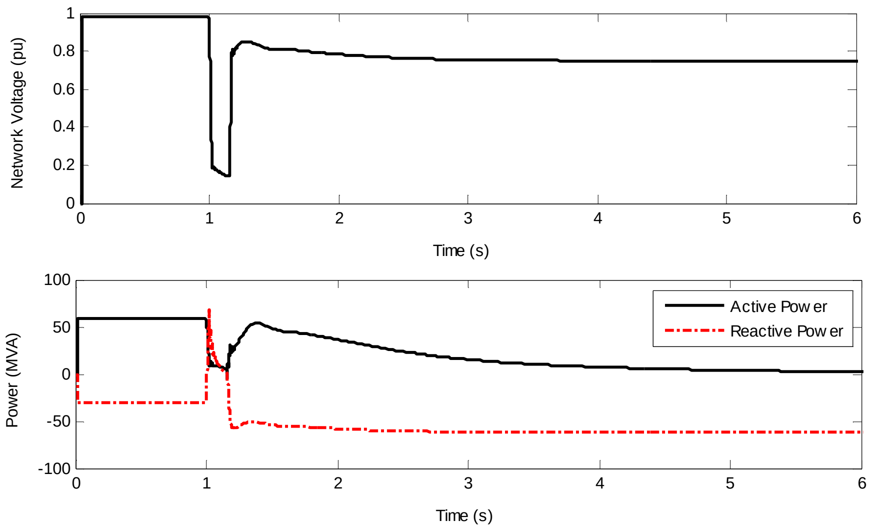


Fig. 8. Single line diagram of the simulated system

Table 1. Parameters of simulated wind turbine

Rated Power	6 MW	Stator Leakage Inductance	0.107 pu
Rated Voltage	11 KV	Rotor Leakage Inductance	0.1407 pu
Stator Resistance	0.0108 pu	Mutual Inductance	4.4 pu
Rotor Resistance	0.01214 pu	Lumped Inertia Constant	3 s

Simulation results with only PFC are shown in Fig. 9. According to this fig during the fault, due to the reduction of the AC voltage, the generated active power and the electric torque are significantly reduced. This causes the rotor speed to increase.



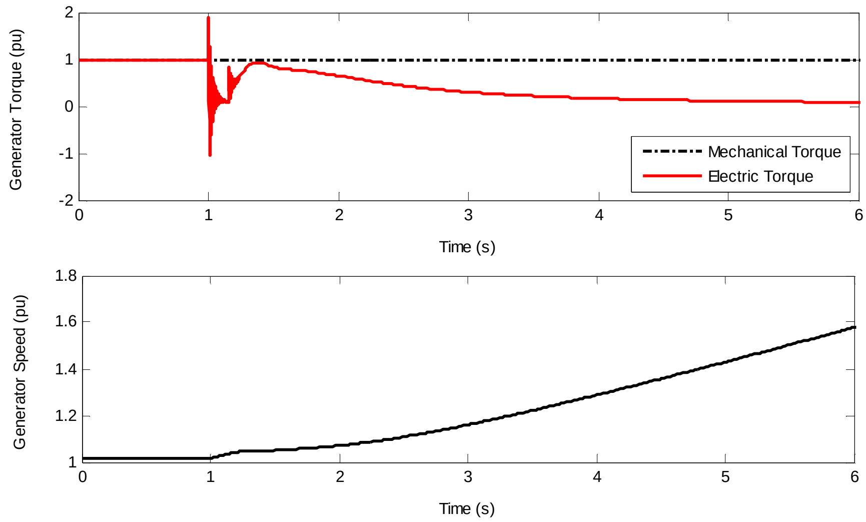
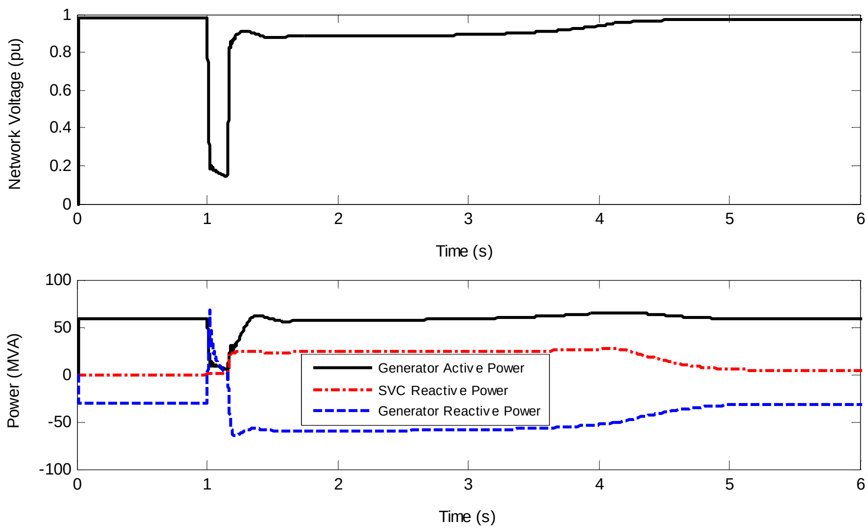


