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Stability Improvement of Power System by Using PI & PD Controller

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Abstract: This paper presents the model of a SVC (Static VAR Compensator) which is controlled externally by a PI (Proportional Integral) & PD (Proportional Differential) controllers for the improvements of voltage stability and damping effect of an on line power system. Both controller parameters has been optimized by using Ziegler-Nichols close loop tuning method. Both single phase and three phase (L-L) faults have been considered in the research. In this paper, a power system network is considered which is simulated in the phasor simulation method & the network is simulated in four steps; without SVC, With SVC but no externally controlled, SVC with PI controller & SVC with PD controller. Simulation result shows that without SVC, the system parameters become unstable during faults. When SVC is imposed in the network, then system parameters become stable. Again, when SVC is controlled externally by PI & PD controllers, then system parameters becomes stable in faster way then without controller. It has been observed that the SVC ratings are only 50 MVA with controllers and 200 MVA without controllers. So, SVC with PI & PD controllers are more effective to enhance the voltage stability and increases power transmission capacity of a power system. The power system oscillations are also reduced with controllers in compared to that of without controllers. So with both controllers the system performance is greatly enhanced.

Key words: SVC (Static VAR Compensator), PI (Proportional Integral), PD (Proportional Differential) Controller, AVR, TCR (Thyristor Controlled Reactor), voltage regulation, MATLAB Simulink.

1. Introduction

Power system stability improvements are very important for large scale system. The AC power transmission system has diverse limits, classified as static limits and dynamic limits [1-2]. Traditionally, fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators were being used to enhance same types of stability augmentation [1]. For many reasons desired performance was being unable to achieve effectively. A SVC (Static VAR Compensator) is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks and it can contribute to improve the voltage profiles in the transient state and therefore, it can improve the qualities and performances of the electric services [3]. A SVC can be controlled externally by using properly designed different types of controllers which can improve voltage stability of a large scale power system. Authors also designed a PI controller [4-5] without properly tuned and system performances were investigated. With a view to getting better performance, PI & PD controller parameters has been designed Ziegler-Nichols method for SVC to injects V_{qref} externally. The dynamic nature of the SVC lies in the use of thyristor devices (e.g., GTO, IGCT) [5]. Therefore, thyristor based SVC with PI & PD controllers has been used to improve the performance of multi-machine power system.

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2. Control Concept of SVC

A SVC is a controlled shunt susceptance (B) which injects reactive power (Q_{net}) into thereby increasing the bus voltage back to its net desired voltage level. If bus voltage increases, the SVC will inject less (or TCR will absorb more) reactive power, and the result will be to achieve the desired bus voltage (see Fig. 1). Here, $+Q_{cap}$ is a fixed capacitance value, therefore the magnitude of reactive power injected into the system, Q_{net}, is controlled by the magnitude of $-Q_{ind}$ reactive power absorbed by the TCR. The basis of the TCR (Thyristor Controlled Reactor) which conduct on alternate half-cycles of the supply frequency. If the thyristors are gated into conduction precisely at the peaks of the supply voltage, full conduction results in the reactor, and the current is the same as though the thyristor controller were short circuited. SVC based control system is shown in Fig. 1 [6].

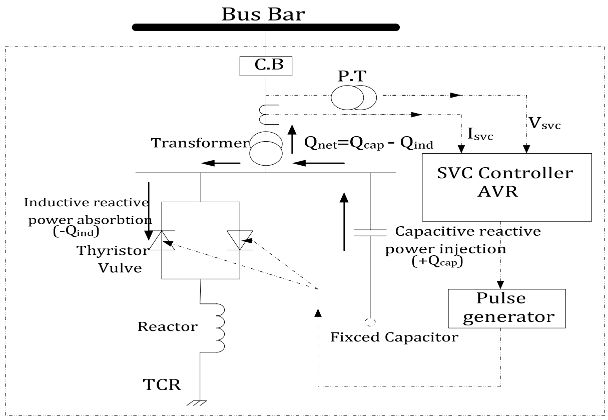


Fig. 1 SVC based control system [6].

