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EFFECT OF STATIC VAR COMPENSATOR ON VOLTAGE STABILITY UNDER NETWORK CONTINGENCIES

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Abstract - This paper focuses on enhancement of system performance under network contingencies through an optimal placement and optimal setting of static var compensator (SVC). The goal of the methodology developed is to identify the weakest bus using an index called Line Flow Index (LFI) and to maintain the voltages at all load buses within their specified limits through an optimal placement and optimal setting of SVC under contingency Condition. This premise is attested on 6-bus and 30 bus systems and the simulation results are presented to show the effectiveness of the method.

***Keywords**—Line Flow Index (LFI), Flexible AC Transmission Systems (FACTS), static var compensator (SVC).*

I. INTRODUCTION

In the present day scenario private power producers are increasing rapidly to meet the increase in demand due to heavily loaded customers. Consequently the transmission system becomes more stressed, which in turn makes the system more vulnerable to stability and security problems [1-4]. In this above process, the voltages at load buses may violate their limits and lead to voltage collapse. So based on the above, maintaining voltages at all load busses within the specified limits and maintaining voltage stability, through proper reactive power allocation is a critical problem in power system operation. Identification of the weakest bus in a transmission system that is prone to voltage collapse is of grate important in voltage stability studies [2].There are several indices / methods proposed in literature for placement of FACTS devices from voltage stability / small signal stability view points [2]-[5]. Among the FACTS controllers, SVC provides fast acting dynamic reactive compensation for voltage support. The main objective of installing SVC's in electrical power system is to provide rapid and smooth control of voltages at weak load buses in electric power systems. The application of SVC is to keep the bus voltage within the permissible values under varying load conditions, and improve the voltage stability. The location of SVC's are considered for improving the voltage profile and improving the overall power system stability [7-10].In order to maintain the steady state voltage stability, the transmission system operators have to take special measures to identify the critical lines and buses of power system network [1-2]. In this paper the voltage stability enhancement is achieved by placing SVC at appropriate location with optimal setting. Further, all line and voltage limits are respected during the assessment of voltage stability. The optimal location of SVC is identified by using line flow indices (LFI) [1]. The power flow studies are carried out using matpower package [6]. The LFI values and the optimal setting of SVC are obtained through a programming code written in MATLAB. The method proposed in the study has been carried out on 6-bus systems and the simulation results are presented.

The contingency analyses are based on a model of the power system and are used to study outages and notify the operators of any potential overloads or out-of-limit voltage. Contingencies such as unexpected line outages often contribute to voltage collapse blackouts. These contingencies generally reduce or even eliminate the voltage stability margin [11-12]. Contingency analysis techniques are used to predict the effect of outages. The analysis procedures model single failure events (i.e., one-line outage) one after another in sequence until "all credible outages" have been studied. However, here in this paper we analyzed the LFI of a power system and in the process rank branch contingencies only for single failure events.

Many power systems are now experiencing voltage problems more frequently and voltage studies have gained increasing attention from operating and planning point of views [13]. To know the impact of every contingency – single failure-on the voltage profile, it is desirable to study the impact of contingency on the line outages. By ranking the contingencies, we are able to substantially reduce the number of contingencies out of all possible contingencies that need to be considered for voltage stability analysis. A contingency is the loss or failure of a small part of the power system (e.g. a transmission line), or the loss/failure of individual equipment.

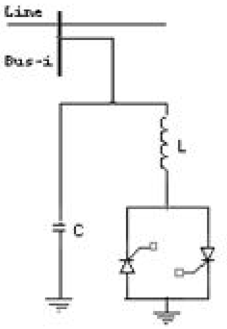
This paper provides initially finding the critical line outage for each line and latter ranking the most critical line outage. In this study, the critical buses under contingency condition are identified by using an index called line flow indices (LFI) from the voltage stability view point.

The method which is introduced in this paper identifies the critical segments further from which we rank the critical bus and SVC is installed at critical bus to enhance the voltage stability of a power system network. The singular value decomposition (SVD) method is used to check whether the system stability is maintained or not.

The study in this paper focuses on enhancement of steady state voltage stability of a power system through an optimal utilization of static var compensator (SVC). The method proposed consists of identifying the weakest bus of the system by using an index called Line Flow Indices (LFI) and next placing SVC at appropriate location, the voltage stability enhancement is achieved with all limits respected under steady state condition. Further, the steady state voltage stability under three cases is assessed through the computation of the Minimum Singular Value (MSV). In case-1, the MSV is computed without SVC. In case-2, the voltage magnitude at SVC installed bus is maintained at 1 p.u and in case-3, the voltage magnitude at SVC installed bus is maintained at maximum voltage. The power flow studies are carried out using matpower package [8]. The MSV, optimal location and optimal setting of SVC is obtained through a programming code written in MATLAB. The method proposed in this paper is carried out on 6-bus, and 30-bus system and the simulation results are presented to authenticate the proposed method.

