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Steady State Operation And Enhancement Of Transient Stability In Hydel Power Plant Using Statcom

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Abstract: *In this paper, the effect of STATCOM for improving the stability and steady state operation of the hydel power system is investigated. The STATCOM is used to control power flow of power system by injecting appropriate reactive power during dynamic state. Simulation results show that STATCOM not only considerably improves transient stability but also compensates the reactive power in steady state. Therefore STATCOM can increase reliability and capability of AC transmission system. To illustrate the performance of the FACTS controller (STATCOM), a three machine nine bus, Multi-Machine Power System has been considered.*
Keywords: *FACTS(statcom), hydel power plant ,steady state operation, Transient Stability ,simulation.*

I. Introduction

Power is extremely fundamental infrastructure on the whole extension of many nations in the world. The requirement for electrical energy is rising speedily in the world. It is being realized that renewable energy sources can supplement the available energy and provide a reasonable option in broad range of applications and plays a significant role in resolving the doppelganger problem of energy supply in the decentralized applications. Micro hydro power plant is considered to be the promising source surrounded by renewable energy. Renewable energy is a major constraint in the economic development of the rural areas which includes solar energy, biomass, wind, tidal, geothermal energy and flowing water stream and these sources are effortlessly accessible in remote areas which are island, ships, villages, military, hilly areas etc. Commercial sources that are produced from the exhaustion of fossil fuels like kerosene, diesel, petrol, coal and petroleum etc include their own disadvantages such as air pollution and global warming.Micro hydro is a type of hydroelectric power which produces up to100 kW of electricity using the natural flow of water. Prime mover of the hydraulic turbine rives the induction generator, and its reactive power consumption is rewarded by the capacitor banks and this whole system is known as self-excited induction generator (SEIG). Induction generators is used now a days because of advantages over synchronous generators i.e. brushless construction with squirrel cage rotor, rugged, low cost, less maintenance,operational simplicity, reduced size, no dc supply is needed ,against faults self-protection, good dynamic reaction, and capability to produce power at varying speed.Induction generator offers poor voltage regulation, frequency regulation under varying speedand its value depends on the prime mover speed, capacitor bank size.

Now a days wind as a significant proportion of non pollutant 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. Various methods to analyze and improve wind farm stability have been performed. The stability of wind driven self excited induction generator SEIG s is analyzed. A breaking resistor to absorb active power during fault to enhance the system stability is developed . Flexible AC transmission system FACTS devices such as Static Synchronous Compensator STATCOM to improve the stability in wind farm is studied .

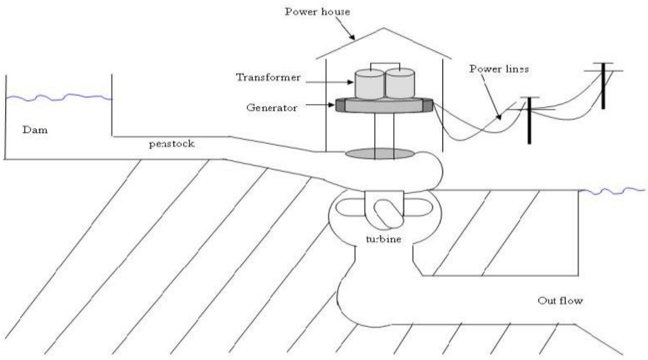
As a consequence, it will become necessary to require wind farms to maintain continuous operation during grid disturbances and thereby support the network voltage and frequency. In addition, in the area of a deregulated electricity industry, the policy of open access to transmission systems, which helped create competitive electricity markets, led to a huge increase in energy transactions over the grid and possible congestion in transmission systems. The expansion of power transfer capability of transmission systems has been a major problem over the past two decades. Under these conditions, the modern power system has had to confront some major operating problems, such as voltage regulation, power flow control, transient stability, and damping of power oscillations, etc. FACTS devices can be a solution to these problems . They are able to provide rapid active and reactive power compensations to power systems, and therefore can be used to provide voltage support and power flow control, increase transient stability and improve power oscillation damping. Suitably located FACTS devices allow more efficient utilization of existing transmission networks.

The STATCOM is used to provide rapid and fast control of voltage during during steady state and transient stability. This issue is even more critical in the case of microgirds, since certain FACTS controllers, particularly STATCOMs, are being considered as a possible solution for some of the voltage and angle stability problems inherent to these power grids. Consequently, typical STATCOM models are validated here using system identification techniques to extract the relevant electromechanical mode information from time-domain signals . System identification techniques are used to readily and directly compare fairly distinct STATCOM models, thus avoiding matrix based eigenvalue studies of complex system models and/or modeling approximations.

In this paper, a STATCOM is added to the power network to provide dynamic voltage control for the wind farm, dynamic power flow control for the transmission lines, relieve transmission congestion and improve power oscillation damping. Simulation results show that the STATCOM devices significantly improve the performance of the wind farm and the power network during transient disturbances.

II. Hydro Power Plant And Electric Generator Model

Hydropower represents 21% of the world power production. The development of hydroelectricity will be increased because of the interest in utilizing the renewable sources. basic principle of hydropower plant is to convert the hydraulic energy to mechanical energy which inturn is converted to electrical energy. Hydropower plants relay on dam which acts as a water reservoir. Gravity causes the water to fall through the penstock. At the end of penstock there is propeller ,which rotates by moving water .rotation in propeller will drive generator to produce the alternating current AC. transformers provided in switchyard of powerhouse converts it into higher voltage currents. Transmission lines are provided which carry the electricity from these transformers to the consumers. outflow carries used water through the pipe downstream which may be used for irrigation purpose.