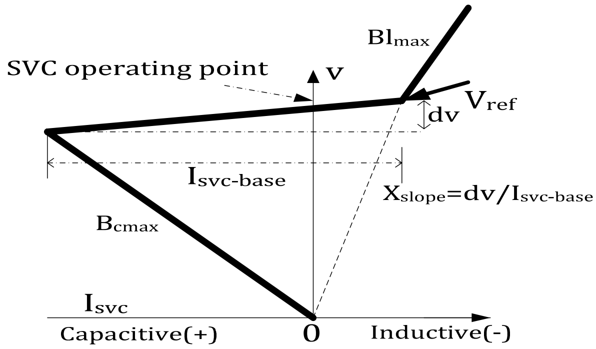


Fig. 2 Steady state (V-I) characteristic of a SVC.

3. SVC V-I Characteristics

The SVC can be operated in two different modes:

(a) In voltage regulation mode (the voltage is regulated within limits as explained below);

(b) In VAR control mode (the SVC susceptance is kept constant).

From V-I curve of SVC, From Fig. 2 [6],

$V = V_{ref} + X_s \cdot I$: In regulation range ($-Bc_{max} < B < Bc_{max}$)

$V = I/Bc_{max}$: SVC is fully Capacitive ($B = Bc_{max}$)

$V = 1/Bl_{max}$: SVC is fully inductive ($B = Bl_{max}$)

4. PI Controller Tuning Process

The process of selecting the controller parameters to meet given performance specifications is called controller tuning. Most controllers are adjusted on-site, many different types of tuning rules have been proposed in the literature [7]. PI (Proportional Integral) controller parameters has been designed by Ziegler-Nichols close loop tuning method.

The PI controller has two term control signal [7],

$$u(t) = K_p e(t) + \frac{K_p}{T_i}\int e(t)dt \tag{1}$$

In Laplace Form,

$$\frac{U(s)}{E(s)} = K_p\left(1+\frac{1}{T_i s}\right) \tag{2}$$

For selecting the proper controller parameters, Ziegler-Nichols close loop Tuning method [7] is described below.

In this method, the parameter is selected at first in proportional action. So consider $T_i = \infty$, $T_d = 0$. Using the proportional controller action (see Fig. 3) only increase K_p from 0 to a critical value $K_{cr.}$ At which the output first exhibits sustained oscillations (see Fig. 4).

Thus the critical gain K_{cr} & the corresponding period P_{cr} are experimentally determined (see Fig. 4). Ziegler and Nichols suggested that the values of the parameters K_pT_i should set according to the following formula:

$$K_p = 0.6K_{cr},\ T_i = 0.5P_{cr}$$

Notice that the PI controller parameters is tuned by this method of Ziegler-Nichols rules gives [7],

$$Gc(s) = K_p\left(1+\frac{1}{T_i s}\right) \tag{3}$$

$$Gc(s) = 0.6K_{cr}\left(1+\frac{1}{0.5\,P_{cr}s}\right) \tag{4}$$

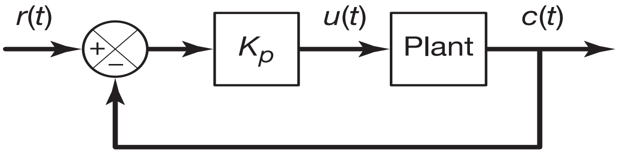


Fig. 3 PI controller is in proportional action.

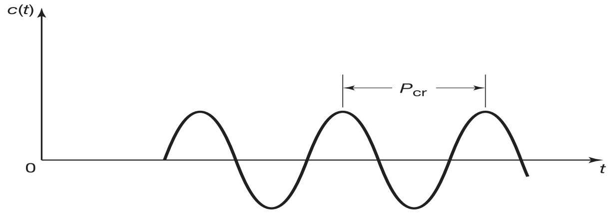


Fig. 4 Determination of sustained oscillation (P_{cr}).

By selecting proper values of K_{cr} & P_{cr}, The PI controller can be designed.

5. PD Controller Tuning Process

Similarly, PD (Proportional Derivative) controller parameters has also been designed by Ziegler-Nichols close loop tuning method.

