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Improve Power Quality in Medium and High Voltage Grids with Wind Power

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Abstract: *Upward trend of the electricity consumption lead to concerns in this field. Due to limitation of the system, it is impossible to add new power lines and make the network larger at times to satisfy the demand. Therefor using renewable energy resources seems a reasonable solution to overcome such issue. The renewable energy sources, as an a lternative as well as promising energy source, however by connecting this type of energy source new challenges are came to the power grid. The fluctuation of the output power of the wind energy due to environmental condition is one of the examples. In the same way, wind power injection into an electric grid affects the power quality due to the fluctuating nature of the wind. Power quality issues such as: voltage dip, harmonic distortion and reliability problems are among concerns in the grid caused by wind variations. Flexible AC Transmission Systems (FACTS) use Thyristor controlled devices and optimally utilizes the existing power networks. FACTS devices plays an important role in controlling the reactive and active power flow to the power network, and henc e, both transient stability and fluctuation in the systems voltage. This paper proposes a state feedback controller for Static VAR controller (SVC), as the controller act as a state feedback in order to enhance the power electronic -based device with ability y to damp the Low Frequency Oscillation (LFO). The control has the ability to control and increase the power quality of the network connected to the high wind power penetration by controlling the active and reactive power of the grid from far distances.*
Keywords: *Power Quality, State Feedback Controller, FACTS, SVC.*

INTRODUCTION

The need to integrate the renewable energy resources, like wind, solar and hybrid power, into grid has been raised a controversial issue about the need to mitigate the environmental impact on conventional plant [1]. Introducing the wind energy into the power system not only lead to some technical challenges but also it requires considering voltage regulation as well as power quality and stability problems. The power quality is an essential in terms of
consumers and also has great impact on the operation of a distribution and transmission network [2]. After a great and fast enhancement on exploitation of wind energy in recent years, individual units has been presented which can be designed in the large capacity, up to 2 MW, feeding the distribution network [3]. By applying the fixed -speed wind turbine, large voltage fluctuations flows to the electrical power grid due to variations in the wind speed, which initiated from the mechanic al torque. Voltage sag, swells, flickers, harmonics and etc. are the power quality issues which can be viewed with respect to the wind generation injected to the transmission and distribution network. Running the induction generator with the direct connect ion to the power grid is mentioned as a method to overcome the wind generating challenges. However the induction generator has cost effectiveness and robustness advantages, induction generator power changes due to wind fluctuation, and, consequently, by absorbing the reactive power terminal voltage of an induction generator will be considerably affected [2].

In [4]to [6], authors have introduced a different approaches of installing UPFC in the power grid. In [7] the characteristics have been completely evaluated. FACTS modeling ,controlling strategy as well as its application and analysis are studied in the recent years. [8] and[9] studied the steady state characteristics for UPFC by presenting a mathematical models by state space calculations without considering the effects of dynamics of generator and the
converters. Authors in [10] and [11] considered the UPFC performance with conventional controllers by designing a series converter. In [12] to [14] different topologies are proposed for the power converter applying the FACTS devices such as multi-pulse converter and multi -level inverters with 24 and 48 pulses. The merits and constraints for the converters with high power are both studied in [15]. Author in [16] studied the dynamic control strategy for t
he UPFC along with the analysis using six pulse converter with switching level model. In this paper by considering all the mentioned problems in above, feed-back line is considered in the controller to add the ability to be smarter in sudden variation as well as being able to be controlled from distances. This paper is categorized as below, section 2. Discuss the mathematical model which is presented in this paper for the state feedback controller for SVC and finally section 3. Presents the simulation and results for the presented controller.

II. MATHEMATICAL MODEL FOR SVC WITH STATE FEEDBACK

Power oscillations damping is a necessary as well as important to lower the risk of instability in transmission system capacity. Using conventional power system stabilizer (CPSS) is of the methods to enhance the system capacity. However, using state feedback with applying PI controller can improve the ability of the damping. In this section the mathematical model for this method, is presented. As illustrated in Figure 1(c), a mathematical model presented the SVC model with a feedback line [17] and [18].