Statcom Model

Figure 1
shows the basic model of a STATCOM which is connected to the ac system bus through a coupling transformer. In a STATCOM, the maximum compensating current is independent of system voltage, so it operates at full capacity even at low voltages. A STATCOM's advantages include flexible voltage control for power quality improvement, fast response, and applicability for use with high fluctuating loads.

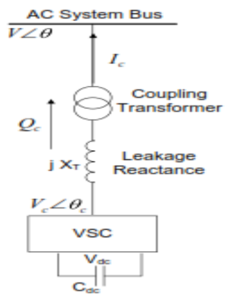


Figure 1. Basic model of a STATCOM

The output of the controller Qc is controllable which is proportional to the voltage magnitude difference (Vc −V) and is given by (1)

$Q_c = V(V_c - V) / X$ (1)

The shunt inverter, transformer and connection filter are the major components of a STATCOM. The control system employed in this system maintains the magnitude of the bus voltage constant by controlling the magnitude and/or phase shift of the voltage reactive power exchange is achieved. By properly controlling i_q, reactive power exchange is achieved.The DC capacitor voltage is maintained at a constant value and this voltage error is used to determine the reference for the active power to be exchanged by the inverter. The STATCOM is a static var generator whose output can be varied so as to maintain or control certain specific parameters of the electric power system. The STATCOM is a power electronic component that can be applied to the dynamic control of the reactive power and the grid voltage. The reactive output power of the compensator is varied to control the voltage at given transmission network terminals, thus maintaining the desired power flows during possible system disturbances and contingencies. STATCOMs have the ability to address transient events at a faster rate and with better performance at lower voltages than a Static Voltage Compensator (SVC). The maximum compensation current in a STATCOM is independent of the system voltage. Overall, a STATCOM provides dynamic voltage control and power oscillation damping, and improves the system's transient stability. By controlling the phase angle, the flow of current between the converter and the ac system are controlled A STATCOM was chosen as a source for reactive power support because it has the ability to continuously vary its susceptance while reacting fast and providing voltage support at a local node. Figure 2 show the block diagram of the STATCOM controller. The values for all the variables in the figure are presented in the appendix

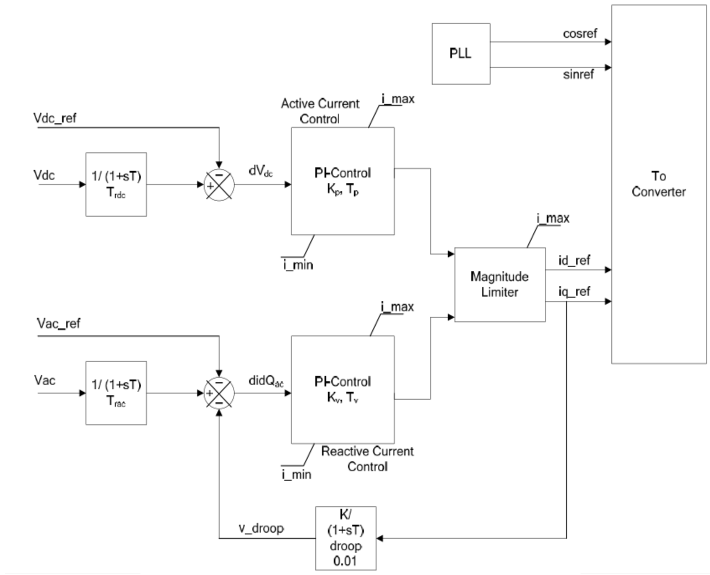


Figure 2 control scheme of the statcom

By controlling the phase and magnitude of the STATCOM output voltage, the power exchange between the ac system and the STATCOM can be controlled effectively. The outputs of the controller are i_d_ref and i_q_ref which are the reference currents in the dq coordinates which are needed to calculate the power injections by the STATCOM as in (2) and (3).

$P_{ini} = Vi\ (i_d\cos\theta_i + i_q\sin\theta_i) = v_d\ i_d + v_q\ i_q$ (2) $Q_{inj} = {}_{Vi}\ (i_d\sin\theta_i - i_q\cos\theta_i) = -v_d i_q + v_q i_q$ (3)

Where i_d and i_q are the reference d and q axis currents of the ac system. The control variables are the current injected by the STATCOM and the reactive power injected into the system. The STATCOM ratings are based on many parameters which are mostly governed by the amount of reactive power the system needs to recover and ride through typical faults on the power system and to reduce the interaction of other system equipment that can become out of synchronism with the grid. Although the final rating of the STATCOM is determined based on system economics, the capacity chosen will be at least adequate for the system to stabilize after temporary system disturbances. The type of faults that the system is expected to recover from also determines the size of the STATCOM. For example, a three phase impedance fault of low impedance requires a very high rating STATCOM while a high impedance short circuit fault needs a lower rating device to support the system during the fault and help recover after the fault. The converter current ratings and the size of the capacitor also decide the capability of the STATCOM. The STATCOM can be connected to the system at any voltage level by using a coupling transformer. The devices in a voltage source converter are clamped against over-voltages across the DC link capacitor bank to minimize losses and not have to withstand large spikes in reverse over-voltage.

