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A Newton Raphson Based Algorithm for Enhancement of Voltage Stability through Optimal Placement of Shunt Facts Controller

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ABSTRACT: The work is concerned about voltage stability enhancement therefore it is important to find the week buses of the system. Here IEEE-30 bus test system is considered and implemented, Newton–Raphson load flow algorithm is used to find the voltages and phase angles at each bus, the bus with lowest voltage is treated as a weakest bus at which the shut FACTS Devices is to be connected in order to control the voltage of the week bus. One of the Shunt FACTS devices SVC is Capable of increasing voltage profile and give maximum voltage support not only to the bus where FACTS is connected but at almost all the buses of the system. To this study MATLAB written program is used to find the voltages and phase angles at each bus of IEEE 30 bus system with and without FACTS devices.

KEYWORDS: Load Flow, Newton Raphson, FACTS, SVC, Voltage Stability

I.INTRODUCTION

Voltage collapse may simply be explained as the inability of the power system to supply the required reactive power or because of an excessive absorption of the reactive power by the system itself. To meet the reactive power demand, and to increase the power transmittable capability of lines reactive power compensation is given. Reactive power compensation in power systems can be either shunt or series. Since most loads are inductive and consume lagging reactive power, the compensation required is usually supplied by leading reactive power. The most common form of leading reactive power compensation is by connecting shunt capacitors to the line. Shunt compensation of reactive power can be employed either at load level, substation level, or at transmission level.Load demand on distribution system is growing rapidly this is the main driving force for the voltage instability. Voltage instability is the inability of the power system to maintain a proper balance of reactive power and voltage control. This problem can be mitigated using FACTS controllers.The instability is caused by overload and some disturbances in the power system. Most important causes of stability problems

- Large disturbance between generation and load
- Unfavourable load characteristics
- More distance between load sources and load centres
- The source voltage is too low
- With insufficient load reactive compensation
- Reduction of coordination between various control and protective systems
- Due to high consumption of reactive power with heavy loads and incorrect position of the FACTS controllers in the system.

II. POWER FLOW SOLUTION OF NEWTON RAPHSON METHOD

Let us, express the net complex power injection in to the bus as $S_K=S_{gk}-S_{dk}$. In this segment, we want to develop the expression for this measure in terms of network voltages and admittances. And consider that all the quantities in per unit. We can express S_k as:

$$S_K=V_K\,I_K^* \tag{1}$$

$$I_K=\sum_{i=1}^{n}(Y_{ik}V_i) \tag{2}$$

$$S_k=V_K\left(\sum_{i=1}^{n}(Y_{ik}V_i)\right)^* \tag{3}$$

Equation (3) can be written as

$$S_K=\sum_{i=1}^{n}(G_{ki}-jB_{ik})\,(|V_k||V_i|\angle\theta_k-\theta_i)$$

$$=\sum_{i=1}^{n}(G_{ki}-jB_{ik})\,|V_k||V_i|\,(\cos(\theta_k-\theta_i)+j\sin(\theta_k-\theta_i))$$

$S_K=P_K+Q_K$, we can express above equation as two equations one is real part P_K, and the other is imaginary part Q_K.

$$P_K=\sum_{i=1}^{n}|V_k||V_i|\,(G_{ki}\cos(\theta_k-\theta_i)+B_{ki}\sin(\theta_k-\theta_i)) \tag{4}$$

$$Q_K=\sum_{i=1}^{n}|V_k||V_i|(G_{ki}\sin(\theta_k-\theta_i)-B_{ki}\cos(\theta_k-\theta_i)) \tag{5}$$

$$J(x)=\begin{bmatrix} J_1(x) & J_2(x) \\ J_3(x) & J_4(x) \end{bmatrix} \tag{6}$$

$J(x)$ is the Jacobean matrix. Each elements of the Jacobian matrix is as follows:

The diagonal and the off diagonal elements of J_1 can be calculated as follows

Off diagonal element:

$$\frac{\partial P_i}{\partial \delta_k}=-\,|Y_{ik}V_iV_k|\sin(\theta_{ik}+\delta_k-\delta_i),\ (i\neq k) \tag{7}$$

Diagonal element:

$$\frac{\partial P_i}{\partial \delta_i}=\sum_{k=1}^{n}|Y_{ik}V_iV_k|\sin(\theta_{ik}+\delta_k-\delta_i),\ (i=k) \tag{8}$$

The diagonal and off diagonal elements of J_2 can be calculated as follows

Off diagonal element: $\frac{\partial P_i}{\partial |V_k|}=|Y_{ik}V_i|\cos(\theta_{ik}+\delta_k-\delta_i),\ (i\neq k)$ (9)