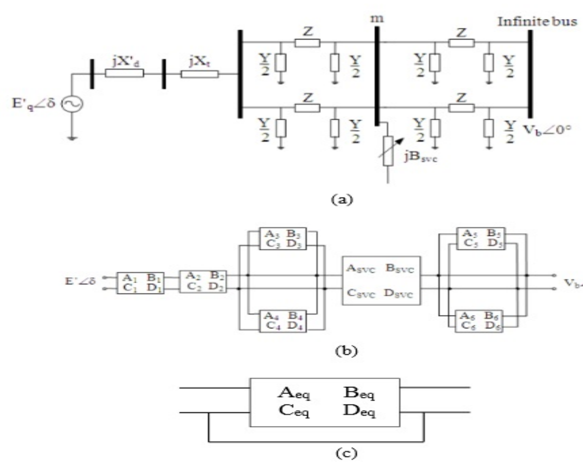


Fig. 1.New Method for SVC

In design for damping controller it is important to linearize the model with incremental controlling ability which is also important to happen around the nominal operating point. As illustrated in Figure1,and also by converting Figure 1(a) to Figure1(b) it is possible to reach equations 1-7which can be presented as below

$A_1 = A_2 = A_3 = A_4 = A_5 = A_6 = A_{SVC=}1$ (1)

$B_1 = jXd$ (2)

$B_2 = jXt$ (3)

$B_3 = B_4 = B_5 = B_6 = A_5 = A_6 = jz_L$ (4)

$C_{TCSC} = B_{SVC}$ (5)

$C_1 = C_2 = C_3 = C_4 = C_5 = C_6 = 0$ (6)

$D_1 = D_2 = D_3 = D_4 = D_5 = D_{SVC} = 1$ (7)

From equations 1to 7and by looking at the figure1(a) and(b) it can be inferred that E_q and Xd are voltage and transient reactance respectively. ZL represents the line model which consist of RL(the resistance) and XL(reactance) and finally, BSVC is shunt susceptance .

.It can be seen from the Figure 1(b) that some ports are in series and in shunt connection. For example, port 1 and port 2 are in series connection whereas port 3 and port 4 are in shunt connection. Thus with the series combination of port 1 and port 2, a new port is given by Equations8-11

$A_s = A_1A_2 + B_1C_2$ (8)

$B_s = A_1A_2 + B_1D_2$ (9)

$C_s = A_2C_1 + C_2D_1$ (10)

$D_s = B_1C_1 + D_1D_2$ (11)

Similarly, with the shunt combination of port 3 and port 4, a new port is given by Equations12-15.

$A_{SH} = (A_3B_4 + A_4B_3)/(B_3 + B_4)$ (12)

$B_{SH} = B_3B_4/(B_3+B_4)$ (13)

$C_{SH} = C_1+C_2((A_1 - A_2)(D_2 + D_1)/(B_1 + B_2)$ (14)

$D_{SH} = (B_4D_3 + B_3D_4)/(B_3 + B_4)$ (15)

With the above concepts, the net two -port network diagram is shown in figurer(c). Here A_{eq}, B_{eq}, C_{eq} and D_{eq} are the element in net matrix of net two-port networks. The output electrical power of synchronous machine (Pe) Equation16[17] and [18].

$$P = \frac{A_{eq}}{B_{eq}}\cos(\theta_{Beq} + \theta_{Aeq}) - \frac{V_b E_{eq}}{B_{eq}}\cos(\theta_{eq} + \delta)$$

Here:

$A_{eq} = A_{eq} < \theta_{eq} B_{eq} = B_{eq} < \theta_{eq}$

$v = \sqrt{v_d^2 + v_q^2}$ (16)

n equation (16),A_{eq}, B_{eq}, C_{eq} and D_{eq} are all the elements of the net matrix illustrated infigure1 (c).

III. SIMULATION AND RESULTS

As it is illustrated in Figure 2, the output of wind turbine is connected to two Y-Y grounded transformers which is made by wind fluctuations. Then, there is the SVC on the transmission line which controls the power flow. A state feedback controller with a feedback line is considered in order to remove the systems inertia and also enhance the system performance. The generator used in this Simulink simulation is an induction type, so it needs reactive power for magnetization. This reactive power will be provided by the SVC. The SVC in simulation is used to illustrate the injection and absorption of reactive power and consequently control the reactive power of the 3rd bus (25kV bus) which also is the load bus. As the generated active power by the wind turbine becomes oscillatory due to wind fluctuations, the terminal voltage of the induction generator will be affected. In this paper, after applying the wind variations to the network SVC act between 0 to 0.2 seconds. At this time, the SVC takes action and the output power has to pursue the main power for stability. After the fluctuations are applied, the outputs of the oscilloscopes showing the output reactive and active power of the generator, the injected P, the injected Q and Iabc and the injected Vb and Vq can be compared to observe the differences between the absence and the presence of the SVC in the network [17]. V_b and V_q are d-and q axis terminal voltage which can be achieved from equation (16).