III. Location Of Statcom

Simulation results show that STATCOM provides effective voltage support at the bus to which it is connected to. The STATCOM is placed as close as possible to the load bus for various reasons. The first reason is that the location of the reactive power support should be as close as possible to the point at which the support is needed. Secondly, in the studied test system the location of the STATCOM at the load bus is more appropriate because the effect of voltage change is the highest at this point. The location of the STATCOM is based on quantitative benefits evaluation. The main benefits of using a STATCOM in the system are reduced losses and increased maximum transfer capability. The location of STATCOM is generally chosen to be the location in the system which needs reactive power. To place a STATCOM at any load bus reduces the reactive power flow through the lines, thus, reducing line current and also the I^2R losses. Shipping of reactive power at low voltages in a system running close to its stability limit is not very efficient. Also, the total amount of reactive power transfer available will be influenced by the transmission line power factor limiting factors. Hence, sources and compensation devices are always kept as close as possible to the load as the ratio $\Delta V/V_{nom}$ will be higher for the load bus under fault conditions.

Newton-Raphson Approach

The Newton-Raphson (NR) method is a powerful method of solving non-linear algebraic equations. Because of its quadratic convergence, Newton's method is mathematically superior to the *Gauss*-Seidel method and is less prone to divergence with ill-conditioned problems. It works faster, and is sure to converge in most cases as compared to the Gauss-Siedel (GS) method. It is indeed the practical method of load flow solution of large power networks. Its only drawback is the large requirement of computer memory, which can be overcome through a compact storage scheme. One of the main strengths of the Newton-Raphson method is its reliability towards convergence. Contrary to non Newton-Raphson solutions, convergence is independent of the size of the network being solved and the number and kinds of control equipment present in the system. Hence in the proposed work Newton-Raphson method is preferred .

The Sample Five Bus Network

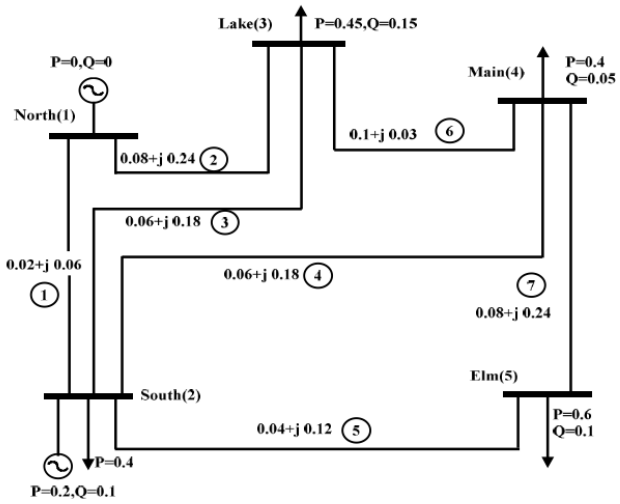


Fig 3 The 5 bus network

For study we have considered the five bus system as shown in Fig. 3, which is a seven line, two generator and three load bus. The input data for the considered system are given in Table 1 for the bus and Table 2 for transmission line . The transmission line impedances and line charging admittances are in per unit.

Table 1 Input bus data(p.u.)

Bus No.	type	Generation		Load		Voltage	
		P	Q	P	Q	|V|	θ
1	Slack	0	0	-	-	1.06	0
2	P-V	0.4	0	0.2	0.1	1	0
3	P-Q	-	-	0.45	0.15	1	0
4	P-Q	-	-	0.4	0.05	1	0
5	P-Q	-	-	0.6	0.1	1	0

Assuming Base Quantity of 100MVA and 100KV

Table 2 Input transmission line data (p.u)

Line no	Line Code	Impedance(R+jX)	Linecharging admittance
1	1-2	0.02+j0.06	0+j0.06
2	1-3	0.08+j0.24	0+j0.05
3	2-3	0.06+j0.18	0+j0.04
4	2-4	0.06+j0.18	0+j0.04
5	2-5	0.04+j0.12	0+j0.03
6	3-4	0.01+j0.03	0+j0.02
7	4-5	0.08+j0.24	0+j0.05

The load flow result and Power flow diagram for the 5-bus system is shown in Table 3 and Fig 4 respectively.

Table 3 Power flow result without FACTS devices(p.u.)

