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Optimal location and number of SVC for improving voltage stability in the electrical networks

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Abstract— Voltage regulation is an essential element for maintaining the stability of the power grid, which requires very efficient means, but this will be reflected in additional costs. What drives us to seek to minimize the cost by trying to optimize the regulation means. In this article, a model of fixed capacitor and thyristor-controlled reactor (TCR-FC) is incorporated in an iterative algorithm which allows to find the optimal angle thyristor's firing, the optimal location and number of SVC .The algorithm was tested for IEEE-6 -Bus and 14 bus. The simulation results are given in order to verify the proposed algorithm.

Index Terms— power flow, Bus, Network, static VAR Compensator (SVC), FACTS, firing angle, Newton Raphson method.

1. Introduction

Voltage stability in electrical grids is one of the major concerns of power systems because of the changes that can occur in complex power systems such as overloads, tap changing in transformers and grid faults. Voltage stability is the ability of a power system to maintain the voltage of all buses in the acceptable zone of tolerance in normal conditions and in disturbance. The increase in electrical energy demand may cause a progressively uncontrolled decline of voltages which lead to voltage instability or voltage collapse. Controllers FACTS (Flexible AC Transmission systems) are used in order to maintain the stability, security and reliability of power systems by providing voltage and power flow controls. Insertion of FACTS devices is found to be highly effective in preventing voltage instability. The static VAR Compensator (SVC) is a FACTS device that controls the reactive power injection at a bus using power electronic switching components. The reactive source is usually a combination of reactors and capacitors [2]. This paper is mainly focused on the use of the mathematical model of SVC [1] in Newton-Raphson method for power flow calculation to find the optimal location and number of SVC in order to ensure the optimal regulation of the voltage in the network and reducing the investment cost.

The first part is a presentation of the SVC model and its use in power flow calculation. The second part presents the iterative algorithm used to find optimal location. The last part presents results of simulation and test of program using the algorithm for IEEE-6Bus and IEEE-14Bus networks.

2. SVC POWER FLOW MODEL

The SVC is an advanced electronic power systems FACTS device. The SVC is used to provide simultaneous control of voltage magnitude, active and reactive power flows in the network. The SVC is widely used for several objectives:

- Increase power transfer in long lines
- Improve stability with fast acting voltage regulation
- Control dynamic overvoltage

There are two popular types of SVC, one is a combination of fixed capacitor and Thyristor Controlled Reactor (FC-TCR), the other one is a combination of Thyristor Switched Capacitor (TSC) and TCR. In this paper the SVC used is (FC-TCR) type [5, 6] Figure 1.

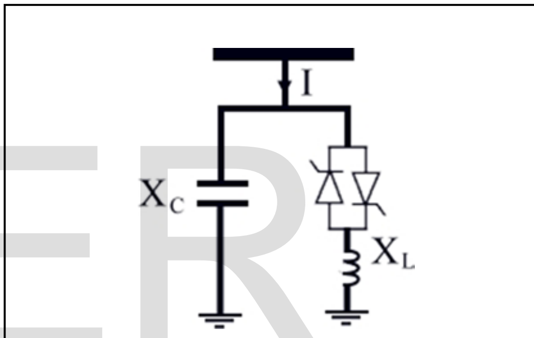

Fig.1. FC-TCR Model

Where:
XC : Capacitive reactance.
XL : Inductive reactance.
The equivalent reactance of the SVC is function of the firing angle, which is variable from 0 to X_{SVC} by varying the firing angle from α_{min}=90° to α_{max}=180°. The operating characteristic of a FC-TCR is shown in figure 2.

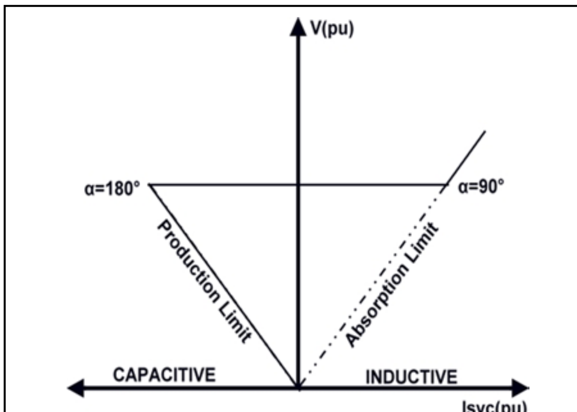

Fig.2. Characteristic of FC-TCR

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The TCR equivalent reactance X_{TCR} is given by Equation 1.