The PD controller has two term control signal [7],

$$u(t) = K_p e(t) + K_p T_d \frac{de(t)}{dt} \quad (5)$$

$$\frac{U(s)}{E(s)} = K_p(1 + T_d s) \quad (6)$$

$$G_c(s) = K_p(1 + T_d s) \quad (7)$$

Ziegler and Nichols suggested that the values of the parameters $K_p T_d$ should set according to the following formula:

$K_p = 0.6K_{cr}$, $T_d = 0.125P_{cr}$

Thus, Transfer Function

$$G_c(s) = 0.6K_{cr}(1 + 0.125P_{cr}s) \quad (8)$$

By selecting proper values of K_{cr} & P_{cr}, The PD controller can be designed.

6. Modeling of Power System with SVC

This example described in this section illustrates modelling of a simple transmission system containing 2-hydraulic power plants. SVC has been used to improve transient stability and power system oscillations damping. The phasor simulation method can be used. A single line diagram represents a simple 500 kV transmission system is shown in Fig. 5.

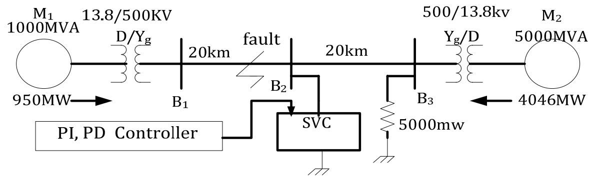


Fig. 5 Single line diagram of 2-machine power.

A 1000 MW hydraulic generation plant (M1) is connected to a load centre through a long 500 kV, total 40km transmission line. A 5000 MW of resistive load is modelled as the load centre. The remote 1000 MVA plant and a local generation of 5000 MVA (plant M2) feed the load. A load flow has been performed on this system with plant M1 generating 950 MW so that plant M2 produces 4046 MW. The line carries 944 MW which is closed to its surge impedance loading (SIL = 977 MW).To maintain system stability after faults, the transmission line is shunt compensated [8] at its centre by a 200MVAR SVC. The SVC does not have any controller unit. Machine & SVC parameters have been taken from [8].

The complete simulink model of this network is shown in Fig. 6. To maintain system stability after faults, the transmission line is shunt compensated at its centre by a 200MVAR SVC. The two machines are equipped with a HTG (Hydraulic Turbine and Governor) (see Fig. 7), excitation system, and PSS (Power System Stabilizer). Another machine is swing generator. PSS is used in the model to add damping to the rotor oscillations of the synchronous machine by controlling its excitation current. Any disturbances that occur in power systems due to fault, which can result in inducing electromechanical oscillations of the electrical generators. Such oscillating swings must be effectively damped to maintain the system stability and reduce the risk of stepping out of synchronism.

6.1 Simulation Results (Without SVC)

The load flow solution of the above system is calculated and the simulation results are shown below. Two types of faults: 6.1.1 Single line to ground fault & 6.1.2 three phase L-L fault have been considered.

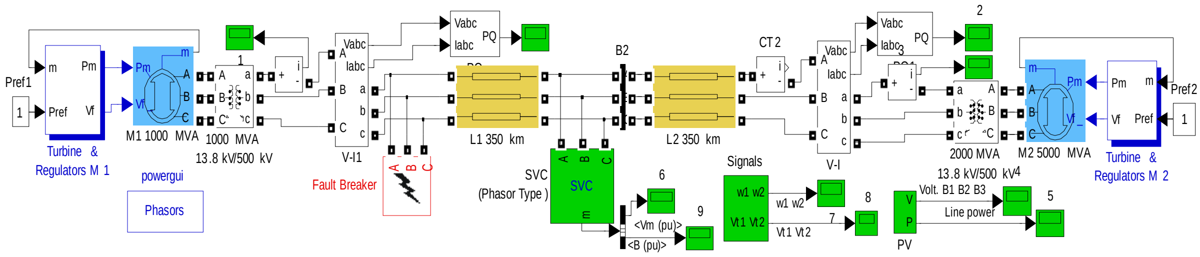


Fig. 6 Complete simulink model of 2-machine power system.