Fig. 9. Simulation Results with only PFC

Once the fault is cleared, the AC voltage recovers and so as the active power and electric torque. As the rotor slip is high, the generator absorbs large amount of reactive power from the network. As shown in Fig. 9, AC voltage is recovered at a low level of about 0.83pu. In this situation As the electric torque is still less than the mechanical input torque, the generator speed continue to rise and the AC voltage remains low and the wind farm has to be disconnected from the Grid.

With the same network configuration and an additional 30 MVar SVC, the simulation results are shown in Fig. 10. As can be seen, the AC voltage due to the extra reactive power support from the SVC recovers to a higher level in comparison with only PFC case at about 0.9pu after the clearing of the fault due to the extra reactive power support from the SVC. In this case the electric torque now is higher than the input mechanical torque and therefore, the rotor speed decreases. Eventually, the rotor slip backs to its nominal value and so as the AC voltage, generated active power and reactive power absorption and generator returns to the condition before the fault and system remains stable. As can be seen from Figure 10, during the fault due to the great drop in voltage, SVC uses a small proportion of its capacity and it can not use its whole capacity. However after fault clearing voltage recovers to some extent and SVC can make system more stable by reactive power generation.



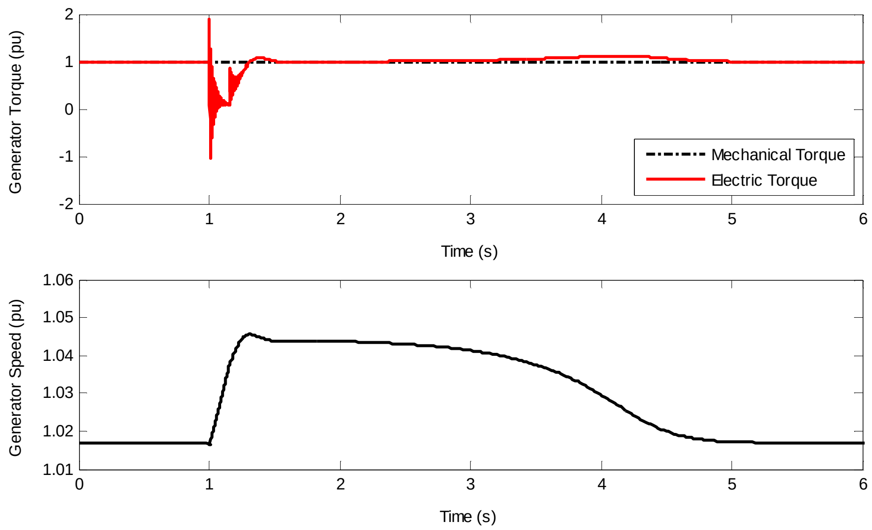
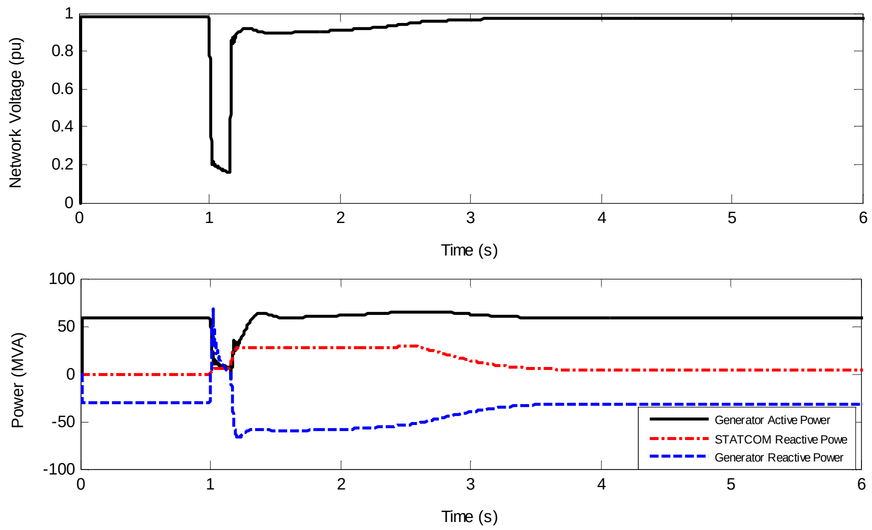


Fig. 10. Simulation Results with SVC

Simulation results for system equipped with a 30 Mvar STATCOM are shown in Fig.11. DC voltage of STATCOM and its capacity are 40kv and 375 μF respectively.