Diagonal element:

$$\frac{\partial P_i}{\partial |V_i|}=2|V_iY_{ii}|\cos\theta_{ii}+\sum_{k=1}^{n}|Y_{ik}V_k|\cos(\theta_{ik}+\delta_k-\delta_i),\ (i=k) \tag{10}$$

The diagonal and off diagonal elements of J_3 are

Off diagonal element:

$$\frac{\partial Q_i}{\partial \delta_k} = |Y_{ik}V_iV_k|\cos(\theta_{ik} + \delta_k - \delta_i), \ (i \neq k) \qquad (11)$$

Diagonal element:

$$\frac{\partial Q_i}{\partial \delta_i} = -\sum_{k=1}^{n} |Y_{ik}V_iV_k|\cos(\theta_{ik} + \delta_k - \delta_i), \ (i = k) \qquad (12)$$

The diagonal and off diagonal elements J_4 are

Off diagonal element:

$$\frac{\partial Q_i}{\partial |V_k|} = |Y_{ik}V_i|\sin(\theta_{ik} + \delta_k - \delta_i), \ (i \neq k) \qquad (13)$$

Diagonal element:

$$\frac{\partial Q_i}{\partial |V_i|} = 2|V_iY_{ii}|\sin\theta_{ii} + \sum_{k=1}^{n} |Y_{ik}V_k|\sin(\theta_{ik} + \delta_k - \delta_I), \ (i = k) \qquad (14)$$

IV. OBJECTIVES OF SHUNT COMPENSATION

The transmissible power in the steady state can be increased and the voltage along the line can be controlled by appropriate reactive shunt compensation. The main objective of this reactive compensation is to modify the natural electrical characteristics of the transmission line to make it more compatible with the prevailing load demand. To minimize line overvoltage under light load conditions, the shunt connected fixed or mechanically switched reactors are used, and shunt connected, fixed or mechanically switched capacitors are applied to maintain voltage levels in high load conditions. The main objective of applying reactive shunt compensation in a transmission system is to increase the transmissible power and may be necessary to improve the transmission characteristics in a steady-state as well as the stability of the system.

V. INTRODUCTION TO SVC

The Static Var Compensator (SVC) is a shunt connected static Var generator or absorber whose output is regulated to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power supply system (typically bus voltage).It is the variable impedance device in which the current through the reactor is always controlled using back to back connected thyristor valves.
Modelling of SVC

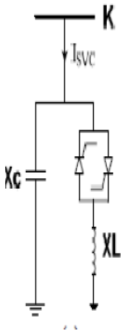

Fig.1. SVC firing angle model

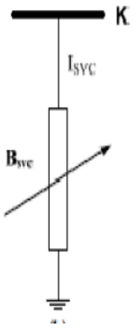

Fig.2. SVC total susceptance model

The SVC parameters must be determined in accordance with the compensation requirements. With Q_{SVC} as the SVC capacity and the bus voltage (voltage at the bus where SVC is to be connected)V_{bus}, the capacitance value and the TCR inductance are:

$$X_C = \frac{V_{bus}^2}{Q_{SVC}}, X_L = \frac{X_C}{2}$$

For a given frequency ‘f’ Hz:

$$X = \frac{1}{2\pi f X_c}, \; L = \frac{X_L}{2\pi f} \qquad (15)$$

A.MODELLING OF SVC:

After evaluating capacitance and inductance values, the initial operating condition of the SVC must be evaluated. Then selection of initial firing angle α, such that under the operating condition the SVC should not interchange power with the AC system. This firing angle resembles to the case when effective reactance’s $X_L$and X_C cancels each other. Under this operating condition, the SVC effective reactance X_{SVC} must be infinite and thus no current flows through the SVC which indicates that there is no power exchange between the SVC and the AC system. At $\propto \; = 90^o$the TCR conducts fully and the equivalent reactance X_{TCR}becomes X_L.At $\propto \; = 180^o$the TCR is blocked and its equivalent reactance becomes extremely large i.e. infinite. By using equation 4.3 and 4.4 in cuckoo search algorithm, the reactive power injected by SVC and equivalent reactance of thyristor controlled reactor (TCR) is calculated. The reactive power Qsvc($\propto$) is givn by:

$$\mathrm{QSVC}(\alpha) = \mathrm{Vbus} * \mathrm{Vbus} \left[\frac{\mathrm{Xc}[2(\pi-\alpha)+sin2\alpha-\pi X_L}{\pi XcXL}\right] \qquad (16)$$

$$X_{TCR} = \frac{\pi X_L}{\sigma - sin\sigma} \quad and \; \sigma = 2(\pi-\alpha) \qquad (17)$$

VI. CASE STUDY AND SIMULATION RESULTS

The simulation is performed in a standard IEEE 30 bus distribution test system as shown in fig (3).The IEEE 30 bus distribution system is a primary power supply operating at a voltage level of 11kV, a test system bus 30 consists of 41 branches with 24 loads,4 transformers,2 capacitors and 6 synchronous condensers used to provide reactive power support to the system. The single line diagram of standard IEEE 30 bus test system is shown in Figure (3) the base voltage of the network is 11kV and the base power is 100MVA.