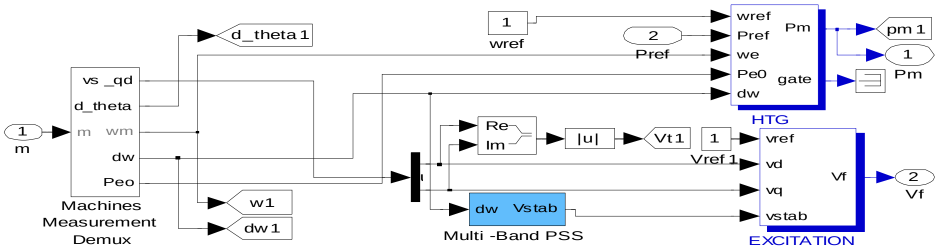
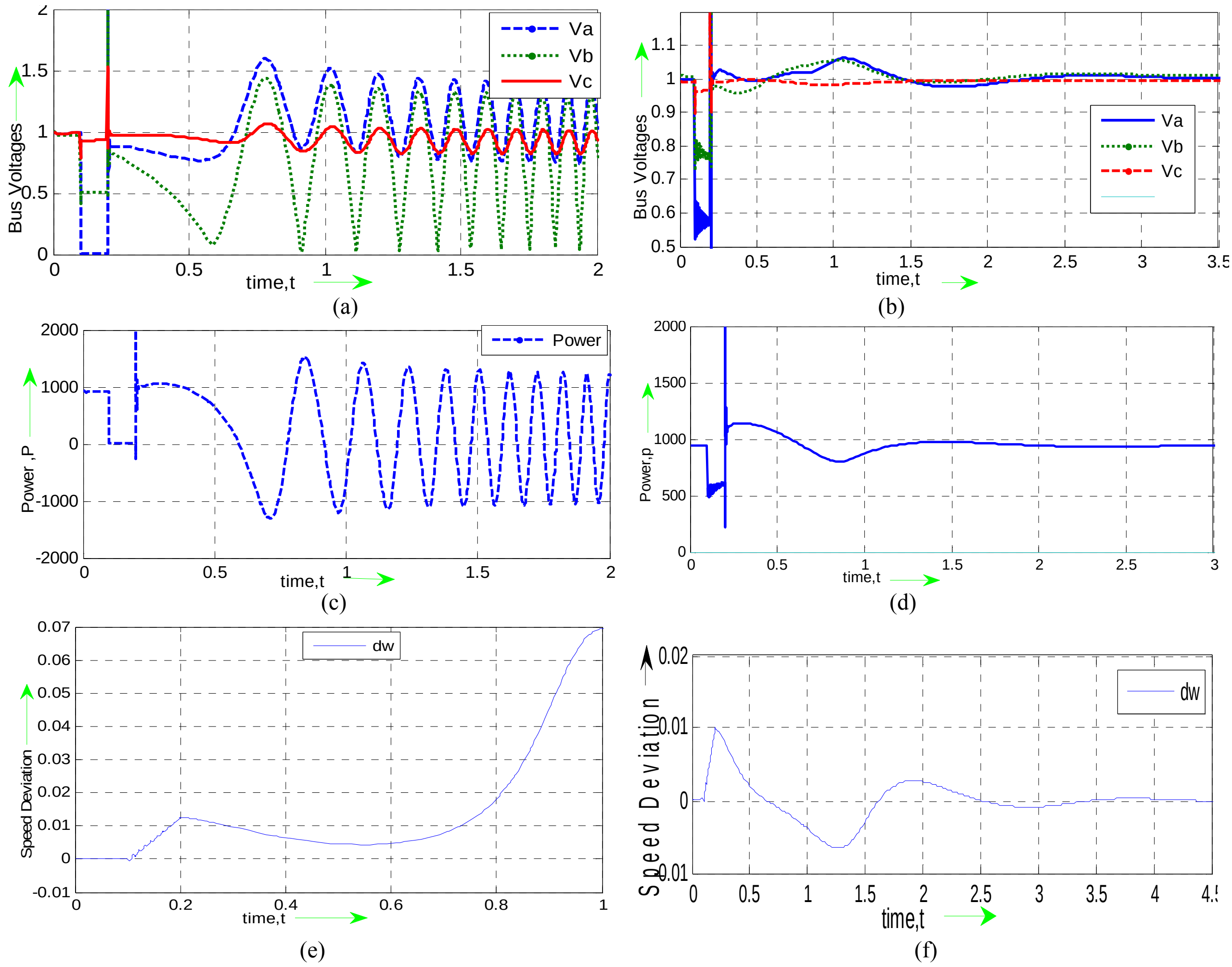
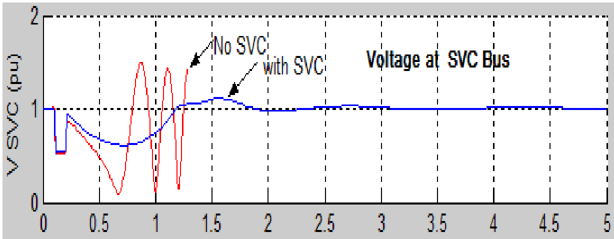
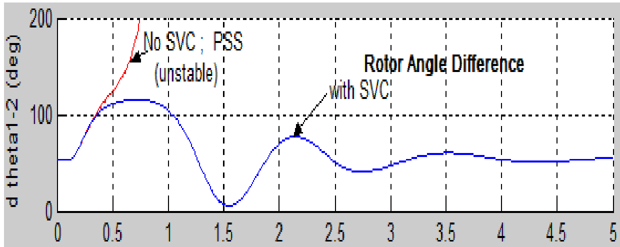