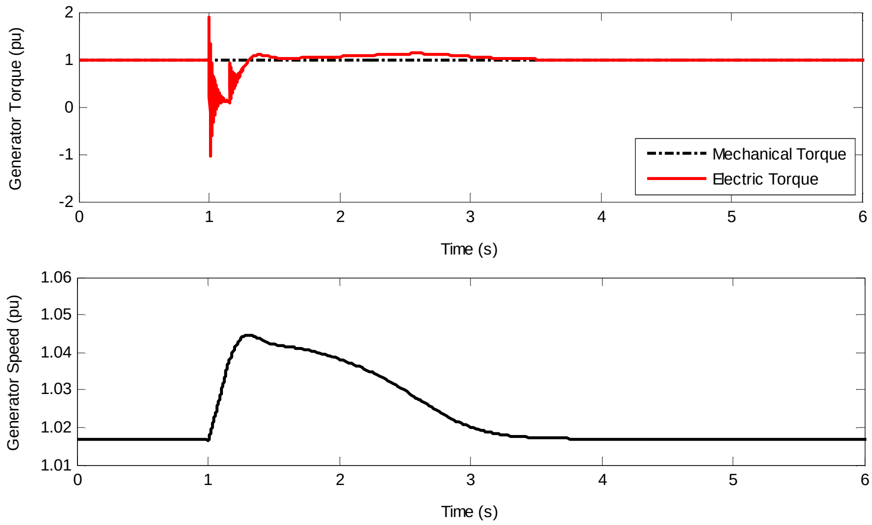
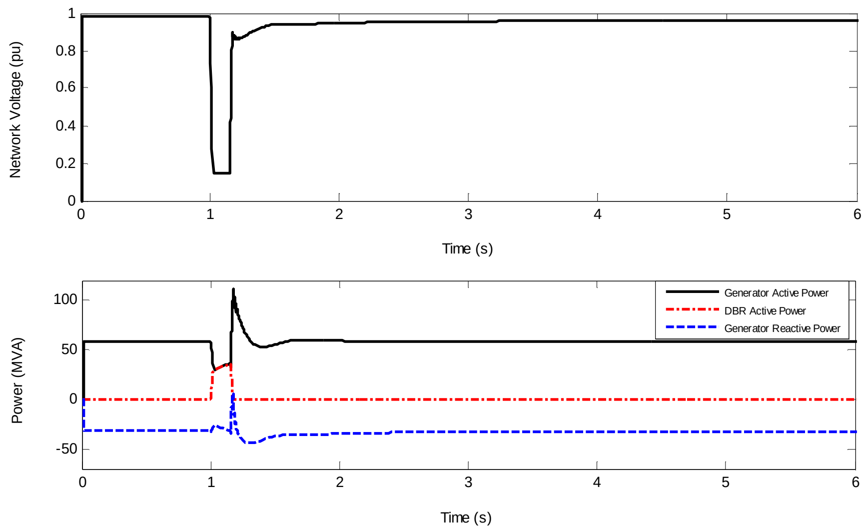


Fig. 11. Simulation Results with STATCOM

As can be seen from figure 11, like the system with SVC, after fault clearing AC voltage recovers at a higher level (0.92 pu) compared to with only PFC case. In this situation because electrical torque is higher than input mechanical torque, rotor speed decreases and finally rotor slip backs to the amount before fault and also AC voltage , reactive power absorption and active power generation back to their nominal amounts. Generator comes back to its work point before fault and consequently wind farm is stable. As can be seen from Figure 11, during the fault due to the great drop in voltage, STATCOM can not use its whole capacity. After fault clearing voltage recovers to some extent and STATCOM can make system more stable by generating required reactive power.

With the same network configuration and a 30Mw DBR, system simulation results are shown in Fig. 12. It illustrates that as fault occurs DBR comes into circuit and prevents the generator from speeding up by consuming generated active power of farm during fault and as a result rotor slip dose not exceed from legal stability limits. After fault clearing DBR comes out of circuit.