Parameter	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5
VM(p.u.)	1.06	1	0.985	0.986	0.9717
VA(deg)	0	-2.05	-4.62	-4.95	-5.78

It is observed from the above table that all the nodal voltages are within acceptable voltage magnitude limits. From the power flow diagram it is clear that the largest power flow takes place in the transmission line connecting the generator buses: 89.42 MW, and 73.93MVAR leave north and 86.63 MW and 72.73 MVAR arrive at South. This is also the transmission line that incurs higher active power loss (i.e. 2.79 MW). The operating conditions demand a large amount of reactive power generation by the generator connected at North (i.e.90.61 MVAR). This amount is well in excess of the reactive power drawn by the system loads (i.e. 40MVAR). The generator at South draws the excess of reactive power in the network (i.e.61.4 MVAR). This amount includes the net reactive power produced by several of the transmissionlines

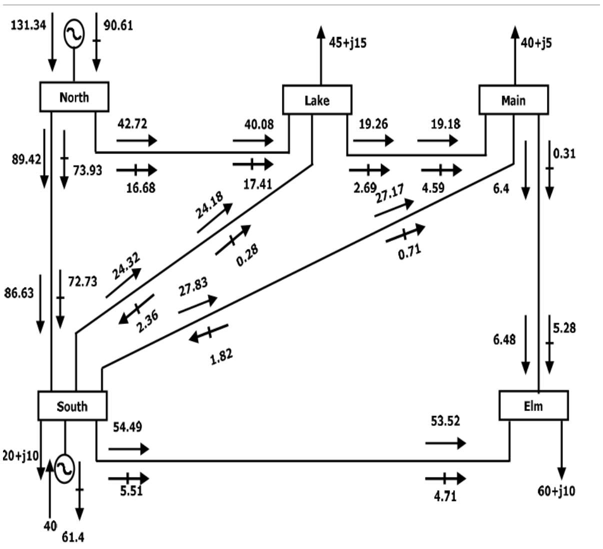


Fig 4 The five bus network and power flow result

Power Flow Model of STATCOM

The STATCOM is the static counterpart of the rotating synchronous condenser but it generates or absorbs reactive power at a faster rate because no moving parts are involved. It is even possible to increase the reactive current in a STATCOM under transient conditions if the devices are rated for the transient overload. The bus at which STATCOM is connected is represented as a PV bus, which may change to a PQ bus in the events of limits being violated. The power flow equations for the STATCOM are derived below from the first principles and assuming the following voltage source representation .

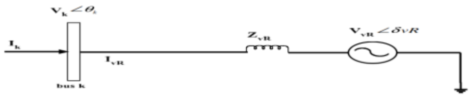


Fig 5 STATCOM-equivalent circuit

Based on the shunt connection shown in Fig 5, the following may be written as

$E_{vR} = V_{vR} (\cos\delta_{vR} + j \sin \delta_{vR})$ (4)

$S_{vR} = V_{vR} I^*_{vR} = V_{vR} Y^*_{vR} (V^*_{vR} - V^*_k)$ (5)

Where V_{vR} and δ_{vR} are the controllable magnitude ($V_{vR}min \le V_{vR} \le V_{vR}max$) and phase angle ($0 \le \delta_{vR} \le 2\pi$) of the voltage source representing the shunt converter. The following are the active and reactive power equations for the converter at bus k,

$P_{vR} = V^2_{vR} G_{VR} + V_{vR} V_k [G_{vR} \cos(\delta_{vR} - \theta_k) + B_{vR} \sin(\delta_{vR} - \theta_k)]$ (2.3)

$Q_{vR} = -V^2_{vR} B_{VR} + V_{vR} V_k [G_{vR} \sin(\delta_{vR} - \theta_k) - B_{vR} \cos(\delta_{vR} - \theta_k)]$ (6)

$P_k = V^2_k G_{vR} + V_k V_{kR} [G_{vR} \cos(\theta_{k-} \delta_{vR}) + B_{vR} \sin(\theta_{k-} \delta_{vR})]$ (7)

$Q_k = -V^2_k B_{vR} + V_k V_{kR} [G_{vR} \sin(\theta_{k-} \delta_{vR}) - B_{vR} \cos(\theta_{k-} \delta_{vR})]$ (8)

Power Flow Stud with Statcom

The STATCOM is included in the bus 3 of the sample system to maintain the nodal voltage at 1 p.u.. Here the STATCOM data are: the initial source voltage magnitude is 1 p.u, Phase angle is 0 degrees and the converter reactance is 10 p.u.
The load flow result and power flow diagram result for the 5-bus system with STATCOM at bus 3 is shown in Table 4 and Fig 6 respective.

Table 4 Result with STATCOM included at bus 3

Parameter	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5
VM(p.u)	1.06	1	1	0.9953	0.9754
VA(deg)	0	-2.06	-4.752	-4.823	-5783