II. SVC MODEL

An SVC is a shunt connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive reactive current so as to maintain or control specific parameters of the power system i.e. typically bus voltages. The static var compensator is a parallel combination of capacitor and inductor; the latter is under phase angle control called as Thyristor Controlled Reactor (TCR). That is, the form of SVC selected in this paper is fixed capacitor (FC) with TCR, shown in Fig. 1. This combination provides a fast variable source of reactive power.



The model of SVC in this paper interprets the FACTS as a shunt element with varying susceptance B [11]. The active and reactive power value of an SVC from the injected power equations [11] is:

$$P_i = 0 \tag{1}$$

$$Q_i = V_i^2 B_t \tag{2}$$

where Pi and Q_i are injected real and reactive power to a bus respectively.

V_i is the voltage at bus-i, at which an SVC is shunted

The total susceptance with SVC shunted at bus-i is:

$$B_t = B_i + B_{svc} \tag{3}$$

The net reactive power generated by SVC is

$$Q_{svc} = Q_C - Q_L \tag{4}$$

In case, the bus voltage that falls below the specified lower limits, the SVC will supply reactive power by working as a capacitor. On the other hand if the bus voltage exceeds the specified upper limits, then the SVC will absorb reactive power by working as an inductor. The rating of SVC at bus-i is obtained by using (2).

III. PROBLEM FORMULATION

The LFI values are computed for all line segments connected between the node-i and node i+1. The LFI method identifies the critical line segments and from this the critical buses are identified under contingency condition. The line segment having the highest positive index value is the critical line segment from the voltage stability point of view. The four line flow indices [2] which are called as line stability factors and are given by:

$$LFISP = 4\frac{r_i}{V_i^2}\left(\frac{P_r + r_i Q_i^2}{V_i^2}\right) \tag{5}$$

$$LFISQ = 4\frac{X_i}{V_i^2}\left(\frac{Q_r + X_i P_i^2}{V_i^2}\right) \tag{6}$$

$$LFIRP = 4\frac{r_i}{V_{i+1}^2}\left(\frac{-P_i + r_i Q_r^2}{V_{i+1}^2}\right) \tag{7}$$

$$LFIRQ = 4\frac{X_i}{V_{i+1}^2}\left(\frac{-Q_i + X_i P_r^2}{V_{i+1}^2}\right) \tag{8}$$

The above four LFI’s are calculated for all the lines in the system and the lines with highest index is considered as critical line and the receiving end bus of the critical line is identified as the weakest bus from the voltage stability point of view.

Specification of Test System:

The effectiveness of the method is carried out on 6-bus system and 9 Bus system. The six-bus system has got eleven transmission lines and nine-bus system has got nine transmission lines with a capacity of 230 kV. The 6-bus test system, which is considered for the purpose of case study, is shown in Fig-2. In the first step the candidate buses for allocation of SVC are to be found assuming that they all have the same installation cost coefficients. The overload limit of the transmission lines is due to thermal considerations. The buses with largest value of LFI's index are considered as the critical buses for allocation of SVC at bus i. The power flow solutions in each case are computed by *matpower* software package [6]. Optimal location and optimal setting of SVC were computed using software code written in *MATLAB*. Simulation studies using MATLAB programming code, on a 6-bus network are presented to illustrate the methodology and to demonstrate the benefits of the proposed method.

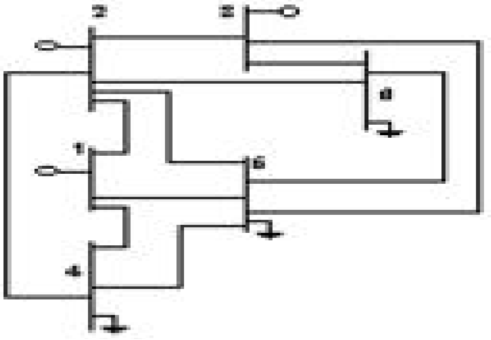


Fig .2. Six-bus test system.

