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Enhancement of Power Quality of Wind Farm Using a SVC

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***Abstract*: In this paper the results of using Static VAR compensator (SVC) to improve reactive power voltage control, power Quality of wind farm. There are of number of wind turbine driven induction generator connected to a grid through a step up transformer and transmission line. The SVC is that it has ability to improve the system stability during and after disturbance when the network is weak. It provides better reactive power support to the network therefore the voltage regulation of the power grid can be effectively achieved by the application of SVC in wind farm.**

***Keywords*: Wind farm Static VAR compensator (SVC); induction generator; voltage control; system stability.**

1. Introduction

Present time due to technology innovation, cost reduction, ecofriendly energy become important green electricity source to replace the polluting and exhausting fossil fuel. The wind turbine with 2-3 MW capacity have already been commercially available and 5MW will also available in few years. However, wind is geographically and climatically uncontrollable resource of energy, this is why induction generator coupled with wind turbine produces active power with significant fluctuations. Wind turbine, connected to often produce active power with significant fluctuations due to the wind speed variation, wind gradient. The output power variation causes the voltage fluctuations. Because of power quality requirement from utilities, theses voltage fluctuations or voltage flickers must be mitigated. Theses voltage fluctuations and flickers have adverse effect power system stability and consumers. Another issue related to wind turbine equipped with induction generator is fault ride through capability. When any fault occurs in grid or three phase fault occur near the wind turbines, wind turbine starts over speeding and causes Voltage instability. As a result, the wind turbines immediately disconnected from the grid. The tripping of wind turbines

Increases the load on the grid, thus the power system stability is affected. Wind farm consists of set of number of induction generator equipped with wind turbine. Squirrel cage induction generator generates active power, but it requires reactive power from the system in steady state operation. The reactive power demand changes with change in rotor slip or speed. So the system requires continuous reactive power source for steady state stability of wind farm. In this paper we study the use of Static VAR compensator (SVC) to improve the power quality and fault ride through capability of wind farm equipped with SCIGs. The issues related to steady state and dynamic voltage control can be effectively achieved by using Static VAR compensator (SVC). An investigation is conducted on the impact of Static VAR compensator (SVC) on system recovery after a network fault.

2. Wind farm and dynamic modeling of individual WTG

Wind farm or Wind Park is a group of wind turbines in the same location used to produce the electricity. A large wind farm consists of several hundred individual wind turbines and covers an extended area of hundreds of squire mile. A wind farm can also be located offshore.

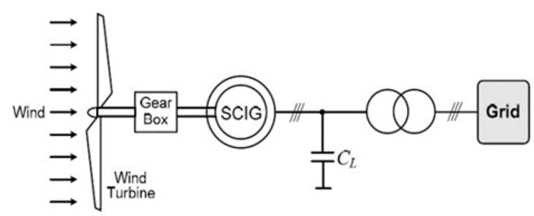


Fig. 1. Configuration of fixed speed wind turbine generator

The typical configuration of an individual fixed speed wind turbine generator is shown in figure. It consists of a squirrel cage induction generator driven by a wind turbine through a mechanical shaft system and operate at a certain wind speed. Gear box is used to connect the low speed wind turbine shaft to the high speed SCIG shaft. Compensating capacitors are generally added at the SCIG stator terminal to generate the magnetizing current for squirrel cage induction generator [3].

The mechanical power produced by a wind turbine is given by,

$$P_w = \frac{1}{2}\rho A_r V_w^3 C_p(\lambda, \beta) \tag{1}$$

Where ρ is the air density in kg/m^3, A_r is the blade impact area in m^3, V_w is the wind velocity in m/s and C_p is the power coefficient of the employed wind turbine [9]. The parameter C_p can be expressed by,

$$C_p(\psi_k,\beta) = \left[c_1 \ \left(\frac{c_2}{\psi_k} - c_3\beta - c_4\beta^{c_5} - c_6\right)\right]\exp\left[-\frac{c_7}{\psi_k}\right] \tag{2}$$

Where

$$\frac{1}{\psi_k} = \frac{1}{\lambda + C_8 \beta} - \frac{C_9}{\beta^3 + 1} \quad (3)$$

$$\lambda = \frac{R_b\, \omega_b}{V_w} \quad (4)$$

Where $c_1 - c_9$ are constants of power coefficient C_p, R_b is the blade radius in meter, ω_b is the blade angular velocity, λ is the tip speed ratio, β is blade pitch angle in degree. Fig shows the steady state characteristics of power coefficient C_p Vs tip speed ratio λ [2].