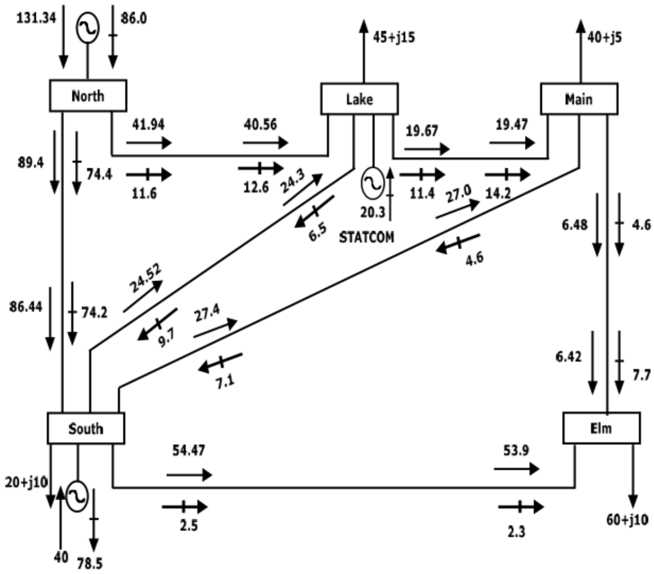


Fig.6 STATCOM-upgraded test network and power flow result

Here the power flow result indicates that the STATCOM generates 20.3 MVAR in order to keep the voltage magnitude at 1 p.u. at bus 3. The largest reactive power flow takes place in the transmission line connecting North and South, where 74.4 MVAR leaves North and 74.2 MVAR arrives at South. In general, more reactive power is available in the network than in the base case, and the generator connected at South increases its share of reactive power absorption compared with the base case. Active power flows are only marginally affected by the STATCOM installation the power flow of the five bus system has been studied without and with FACTS devices performing the Newton-Rapson method. Power flow without FACTS devices shows that the operating conditions demand a large amount of reactive power generation by the generator connected at bus 1 (i.e. 90.61 MVAR). This amount is well in excess of the reactive power drawn by the system loads (i.e. 40 MVAR). The generator at bus 2 draws the excess of reactive power in the network (i.e. 61.4 MVAR).

Use of STATCOM results in an improved network voltage profile, except at bus 5, which is too far away from bus 3 to benefit from the influence of STATCOM. The power flow result indicates that the STATCOM generates 20.3 MVAR in order to keep the voltage magnitude at 1 p.u at bus 3. The SVC injects 20.28 MVAR into bus 3 and keeps the nodal voltage magnitude at 1p.u. The action of the SVC results in an overall improved voltage profile. The STATCOM is superior to the SVC in providing voltage support under large system disturbances during which the voltage excursions would be well outside of the linear operating range of the compensator

The Sample Nine Bus System

For the proposed work we have considered the three- machine, nine- bus WSCC (Western System Coordinating Counsel) system as shown in Figure 7

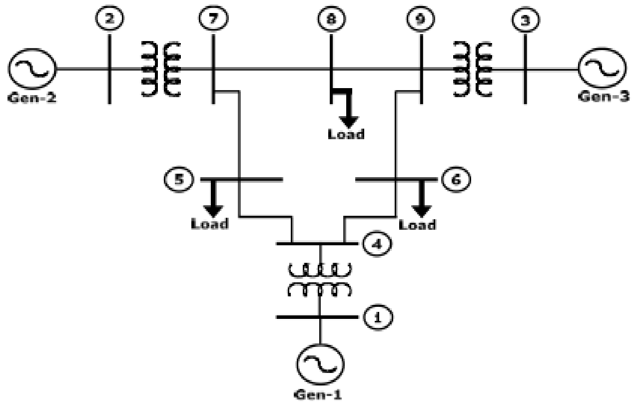


Figure 7

Thae input data for the considered system are given in table 5 for the bus and table 6 for the transmission line.the transmission line impedances and the line charging admittances are in per unit

Table input 5 Bus data (p.u)

Bus no	Type	Generation		Load		Voltage	
		P	Q	P	Q	|V|	θ
1	Slack	0	0	0	0	1,04	0
2	P-V	1.63	0	0	0	1.025	0
3	P-V	.85	0	0	0	1.025	0
4	P-Q	0	0	0	0	1	0
5	P-Q	0	0	1.25	.50	1	0
6	P-Q	0	0	.90	.30	1	0
7	P-Q	0	0	0	0	1	0
8	P-Q	0	0	1.0	.35	1	0
9	P-Q	0	0	0	0	1	0

Assuming base quantity of 100 MVA and 100 KV

Table 6 input transmissinion line data (p.u)

Bus No	***Line Code***	***Impedance (R+jX)***	***Line Charging Admittance***
1	1-4	0+j.0576	0+j0
2	2-7	0+j.0625	0+j0
3	3-9	0+j.0586	0+j0
4	4-5	0.01+j.0850	0+j.088
4	4-6	.017+j.0920	0+j.079
5	5-7	.0320+j.161	0+j.153
6	6-9	.0390+j.17	0+j.179
7	7-8	.0085+j.072	0+j.0745
8	8-9	.0119+j.1008	0+j.1045

The disturbances for the sample system are 3-phase faults at each end of each line (3-phase to earth), followed by clearing the fault via removing one of the lines connected to the faulted bus, followed by a successful three phase reclosure of the faulted line.

IV. Modelling

A three-phase fault is simulated in one of the lines of the nine-bus system i.e. three phase to earth fault. The simulation is done in three phases. To start with, the pre-fault system is run for a small time. Then a symmetrical fault is applied at one end of a line (Fig. 3.8). Simulation of the faulted condition continues until the line is disconnected from the buses at both of the ends of the faulted line after a fault clearing time tcl s. Then the post-fault system is simulated for a longer time (say,10 s) to observe the nature of the transients. We start with tcl = 0.1 s (which is six cycles for a 60-Hz system) and then tcl =.15s. Now the STATCOM is connected to the midpoint of one of the lines. To ensure the reactive power injection mode of operation, the magnitude of the voltage of the STATCOM is set at a value higher than the magnitudes of the pre-fault line midpoint voltage.

Plots of relative machine angles delta-(1-2) and (1-3) are shown in Fig. 7.1 and Fig. 7.2 with fault clearing time tcl = .1 (s) in line 5-7 respectively.

