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SVC for Enhancing Loadabilty Margin and Voltage Profile of Power System

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Abstract. **Voltage disparity is a common problem in heavily loaded power system. Flexible Alternating Current Transmission Systems controllers may play a significant part to provide reactive power support to maintain voltage within acceptable level. For determining the optimal location of Static Var Compensator which maximizes voltage stability, Continuation power flow method has been applied using UWPFLOW. Effectiveness of proposed method has been tested on IEEE 30 bus systems. From the simulation results, it is observed that maximum loadability margin and voltage profile of power system have been improved significantly.**

Keywords: Continuation power flow (CPF),Flexible AC Transmission System (FACTS), Static Var Compensator (SVC), voltage stability, Load ability margin.

1. INTRODUCTION

In last decade of 20th century, the electricity industry has been changed due to a worldwide power system restructuring that have significantly affected power system management. Further, due to integration of renewable energy system into grid, complexity and size of power grid has been expanded around the globe. The demand of electricity is increasing day by day; therefore, the complexity and voltage stability problem are also increasing.

The main concern of power grid to maintain voltage at all the buses within permissible limit during normal conditions as well as under the disturbances. Voltage instability in a power system occurs due to lack of reactive power. Various methods have been suggested by researchers for overcoming voltage stability problem. These methods suggested about the change in real and reactive power controllers setting to improve the margin of voltage stability[1]. In past years, Grid failure in various countries such as USA, France, Bbalgium, Sweden and Japan has been taken place only because of voltage stability problem [2]. To save the system from voltage collapse, FACTS can provide reactive power compesation[3]. The SVC used to control voltage by suppling or absorbing reactive power into or from Grid. Global level support of recative power may enhance the voltage drop which leads to current enhancement in transmission network. SVC maintains the demand of reactive power [4]. An automatic FACTS device allocation process based on evolutionary algorithm has been proposed in [5] to enhance the voltage stability of power systems. A comprehensive review for increasing the stability and power flow capability using FACTS controller has been given in [6].

Organization of paper is as follows, the section -2 describe the methods of voltage stability assessment. The simulation results, illustrating the effect of the proposed methodology are presented and discussed in section 3.conclsion is given in section 4.

2. METHODS OF VOLTAGE STABILITY ASSESSMENT

Methods used for voltage stability analysis in a power grid are classified in two types, static and dynamic voltage analysis. For static voltage analysis of an interconnected system, power flow model has been generally considered. From the literature, it is observed that the power flow diverges and Newton-Raphson load flow (NRLF) Jacobian becomes ill condition at system maximum loadability point. The NRLF equations in polar coordinates can be written as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V / V \end{bmatrix} \qquad (1)$$

Singularity of reduced Jacobian [J_R] defining Q-V sensitivity has also been used to determine static voltage instability, where

$$[J_R] = [J_4 - J_3 . J^{-1} . J_2] \qquad (2)$$

2.1 Static Voltage Stability Analysis of Interconnected Systems

Some of the methods which stabilized singularity of Jacobian are as follows.

2.1.1 Continuation Power Flow Method

This method overcomes the divergence of NRLF method near maximum loadability of the system. The method uses predictor-corrector approach and selects continuation parameter as additional variable to overcome ill conditioning of NRLF Jacobian. It is a robust method, which can simulate load changes at all the buses in any assumed direction and can trace both high voltage as well as low voltage solutions of the network.
This method involves a predictor and a corrector step as given below:

- **Predictor Step**

The following relation applies at equilibrium point:

$$g(y_p,\lambda_p)=0 \Rightarrow \left.\frac{dg}{d\lambda}\right|_p = 0 = \nabla_y g\big|_p \left.\frac{dy}{d\lambda}\right|_p + \left.\frac{\partial g}{\partial \lambda}\right|_p \tag{3}$$

And the tangent vectors can be approximated by:

$$\tau_p = \left.\frac{dy}{d\lambda}\right|_p \approx \frac{\Delta y_p}{\Delta \lambda_p} \tag{4}$$

From equations (3) and (4):

$$\tau_p = -\nabla_y g\big|_p^{-1} \left.\frac{\partial g}{\partial \lambda}\right|_p \tag{5}$$

$$\Delta y_p = \tau_p \Delta \lambda_p \tag{6}$$

A step size control k has to be chosen for determining the increment Δy_p and $\Delta \lambda_p$, along with a normalization to avoid large step when $|\tau_p|$ is large:

$$\Delta \lambda_p \overset{\Delta}{-} \frac{k}{|\tau_p|} \;\&\; \Delta y_p \overset{\Delta}{-} \frac{k\tau_p}{|\tau_p|} \tag{7}$$

When k=± 1, and its sign determines the increase or the decrease of λ .

