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DYNAMIC COMPENSATION REQUIREMENT ANALYSIS FOR AN INDIAN UTILITY

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ABSTRACT

This paper presents a technique to find out the suitable dynamic compensation requirement for an Indian utility i.e. Maharashtra region. The practical system considered was a part of western grid which is very critical for power evacuation from a major generating station. The objective of this paper was to increase the power flow in identified weak lines using dynamic compensation. As the variable capacitor does not suite economically, the option of using the series compensation which is used for reducing the angular separation and shunt compensation with Static VAR Compensator (SVC) was used for damping out the voltage oscillations at the receiving end is explored. The study result showed that the power flow could be increased considerably in the weak lines and also the system was stable in the steady state as well as in the dynamic conditions.

Keywords: dynamic compensation, shunt compensation, static var compensation, sensitivity analysis, transient stability analysis.

1. INTRODUCTION

Recent power systems are undergoing a profound transformation in the form of restructuring. Many private power companies have entered in to the power industry. This has resulted in complex operation and control of large interconnected grid systems. In this changing scenario, the primary challenge for power engineers is to efficiently control the active and reactive power flows in a specific transmission line or the corridor due to dynamically changing inter grid transactions. Control of power flows should be achieved without generation rescheduling or topological changes in order to enhance the power system performance [1]. Flexible AC Transmission systems (FACTS) controllers are proved to be very useful in achieving this and in addition these devices will also enhance the secured operation of power systems [2, 3].

Reactive power control has grown in importance for a number of reasons. First, the requirement for more efficient operation of power systems has increased with the price of fuels. For a given distribution of power, minimizing the total flow of reactive power can reduce the losses in the system. This principle is applied throughout the system, from the simple power factor correction capacitor used with a single inductive load, to the sophisticated large interconnected networks. Second, the extension of transmission networks has been curtailed in general by high interest rates and in particular cases by the difficulty of acquiring right-of-way. In many cases the power has been increased, requiring the application of reactive power control measures to restore stability margins. Third, the exploitation of hydropower resources has proceeded spectacularly to the point where remote, hostile generation sites have been developed. Inspite of parallel development of dc transmission technology, ac transmission has been preferred in many cases. The problem of stability and voltage control are identifiable as problems in reactive power control, and a wide range of different solutions has been developed, ranging from the use of fixed shunt reactors and capacitors, to series capacitors, synchronous condensers and modern static compensators. Fourth, the requirement for a high quality of supply has increased because of the increasing use of electronic equipment and because of growth of continuous-process industry.

Among the family of FACTS controllers, SVCs are used in power systems for rapid control of voltage control at weak points in the network. By virtue of their ability to provide continuous and rapid control of reactive power and voltage, SVCs enhance several aspects of transmission system performance such as control of temporary over voltage, prevention of voltage collapse, enhancement of transient stability [4]. At the sub transmission and distribution system levels, SVCs are used for balancing the three phases of systems supplying unbalanced loads. They are also used to minimize fluctuations in supply voltages caused by repetitive-impact loads such as dragline loads of mining plants, rolling mills, and arc furnaces [5].

In this paper suitable dynamic compensation for the given system has been found out which will allow increasing the generation at Chandrapur in future and enhancing the power flow through the identified weak lines while maintaining the system stable from steady state as well as dynamic point of view. Suitable degree of series compensation has been found out using power flow analysis which will enhance the power flow through the identified weak lines, reduce the angular separation between sending end and receiving end and improve the dynamic stability of the system. Suitable amount of fixed shunt compensation has been found out using power flow analysis which will maintain the voltage profile almost constant at the point of connection. Sensitivity analysis of SVC was done to find out the most suitable parameters of SVC to be connected at receiving end.

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Transient stability analysis was performed for the future generation schedule with and without SVC. It is important from the viewpoint of maintaining system security- that is, the incidence of a fault should not lead to tripping of generating unit(s) due to loss of synchronism and the possibility of a cascaded outage leading to system black out. With the incorporation of SVC at receiving end, voltage oscillations were damped out and voltage at the point of connection was maintained within acceptable limits.