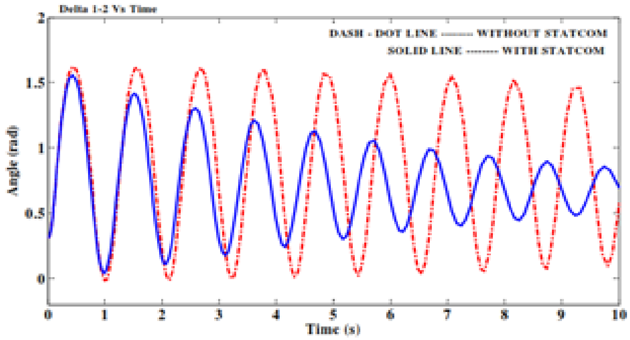


Fig. 7.1. Response of relative machine angles delta 1-2 for fault at bus 7, line removed at 5-7 without STATCOM and with STATCOM

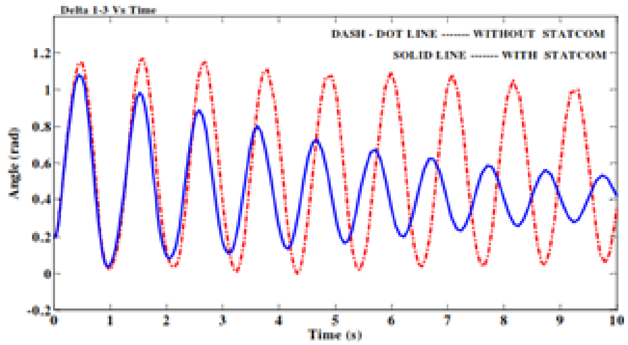


Fig. 7.2. Response of relative machine angles delta 1-3 for fault at bus 7,line removed at 5-7 without STATCOM and with STATCOM

Plots of relative machine angles delta-(1-2) and (1-3) are shown in Fig. 7.3 and Fig. 7.4 with fault clearing time tcl = .15 (s) in line 5-7 respectively.

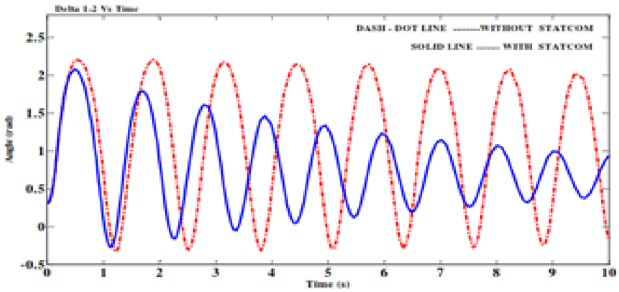


Fig. 7.3. Response of relative machine angles delta 1-2 for fault at bus 7, line removed at 5-7 without STATCOM and withSTATCOM

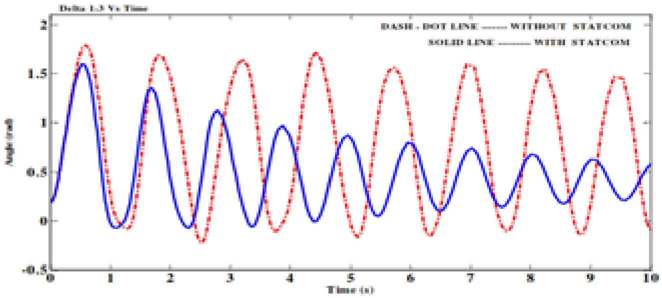


Fig. 7.4. Response of relative machine angles delta 1-3 for fault at bus 7, line removed at 5-7 without STATCOM and with STATCOM

Plots of relative machine angles delta-(1-2) and (1-3) are shown in Fig. 7.5 and Fig. 7.6 with fault clearing time tcl = .1 (s) in line 4-5 respectively.

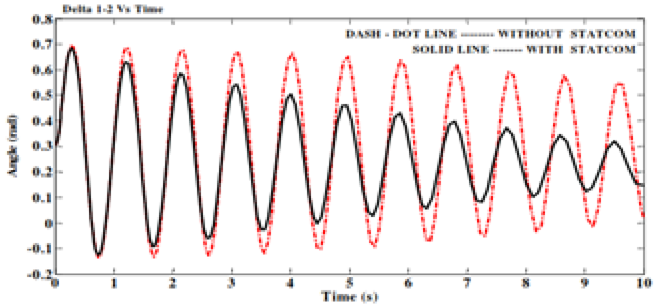


Fig. 7.5. Response of relative machine angles delta 1-2 for fault at bus 5, line removed at 4-5 without STATCOM and with STATCOM

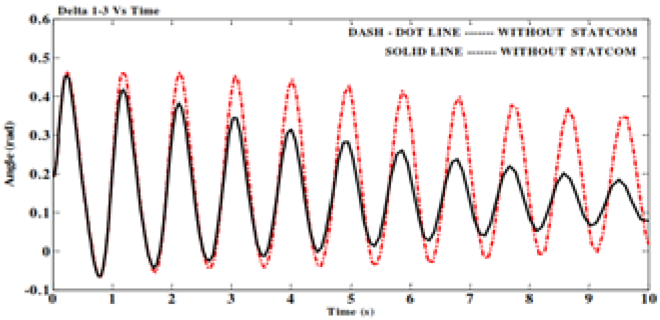


Fig. 7.6. Response of relative machine angles delta 1-3 for fault at bus 5, line removed at 4-5 without STATCOM and with STATCOM

Plots of relative machine angles delta-(1-2) and (1-3) are shown in Fig. 7.7 and Fig. 7.8 with fault clearing time tcl = .15 (s) in line 4-5 respectively.