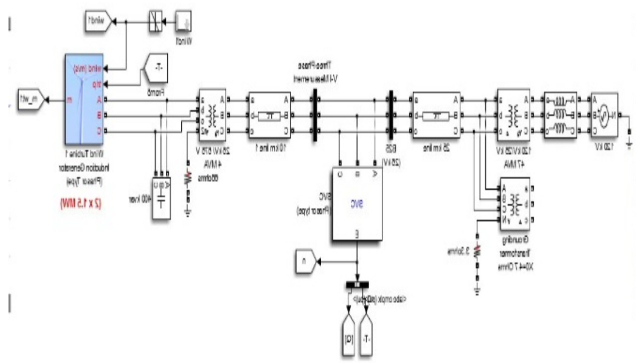
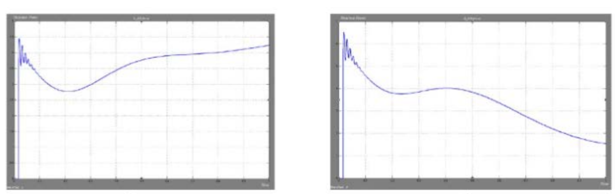


Fig. 3. (a) Real Output Power with the Controller and (b) without the Controller

As illustrated in Figure 3, in (b) the system is without the feedback line, and consequently, when the system injected by interruption the system does not respond properly and the power even goes to negative mode instead of positive mode and even in (a) consumed time for respond to the system and make it return to its normal condition is far more less than the time illustrated in (b).



(a) (b)

Fig. 4. (a) Reactive Output Power with the Controller and (b) without the Controller

Figure 4 , presents the reactive in the power system. In comparison between (a) and (b), in the initial time of interruption the amount of reactive power decrease from around 4.5Mvar to 6.5Mvar. Furthermore, after the first5 seconds of the interruption in (a) system can return to its normal condition while in (b) the system does not return to its normal situation.

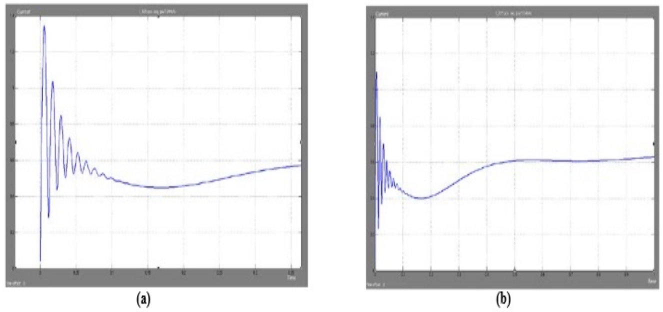


Fig. 5.(a) Current in the System with the Controller and (b) without the Controller

In Figure 5, in comparison between (a) and (b) the consumed time for the power system to return to its normal condition is far less than when the feedback is not applied to the SVC.

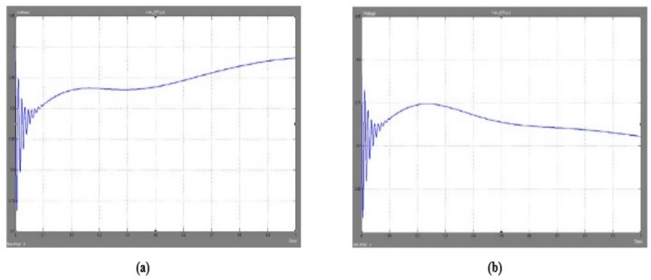


Fig. 6. (a) Voltage in the System with the Controller and (b) without the Controller in (pu)

In Figure 6(b), not only the amount of voltage, in pu, at the initial time of interruption went less than the standard condition but also in comparison with (a) it does not return to higher than 0.95 pu.

As presented in Figure 3,the real output power in (a) the system output power oscillates between 0 to 1.4 MW and in (b) the output power oscillation is between -8 to around 6 MW. Moreover, Figure 4, 5and 6, illustrate the reactive power, current and voltage in the system respectively after and before using the controller with the ability to damp the low frequency oscillation.

As presented in Figure 6,the presented feedback controller [18]not only decrease the stress released to the system, due to the presence of the wind energy, but also is make the system able to return to the ordinary conditions, in which system is not under the pressure and oscillation.

Iv. CONCLUSIONS

In this paper, by introducing a state feedback controller for SVC in MATLAB simulation environment, wind variations is app lied to the system in order to illustrate the response from the controller. The State Feedback controller [18] is designed to increase the system damping and create a reliable as well as fast respond component .Moreover, by applying the state feedback system, SVC become more improved in stability when acting in the power system. By using the controller for the SVC, system is able to control the power flow active/reactive) on power lines simultaneously or selectively as well as improving voltage stability margin. Also the SVC can act in anti-robust situation where the respond to the system variation is not intense. Another prominent point is that, as illustrated in figures 3-6, by applying the PI feedback controller, the damping strategy which has a direct effect on system voltage, current, active and reactive power, easily avoid ncoordinated control strategy which consequently lead to unpredictable performance. The simulation results showed that the system composed with controller has a superior operation in fast damping of oscillations of the power system. Moreover, by applying the feedback to SVC the consumed time that can help the system to return to its normal condition is far less than the system without the feedback and also enhanced the controllability y of the power system.

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