2. PROBLEM DEFINITION

After carrying out an exhaustive contingency analysis, it is found that in the Western Regional system, the 400kV lines between Chandrapur to Parli (three circuits) were very critical. The criticality is mainly in account of angular separation which has led to many blackouts and brownouts. Further additional interconnections have been planned along with the new generations in and around Chandrapur area. In order to take care of additional import and new generation, a new 400kV double circuit line is planned between Chandrapur and Parli which is getting delayed due to various reasons.

The increased generation and import results in angular separation between Chandrapur and Parli to be more than 30 degrees during normal operation which is very critical and the system can't handle any contingency. Hence in this study, the problem of increasing power flow and reducing angular separation as well as improving stability with the dynamic compensation has been carried out.

3. STATIC VAR COMPENSATOR

3.1 SVC modeling

The IEEE has proposed two basic models for SVC: the IEEE Basic SVC Model 1, which corresponds to the gain-time constant format, and the IEEE Basic SVC Model 2, which relates to the integrator with current-droop format [6, 7]. Voltage regulator block for Model 1 is shown in Figure-1. The gain K_R (inverse of the current slope) is typically between 20 pu (5% slope) and 100 p.u. (1% slope) on the base of the SVC-rated reactive power. The time constant T_R usually lies between 20 and 150 ms, and the time constants T_1 and T_2 are zero in most cases.

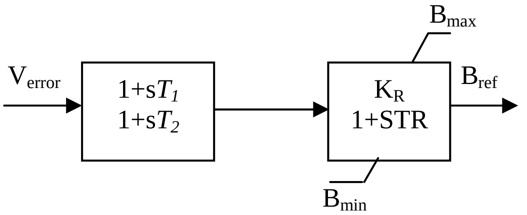

Figure-1. The voltage regulator model (proportional type) [15].

The transfer function of voltage regulator in Model 1 is given by Equation (1)

$$G(s) = \frac{K_R}{1+T_R}\,\frac{1+sT_1}{1+sT_2} \qquad \text{------------------- (1)}$$

Voltage-regulator block for Model 2 is shown in Figure-2. A proportional gain K_I is employed to increase the speed of response.

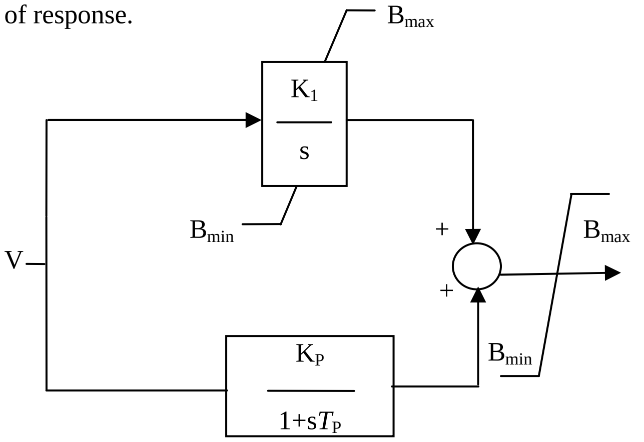

Figure-2. The voltage regulator model (integral type) [15].

The voltage regulator for Model 2 can be equivalently expressed as in Equation (2)

$$G(s) = \frac{K_1}{S}\,\frac{1+sT_Q}{1+STP} \qquad \text{------------ (2)}$$

Generally, Tp is kept at zero, thereby rendering the controller to be of the simple proportional-integral (PI) type. The integrators in both the models are of non-windup type.

3.2 Sensitivity analysis of SVC

Sensitivity analysis of SVC refers to calculating the standard deviation in voltage for certain duration for different values of K, T1 and T2 which constitute the voltage regulator model of SVC. Setting of K, T1, and T2 which gives the minimum standard deviation in voltage will be the most suitable parameters for SVC.

4. METHODOLOGY

a) For the possible generation schedule, load flow analysis was performed with and without compensation (for both no outage and one outage cases).
b) Suitable degree of series compensation was found out using load flow analysis which will reduce the angular separation within the acceptable limits and increase the power flow through the lines considerably in case of no outage and one outage.
c) Suitable amount of shunt compensation was found out using load flow analysis which is necessary to maintain the voltage constant at the point of connection in case of no outage and one outage.
d) For the given generation schedule, sensitivity analysis was performed using transient stability analysis to find out the most suitable parameters for SVC.