$$X_{TCR} = X_L \frac{\pi}{2(\pi-\alpha)+\sin(2\alpha)} \quad (1)$$

Where:
α : The thyristor's firing angle
The SVC equivalent reactance X_{SVC} is the parallel combination of TCR reactance X_{TCR} and the capacitor reactance X_C , given by Equation 2.

$$X_{SVC}(\alpha)= \frac{\pi.X_L}{2(\pi-\alpha)+\sin(2\alpha)-\pi\frac{X_L}{X_C}} \quad (2)$$

Figure 3 shows the variation of the SVC equivalent susceptance according to the firing angle.

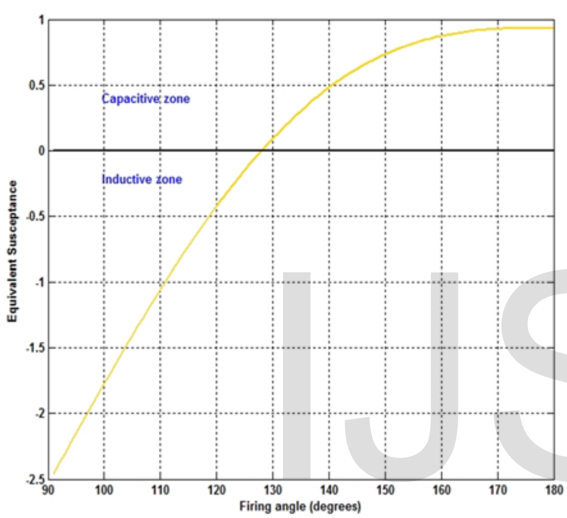

Fig.3. Equivalent susceptance of SVC

The insertion of the SVC at a bus k of the network changes the admittances matrix by adding the admittance of SVC. The new admittance matrix is given as follows:

$$Y_{bus} = \begin{pmatrix} Y_{11} & .. & Y_{1k} & .. & Y_{1n} \\ \vdots & & \vdots & & \vdots \\ Y_{k1} & .. & Y_{kk}+Y_{SVC} & .. & Y_{kn} \\ \vdots & & \vdots & & \vdots \\ Y_{n1} & .. & Y_{nk} & .. & Y_{nn} \end{pmatrix} \quad (3)$$

This matrix will be used in power flow calculation by varying the thryistor's firing angle.

3. ALGORITHM

The algorithm proposed to determine the optimal location of SVC with the best firing angle is an iterative algorithm; In every cycle, the SVC is inserted at a PQ-bus and by varying the firing angle from the lower Limit to the upper limit, the power flow is calculated and voltage data is saved. After testing all PQ-bus the best location is chosen according to the minimization of function F :

$$F = \min\left(\sum_{i=1}^{NPQ} \frac{|V_i-1|}{NPQ}\right) \quad (4)$$

The algorithm is described below:
Step 0: initiate the firing angle $\alpha=\alpha_{min}$
Step 1: insert SVC at PQ bus (First PQ bus)
Step 2: Calculate YSVC for the firing angel α
Step 3: update the Ybus admittances matrix
Step 4: Calculate power flow using Newton Raphson method
Step 5: Save buses voltage
Step 6: Check if $\alpha = \alpha_{max}$ go to Step 8 else go to Step 7
Step 7: update the firing angle $\alpha(i+1) = \alpha(i) + \alpha_{step}$ go to Step2.
Step 8: check if all PQ buses were tested go to Step9 else go to Step 1
Step 9: Upload Saved Data
Step 10: find bus and angle where $\min(\sum_{i=1}^{NPQ} \frac{|V_i-1|}{NPQ})$
Step 11: if 0.95 pu > $V_{PQ\text{-}Bus}$ >1.05pu go to Step 12.
Step12: Fix the SVC in the bus from Step10 and delete the bus from PQ list and go to Step 0.

4. CASE STUDIES AND RESULTS

The proposed algorithm was tested for the IEEE 6-bus and IEEE 14-Bus networks in order to verify if it works as planned. The parameters of the SVC are given below:

- Capacitive reactance = 1.070 p.u.
- Inductive reactance = 0.288 p.u.
- SVC's initial firing-angle = 91 deg.
- Lower limit of firing-angle = 90 deg.
- Upper limit of firing-angle = 180 deg.

The network used for simulation contains 3 generators, 3 load bus and 11 transmission lines (shown in fig 4). The characteristics of transmission lines and Buses are given in table 1 and table 2.