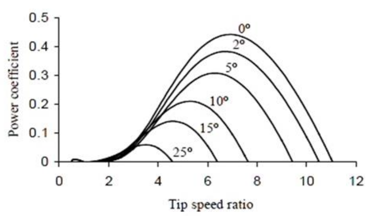


Fig. 2. Steady state characteristics between C_p and λ for different pitch angle (β)

3. Static VAR compensator (SVC)

A Static synchronous compensator is a shunt compensating FACTS device. Static VAR compensator regulates the system voltage by controlling amount of reactive power injected into or absorbed from the power system network. A Static VAR compensator is a voltage source converter based device, DC voltage source is provided by a capacitor and therefore Static VAR compensator has a little active power capability. However, its active power capability can be increased if a suitable energy storage device connected across the capacitor. If the terminal voltage of Static VAR compensator is higher than ac line voltage, the SVC inject reactive current to the system, on the other hand, if the magnitude of the Static VAR compensator output is lower than line voltage, it absorbs reactive power.

A. Modeling of SVC

The basic models attribute is reactive power range (capacitive and inductive) at one per unit high side bus voltage, slope, voltage set point, high side reactive power set point, and voltage dead band for reactive power control mode. The slope should be in per unit on the specified SVC base. The base model as per CIGRE report is given in Fig.

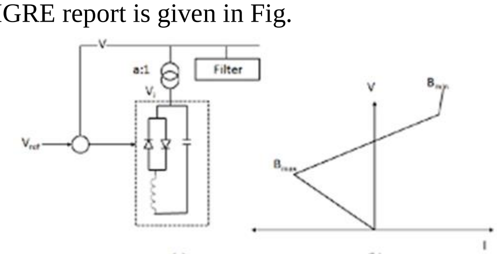


Fig. 3. Basic model and Voltage current characteristics of SVC

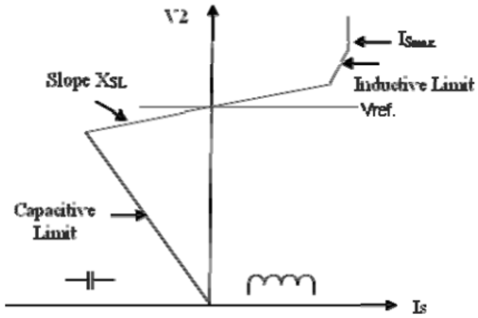


Fig. 4. SteadyState V-I Characteristic of SVC

General approach for modeling of SVC, by taking different blocks, first we consider measurement modules. It converts voltages and currents to DC control signal that is proportional to the amplitude of the positive sequence an d the fundamental. Thyristor block represents the variation of reactor susceptance as a function of firing angle. The thyristor controlled reactor can be modeled as shown in Fig.6, depending upon application with gain K4 and time delay signal T1. Considering rector rating double the size of fixed capacitor the variation is considered 0.0 p.u. to 2.0 p.u.

Main SVC combinations are, Thyristor Controlled Reactor. (TCR) and Fixed Capacitor (FC) SVC, mechanical controlled switched reactor and capacitor SVC and Thyristor controlled reactor and Capacitor SVC. The voltage stability at the connected bus can be maintained by controlling the inductive or capacitive current output. TCR uses firing angle control to decrease/increased the inductive current. The reactive power compensation in electric power system achieved by SVC in the different ways.

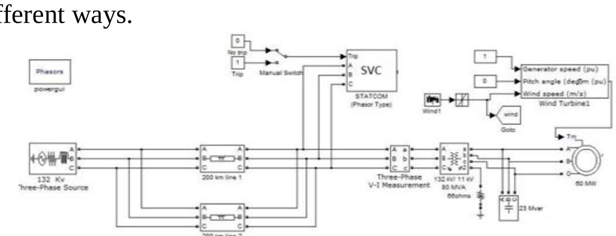


Fig. 5. Simulink diagram

The system performance with PFC only is shown in figure. A 3 phase fault was applied at 0.5s and lasted for 0.14s and fault is cleared by disconnecting line 2 from the network. During fault, due to reduction in voltage the generated active power and electric torque significantly reduced. Once the fault is clear, the voltage starts recovering and so as active power. Since electric torque is now less than mechanical input torque, the generator speed continues to rise and system become unstable.

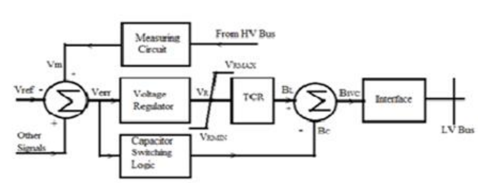


Fig. 6.

4. Case study of simulated results

The power system model which is used for investigation of system performance, when it is subjected to various disturbances, is shown in fig. 6. The system short circuit level is fixed at 1200 MVA with an X_1/R_1 ratio of 20. The mechanical input torque to the FSIG was set at 1 pu [5]. The parameters of lumped FSIG are given in table.