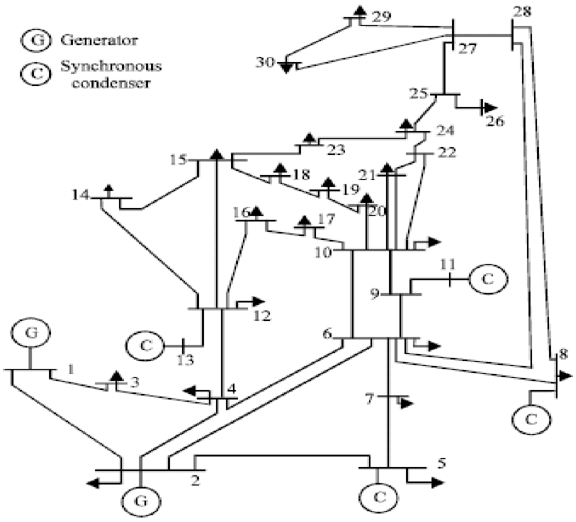

Fig.3. Standard IEEE 30 Bus Distribution Network.

A. CASE 1**:**This is the base case without any FACTS device in the system. Newton-Raphson (NR) load flow analysis is carried out for IEEE 30 bus system and the system voltage and angle of the test system are obtained. Load flow program is coded in MATLAB to obtain the results. The extent of the voltage magnitude at different nodes of the system is given in Table 5.1. The minimum voltage is 0.9246 in node 26 and 0.9249 in node 30 for the considered base case.

Table 1:The voltage profile of the test system before placement of SVC

Bus No.	Voltage (p.u)	V.Angle (deg)	Bus No.	Voltage (p.u)	V.Angle (deg)
1	1	0.0000	16	0.9643	-17.7353
2	0.9900	-6.2058	17	0.9532	-18.0388
3	0.9651	-8.5933	18	0.9446	-18.8678
4	0.9577	-10.5956	19	0.9398	-19.0585
5	0.9800	-16.2904	20	0.9432	-18.8155
6	0.9617	-12.6423	21	0.9424	-18.4408
7	0.9610	-14.7114	22	0.9474	-18.1760
8	0.9700	-13.6142	23	0.9427	-18.4516
9	0.9740	-15.9981	24	0.9347	-18.5501
10	0.9567	-17.8215	25	0.9437	-18.3311
11	1.0000	-15.9981	26	0.9246	-18.8202
12	0.9833	-17.1354	27	0.9586	-17.8820

13	1.0000	-17.1354	28	0.9604	-13.3908
14	0.9652	-18.1409	29	0.9373	-19.2878
15	0.9584	-18.1692	30	0.9249	-20.3012

B. CASE 2**:** In this case, the system improves by connecting two SVC at bus 26 and 30 which are found as a weakest buses from case 1. A SVC model of shunt variable susceptance is incorporated to maintain the magnitude of the bus voltage of bus 26 and 30 equal to 1pu respectively. The SVC retains the voltage magnitude of bus 26 and bus 30 equal to 1pu by injecting reactive power of -0.0298pu to bus 26 and -0.0525 pu to bus 30 respectively, By connecting SVC an overall enhancement in the voltage profile is seen in all most all buses when compared to the system without SVC.

Table 2: The voltage profile of the test system after placement of SVC

Bus No.	Voltage (p.u)	V.Angle (deg)	Bus No.	Voltage (p.u)	V.Angle (deg)
1	1	0.0000	16	0.9719	-17.6302
2	0.9900	-6.1978	17	0.9630	-17.9531
3	0.9694	-8.6517	18	0.9537	-18.7593
4	0.9630	-10.6613	19	0.9491	-18.9515
5	0.9800	-16.2387	20	0.9531	-18.7168
6	0.9693	-12.7997	21	0.9545	-18.3756
7	0.9655	-14.7481	22	0.9635	-18.1568
8	0.9800	-13.7540	23	0.9552	-18.3942
9	0.9812	-15.9933	24	0.9575	-18.6422
10	0.9674	-17.7501	25	0.9905	-18.8599
11	1.0000	-15.9933	26	1.0000	-18.3588
12	0.9886	-17.0070	27	1.0049	-20.3588
13	1.0000	-17.0070	28	0.9725	-18.2080
14	0.9719	-18.0026	29	0.9975	-19.8552
15	0.9665	-18.0647	30	1.0000	-21.1614

In the fig.4, it shows the voltage profile corresponding to each bus of IEEE 30 bus test system. It is the graph of bus number verses voltage magnitude.

