Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 1, Number 5 (2014) pp. 54-58

http://www.krishisanskriti.org/areee.html

Optimal Placement of SVC for the Transmission Congestion Management

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Abstract: **This paper presents a method to seek the optimal location of SVC in power system based on their minimum power loss with voltage stability base. The location and size of FACTS improves the power system performance and also congestion management can be done. In this paper power system stability, minimum power loss with voltage stability is used as an index for optimal allocation of the controllers. First SVC is placed based on model analysis and GA in a power system. After placing the SVC based on minimum power loss with voltage stability index, the most appropriate location and size of SVC can be found. The case study is carried out on IEEE6 bus system.**

1. INTRODUCTION

A. Motivation & Approach

Due to the limitation of energy resources and also economic constraints forcing the power system to operate near its stability and loadability margins. Secure and stable operation of power system has always been a concern to the system operators. Because of increment in demand, supply has to be increased and consequently congestion management problem arises. In order to overcome the congestion management problem and to use the maximum capacity of power transmission lines while avoiding overloaded lines, utilities have expensive and time consuming solutions such as building new lines. During the outage of some critical lines, power system may become insecure and vulnerable to the voltage collapse due to lack of reactive power support and / or overloading of the network.

Low voltage profile in the system may increase spot prices in the electricity markets. Hence reactive power compensators are required in the network. Many studies have been carried out on the use of FACTS devices for voltage stability problems. Identifying the location and size of the FACTS devices is very important to improve the power system efficiency to get more benefits. Among all shunt controllers SVC is more popular due to its lower cost, voltage profile under different contingencies as well as transmission loss, maximization of loading margin, stability. It should be emphasized that the methodology proposed in this paper can be straightforwardly applied to locate any type of FACTS devices. However, for the sake of clarity and simplicity, we consider only the placement of SVC for stability and congestion management.

B. Literature review

In [1] enhancement of small signal stability based on critical modes is used for SVC placement. In [2] genetic algorithm is used to determine the optimal allocation of multi-type FACTS devices in power system to maximize the power system loadability. In[3], in deregulated electricity market, optimal choice and allocation of FACTS devices is done using genetic algorithm. In [4], optimal number and location of thyristor controlled phase shifters are identified using genetic algorithm. In [5], optimal placement of static Var compensators is done based on reactive power spot price. In[6], using parallel simulated annealing and a Lagrange multiplier approach called hybrid scheme is proposed for optimal SVC planning to enhance the power system reactive power (Var) margin, reduction in system losses and voltage depressions at critical points. In [7], to maximize the power system loadability, a mixed integer linear programming is used for the optimal allocation of SVC.

In [8], to obtain the best placement of FACTS devices, a linear iterative method is proposed to minimize the expected thermal generation cast and investment cost on these devices in hydrothermal coordination problem. In [9], using genetic algorithm, a novel approach is proposed for the optimal allocation of SVC. In [10], for security enhancement against voltage collapse, the allocation FACTS is done with a new formulation. In [11] & [16], for Var planning, the optimal locations of FACTS devices are obtained. In [12], for the dynamic security constrained optimal power flow, a Var planning tool is provided. In [13], to lower the cost of energy production and to improve the system loading margin, optimal location of FACTS is done by using genetic algorithm. In [15] deregulated electricity market congestion management was done by locating series FACTS devices. In [15], to locate thyristor – controlled series capacitors (TCSCs) and unified power flow controllers (UPFCs), a sensitive analysis is used to increase maximum transfer level of the system. In [17], to locate SVC and other shunt compensators modal analysis tool based on determination of critical modes to avoid voltage instability. In [18] – [20], line flow index (LFI) is used by the authors as their allocation criterion. In [21], optimal placement of SVC has proposed by the authors in the static as well as dynamic voltage security enhancement. In [22], for the optimal allocation of FACTS in power system, parallel tabu search based method was used. In [23], indices were proposed by the authors for the optimal location of SVC and its impact on the system was evaluated by means of voltage profile under different contingencies. In [24], to locate thyristor controlled phase shifting transformers in a system using a dc load flow method, a two step procedure is proposed. First loading margin is maximized and secondly total investment cost is minimized. By this survey, optimal placement of SVC plays a major role in power system. By using different algorithms we get different solutions for the same problem. So detailed study is carried out on IEEE6 bus system which can be applied for any type of FACTS devices.

2. STATIC MODEL OF SVC

All The static Var compensator is simply a static reactor/ capacitor with susceptance B_{SVC} [27]. The equivalent circuit of SVC may be modeled as a shunt connected variable susceptance B_{SVC} at bus-p is shown in fig.1.