Fig. 7 PSS, HTG and excitation system block diagram for machine 1.





(g)



(h)

Fig. 7 (a) Bus voltages in p.u for 1-phase fault (without SVC); (b) Bus Voltages in p.u for 1-phase fault (with SVC); (c) Bus power, P in MW during fault (without SVC); (d) Bus Power (P) in MW for 1-Ø faults (with SVC); (e) Speed deviation for 1-phase fault (without SVC); (f) Speed oscillations for 1-phase fault (with SVC); (g) Bus Voltage (Va) in p.u for L-L phase fault; (h) Machines speed deviation for L-L fault.

6.1.1 Single line to ground faults

Consider a 1-phase fault occurred at 0.1s & circuit breaker is opened at 0.2s (4-cycle fault), Without SVC, the system voltage, power & machines oscillates goes on unstable (see Fig. 7a, 7c and 7e). But if SVC (without controller) is applied then voltage becomes stable within 3s (see Fig. 7b), power becomes within 3s (see Fig. 7d) & machines oscillation becomes stable within 4.5s (see Fig. 7f). All results have been summarized in Table 1.

6.1.2 Three phase faults (line-line)

During 3-phase faults, If no SVC is applied then system voltage & machines speed deviations becomes unstable But when SVC (without controller) is applied then the system voltage becomes stable within 5s (see Fig. 7g) & machines speed deviation becomes stable within 5s (see Fig. 7h).

7. Design of PI Controller

The proposed PI (Proportional Integral) controller parameters has deigned by using Ziegler-Nichols tuning method. The critical gain (K_{cr}) for which the plant output gives a sustained oscillation (see Fig. 7a) is determined for this network (K_{cr} = 200) & corresponding period of P_{cr} (see Fig. 4) is also determined from Fig. 7a & found P_{cr} = 0.2. Thus the transfer function or parameters of PI controller is determined based on Ziegler-Nichols tuning method (Eq. 4) which is shown in Eq. 9. During faults the machines angular speed deviation (dω) & mechanical power (Pm), line voltage, line current, power all are changed. So dω & pm are taken as input parameters for improving the SVC performance of newly designed PI controller. The proposed PI controlled SVC simulink model is shown in Fig. 8a-8d.

$$Gc(s) = 120\left(\frac{S+10}{S}\right) \qquad (9)$$

7.1 Simulation Results (With PI Controller)

The network remains same (see Fig. 6), just simple SVC is replaced by PI controlled SVC (see Fig. 8b and 8d). During

fault, Machines speed deviation (dω) & mechanical power deviation (pm) always monitored by PI controller & taking input of those oscillation, after processing as shown in Fig. 8a and 8c. PI reduces damping of power system oscillation. Two types of faults have been considered: 7.1.1 Single line to ground fault and 7.1.2 three phase L-L fault.

7.1.1 Single line to ground faults

During 1-phase faults, if PI is used as SVC controller then, the system voltage becomes stable within 2s with 0% damping (see Fig. 8e) & power (P) becomes stable within 1s (see Fig. 8f) & Machines speed deviation becomes stable within 2.5s (see Fig. 8g). All results have been summarized in Table 1.