A. *Case Study and Results*

This paper presents a methodology for ranking transmission line outages according to severity of their efforts on line flows. The contingencies ranking accomplished by ordering these normalized sensitivities from greatest to the least. As such, the method does not explicitly indicate whether a contingency is going to give bus voltage or circuit over load problem. The identified critical segments/buses have to be taken care first by the Transmission System Operator (TSO) in order to avoid voltage collapse /system blackout. In the study, the critical segments and/or buses under contingency conditions are identified by using an index called Line Flow Index (LFI). The LFI identifies the critical segments / buses with computation of the jacobian matrix. The various LFI values for all test systems are estimated using equations (5) to (8) for all possible contingencies.

(i) Branch outage for 6 bus system

The LFI indices calculated for branch outages are listed in Table 1. In this illustrated example, it is evident that the line outage 2-4 has the highest (LFIRQ) index value and therefore the line segment is 5-6 which is critical line segment (rank-1) and the receiving end bus-5 is most critical from voltage stability viewpoint. The ranking column has been formed by considering only load buses and therefore bus 5 is ranked as 1 since it is not a generator bus. The next most critical segment is 3-5 (rank 2) and the associated index is LFIRQ, hence bus-5 is critical bus and so on.

Table: 1

Ranking of critical contingencies for 6-Bus system

Line Outage	**Index**	**Value**	**Line segment**	**Bus No**	**Rank**
1-2	LFIRQ	0.1268	5 – 6	5	6
1-4	LFIRQ	0.1407	5 – 6	5	5
1-5	LFIRQ	0.1687	5 - 6	5	4
2-3	LFIRQ	0.1158	5 - 6	5	8
2-4	LFIRQ	0.2697	5 - 6	5	1
2-5	LFIRQ	0.1692	5 - 6	5	3
2-6	LFIRQ	0.0984	5 - 6	5	9
3-5	LFIRQ	0.1847	5 - 6	5	2
3-6	LFIRQ	0.0697	2 - 3	2	---
4-5	LFIRQ	0.1232	5 - 6	5	7
5-6	LFIRQ	0.0565	4 – 5	4	10

From the table 1 it is clear that bus-5 should be taken care first to avoid voltage collapse. The voltage stability assessment is carried out by installing the first available SVC at bus-5 (rank 1). The three different cases are studied and the results are presented. In case-1, the MSV is computed without SVC, case-2 refers to the voltage magnitude at SVC installed bus is maintained at 1 p.u and case-3 refers to the voltage magnitude at SVC installed bus is maintained at maximum voltage. The MSV and the optimal setting of SVC for all the cases are tabulated in Table 2.

Table:2

MSV of 6-bus system for 2-4 line outage

	Case-1	Case-2	Case-3
Voltage (p.u)	0.970	1.001	1.038
MSV	1.8116	1.8452	1.8847
Optimal setting of SVC (Mvar)	----	42	90

It is clear that for 2-4 line outage the minimum singular value (MSV) is improved from 1.8116 (case 1) to 1.8452 (case2). Further MSV value is improved from 1.8116 (case 1) to 1.8847 (case3) i.e the MSV of the load flow jacobian is maximized with the increase in the injected Mvar due to SVC, which indicates that the steady state voltage stability is improved. This voltage stability enhancement is achieved by installing SVC at bus-5 with an optimal setting of 42 Mvar (case 2) and 90 Mvar (case 3). Furthermore placing SVC at bus-5 with an optimal setting not only improves the voltage at the weakest bus, but also improves the voltage profile of the remaining buses. Furthermore placing SVC at bus-5 with an optimal setting not only improves the voltage at the weakest bus, but also improves the voltage profile of the remaining buses as shown in table 3.

Table:3

Voltage Profile for 6-bus system

Line Outage	Case-1	Case-2	Case-3
3-5	0.954	0.999	1.049
2-5	0.963	1.000	1.049
1-5	0.959	1.000	1.049
2-4	0.970	1.001	1.049
1-4	0.980	1.000	1.049
1-2	0.986	1.000	1.049
4-5	0.982	1.001	1.049
2-3	0.985	1.000	1.050
2-6	0.981	1.001	1.050
5-6	0.988	1.000	1.050

