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Full Length Research Paper

Investigation of the control voltage and reactive power in wind farm load bus by STATCOM and SVC

Ali Ozturk* and Kenan Dosoglu

Department of Electric Education, Faculty Technical Education, Duzce University, 81620-Becı/Yorukler, Duzce, Turkey.

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In this study, the voltage stability of the bus load in various static and dynamic load systems that are fed by a wind farm has been examined. In the control of load voltage and reactive power, 10 MVAr static synchronous compensator (STATCOM) and static var compensator (SVC) is used. In the wind farm examined, double feed induction generator (DFIG) is used. In voltage and reactive power control, the results of time response and damping oscillation have been found using MATLAB / Simulink. The results achieved have proved that SVC and STATCOM yield good results when used in terms of voltage stability of the system.

Key words: Wind farm, STATCOM, SVC.

INTRODUCTION

One of the renewable energy sources, wind turbines have been used widely in recent years. The motives behind this common use of wind turbines can be the low cost and its being environment friendly. However, when wind turbines are produced with large power, some problems arise in connecting it to power systems. One of the reasons for this is that the changes in load demand of the system make the system unstable. This instability in the power system brings about the voltage and reactive power problem of the system.

In Power systems, voltage and reactive power control problems are important for continuous case stability. These problems have been solved through power electronics drivers included in Flexible AC Transmission systems (FACTS). Parallel FACTS drivers such as SVC and STATCOM have been used widely in transient voltage control due to their high performance (Wei, 2006). When the load connected to a bus load in STATCOM controlled wind farm which is installed into the circuit, the effects of terminal voltage, reactive power and speed regulation have been examined in terms of rotor stability performance, and STATCOM control has been observed to yield good results (Paulo Fischer de Toledo, 2005). The moment-slip characteristics of Induction Generator operating under low voltage in the system to which wind farm is connected were examined. It was found that with the use of SVC and STATCOM, the results can be improved in case of an unexpected condition in the system (Jon are Suul, 2008). By using SVC and STATCOM, failure analysis was done in DFIG at different times, and it was observed that SVC and STATCOM yielded time responses quickly in the control of voltage, reactive power and speed characteristics (Foster, 2007). Damping oscillation at the bifurcation point and at the time of overload in the power system was examined in terms of voltage stability; and it was observed that oscillation dam-ping's can extinguish in a shorter span of time when STATCOM and SVC are used (Mithulananthem, 2003; Rahim, 2003) STATCOM and the installation of various load values at different times were performed with the use of Proportion Integrate and Fuzzy Logic in bus load voltage and reactive power control (Kenan and Altas, 2008). Generic STATCOM has been designed in order to improve wind farm stability that is formed in fixed speed induction generator. PV curves in bus loads with and without STATCOM were examined. It was shown that the stability points of this generic

*Corresponding author. E-mail: aliozturk@duzce.edu.tr. Tel: +905327817641. Fax: +903805421134.

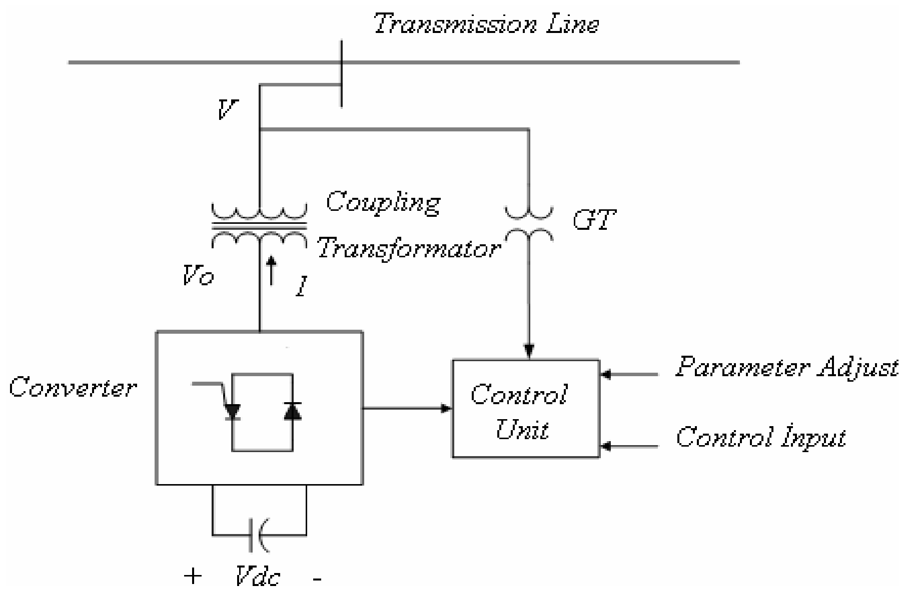

Figure 1. Systematic study of STATCOM.

STATCOM in dynamic systems can spread into a wider area (Qi, 2008). In power system, the voltage and current change in bus loads were examined at different times. In this study, SVC and Thyristor Controlled Series Compensator (TCSC) have approached the reference value of time responses in dynamic loads (Eminoglu, 2003). The effects of various dynamic loads on the voltage profile of load system have been examined through SVC; and good results were obtained in the active and reactive power control of bus load in terms of voltage regulation (Eminoglu, 2004).