7.1.2 Three phase faults (line-line)

During 3-phase (L-L) faults, if PI is used as SVC controller then, the system voltage becomes stable within 3.1s with 0% damping (see Fig. 8h) & Power (P) becomes stable within 2s (see Fig. 8i) & Machines speed deviation becomes stable within 4s (see Fig. 8j).

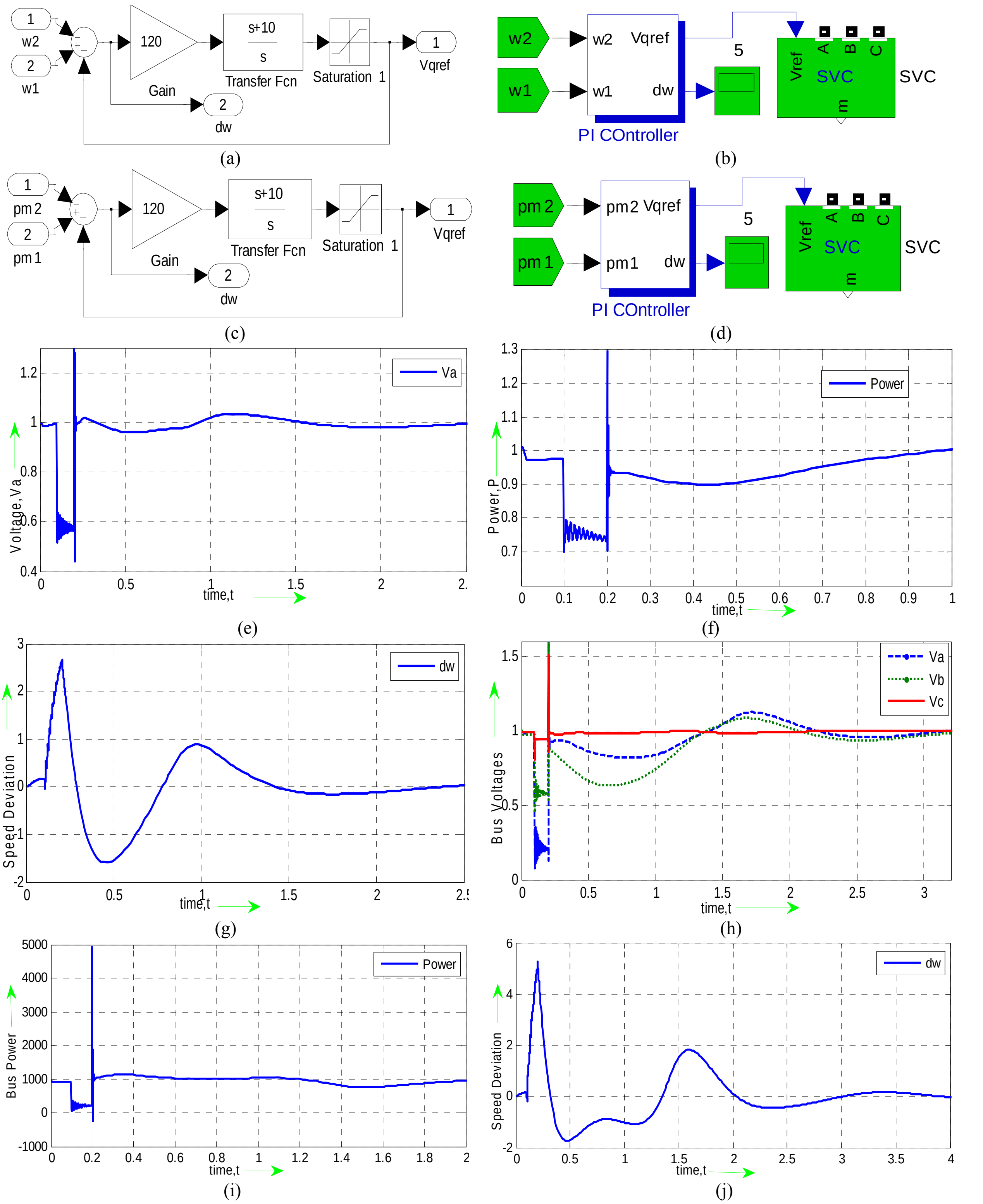


Fig. 8 (a) Internal Structure of PI controller with dω input; (b) PI controlled SVC Model with dω input; (c) Internal Structure of PI controller with pm input; (d) PI controlled SVC Model with pm input; (e) Voltage (Va) in p.u for 1-phase fault (SVC with PI); (f) Bus Power (P) in p.u for 1-phase fault (SVC with PI); (g) Speed deviation for 1- phase fault (SVC with PI); (h) Bus voltages in p.u for L-L faults (with PI); (i) Bus power in MW for L-L faults (with PI); (j) Machines speed deviation for L-L fault (with PI).