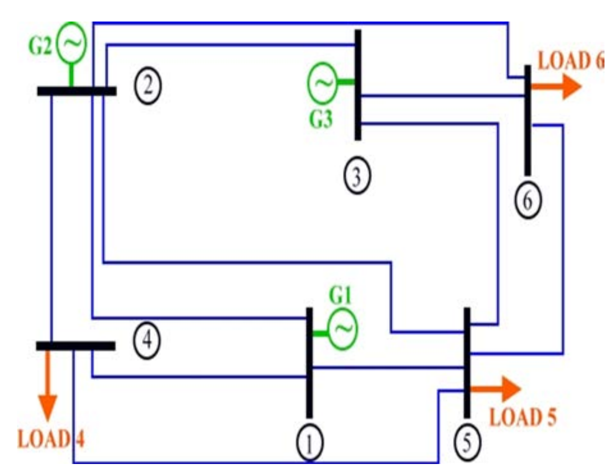

Fig.4. IEEE 6-bus system

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From Bus	To Bus	R (p.u)	X (p.u)	B (p.u)
1	2	0,2	0,4	0,01
1	4	0,1	0,4	0,01
1	5	0,16	0,6	0,015
2	3	0,1	0,5	0,015
2	4	0,1	0,2	0,005
2	5	0,2	0,6	0,01
2	6	0,14	0,4	0,0125
3	5	0,24	0,52	0,0125
3	6	0,04	0,2	0,005
4	5	0,4	0,8	0,02
5	6	0,2	0,6	0,015

Tab.1. characteristics of transmission lines

Bus	Type	V (pu)	P_G (pu)	P_L (pu)	Q_L (pu)
1	Slack	1.05		0	0
2	PV	1.05	0.25	0	0
3	P V	1.07	0.3	0	0
4	PQ		0	0.7	0.7
5	PQ		0	0.7	0.7
6	PQ		0	0.7	0.7

Tab.2. characteristics of bus

The results of power flow calculation without SVC show an under voltage of 0.05 pu in Bus 4,5 and 6. After executing the program we got the following results: to insert two SVC in Bus 5 and 4 respectively with angle 159° and 142°, this is equivalent to a compensation of 172.78MVAR in bus 5 and 108.18MVAR in bus 4, the voltages of bus are in zone of stability [0,95 - 1,05]pu.

In fact, the insertion of only one SVC in bus 5 is insufficient because we have an under voltage in bus 4 and 6. Tab3 shows the results of calculation without SVC, with one SVC and with two SVC. The figure 5 gives the voltage variations of Buses 4,5 and 6 according to the number of SVC.

Bus	Without SVC	With SVC in BUS 5 $\alpha_5 = 159°$	With SVC in BUS 4 & 5 $\alpha_4 = 142°$ $\alpha_5 = 159°$
1	1.0500	1.0500	1.0500
2	1.0500	1.0500	1.0500
3	1.0700	1.0700	1.0700
4	0.9054	0.9273	1.0002
5	0.8670	0.9998	1.0157
6	0.9219	0.9499	0.9532

Tab.3. comparison of solutions with and without SVC on IEEE 6-Bus network

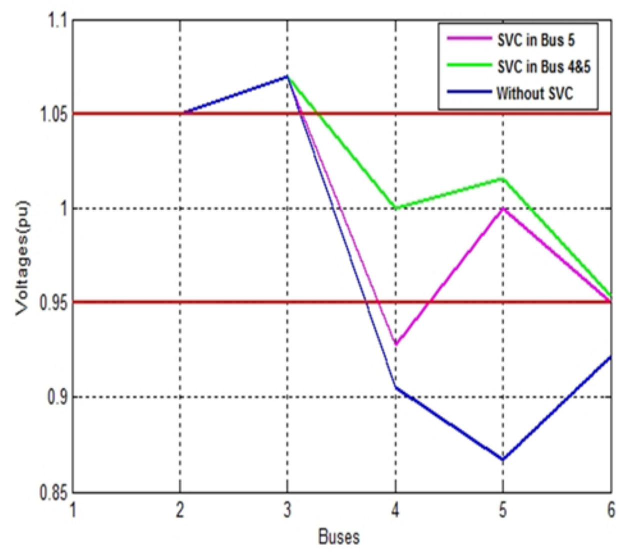

Fig.5. Voltage profiles with and without SVC

The program is tested on 14-Bus network IEEE in figure 6. After executing the program we got the following results: to insert two SVC in bus 10 and 12 respectively with angle 113° and 121° is equivalent to absorption of 85.5 MVAR in bus 10 and 36.57MVAR in bus 12. Simulation results are grouped in table 4.