5. SYSTEM DETAILS

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System which has been considered for study is Maharashtra Grid which contains 1405 buses, 54 generators, 977 transformers. Maharashtra network varies from transmission level of 400kV up to the distribution level of 110kV. All the import points have been modeled as generators with generation equal to the power being imported from those points and with equivalent fault level.

6. SIMULATION RESULTS

6.1 Load flow results

Table-1 represents sending end and receiving end voltages, angular separation and active power flow through the lines in case of no outage condition for different compensation.

Table-1. Comparison of bus voltages and power flow for different compensation in case of no outage.

No outage				
Condition	**Sending end voltage** (pu)	**Receiving end voltage** (pu)	**Angular difference** (Degrees)	**Power flow** (MW)
No compensation	0.983 (-48.07)	0.9023 (-16.74)	31.33	1786.5
40 % series compensation	0.9906 (-38.28)	0.938 (-17.8)	20.48	2015.3
182 MVAR shunt compensation	0.9870 (46.89)	0.9290 (16.16)	30.73	1808.78
40 % series and 182 MVAR shunt compensation	0.9929 (37.66)	0.9571 (17.35)	20.31	2030.91

Table-2 represents sending end and receiving end voltages, angular separation and active power flow through the lines in case of one outage condition for different compensation.

Table-2. Comparison of bus voltages and power flow for different compensation in case of no outage.

One outage				
Condition	**Sending end voltage** (pu)	**Receiving end voltage** (pu)	**Angular difference** (Degrees)	**Power flow** (MW)
No compensation	**System does not converge**			
40 % series compensation	0.9821 (-45.9)	0.903 (-16.14)	29.82	1774.15
182 MVAR shunt compensation	**System does not converge**			
40 % series and 182 MVAR shunt compensation	0.986 (-44.94)	0.9287 (-15.6)	29.34	1795.37

Tables 1 and 2 clearly show the increase in power flow through the lines and reduction in angular separation with the help of series compensation. It can also be observed from Tables 1 and 2 that shunt compensation improves the voltage profile and maintains constant at the point of connection.

6.2 Transient stability analysis results

Transient stability analysis was performed for the given system with 40 % series compensation between Chandrapur to Parli lines for no outage and one outage condition. A three phase to ground fault was created at the receiving end for time duration of 100 ms.
All the graphs have been shown for more severe case i.e. one outage condition. Figure-3 represents swing curve of Chandrapur generators for one outage condition without SVC at Parli.

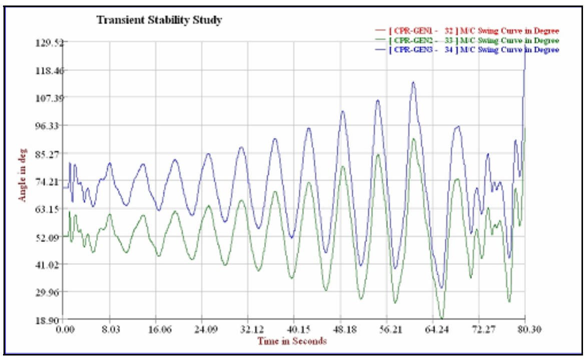

Figure-3. Chandrapur swing curve for one outage without SVC.

Figure-4 represents swing curve of Parli generators for one outage condition without SVC at Parli.

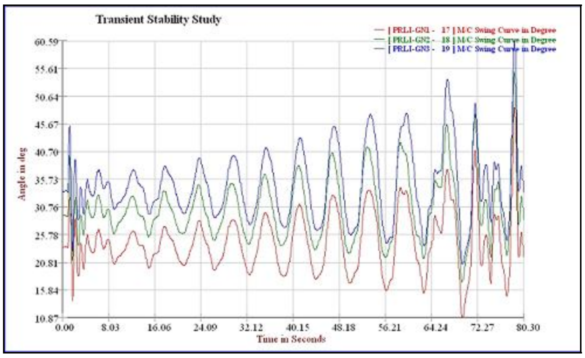

Figure-4. Parli swing curve for one outage without SVC.