8. Design of PD Controller

The proposed PD (Proportional Derivative) controller parameters has also been deigned by using Ziegler-Nichols tuning method. The critical gain (K_{cr} = 200) & oscillation period of P_{cr} (see Fig. 4) is also determined from Fig. 7a & found P_{cr} = 0.2.Thus the parameters of PD controller is determined based on Ziegler-Nichols tuning method (Eq. 8) which is shown in Eq. 10. The proposed PD controlled SVC simulink model is shown in Fig. 9a-9b.

$$Gc(s) = 120\left(\frac{S+40}{40}\right) \tag{10}$$

8.1 Simulation Results (With PD Controller)

The network remains same (see Fig. 6), just simple SVC is replaced by PD controlled SVC (see Fig. 9b) & the network is simulated in phasor simulation method. Two types of faults has been considered: 8.1.1 Single line to ground fault and 8.1.2 three phase L-L fault.

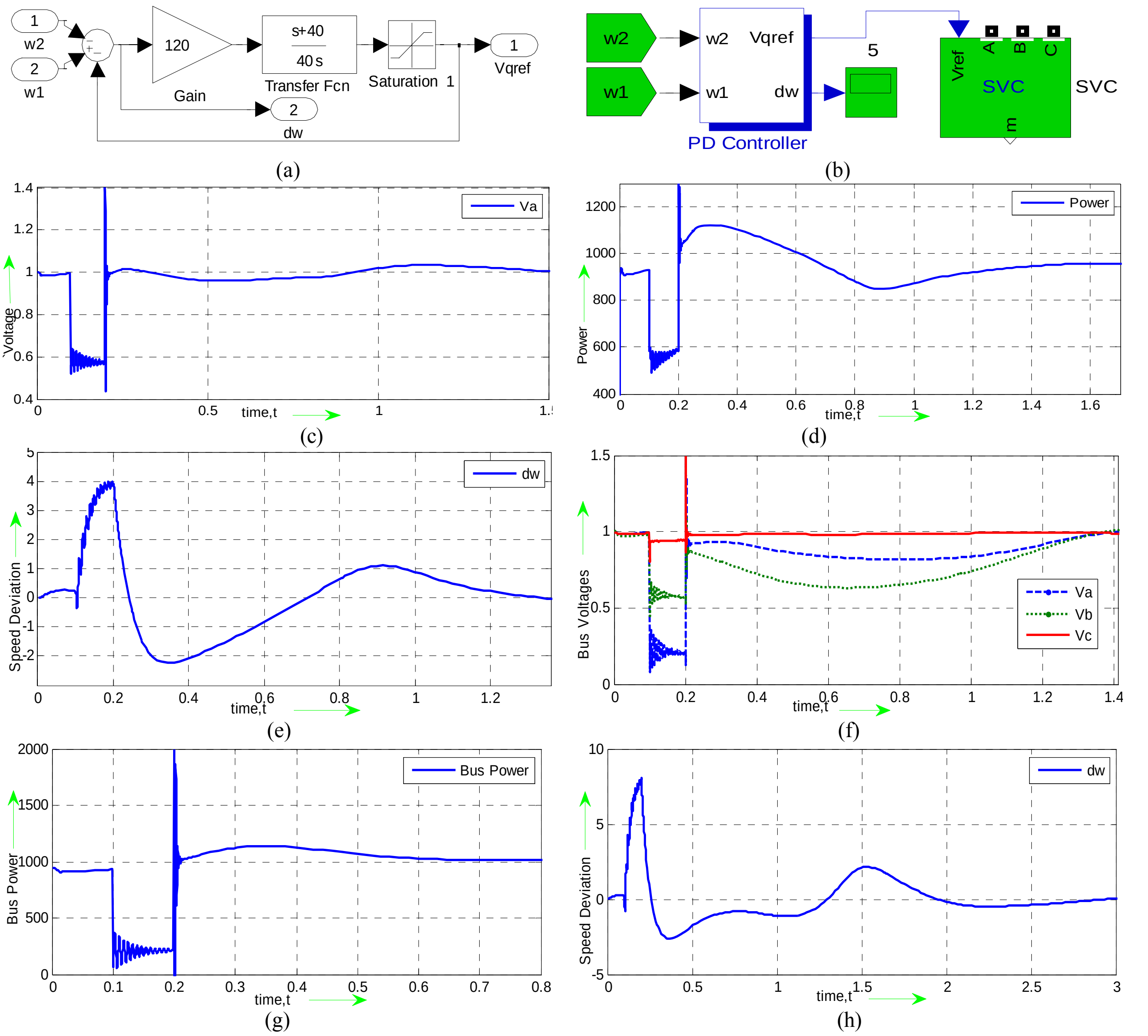


Fig. 9 (a) Internal Structure of PD controller; (b) PD controlled SVC Model with dω input; (c) Voltage (Va) in p.u for 1-phase fault (SVC with PD); (d) Bus Power (P) in p.u for 1-phase fault (with PD); (e) Speed deviation for 1-phase fault (SVC with PD); (f) Bus voltages in p.u for L-L faults (with PD); (g) Bus power in MW for L-L faults (with PD); (h) Machines speed deviation for L-L fault (with PD).

Table 1 Performance Comparison of PI & PD Controllers.

		1-Øfault (stability time)			L-L fault (stability time)		
Controller	SVC rating	volt	P	dω	volt	P	dω
No SVC	200MVA	α inf	α inf	α inf	α inf	α inf	α inf
SVC	200MVA	3s	3s	4.5s	5s	5s	5s
SVC+PI	50MVA	2s	1s	2.5s	3.1s	2s	4s
SVC+PD	50MVA	1.5s	1.6s	1.3s	1.4s	0.6s	0.6s

8.1.1 Single Line to Ground Faults

During 1-phase faults, if PD is used as SVC controller then, the system voltage becomes stable within 1.5s with 0% damping (see Fig. 9c) & power (P) becomes stable within 1.6s (see Fig. 9d) & Machines speed deviation becomes stable within 1.3s (see Fig. 9e). All results have been summarized in Table 1.

8.1.2 Three phase faults (line-line)