In this study, a 9 MW wind farm operates as connected to network. SVC and STATCOM were used in order to stabilize the voltage and reactive power flow in the bus load of this power system when static and dynamic powers entered the current. In voltage and reactive power control of bus load, the curves of various static and dynamic load time responses and oscillation damping were drawn. In time responses and oscillation damping, SVC and STATCOM were compared with one another.

STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

STATCOM work produces active and reactive power dependent on the transform leakage reactance between voltage source inventor generator and AC voltage source control (Wang, 2003). The ultimate goal of STATCOM is to produce reactive impedance that can be adjusted in continuous or gradual manner in order to meet the compensation need of transmission line (Shenghu, 2009). STATCOM voltage source convertor and transformer are connected to AC system in a parallel manner. In STATCOM control system, d-q reference can usually be defined in frame network voltage synchronism. It is possible to control d-q current independent of DC voltage and reactive power of STATCOM. The calculation of Re-active Power related to STATCOM DC voltage are expressed as given:

$$Q = -V^2 B + kV_{dc} VB \cos(\theta - \alpha) - kV_{dc} VG \sin(\theta - \alpha) \tag{1}$$

Here, V is the transmission voltage, B is the suseptance, k the modulation index, Vdc the capacitor voltage, alpha the thyristor firing angle, theta phase angle of the transmission line, G is the admittance of coupling transformation. STATCOM circuit model has been shown Figure 1.

The voltage produced by STATCOM is beneficial in providing for the network. The leakage reactance used in transformation, however, enables the system to function in a stable manner by enabling the unexpected current that comes out when the voltage value is higher than the voltage generated by STATCOM to flow on itself. Moreover, STATCOM improves the damping oscillation that come out in dynamic voltage control with the rise in demand of the load system.

STATIC VAR COMPENSATOR (SVC)

The line voltage, in closed loop AC voltage control, gives out reference value and error signal in the measurement

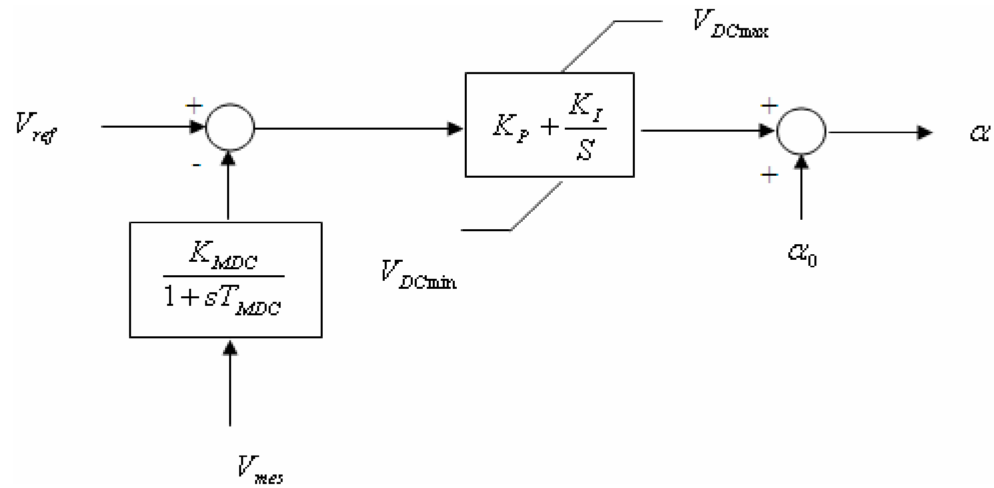

Figure 2. STATCOM voltage control unit.

of the point in which SVC is connected to the network (Shenghu, 2009). SVC has been designed for reactive power control against dissipation and fast voltage control. In most of its application fields, SVC has been designed for reactive power generation and control. Moreover, it is used for voltage control. It can be used for reducing power oscillations, as well. The fundamental function of SVC is to control bus voltage for reactive power control in the area into which it is installed. SVC circuit model is as shown on Figure 2.

In general, SVC consists of Thyristor Controlled Reactor (TCR) and thyristor switching compensators (TSC) (Masood, 2006). Depending on operating conditions of the circuit, the trigger angles of thyristors have been identified and they have been introduced into the circuit. In Forward and backward operation of the circuit, the triggering angles are set during the operation and reactors and capacitors are introduced into the circuit. A capacitive and inductive working situation supplies the variable of the inductance. This inductance value is calculated as follows:

$$X_v = X_L = \frac{\pi}{2(\pi - \alpha) + \sin 2\alpha} \tag{2}$$

Total equivalent impedance of the controller can be representing as:

$$X_e = X_c \frac{\pi / r_x}{\sin 2\alpha - 2\alpha + \pi(2 - \frac{1}{r_x})} \tag{3}$$

where, $r_x = \frac{X_c}{X_L}$ limit of the controller are given by the firing angle limits, which are fixed by design (Kamarposhi, 2008). In converter circuit, just as capacitor, provides voltage for the circuit as a generator, so it can minimize the loss that will come out as a result of switching losses of Insulated Gate Bipolar Transistor and Gate Turn off Thyristor, used as power electronics elements.