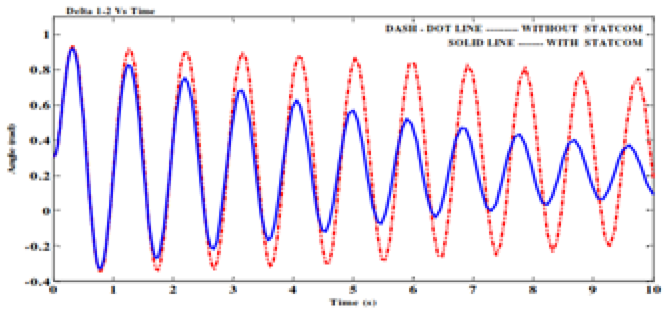


Fig.7.7. Response of lative machine angles delta 1-2 for fault at bus 5, line removed at 4-5 without TATCOM and with STATCOM.

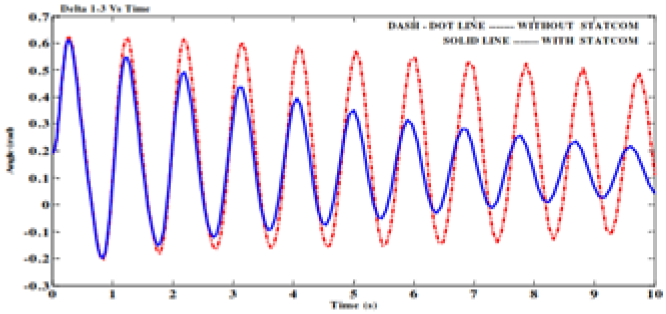


Fig. 7.8. Response of relative machine angles delta 1-3 for fault at bus 5, line removed at 4-5 without STATCOM and with STATCOM.

Plots of relative machine angles delta-(1-2) and (1-3) are shown in Fig. 7.9 and Fig. 4.10 with fault clearing time tcl = .1(s) in line 6-9 respectively.

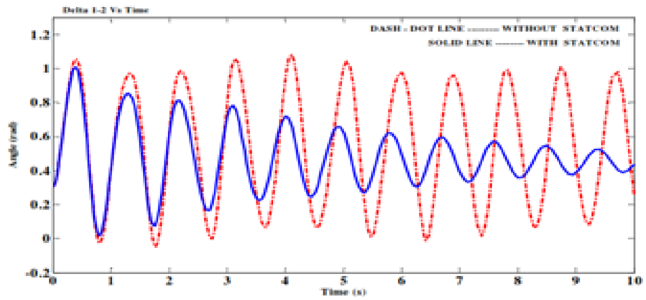


Fig. 7.9. Response of relative machine angles delta 1-2 for fault at bus 9, line removed at 6-9 without STATCOM and with STATCOM.

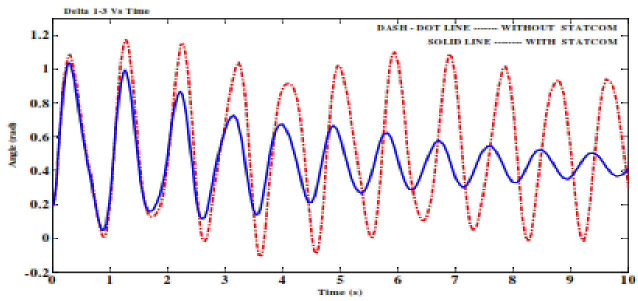


Fig. 7.10. Response of relative machine angles delta 1-3 for fault at bus 9, line removed at 6-9 without STATCOM and with STATCOM.

Plots of relative machine angles delta-(1-2) and (1-3) are shown in Fig. 7.11 and Fig. 7.12 with fault clearing time tcl = .15 (s) in line 6-9 respectively.

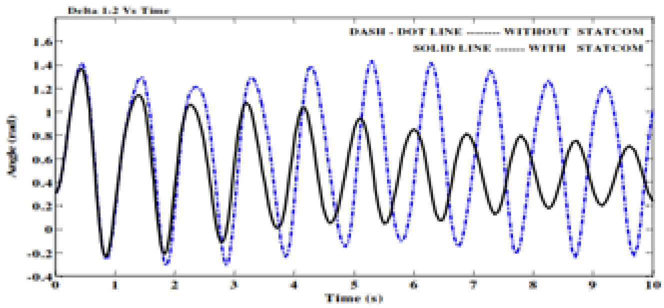


Fig. 7.11. Response of relative machine angles delta 1-2 for fault at bus 9, line removed at 6-9 without STATCOM and with STATCOM

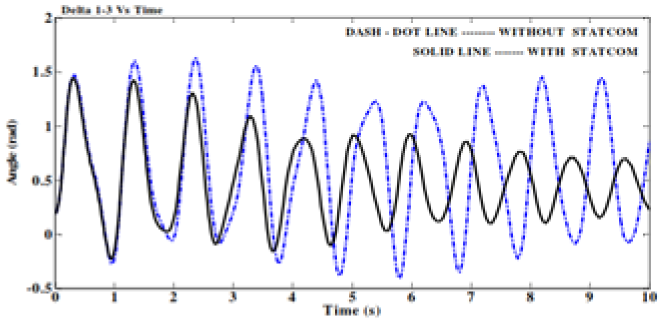


Fig. 7.12. Response of relative machine angles delta 1-3 for fault at bus 9, line removed at 6-9 without STATCOM and with STATCOM.