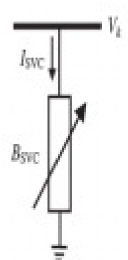

Fig.1. Variable shunt susceptance model

With reference to fig.1, the current drawn by the SVC is,

$$I_{SVC} = j\, B_{SVC}\, E_p \qquad (1)$$

And the reactive power drawn by the SVC, which is also the reactive power injected at bus p, is

$$Q_{SVC} = Q_p = -\, E_p^{2}\, B_{SVC} \qquad (2)$$

The equivalent susceptance B_{SVC} is taken to be the state variable.

$$\begin{bmatrix} \Delta P_p \\ \Delta Q_p \end{bmatrix}^{(k)} = \begin{bmatrix} 0 & 0 \\ 0 & Q_p \end{bmatrix}^{(k)} \begin{bmatrix} \Delta \theta_k \\ \dfrac{\Delta B_{svc}}{B_{svc}} \end{bmatrix}^{(k)} \qquad (3)$$

At the end of the iteratin (k), the variable shunt susceptance B_{SVC} is updated according to

$$B_{svc}^{(k)} = B_{svc}^{(k-1)} + \left(\frac{\Delta B_{svc}}{B_{svc}}\right)^{(k)} B_{svc}^{(k-1)} \qquad (4)$$

The changing susceptance represents the total SVC susceptance necessary to maintain the nodal voltage magnitude at the specified value. After the computation of level of compensation the firing angle can be calculated. After adding SVC at bus – p of a general power system, the new system admittance matrix Y_{bus}^{l} can be updated as:

$$Y_{bus}^{'} = Y_{bus} + \begin{bmatrix} 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & Y_{shunt} & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & 0 & \dots & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \end{bmatrix} \begin{matrix} \\ row-i \\ \\ \\ \\ row-j \\ \\ \end{matrix}$$
$$\qquad\qquad col-i \qquad\qquad col-j$$

For constant active power flow and supply voltage E_p, the required capacitive VAR is the difference between the precompensation VAR and the required compensated VAR as given in (2).

$$Q_{SVC} = Q_{SVC} - Q_{\,uncompensated} \qquad (5)$$

3. CONGESTION MANAGEMENT

In deregulated power system transmission companies (TRANSCOs), generation companies (GENCOs) and distribution companies (DISCOs) are under different organizations. To maintain the coordination between them there will be one system operator in all types of deregulated power system models, generally it is independent system operator (ISO). In a competitive electricity market, sufficient freedom is provided to the market participants to interact among themselves.

Here, both the buyers and sellers try to buy and sell electric power so as to maximize their profit. In deregulated electricity market transmission congestion occurs when there is insufficient transmission capacity to simultaneously accommodate all constraints for transmission of a line. Congestion should be alleviated as fast as possible since it may lead to tripping of overloaded lines, consequential tripping of other lines, and in some cases to voltage stability problem. Hence, to maintain the market efficiency, it is very important that the congestion be relieved in a fast, systematic and efficient manner.

Flexible Alternative Current Transmission System (FACTS) devices can be an alternative to reduce the flows in heavily loaded lines, resulting in an increased loadability, low system loss, improved stability of the network, reduced cost of production and fulfilled contractual requirement by controlling the power flow in the network.

4. PROBLEM FORMULATION

A. Screening for critical contingency

Without contingency the optimal placement of SVC should not be decided. In most of the operating conditions, an optimal location is the one which gives the best results. The severe line outage contingency is found with real power flow performance index [PI] is defined as PI = max $\left(\sum_{i=1}^{b} |1 - Vinitial|\right)$ (6)

Depending on the voltage drops, the ranking of the critical lines were considered.

B. Proposed Index For Optimal Placement of SVC

Minimum power loss with voltage stability index have been used in this work to optimally place a SVC controller to increase the power system stability, power system security and also the congestion management. The purpose of the voltage stability analysis is to improve the voltage profile and to minimize system real power losses through the optimal reactive power controls and can be achieved by proper adjustments of VAR variables in power networks through seeking the weak buses in the system.

After screening the critical line outage at all buses without violation of voltage limit with minimum power loss, an index called MPVS index is designed.

$MPVS_i = \min(P_G - P_R)$ at V_L within 1±5% (7)

Where P_G is the generated real power & P_R is receiving side real power and V_L load volages.

The optimal location of SVC has been decided by the minimum power loss with voltage stability index, computed at each bus, as defined as following.

$MPVS_i^* = \min[(\min(P_G - P_R)$ at V_L within 1±5% (8)

The bus with minimum amount of real power loss and with voltage stability is considered as the best location for SVC. The optimal SVC parameters (rating) have been obtained by solving OPF with SVC defined in [1], [6], [23].

5. SYSTEM STUDIES

The proposed method for optimal location of SVC has been tested on IEEE6 bus system. The IEEE6 bus system represents three generators and eleven transmission lines as shown in fig.2.