STATCOM AND SVC CONTROLLER

With the connection of STATCOM to the system, the supply of voltage and reactive power control has been aimed in the load bus. STATCOM of voltage control circuit is shown in Figure 3.

Here, the measured value of voltage V to the bus, Vref (reference voltage) and the T1 and T2 are constant time, the measured voltage value of load bus was compared with the reference value. Specifying the error rate between them, reactive current maximum and minimum values were entered into the modulation index by means of park transformation. This value and the previous modulation index value were collected so that the system would have taken the last modulation index coefficient.

The control unit in SVC is more basic to STATCOM. SVC of voltage control circuit is shown in Figure 4. Error value, the difference between the measured bus voltage and the reference voltage, is the input of the control unit. The thyristor are fired related to these values.

In this study, the wind farm connected to the network running of load bus will be voltage control and reactive power control. 10 MVAr STATCOM and SVC will be used for Reactive power and voltage control. It is expected that the voltage per bus load and reactive power will decrease somewhere in the reference value through control. The study is aimed at providing the Proper Proportion Integrate (PI) coefficients so that the response time of reactive power and voltage that correspond to reference

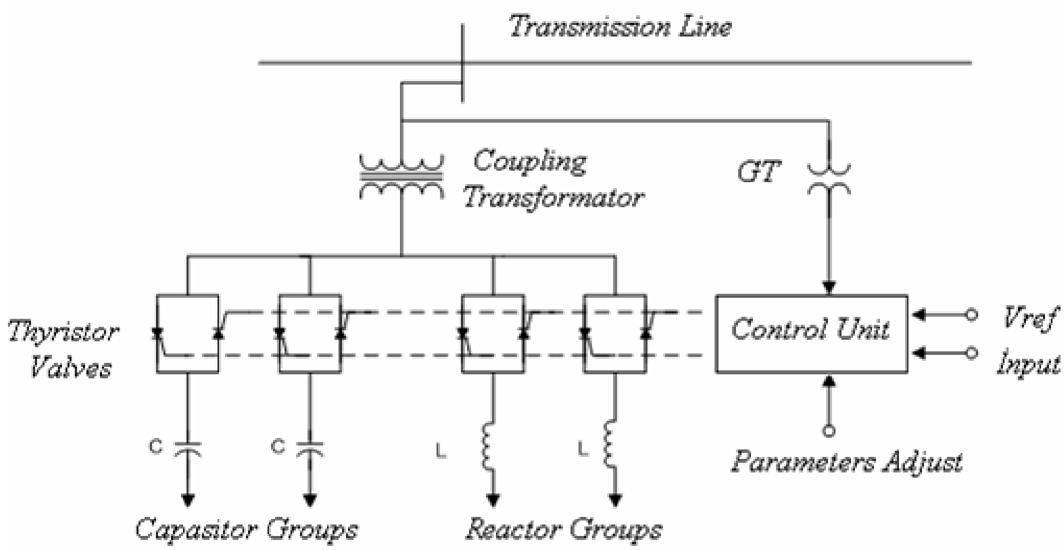

Figure 3. Systematic study of the SVC.

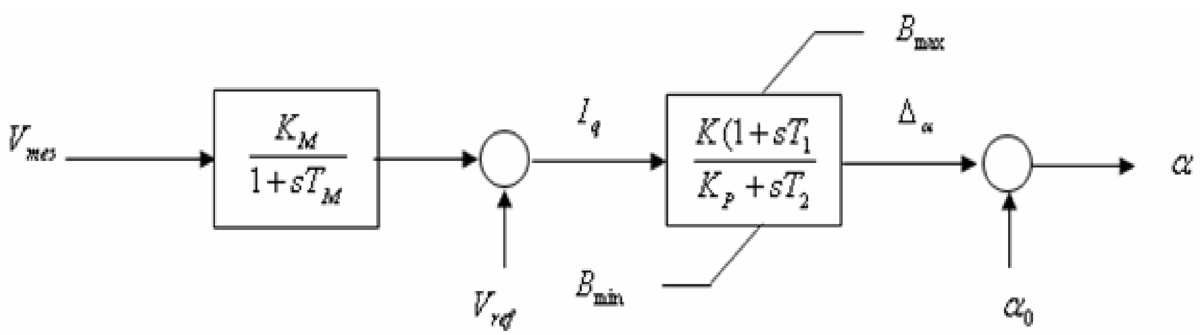

Figure 4. SVC voltage controller unit.