Plots of relative machine angles delta-(1-2) and (1-3) are shown in Fig. 7.13 and Fig. 7.14 with fault clearing time tcl = .1(s) in line 7-8respectively.

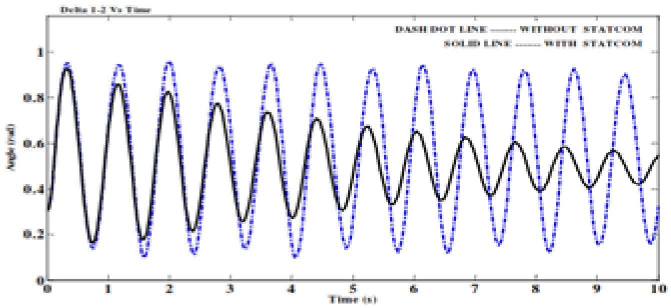


Fig. 7.13. Response of relative machine angles delta 1-2 for fault at bus 8, line removed at 7-8 without STATCOM and with STATCOM

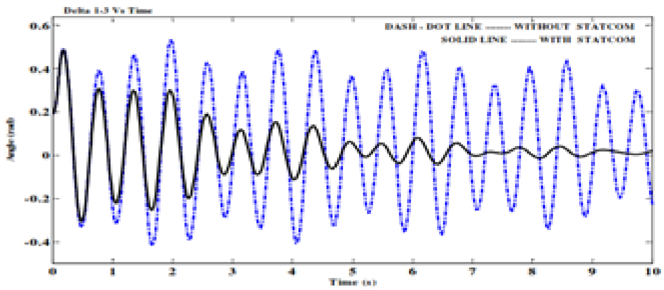


Fig. 7.14. Response of relative machine angles delta 1-3 for fault at bus 8, line removed at 7-8 without STATCOM and with STATCOM.

Plots of relative machine angles delta-(1-2) and (1-3) are shown in Fig. 7.15 and Fig. 7.16 with fault clearing time tcl = .15(s) in line 7-8 respectively.

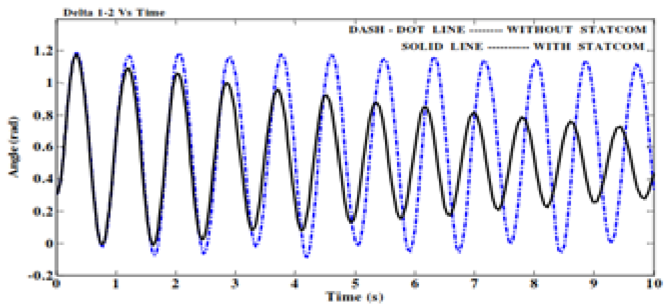


Fig. 7.15. Response of relative machine angles delta 1-2 for fault at bus 8, line removed at 7-8 without STATCOM and with STATCOM.

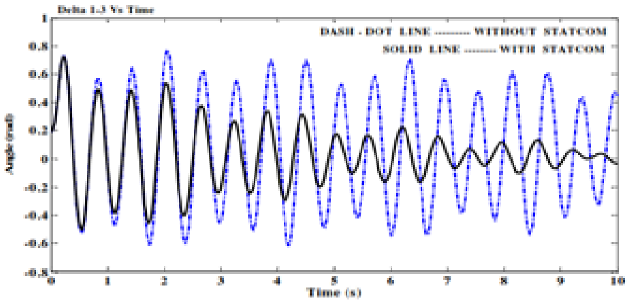


Fig. 7.16. Response of relative machine angles delta 1-3 for fault at bus 8, line removed at 7-8 without STATCOM and with STATCOM.

From the above simulation results we conclude that STATCOM not only considerably improves transient stability but also compensates the reactive power in steady state. The STATCOM is used to control power flow of power system by injecting appropriate reactive power during dynamic state. The best possible location of the FACTS device (STATCOM) is found to vary with the location of the fault and the operating criteria of the device. We also conclude that if the fault clearing time is less, more stability improvement. On the other hand less transient stability improvement occurs if fault clearing time is more.

V. Conclusion

In this thesis, the effect of STATCOM for improving transient stability of the multi- machine power system is investigated in terms of the Fault Clearing Time. The STATCOM is used to control power flow of power system by injecting appropriate reactive power during dynamic state. Computer simulation results show that STATCOM not only considerably improves transient stability but also compensates the reactive power in steady state. Therefore STATCOM can increase reliability and capability of AC transmission system .It is also found that the best possible location of the STATCOM for transient stability improvement is not fixed for the nine-bus system; rather it varies depending on the fault location.

It is quite clear that before compensating a power system with FACTS device to improve transient stability, we need to assess the system stability conditions for different locations of the fault and the compensator and also with different amounts of compensation. The transient stability improvement of the multi-machine power system at different fault condition is investigated in this work. The proposed work is also analyzed for different fault clearing times.

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