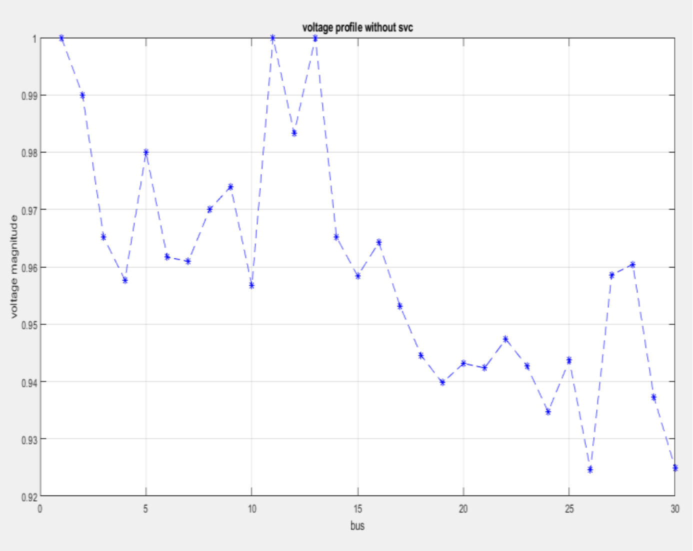

Fig.4. Voltage Profile of IEEE 30 Bus System without SVC.

In the fig.5, it shows the voltage profile corresponding to each bus of IEEE 30 bus test system after placement of SVC at optimal location. It is the graph of bus number verses voltage magnitude.

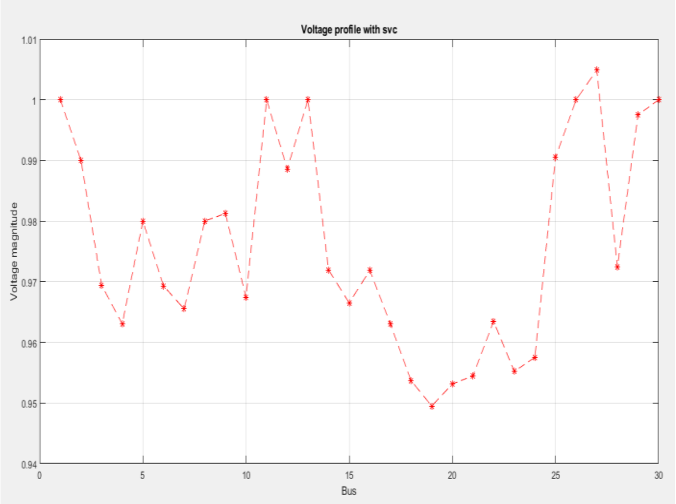

Fig.5. Voltage Profile of IEEE 30 Bus System with SVC at bus 26,30.

In the fig.6, it shows the voltage profile corresponding to each bus of IEEE 30 bus test system before and after placement of SVC at optimal location that is at bus 26 and 30. It is the graph of bus number verses voltage magnitude.

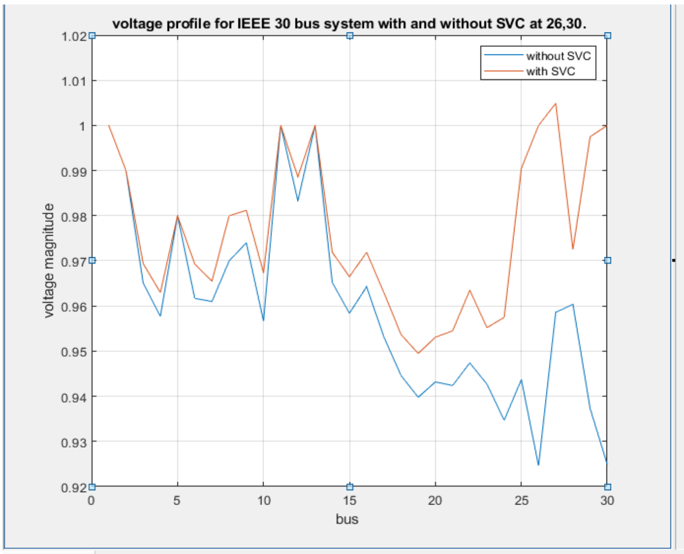

Fig.6. Voltage Profile (IEEE 30 bus system) before and after SVC at bus 26 and 30.

VII. CONCLUSION.

Newton Raphson load flow study is performed for IEEE-30 Bus test system with and without shunt FACTS bypass device. It has found that SVC has the ability to improve voltage profile and gives maximum assistance by providing stable and constant voltage support, not only to the bus where SVC is coupled, but also to almost all system buses. And the graph of the bus voltage profile is plotted for with and without shunt FACTS devices for the base case. The main objective of this project work is to maintain voltage stability and that has been reached effectively with the incorporation of SVC, therefore it is possible to maintain the stability of the system.

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