Figures 3 and 4 clearly show that generators at Chandrapur and Parli are going out of synchronism. Figure-5 represents swing curve of Chandrapur generators for one outage condition with SVC connected at Parli.

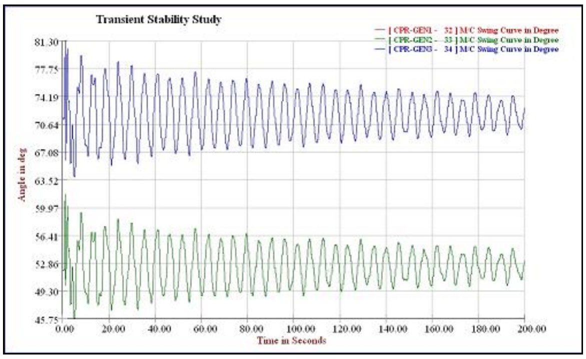

Figure-5. Chandrapur swing curve for one outage with SVC.

Figure-6 represents Parli swing curve for one outage condition with SVC connected at Parli.

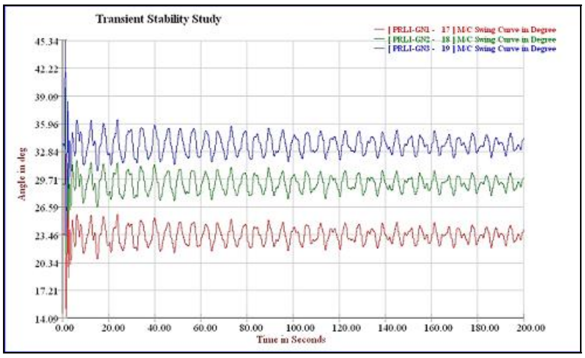

Figure-6. Parli swing curve for one outage with SVC.

Figures 5 and 6 show that with suitable parameters of SVC generators at Chandrapur and Parli are stably in synchronism. Figure-7 represents Parli voltage with and without SVC.

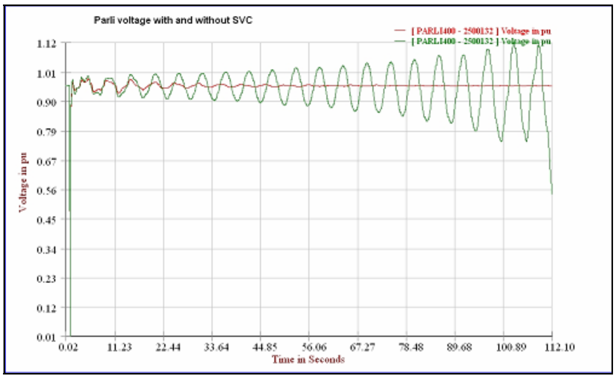

Figure-7. Parli swing curve for one outage with and without SVC.

Figure-8 represents SVC output for one outage condition.

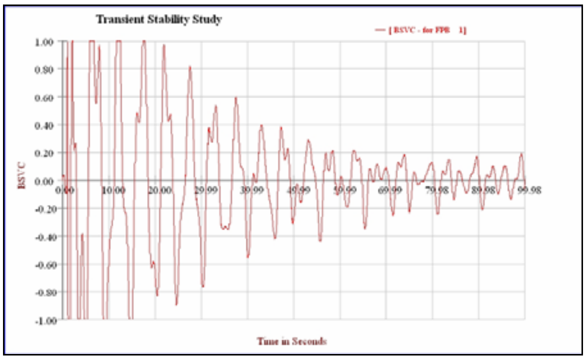

Figure-8. B_{SVC} output.

7. CONCLUSIONS

This paper concludes that series compensation will increase the power flow through the lines and reduces the angular separation between the sending ends receiving end. It is also found that Series compensation improves the steady state stability as well as transient stability of the system. Shunt compensation maintains the voltage profile of the system.

For the given system, 40% Series compensation increases the power flow through the lines considerably and reduces the angular separation between the sending ends and receiving end within the acceptable limits. 182 MVAR fixed Shunt compensation maintains the voltage profile of the system as per the grid code. ±100 MVAR capacity of SVC is required to damp out the voltage oscillations and improve the transient stability of the system.

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