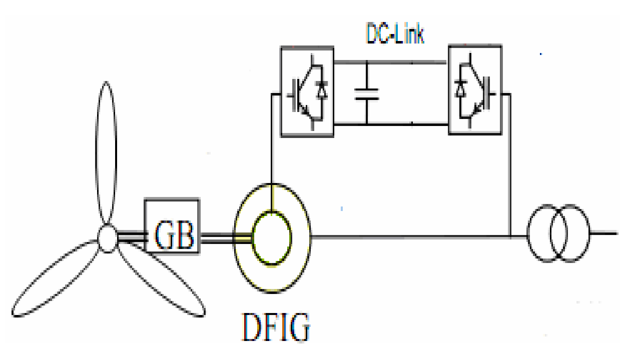

Figure 5. Double feed induction generator.

value will be short and damping oscillations will not pose unfavorable effects for the sake of voltage stability of bus load.

WIND TURBINE

In this study, the focus is set on the DFIG. DFIG are preferred due to the fact that they can be frequency and voltage control. The stator of DFIG is directly connected to the grid, whereas the rotor winding is connected with voltage source convertor. By supplying a voltage with variable frequency and variable amplitude to the rotor circuit, the voltage at the stator terminal can be kept constant. Rotor side converter usually provides active and reactive power of the machine while the line side converter keeps the voltage of the DC circuit constant (Wilch, 2007). Wind Turbine circuit model is shown in Figure 5.

The DFIG wind turbine was represented by the modeling of the rotor, drive train, induction generator, and power converter and protection system. The rotor model expresses the mechanical power extracted from the wind by the rotor, given as:

$$P_w = \frac{1}{2} PAu^3 C_p(\lambda, \theta) \qquad (4)$$

where, Pw (W) is the aerodynamic power, r (kg/m) the air density, A (m2) the rotor disk area, R (m) the rotor radius, u (m/s) the wind speed, and Cp the power coefficient which is a function of the tip speed ratio l (ratio between blade tip speed and wind speed) and y the pitch angle of rotor blades.

The electrical differential equations are presented next, express per unit and using generator convention, which means that the currents are positive when flowing towards the grid, and active and reactive powers are positive when fed into the grid.

$$\frac{de_d^{\prime}}{dt} = -\frac{1}{T_o}(e_d^{\prime} - (X_s - X_s^{\prime})i_{qs}) + SW_s e_q^{i} - W_s \frac{L_m}{L\sigma r + L_m} u_{qr} \qquad (5)$$

$$\frac{de_q^{\prime}}{dt} = -\frac{1}{T_o}(e_q^{\prime} - (X_s - X_s^{\prime})i_{ds}) + SW_s e_d^{i} - W_s \frac{L_m}{L\sigma r + L_m} u_{dr} \qquad (6)$$

$$T_g = L_m(i_{ds} i_{qr} - i_{qs} i_{dr}) \qquad (7)$$

where u denotes voltage, ı denotes current, indexes d and q, the direct and quadrate components, indexes s and refers to stator and rotor, $e_d^{\prime}$ and $e_q^{\prime}$ are the internal voltage components of induction generator, W_s is the synchronous speed, s is the generator slip, $T_o^{\prime}$ is the transient open circuit time constant, X_s is the stator reactance and $X_s^{\prime}$ is the transient reactance, expressed as

$$T_o^{\prime} = \frac{L_{\sigma r} + L_m}{R_r} \qquad (8)$$

$$X_s^{\prime} = W_s(L_{\sigma s} + L_m) \qquad (9)$$

$$X_s^{\prime} = X_s = W_s \frac{L_m^2}{L_{\sigma r} + L_m} \qquad (10)$$

With R_s and R_r the stator and rotor resistances, $L_{\sigma s}$ and $L_{\sigma r}$ the stator and rotor leakages inductances and L_m the magnetizing inductance (Fernandez L.M., 2007).

SYSTEM OF STUDY

In this study, 575 V, 60 Hz and 9 MW wind farm was used .The wind farm generators was powered with the induction generator in it. The wind farm produces voltage regulation, which is dependent on the voltage value of the capacitor included in the back to back convertor. With the control of the system frequency depending on the f convertor, network voltage is assured to be equal. Moreover, thanks to a booster transformer, voltage was raised from 575 V to 25 Kv. Network voltage and frequency values are regarded to be 120 Kv, 60 Hz. In the network, the voltage was reduced from 120 - 25 Kv with the use of transformer as in the wind farm. In the system, number 1 bus is connected to the network, number 2 bus is connected to wind farm, and number 3 bus has been examined as the bus that is involved in the area where the network and wind farm was converted to 25 Kv. Various active and reactive powers were connected in load bus. Both dynamic and static load measurements of these loads were conducted at the same values. In this simulation study, SVC and STATCOM of 10 Mv were used as parallel to bus load. In control unit of STATCOM and SVC, PI controller was used due to the fact that they can react more quickly and less oscillation, which is aimed at voltage and reactive power controls are conducted with PI control and the reactive power will be brought to reference values in the number 3 load bus of the system. Kp = 1, Ki = 500 were adopted for voltage control, how-ever, for reactive power control, Kp=0.1, Ki= 50 were adopted. In this study, for voltage reference value, 1.0 p.u was identified, yet for reactive power reference value, 0.0 has been identified. System circuit model is as shown in Figure 6.