Table 1
Parameters of lumped FSIG model

Rated power	60 MW
Rated voltage	11KV
Stator resistance	0.0108 pu
Rotor resistance	0.01214 pu
Stator leakage inductance	0.107 pu
Rotor leakage inductance	0.1407 pu
Mutual inductance	4.4 pu
Lumped inertia constant	3s

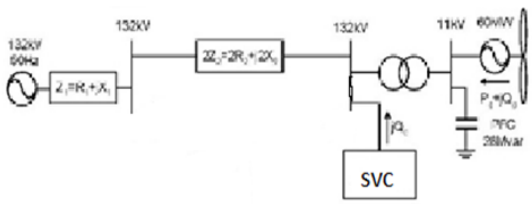


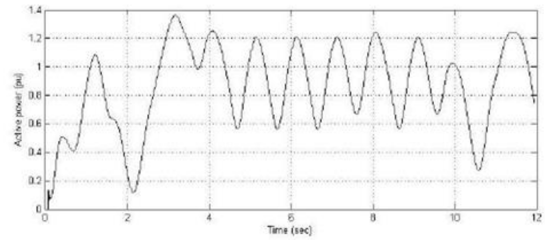
Fig. 7. Schematic diagram of simulated system

A. Application to a real power system

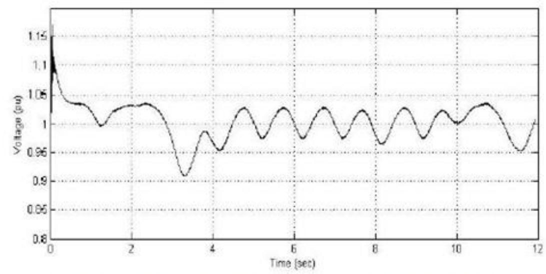
The application of an SVC based damping controller for a real power system is demonstrated in this section. For this study, a portion of a large power system was modeled by representing external power systems using static equivalent Models. The reduced power system has 59 buses, six Types 3 wind farms and 5 series compensated transmission lines. The wind farms were located in near electrical proximity of the series capacitors. For an N-1 contingency, one wind farm showed a sub synchronous interaction with the series compensated AC network.

The frequency of the SSI mode is 40.4Hz and its damping is 0.5%. Investigation of the observability and controllability of this mode revealed that the SSI mode is observable in the PCC transformer current and it is controllable through the SVC voltage reference. Therefore, an SSI damping controller was added to the SVC. With the SVC damping controller, the damping of the SSI mode improved to 3%.

Figures 9 shows the response of the wind farm active power output with and without the SVC when an N-1 contingency Occurs in the power system network. Figure shows the response of the same variables when a high impedance fault occurs during the N-1 contingency. Also, the SVC reactive power output for the two disturbances are shown in the two figures. As shown in the figures the damping of the sub synchronous oscillation improves with the addition of the SVC.



ACTIVE POWER FLUCTUATION DUE TO WIND SPEED VARIATION



VOLTAGE FLUCTUATIONS DUE TO POWER FLUCTUATIONS (WITHOUT SVC)

System results with Static VAR compensator are shown in figure. It is clear from characteristics the ac voltage after the fault clearance, recovers to higher value compared to system with PFC only, that results high post fault electric torque.

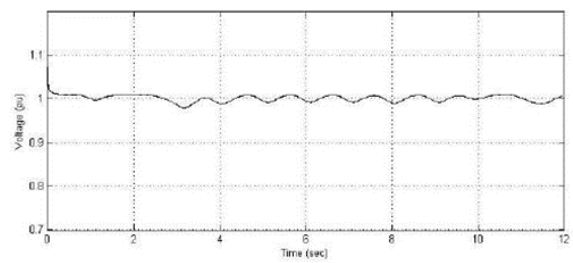


Fig. 9. Simulated results with PFC and SVC

5. Conclusion

From the studies it can be concluded that, the wind farm connected to grid causes voltage fluctuations during normal operation and faulty conditions. When fault occurs in the system, the operation become unstable, due to excessive reactive power absorption of induction generator and wind farms has to be disconnected from grid. The system requires dynamic reactive compensator to deal with such situations. Only PFC is not capable of providing voltage control during disturbances. SVC along with PFC provides better reactive power control during normal operations, during faults and after faults to the system and maintains the power quality.

Modeling and simulation of a static var compensator (SVC) for reactive power control in high penetration wind power system under field conditions carried out, for analysis Mi-Power software used. It is seen that modelled SVC mitigating reactive power, reducing voltage dip, maintain bus voltages and helping the best utilization of transmission capacity. It is also seen under sudden addition of wind generation, even improve swing performance of the generator. The results are positive side and matching with the expected behavior of SVC, as such the modeling and simulation of SVC under field condition is considered successful.

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