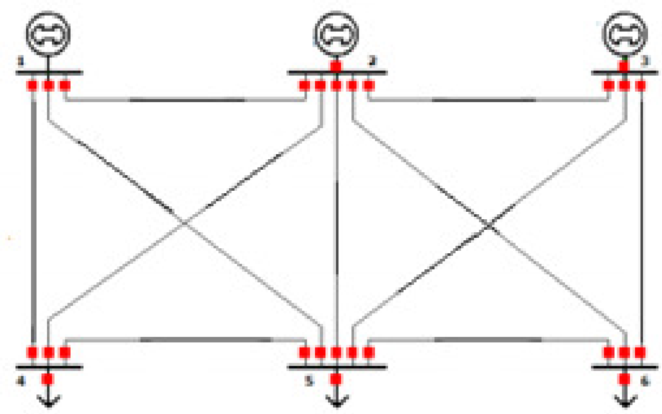

Fig.2. Single line diagram of IEEE6 bus system .

Table I: Line Outage Contingency Ranking (Base Case Loading)

S.NO	IEEE6 BUS SYSTEM		
	Line Outage	End Buses	Rank
1	9	3-6	1
2	7	2-6	2
3	5	2-4	3
4	6	2-5	4
5	3	1-5	5

A. Line Outage Contingency Ranking

To obtain the critical contingency (line outage) ranking in IEEE6 bus system, the PI values are computed for each single line outage case. For IEEE6 bus system, five most critical lines at base case loading in the order of voltage levels at the load buses (descending order) are given in table 1.means the rank is given on the severity of the voltage disturbance at the load buses. It can be seen from table 1 that the outage of line 9 in IEEE6bus system is the most critical contingency.

Table II

Order	Bus No.	Proposed MPVS* index			
		P_{min} (MW)	Load voltages (p.u)		
			V_4	V_5	V_6
1	6	7.7370	0.99821	1.00293	1.01017
2	4	38.508	0.80320	0.91343	0.83913
3	5	52.144	0.92300	0.72566	0.74492

B. Placement of SVC in IEEE6 bus system

To find the optimal location of SVC, MPVS index has been calculated at each bus. Using the most critical contingency and then MPVC* was computed. Table 2 represents the top three optimal locations in descending order.

It can be seen that at bus six minimum real power loss and voltage stability at all load buses was occurred. So the most suitable location for the placement of SVC, followed by bus four and bus five. The system performance in terms of reduction in real power loss, voltage stability, and cost of SVC has been obtained for the following cases.

Case 1 – No SVC placed in the system
Case 2 – SVC placed at bus 6, the most optimal location using MPVS*;

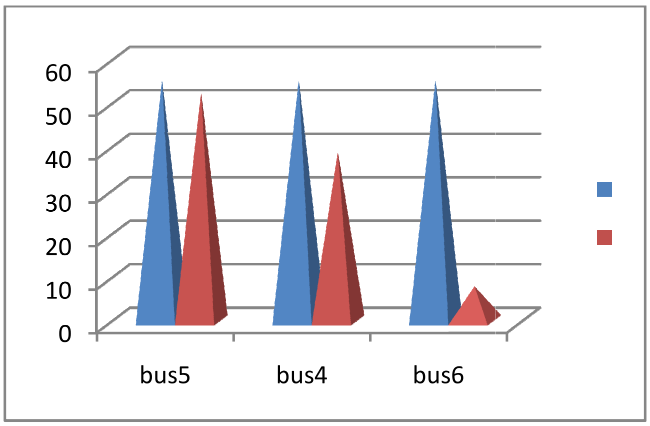

Fig.4

For the above three optimal locations of SVC (Table.II), the corresponding reactive powers are tabulated as follows.

Order	Bus No.	Reactive power	Cost of SVC $/var
1	6	-87.3431	121
2	4	12.82888	153.28
3	5	63.18716	171.78

The cost of SVC is computed as in [29]

$$C_{SVC} = 0.0003S^2 - 0.305S + 127.38 \quad (9)$$

Where C_{SVC} is cost of SVC in $/var
S is operating range of SVC in MVAR

$$S = |Q_2 - Q_1| \quad (10)$$

Q_1 is MVAR flow before placing FACTS device.
Q_2 is MVAR flow after placing FACTS device.

6. CONCLUSION

In this paper, a new index, called the minimum real power loss with voltage stability (MPVS*), has been proposed for optimal placement of SVC in the power system. this index was obtained for the severe line outage contingency. The proposed approach has been tested on IEEE6 bus system. The test results demonstrate the effectiveness of the proposed method in terms of reducing the system real power loss, improving the system stability, transmission capacity i.e. congestion management and the corresponding cost of SVC during normal operating condition and line outage contingency cases. The proposed method of optimal placement of SVC can be applied to any type of FACTS devices in the power system. It was found that in the small system, a single SVC may be effective. In case of IEEE6 bus system, SVC at bus six is found to be best location using MPVS* index.

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