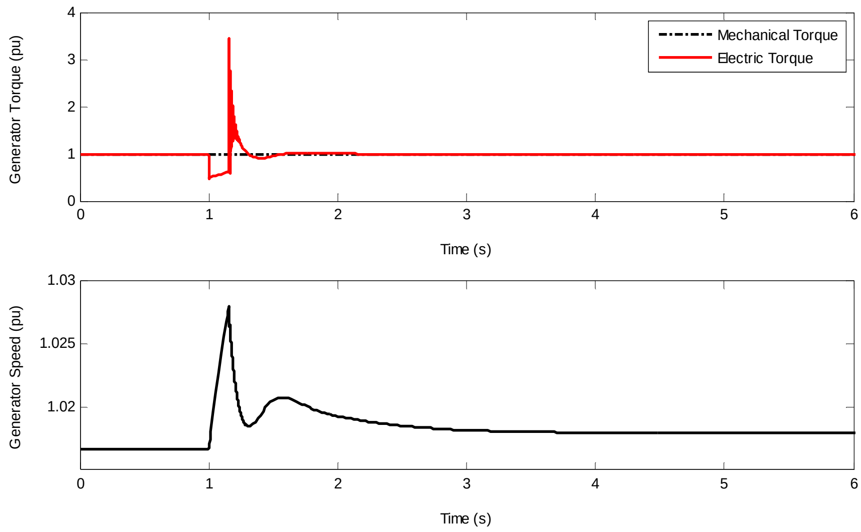


Fig. 12. Simulation Results with DBR

In this situation because electrical torque is higher than input mechanical torque, rotor speed decreases and finally rotor slip backs to the amount before fault and also AC voltage , reactive power absorption and active power generation come back to their nominal amounts. Generator comes back to its work point before fault and therefore wind farm is stable.

According to Fig 11 although DBR makes the farm more stable, due to reactive power shortage during the time that wind farm is isolated from network when it is connected again there would be some transients in delivered active power by wind farm to network and it decreases quality of active power delivered to network. In order to compare SVC,STATCOM and DBR effect on stability of simulated system operations, Fig.13 presents a comparison of network voltage, active and reactive power of wind farm, nominal power of each of studied devices, electrical torque and rotor speed under SVC,STATCOM and DBR operation. From Fig.13 during fault AC voltage, using DBR is lower than when SVC is used and in turn it is lower compared to the case in which STATCOM is used. It is because of SVC and STATCOM capability of generating reactive power that DBR dose not have this capability. After fault clearing, in case of using DBR, system voltage reaches its stable condition about 0.5 second sooner than the case of using STATCOM and this one in turn recovers 1.5 second sooner than the case of using SVC. This shows recovery speed of system using DBR is more than the others. However stable amount of voltage using SVC and STATCOM is about 0.02 pu more than DBR. This is because of increase in transmission line reactance that SVC and STATCOM compensate this increase in reactance using their compensation capability. According active power curves of system, overshoot of this curve using DBR is much more than using two other devices. This subject causes power decrease and some damages to different equipments of system. Fluctuations in reactive power in the case using DBR is much less than the two other devices and the time of being stable of active and reactive power curves are like voltage curves. It can be seen from nominal power curves of used devices, during fault DBR absorbs an amount of active power from wind farm equal to its nominal power and SVC and STATCOM generate 1 and 5 Mvar reactive power during fault and 24 and 27Mvar after fault clearing respectively. This is due to this fact that the maximum reactive power of SVC is related to square of network voltage while in case of STATCOM it is related to the network voltage.