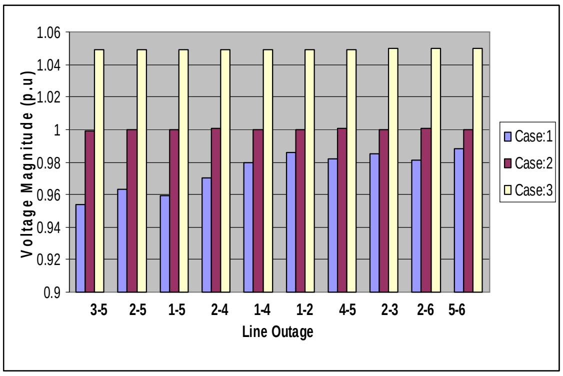


Fig. 3 Voltage profile for 6-bus system

(ii) Branch outage for 30 bus system

The LFI indices calculated for branch outages are listed in Table 4. In this illustrated example, it is evident that the line outage 1-3 has the highest (LFIRQ) index value and therefore the line segment is 2-6 which is critical line segment (rank-1) and the receiving end end bus-6 is most critical from voltage stability viewpoint. The ranking column has been formed by considering only load buses and therefore bus 6 is ranked as 1 since it is not a generator bus. The next most critical segment is 2-6 (rank 2) and the associated index is LFIRQ, hence bus-6 is critical bus and so on.

Table: 4 Ranking of critical contingencies for 30-Bus system

Line Outage	Index	Value	Line segment	Bus No	Rank
1-3	LFISQ	0.167062	2-6	6	3
3-4	LFISQ	0.163269	2-6	6	4
2-5	LFISQ	0.217842	2-6	6	1
4-6	LFISQ	0.207600	2-6	6	2
6-9	LFISQ	0.145992	6-10	10	6
9-10	LFISQ	0.102072	6-9	9	7
4-12	LFISQ	0.159249	6-10	10	5

From the table 4 it is clear that bus-6 should be taken care first to avoid voltage collapse. The voltage stability assessment is carried out by installing the first available SVC at bus-6 (rank 1). The three different cases are studied and the results are presented. In case-1, the MSV is computed without SVC, case-2 refers to the voltage magnitude at SVC installed bus is maintained at 1 p.u and case-3 refers to the voltage magnitude at SVC installed bus is maintained at maximum voltage. The MSV and the optimal setting of SVC for all the cases are tabulated in Table 5.

Table:5

MSV of IEEE 30-bus system for 2-5 line outage

	Case-1	Case-2	Case-3
Voltage (p.u)	1.005	1.001	1.024
MSV	0.2117	0.2106	0.2146
Optimal Setting of SVC(Mvar)	----	-21	90

From the table 5, it is clear that the minimum singular value (MSV) has reduced from 0.2117 (case 1) to 0.2106 (case2), as voltage is already beyond its maximum limits. Further MSV value is improved from 0.2117 (case1) to 0.2146 (case3), which indicates that the steady state voltage stability is improved. This voltage stability enhancement is achieved by installing SVC at bus-6 with an optimal setting of -21 Mvar (case 2) and 90 Mvar (case 3). Here the negative sign indicates that there is absorption of the reactive power.

Furthermore placing SVC at bus-6 with an optimal setting not only improves the voltage at the weakest bus, but also improves the voltage profile of the remaining buses as shown in table 6.

Table 6

Voltage profile for IEEE 30 bus system

Line Outage	Case-1	Case-2	Case-3
2-5	1.005	1.001	1.024
4-6	1.009	1.001	1.031
1-3	1.006	1.001	1.025
3-4	1.006	1.001	1.025
4-12	1.045	1.000	1.055
6-9	1.044	1.000	1.06
9-10	1.049	1.001	1.06

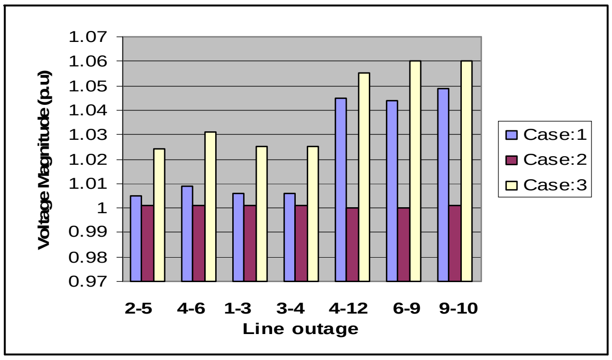


Fig .4 Voltage profile for IEEE 30-bus system

IV. CONCLUSION

In this paper a methodology is demonstrated to improve the voltage stability of a power system network using LFI. Simulation studies using MATLAB programming code, on 6-bus & IEEE 30 bus system are presented to illustrate the methodology and to demonstrate the benefits of the proposed method. From the above result and discussion, placing SVC at appropriate location with an optimal setting can improve the system performance and system stability under contingency condition.

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