SIMULATION RESULTS

On the operation of the system, the static and dynamic load values dependent on load bus have been shown in the table given. Static and dynamic load values remain the same.

Voltage and reactive power control of STATCOM which is connected to the load bus when active load is 4 MW and reactive load is 2MWAr static is shown Figure 7 and 8.

Voltage and reactive power control of SVC which is connected to the load bus when active load is 4 MW and reactive load is 2 MWAr static can be seen in Figures 9

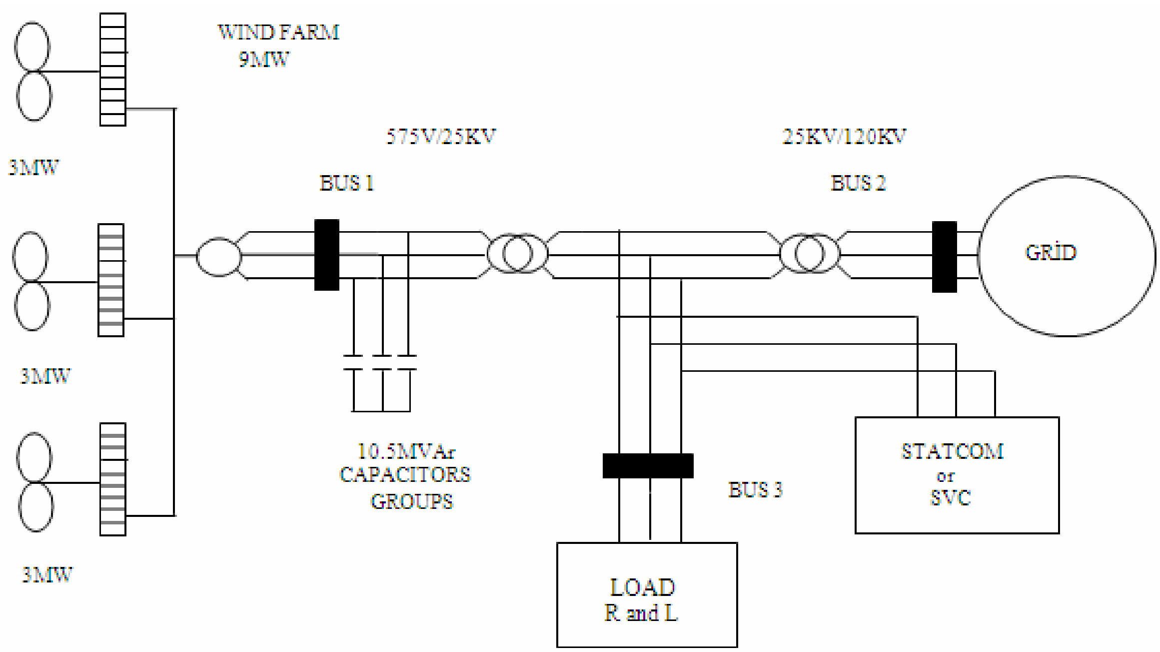

Figure 6. System circuit model.

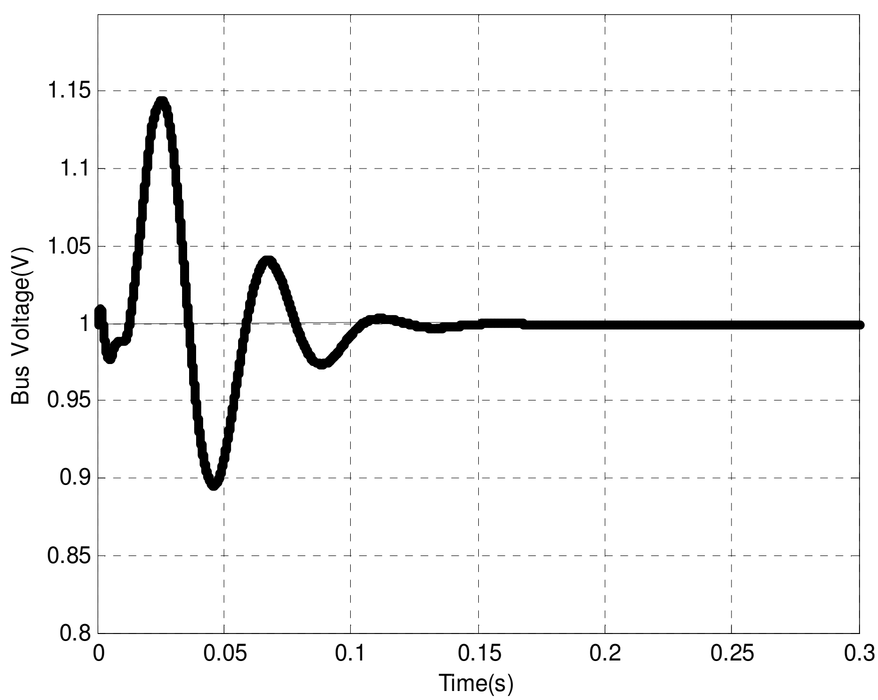

Figure 7. STATCOM voltage controller.

and 10.