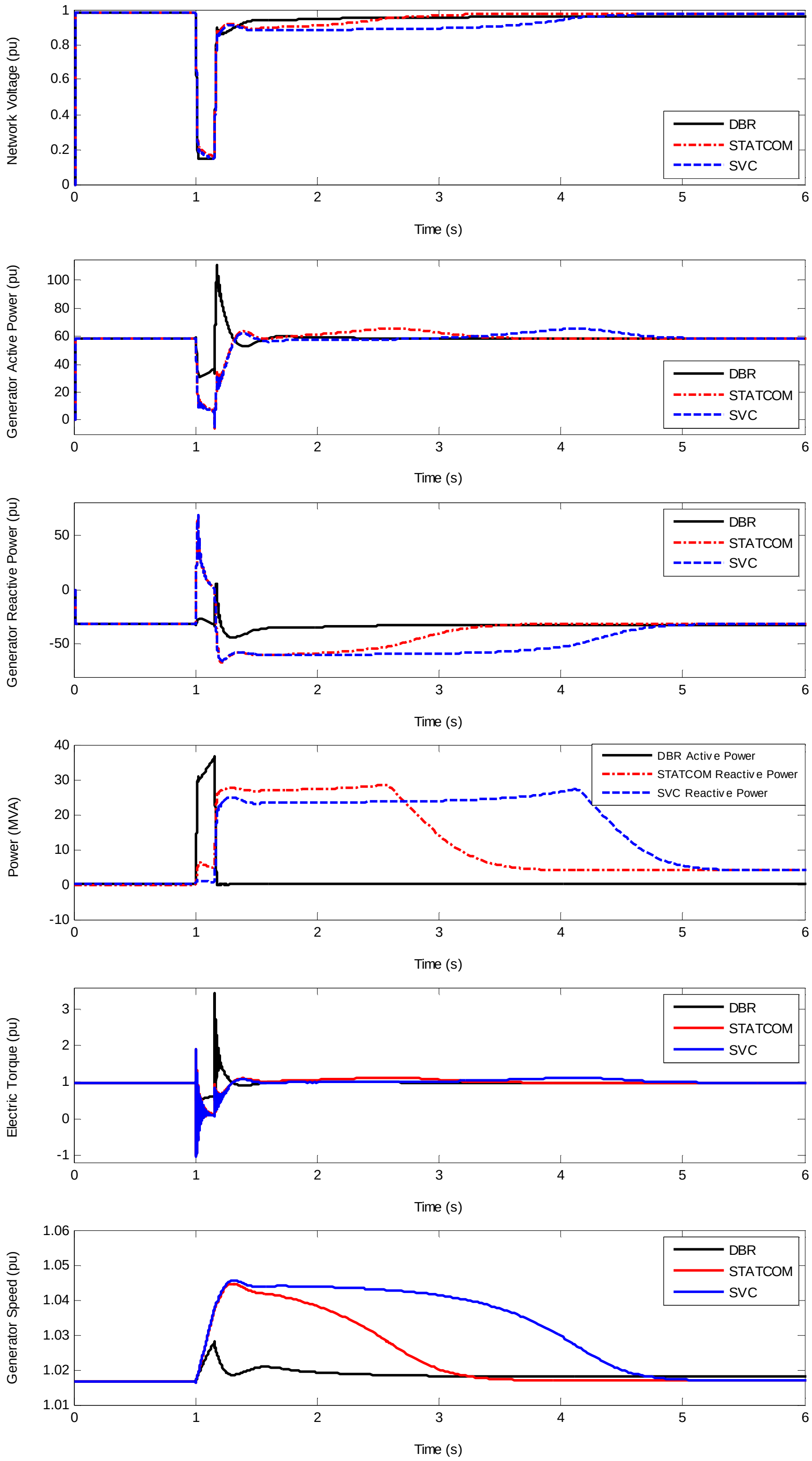


Fig.14. Comparison of system simulation result using SVC, STATCOM and DBR

According to electrical torque curves, in case of DBR the most disturbance of electrical torque is at the moment of fault clearing and it occurs on top of mechanical torque curve. According to investigations It can be observed that as nominal power of DBR increases move to beyond of mechanical torque curve and their severity decreases. But in case of the two other devices the most disturbances occurs at the moment of fault occurance and below the mechanical torque curve. It can be seen from generator speed curves that increase of speed amount in case of DBR is much less than the two other devices that its reason is consumption of active power of wind farm at the moment of fault. Also speed increase in case of STATCOM is slower than SVC. It shows that capabilities of STATCOM are better than SVC. For more investigation about the impact of SVC, STATCOM and DBR on the stability of mentioned system, studies were carried out with different nominal powers of these devices. Simulation results are shown in Fig. 15. According to Figure 15 with increasing reactive power for SVC and STATCOM from 5Mvar to 60 Mvar, CCT increase in linear mode. This increase for SVC is from 101 ms to 221 ms and for STATCOM is from 103 ms to 240 ms and increase slope for STATCOM is a little more than SVC. STATCOM behavior is better than SVC especially in higher nominal powers. For DBR with power increase from 5 Mw to 50 Mw, CCT increase in nonlinear mode from 137 ms to 317 ms. However as nominal power increases more, CCT starts to decrease and also in low nominal powers of DBR during fault absorbed power by DBR increases gradually. But as nominal power of DBR increases, the slope of absorbed power increase starts to decrease and finally it change to be negative. It means that in DBRs with higher nominal power, absorbed power during fault decreases gradually.

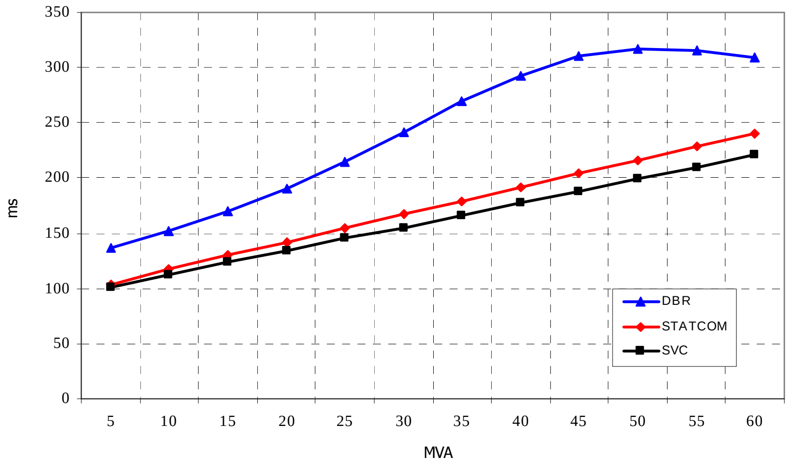


Fig. 15. CCT changes vs. nominal power changes of SVC, STATCOM and DBR

The mentioned results could be explained as following: Because reactive power of farm is limited and it is disconnected from network during fault, in higher nominal powers of DBR due to reactive power shortage total capacity of DBR could not be used and during fault due to gradual decrease of magnetic field of induction generator core because of reactive power shortage, generated power of farm and as a result of it absorbed power by DBR decrease gradually.