- **Corrector Step:**

In the Corrector Step, a set of n+1 equation is solved, as given below:

$$\begin{aligned} g(y,\lambda) &= 0 \\ \rho(y,\lambda) &= 0 \end{aligned} \tag{8}$$

Where the solution of g must be in the bifurcation manifold and ρ is an additional equation to guarantee a non-singular set at the bifurcation point. As for the choice of ρ, there are two options: the perpendicular intersection and the local parameterization. In case of perpendicular intersection, the expression of ρ becomes

$$\rho(y,\lambda) = \begin{bmatrix} \Delta y_p \\ \Delta \lambda_p \end{bmatrix}^T \begin{bmatrix} y_c - (y_p + \Delta y_p) \\ \lambda_c - (\lambda_p + \Delta \lambda_p) \end{bmatrix} = 0 \tag{9}$$

Whereas for the local parameterization, either the parameter λ or a variable y_i is forced to be a fixed value:

$$\rho(y,\lambda) = \lambda_c - \lambda_p - \Delta \lambda_p \tag{10}$$

$$\rho(y,\lambda) = y_{ci} - y_{pi} - \Delta y_{pi} \tag{11}$$

2.1.2 Energy Function Method

Energy function method is derived from, Lyapnov’s second stability criterion. It provides direct solution to the stability problem without involving numerical integration. It has been recently suggested to the voltage stability and margin calculation.

2.1.3 Eigen Value Analysis

As per the static analysis the voltage collapse limit in power grid is a point where the total system Jacobian becomes singular. This implies that the least eigen values of the total system Jacobian approaches to zero. Moreover, under specified assumptions, there is a explicit relation between singularity of the load flow Jacobian and system dynamic state Jacobian.

Thus in order to evaluate the voltage stability conditions, compute the least eigen value λ_l of J. Enlarge power system; size of Jacobian makes the calculation of λ_l difficult. Hence a partitioning technique described below can be used.
As an approximation to the direct calculation of λ_1, partition of the system into smaller sub networks N_1, N_2………N_k with n_1, n_2……….n_k nodes respectively can be used. This partition of the system resulting in a set of isolated sub system.If α_1, α_2…………α_k of each subsystem λ_l is estimated as

$$\lambda = \overline{\lambda_1} = \min(\alpha_1, \alpha_2 \ldots\ldots \alpha_k) \qquad (12)$$

Thus selection of a proper criterion to split the network is a key aspect of this method.

2.1.4 Direct Method Based On Power Flow Solvability

This method does not require repeated load flow solution and can be used to trace load flow feasibility boundary corresponding to static voltage stability limit in load parameter space. The distance to new power flow solution boundary ∑ corresponding to any extreme contingency (in load parameter space) can be used as measure of unsolvability. The method also suggests the control action to bring the operating point into solvable region. The load parameter space in a system will be a hyper surface.

2.2 Dynamic Voltage Stability Prediction

In the voltage instability or collapse phenomenon, both static and dynamic factors are involved. Saddle- node and Hopf bifurcations have been identified as the key reasons for the voltage stability problem of the grid. Saddle node bifurcation is a static bifurcation. Hopf bifurcation is a dynamic bifurcations. Hopf bifurcation is responsible for oscillatory voltage instability.

3. SIMULATION RESULTS AND DISCUSSION

Effectiveness of CPF method for Voltage Stability problem has been tested on IEEE -30 bus system (Appendix-A). Local bifurcation pertaining to system limits or system Jacobion singularities have been calculating using UWPELOW software.Voltage stability assessment has been carried out for the following two cases.

Case I: without SVC **Case II: with SVC**

3.1 Voltage Stability Assessment without SVC

Weak or critical buses are identified using contingency analysis. Based on bus no. 10, 18,19,24,25,26,29,30 are critical buses. P-V curves are drawn using UWPFLOW software for all the critical buses without considering SVC.