During 3-phase(L-L) faults, if PD is used as SVC controller then, the system voltage becomes stable within 1.4s with 0% damping (see Fig. 9f) & Power (P) becomes stable within 0.62s (see Fig. 9g) & Machines speed deviation becomes stable within 3s (see Fig. 9h).

9. Results & Discussions

The performance of both proposed PI & PD controller of power system network with SVC has been summarized in the Table 1. In Table 1, α (infinite time) means the system is unstable. The network is simulated in four steps; without SVC, With SVC, SVC with PI & SVC with PD controller.

10. Conclusions

This paper presents the stability improvement of voltage level, machine oscillation damping, bus power in a large scale power system model of SVC with or without properly tuned PI & PD controllers for different types of faulted conditions. Both are very cheapest & efficient controllers for SVC to enhance the power system stability. Advantages of those controllers is that only a small controller can handle a robust interconnected power system efficiently. For stability improvements, if a externally (PI & PD) controlled SVC is connected in the network, then a small rating SVC can damp out all types of oscillation & the system becomes stable in faster way. From above results, this proposed PI & PD controllers which is properly & easily tuned by using Ziegler-Nichols tuning method may be highly suitable as SVC controller. Compared to those two controllers, PD controller may be highly suitable. The proposed controller can take as input only change of machines angular speed deviation & mechanical power deviation. But a new controller can be designed which always monitor every network parameters i.e. change of bus voltage, current, machines angular speed deviation, mechanical power deviation etc& taken those parameters as input & after internally processing it injects V_{qref} into SVC for stability improvements. Another FACTS devices namely SSSC, STATCOM, UPFC which may be controlled externally by designing different types of controllers for stability improvement of a power system.

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