To investigate the impact of X/R ratio of transmission line on system stability, studies were carried out to specify CCT changes in turn of changes in X/R ratio of transmission line in a system with only PFC, SVC, STATCOM or DBR. According to Fig. 16 in a system with only PFC or DBR with a X_2/R_2 ratio more than 13 any disturbance in network cause instability. However in a system with SVC or STATCOM with a ratio of 15, system could still be stable. Behavior of systems with only PFC and with only DBR in higher X_2/R_2 ratios is similar and it shows that main problem of wind farms is reactive power absorption. Because as X_2/R_2 ratio increases, line reactance increases and therefore reactive power is more required.

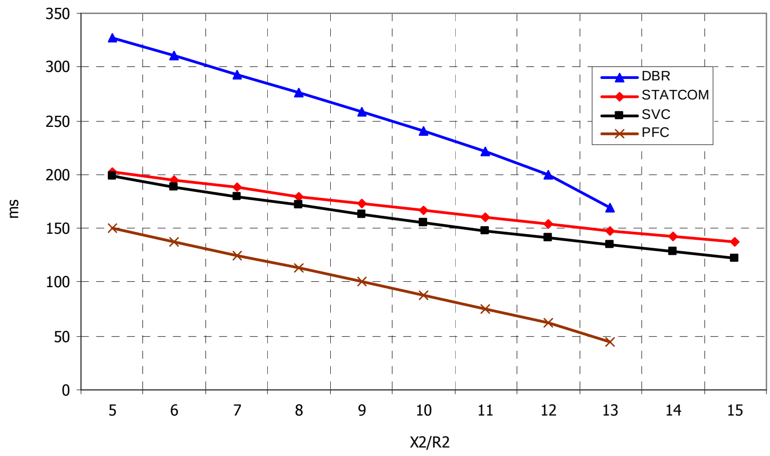


Fig. 16. CCT changes in return for X_2/R_2 ratio changes

According to this study as X_2/R_2 increases from 5 to 13, CCT decreases from 150ms to 44ms for PFC and from 327 ms to 69 ms for DBR respectively. Also when X_2/R_2 increases from 5 to 15, CCT decreases in liner mode from 198 ms to 122 ms for SVC and from 233 ms to 137 ms for STATCOM respectively. According to this study in higher X_2/R_2 ratios STATCOM results are better than SVC and DBR.

In order to study impact of nominal power of wind farm on system stability, studies were carried out on system with different nominal powers of wind farm and simulation results are shown in Fig. 17. According to this study a wind farm with nominal power more than 64 Mw with only PFC or DBR become instable with any disturbance and its reason is reactive power shortage in higher powers of wind farm. Simulation results shows that fault tolerance time in system with only PFC decreases from 131 ms to 49 ms and with DBR decreases from 420 ms to 154 ms. While farm power increases from 55 ms to 64 ms using SVC and STATCOM fault tolerance time decreases from 199 ms to 119 ms and from 210 ms to 129 ms respectively when wind farm capacity increases from 55 Mw to 65 Mw.