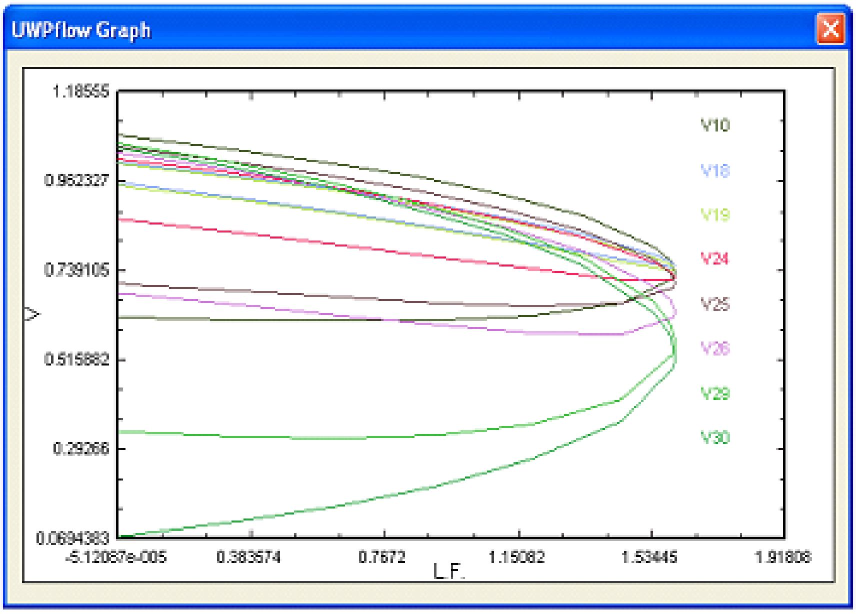


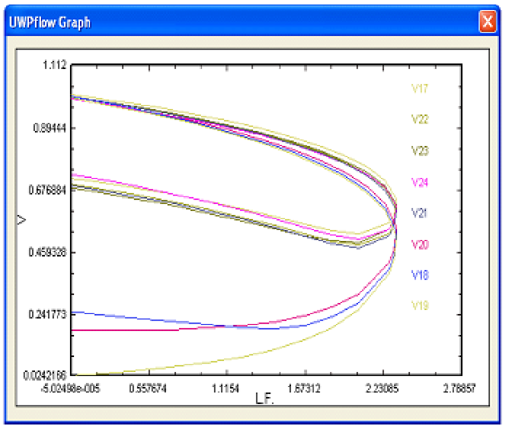
Fig.1. PV curves at weak buses

Table 1. Critical voltage at weak buses without using SVC

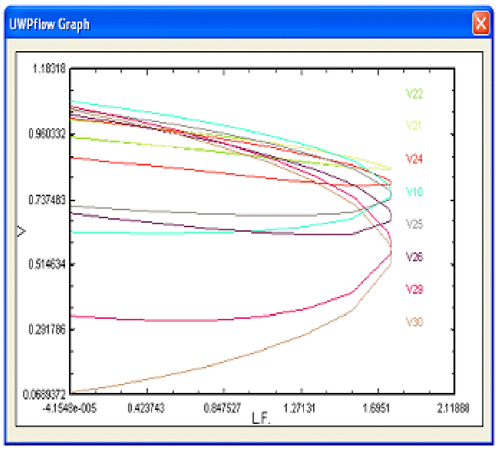
S. No.	Bus number	Critical voltage (p.u.)
1.	10	0.74264
2.	18	0.75433
3.	19	0.74670
4.	24	0.72725
5.	25	0.71441
6.	26	.0.64241
7.	29	0.57060
8.	30	0.53888

From P-V curves, it is observed that maximum load ability margin for base case is 1.5984 pu. Critical voltages for all weak buses are given in table-1.