Voltage and reactive power control of STATCOM which is connected to the load bus when active load is 4MW and reactive load is 2 MWAr dynamic have been shown Figures 11 and 12.

Voltage and reactive power control of SVC which is connected to the load bus when active load is 4 MW and reactive load is 2 MVAr dynamic is shown in Figures 13

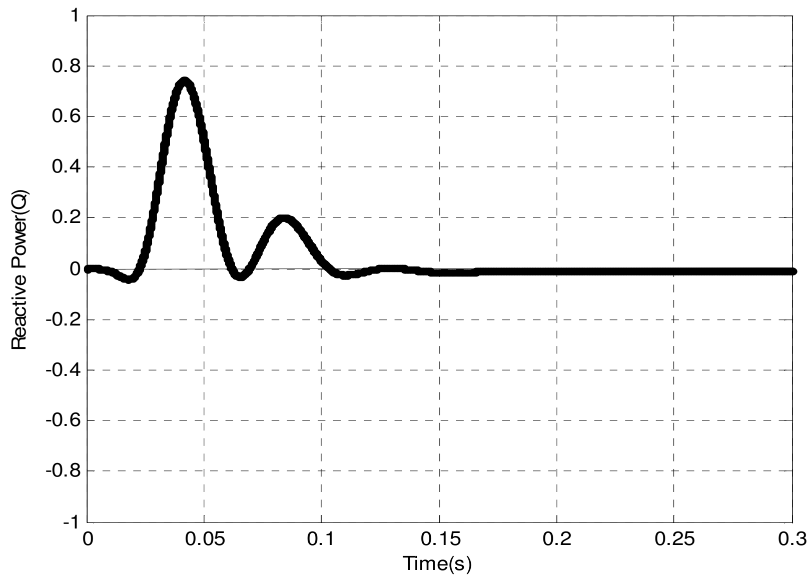

Figure 8. STATCOM reactive power controller.

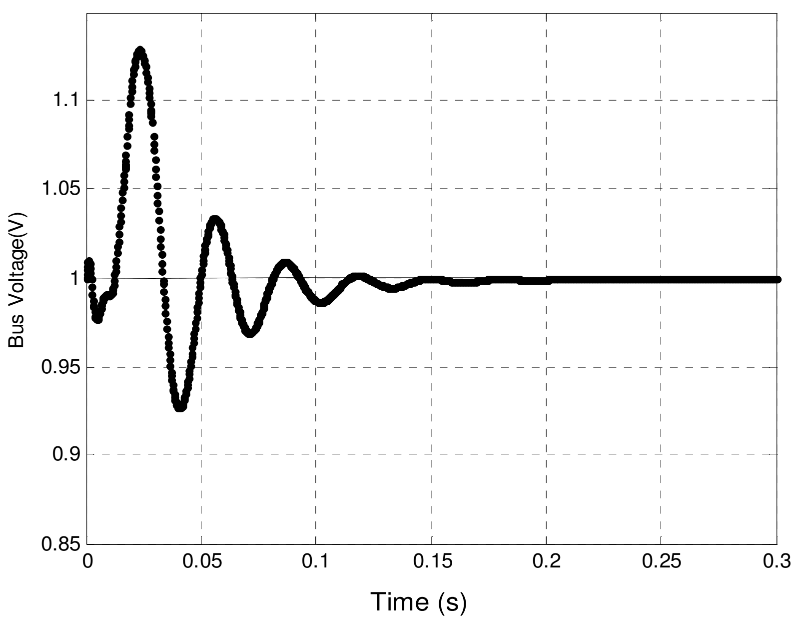

Figure 9. SVC voltage controller.

and 14.

CONCLUSIONS

In the wind farm which operates as connected to the network, the control of the decrease in voltage as a result of the connection of load to load bus was examined through STATCOM and SVC. The Proportion Integrate time stables used to control voltage and reactive power were taken to be the same for different static and dynamic loads. Voltage reference value in the bus was given as 1 p.u while reactive power change value in the bus was given as 0 p.u. In this simulation study, it was observed that both STATCOM and SVC have made the voltage and reactive power changes closer to reference