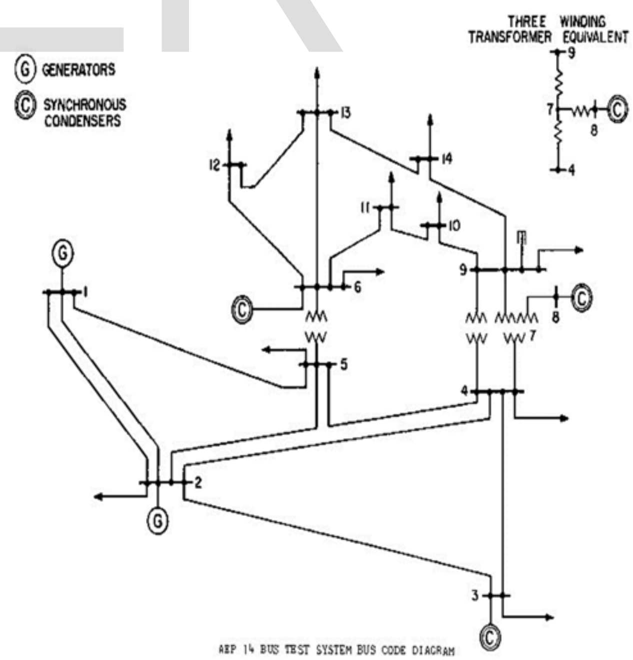

Fig.6. IEEE14-bus network

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Bus	Without SVC	With SVC in BUS 10	With SVC in BUS 9 & 12
		$\alpha_{10} = 113°$	$\alpha_9 = 113°$ $\alpha_{12} = 121°$
1	1.0600	1.0600	1.0600
2	1.0450	1.0450	1.0450
3	1.0100	1.0100	1.0100
4	1.0229	1.0116	1.0109
5	1.0235	1.0160	1.0155
6	1.0700	1.0700	1.0700
7	1.0693	1.0330	1.0315
8	1.0900	1.0900	1.0900
9	1.0700	0.9978	0.9950
10	1.0892	0.9743	0.9722
11	1.0764	1.0177	1.0166
12	1.0563	1.0508	0.9974
13	1.0524	1.0418	1.0238
14	1.0445	0.9983	0.9887

Tab.4. comparison of solutions with and without SVC in IEEE 14-Bus Network

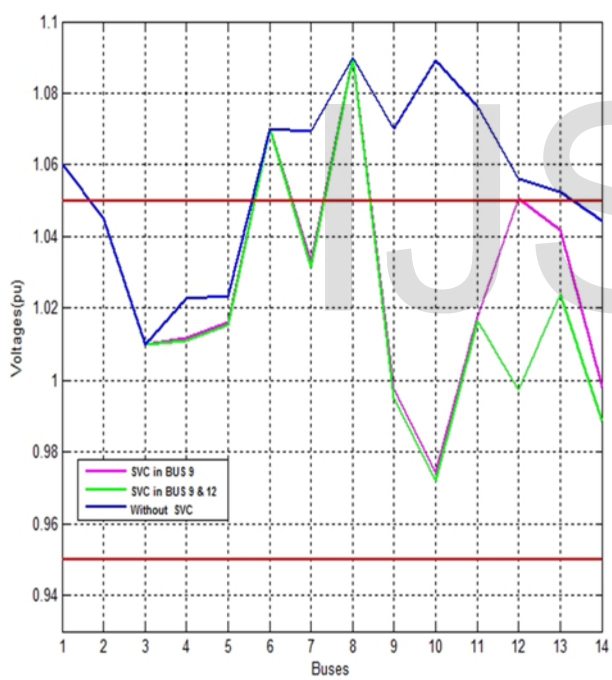

Fig.7. Voltage profiles with and without SVC

5. CONCLUSION

The proposed algorithm for finding the optimal location and number of SVC was tested in two networks. The results we got show the efficiency of the algorithm. In fact, the voltage profiles have been improved by the insertion of the SVC at the optimal bus with the precise firing angle given by the algorithm.

This approach allows us to optimize the voltage regulation by optimizing the number of FACTS and the amount of power which be injected into the network.

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