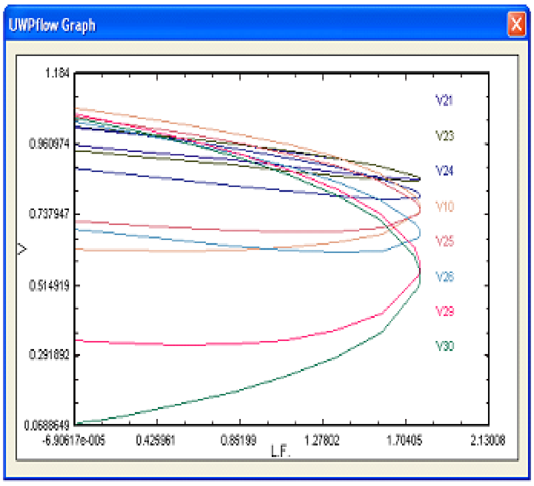
3.2 Voltage Stability Assessment with Using SVC



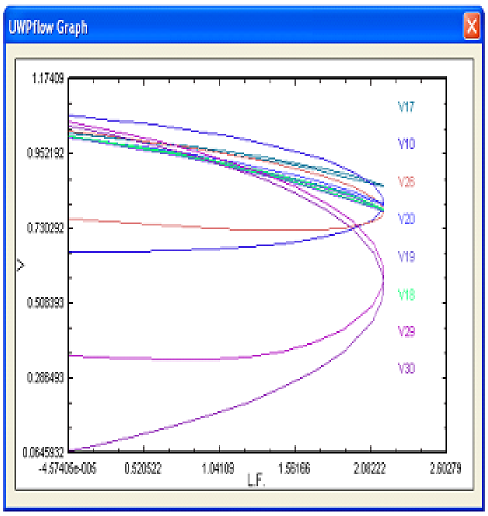
PV curves using SVC at bus no.10



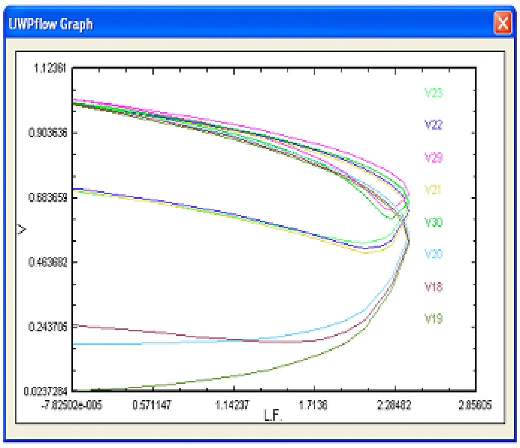
PV curves using SVC at bus no.18

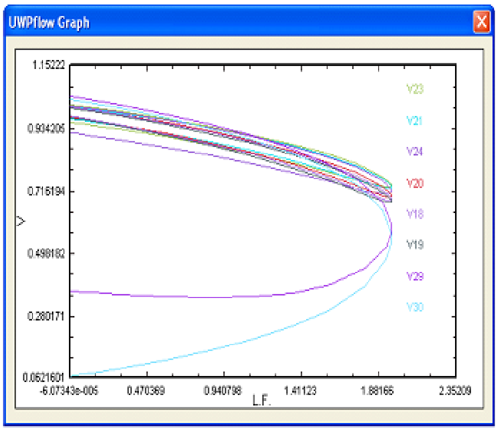


PV curves using SVC at bus no.19



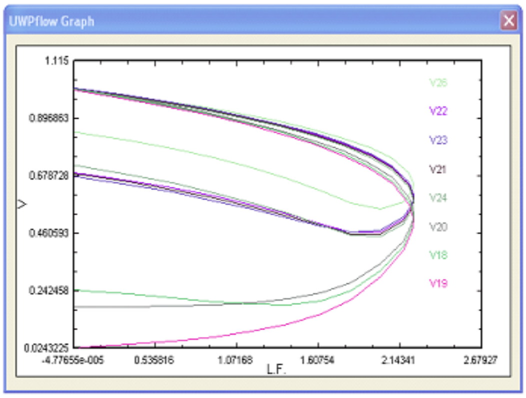
PV curves using SVC at bus no.24

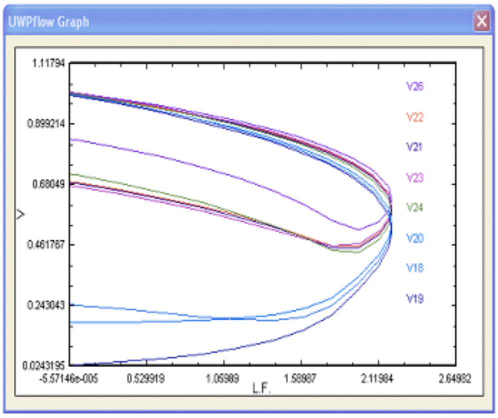




PV curves using SVC at bus no.25

PV curves using SVC at bus no.26





PV curves using SVC at bus no.29

PV curves using SVC at bus no.30

Fig.2. P-V curves using SVC at all the critical buses

Exhaustive method has been utilized, to find out the optimum location of SVC. Continuation Power Flow is carried out by placing SVC at all the buses one by one. For this, input data are modified. P-V curves drawn for all the scenarios using UWPFLOW are shown in figure 2. Load ability margin and critical voltage obtained in each scenario is given in table 2.

Table.2 Critical voltage and load ability margin at each bus.

S.No.	Bus No.	Critical voltage in p.u.	Loadability margin in p.u.
1.	10	0.74264	2.3238
2.	18	0.75433	1.7657
3.	19	0.74670	1.7751
4.	24	0.72725	2.1690
5.	25	0.71441	2.3800
6.	26	0.64241	1.9601
7.	29	0.57060	2.2327
8.	30	0.53888	2.2082

From the results, it can be easily seen that the optimal location for SVC placement is bus no. 25 as load ability margin is highest i.e 2.38 pu. Further, results obtained without SVC and with SVC shows that placement of SVC is beneficial for utilities as it will enhance system load ability which shall further improve system reliability and security.

4 CONCLUSION