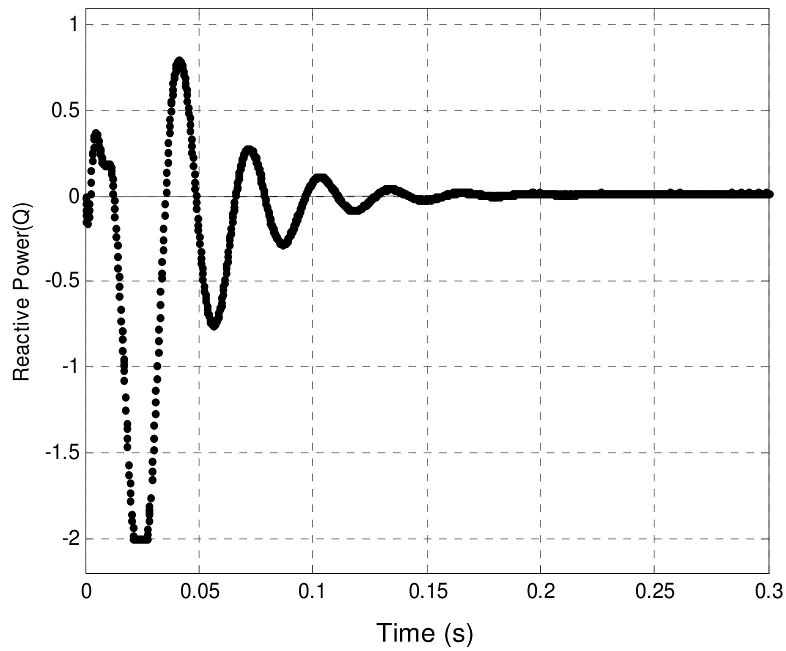

Figure 10. SVC Reactive power controller.

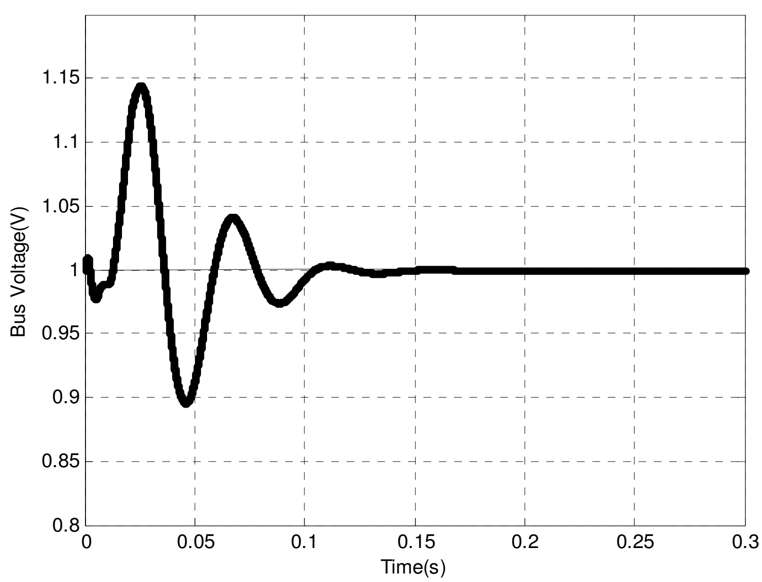

Figure 11. STATCOM voltage controller.

value and made them stable. It was found that STATCOM yielded better results in terms of time response than SVC in voltage control. Reactive power wise, it was found that STATCOM becomes stable in a shorter time span relative to SVC. Taking the system into consideration in terms of damping oscillation, the fluctuation in SVC is less than STATCOM.

On the operation of the system, the static and dynamic load values dependent on load bus have been shown on the Table 1. The results of voltage and reactive power controls in load bus with 4MW and 2 MVAr load values voltage and reactive control have been shown Table 2.

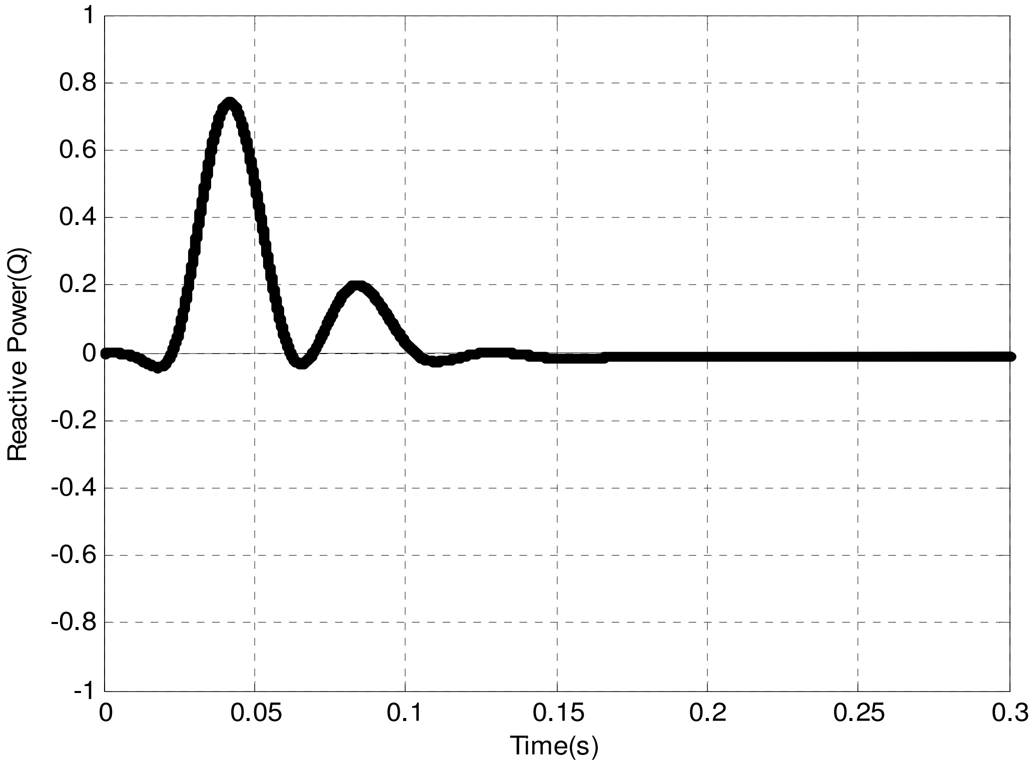

Figure 12. STATCOM reactive power controller.