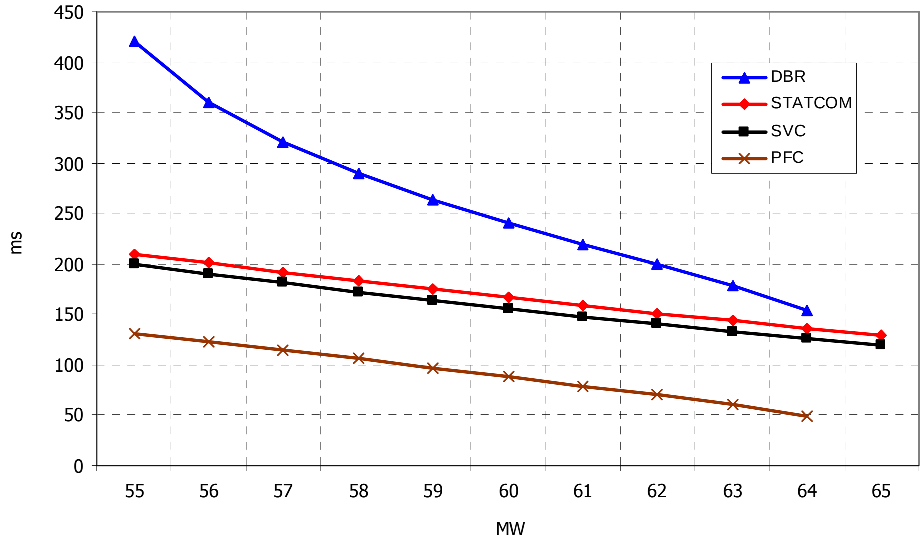


Fig. 17. CCT changes in turn of different powers of wind farm

To show wind speed effect on wind farm stability which enters in to turbine as input mechanical torque, a study was carried out on system with different mechanical torques. Simulation results are shown in Fig. 18. According to these results in torques higher than 1.04 pu with any disturbance system with only PFC or DBR becomes instable. The reason again is reactive power shortage, because with increase in input torque the output power of farm increases and as a result the need for reactive power increases. According to Fig 18 when mechanical torque increases from 0.95 pu to 1.04 pu, CCT decreases from 134 ms to 46 ms and from 351 ms to 155 ms in systems with PFC and with DBR respectively. While input torque increases from 0.95 to 1.05, CCT decreases from 203 ms to 115 ms in SVC and from 215 to 125 in STATCOM.

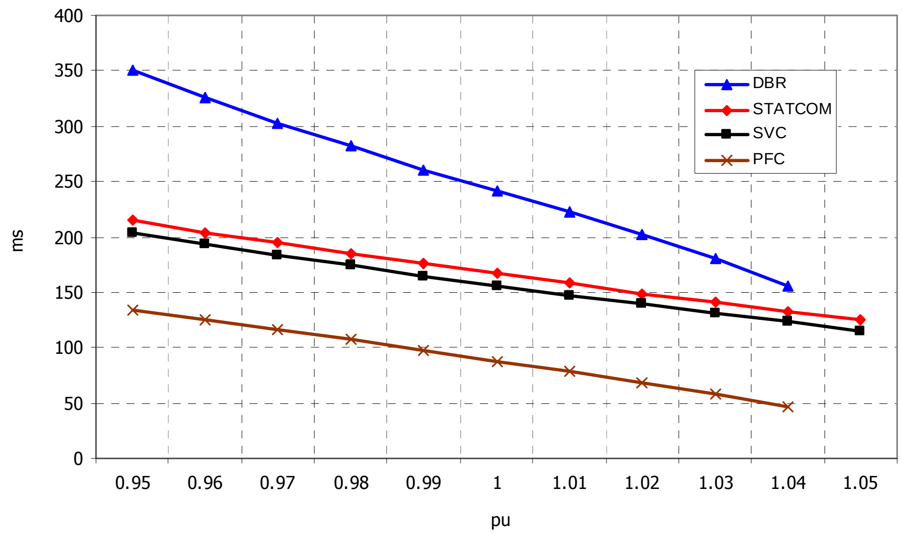


Fig. 18. CCT changes in turn of wind speed (input mechanical torque) variations

To study effect of network short circuit power on system stability, operation of mentioned devices in different powers of network was compared. Results of this study are shown in Fig. 19 .It can be seen from Figure 19 that system with PFC or DBR in powers lower than 1000 MVA for network and lower than 500 MVA for each line with any disturbance became instable. But in systems with SVC and STATCOM with network power of 800 MVA and line power of 400 MVA the system is still stable.

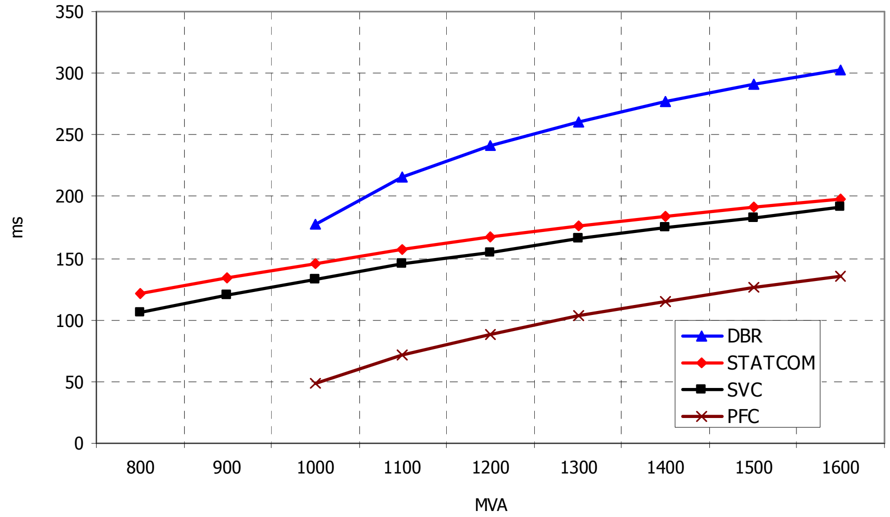


FIG. 19. CCT changes with different powers of network

According to these results as network power and line power increase from 1000 and 500 MVA to 1600 and 800 MVA, CCT in system with only PFC increases from 48 ms to 136 ms and in system with DBR it increases from 177 ms to 303 ms and also as network power and line power increase from 800 and 400 MVA to 1600 and 800 MVA, CCT increases from 106 ms to 191 ms for SVC, and for STATCOM it increases from 121 ms to 198 ms. In this study STATCOM results in lower powers of network are better than SVC and DBR.