In this paper, continuation power flow method is applied to obtain PV curve. Impact of SVC on system load ability margin has been analyzed by comparing results obtained with SVC and without SVC. Further, simulation results highlighted that placement of SVC at optimum location has enhanced the load ability margin from 1.5984 pu to 2.3800 pu. In future work, Artificial Intelligence based approach for optimum placement of SVC's may be explored .

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APPENDIX A

Table A-1

Generation Bus Data for IEEE 30-Bus System

Bus no.	Scheduled Real Power Generation [MW]	Specified Voltage Magnitude [p.u.]	Real load [MW]	Reactive Load [MVAr]
1	300.00	1.0600	0.00	0.00
2	40.00	1.0450	21.70	12.70
3	20.00	1.0100	0.00	30.00
4.	-	1.082	30.00	0.00
5.	-	1.010	9.42	19.0

Table A-2

Generator Data for IEEE 30-Bus System

Bus no.	Real Generation Limit		Reactive Generation Limit	
	Maximum (MW)	Minimum (MW)	Maximum (MVAr)	Minimum (MVAr)
1	300.0	-	150.0	-100.0
2	40.0	-	50.0	-40.0
3	20.0	-	40.0	-10.0
4	-	-	24.0	-06.0
5	-	-	40.0	-40.0
6	-	-	24.0	-06.0

Table A-3

Transformer Data for IEEE 30-Bus System

Line No.	From bus	To bus	Series impedance		Tap Setting
			Resistance [p.u.]	Reactance[p.u.]	
1	13	07	0.0000	0.2080	0.978
2	13	08	0.0000	0.5560	0.969
3	11	09	0.0000	0.2560	0.962
4	28	10	0.0000	0.3960	0.968

Table A-4

Load Bus Data for IEEE 30-Bus System

Bus no.	Load		External shunt susceptance [p.u.]
	Real load [MW]	Reactive Load [MVAr]	
7	0.0	0.0	0.00
8	5.8	2.0	0.00
9	11.2	7.5	0.00
10	0.0	0.0	0.19
11	7.6	1.6	0.00
12	22.8	10.9	0.00
13	0.0	0.0	0.00
14	6.2	1.6	0.00
15	8.2	2.5	0.00
16	3.5	1.8	0.00
17	9.0	5.8	0.00
18	3.2	0.9	0.00
19	9.5	3.4	0.00
20	2.2	.7	0.00
21	17.5	11.2	0.00
22	0.0	0.0	0.00
23	3.2	1.6	0.00
24	8.7	6.7	0.043
25	0.0	0.0	0.00
26	3.5	2.3	0.00
27	2.4	1.2	0.00
28	0.0	0.0	0.00
29	2.4	0.9	0.00
30	10.6	1.9	0.00