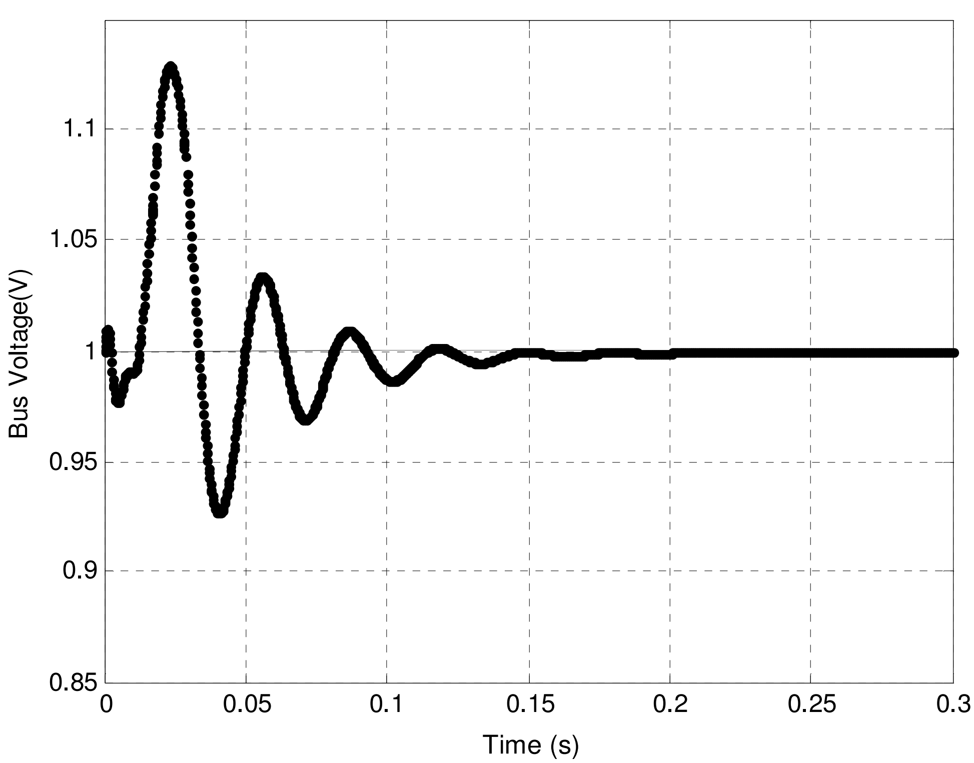

Figure 13. SVC voltage controller.

Table 1. Different loads.

Active load (P) (MW)	Reactive power (Q) (MVAr)
4	2
3	2.1
5	1.5

Table 2. Measurement values.

Compensator type and load	Vmes (p.u)	Qmes (p.u)	Time response (s)	Damping oscillation between (p.u)
STATCOM static load	0.9970	-0.0030	0.17	(1.145 -0.896)
SVC static	0.9965	-0.0035	0.23	(1.129 - 0.930)
STATCOM dynamic	0.9950	-0.0050	0.15	(1.150 - 0.890)
SVC dynamic	0.9945	-0.0055	0.21	(1.132 - 0.925)

The results of voltage and reactive power controls in load bus with 5MW and 1.5 MVAr load values have been voltage and reactive control.

Table 3. Measurement values.

Compensator type and load	Vmes (p.u)	Qmes (p.u)	Time Response (s)	Damping oscillation Between (p.u)
STATCOM static	1.0003	0.003	0.17	(1.145 - 0.896)
SVC static	1.0002	0.002	0.23	(1.129 - 0.930)
STATCOM dynamic	1.0001	0.001	0.15	(1.150 - 0.890)
SVC dynamic	1.0000	0.000	0.21	(1.132 - 0.925)

The results of voltage and reactive power controls in load bus with 3MW and 2.1 MVAr load values have been voltage and reactive control.

Table 4. Measurement values.

Compensator type and load	Vmes (p.u)	Qmes (p.u)	Time Response (s)	Damping oscillation Between (p.u)
STATCOM static	1.0003	0.003	0.17	(1.145 - 0.896)
SVC static	1.0002	0.002	0.23	(1.129 - 0.930)
STATCOM dynamic	1.0002	0.002	0.15	(1.150 - 0.890)
SVC dynamic	1.0002	0.002	0.21	(1.132 - 0.925)

The results of voltage and reactive power controls in load bus with 5MW and 1.5 MVAr load values voltage and reactive control have been shown Table 3. The results of voltage and reactive power controls in load bus with 3MW and 2.1 MVAr load values voltage and reactive control have been shown Table 4.

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