5.Conclusions

In this paper operation of a wind farm based on fixed speed induction generator and connected to network with only PFC, SVC, STATCOM or DBR in different conditions and with various variables like: nominal power of the used devices, the X/R ratio of transmission line, nominal power of wind farm, wind speed and short circuit power of the network connected to wind farm is studied. Following results are concluded from these studies:

The main reason of instability of wind farms based on fixed speed induction generator is extreme reactive power absorption by generator Due to rotor slip caused by fault occurrence.

PFC can not compensate reactive power absorbed by generator after fault individually (especially in networks with a low short circuit power). So there is a need to compensate reactive power dynamically beside this device.

SVC and STATCOM dynamically compensate reactive power absorbed by generator. Therefore they increase CCT and considerably improve wind farm stability.

DBR due to active power of farm and preventing generator from speeding up, increases wind farm CCT more than the two other devices. However because of disconnecting farm from network and also existing transients when farm is again connected to network which can be a factor for instability, quality of output power of wind farm comes down.

Increasing nominal power of SVC and STATCOM raises CCT and wind farm stability due to increasing reactive power compensation capability. However increasing nominal power in DBR to a specific limit increases CCT but if it continues CCT starts to decreases. Its reason is that the need for reactive power in higher powers of DBR increases.

As X/R ratio of transmission line increases due to increasing need for reactive power in order to compensate line reactance, network becomes more instable and therefore in higher X/R ratios wind farm using SVC and STATCOM is stable but it is instable using DBR.

As wind farm size and also wind speed grow, output power of wind farm and need for reactive power increase. So in higher powers of wind farm and higher wind speed, wind farm using SVC and STATCOM is stable but it is instable using DBR.

If short circuit power of network decreases, wind farm becomes instable. The reason is decrease in reactive power supply caused by network. So in low powers of network, wind farm using SVC and STATCOM is stable but it is instable using DBR.

According to simulation results and what is mentioned before, reactive power compensation capability by STATCOM especially in low voltages of network is better than SVC. Therefore System using STATCOM is more stable.

Considering all aspects and previous results, the best choice for increasing stability of wind farms connected to network is using STATCOM.

6. Refrences

[1] D. Richardson, "Wind Energy Systems", Proceedings of the IEEE, Vol. 81, Issue. 3, March 1993, PP: 378-389

[2] M. Sedighizadeh, A. Rezazadeh, M. Parayandeh, "Comparison of Impacts on Wind Farm Stability Connected to Power System", International Journal of Engineering and Applied Sciences (IJEAS), Vol.2, Issue. 2, 2010, PP: 13-22

[3] V. Akhmatov, H. Knudsen, A.H. Nielsen, J.K. Pedersen, and N.K. Poulsen, "A Dynamic Stability Limit of Grid-connected Induction Generators". Proc. International IASTED Conference on Power and Energy Systems, Marbella, Spain, September 2000.

[4] L. Holdsworth, N. Jenkins, and G. Strbac, "Electrical Stability of Large, Offshore Wind Farms", IEE Seventh International Conference on AC-DC Power Transmission, pp. 156-161, 2001.
[5] X. G. Wu, A. Arulampalam, C. Zhan, and N. Jenkins, "Application of a Static Reactive Power Compensator (STATCOM) and a Dynamic Braking Resistor (DBR) for the Stability Enhancement of a Large Wind Farm", Wind Engineering Journal, Vol. 27, No. 2, PP. 93-106, March 2003.
[6] R. Griinbanm, P. Halvarsson, D. Larsson, P. R. Jones, "Conditioning of Power Grid Serving Offshore Wind Farms Based on Asynchronous Generators", ABB Power Technologies, Sweden, 2004
[7] D. Povh, "Use of HVDC and FACTS," Proceedings of the IEEE, Vol. 88, No. 2, pp. 235-245, February 2000.
[8] D. D. Eronmon, "Distributed Energy Resources (DER) Using FACTS, STATCOM, SVC and Synchronous Condensers for Dynamic System Control of VAR", 2005 National Association of Industry Technology Convention, USA, Nov. 2005.
[9] N. G. Hingorani, L. Gyugyi, " Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems", Wiley-IEEE press, Dec. 1999.