# FACTS Controllers Impacts on Security Margin Enhancement in Power System

Payam Farhadi, Tina Sojoudi, Shabnam Zabihi, and Mohammad Karimi

***Abstract*—In this paper, voltage stability of power system has been investigated in the presence of three types of FACTS controllers including SVC, STATCOM and UPFC. Voltage stability and voltage collapse point and the loading amount are calculated with and without FACTS controllers. Simulations have been carried out on 33-bus network test system in PSAF software. It was found that without the installation of FACTS controllers, the maximum loading amount is 1.71 (p.u), which by installing any of these FACTS controllers and changing their installation place, loading value is also changed. In this paper, the installation of various types of FACTS controllers has been examined simultaneously as well as by installing several numbers of just one of these FACTS controllers.**

***Index Terms*—Voltage stability, FACTS controllers, security margin, continuity power flow.**

## I. INTRODUCTION

Nowadays, due to increasing demand for electrical energy resulting in creating interconnected networks, more attention has been paid to reliable and accurate exploiting of power systems. Improving power system voltage stability is directly proportional to increased network security margin. To increase the voltage stability of power systems, different and common methods are presented which some of them are as follows:

- Using under load tap change transformers
- Using load shedding techniques
- Direct reactive power generation by generators and condensers
- Installing Fixed capacitor banks near induced loads
- Installing FACTS controllers

The use of the FACTS controllers to increase the voltage stability has been widely investigated in recent years. In [1], for damping power system oscillation, a Unified Power Flow Controller (UPFC) has been used. For this, UPFC has been installed in hypothetical test system with three bus and two machines. Results of simulation confirm the ability of UPFC in damping active and reactive power oscillations. Static VAr Compensator (SVC) is the most common FACTS controller in power flow and voltage stability studies. El-Sadek *et al.* have combined SVC and series capacitors (SC) to improve steady state voltage stability [2]. To select best case among SVC types, Karimi *et al* have installed six branches of SVC in a novel test system and by statistical indices have studied the results of these SVCs. Results of simulation confirm that from the viewpoint of power flow control range priority, these six kinds of SVC can be classified as follows (from lowest to highest range), FC-TCR, TCR, FC-TCR-TSC, FC-TSR-TCR, TCR-TSC and the TSC, respectively [3]. Authors of [4] have proposed a coordinated control strategy for SVC for reactive control which improving voltage stability in a deregulated environment. The proposed technique has been tested on IEEE 118-bus.

In [5], the effect of the large wind power plants to increase the voltage stability on power systems has been investigated. The network loss reduction along with increased stability of the network is given.The optimal SVC placement for voltage stability enhancement is a non-differentiable problem which has been solved using simulated annealing and Lagrange multiplier techniques in [6]. Authors in [7] have evaluated voltage stability in the presence of SVC using a technique based on Fuzzy neural network. The proposed technique has two stages; Kohonen self-organizing map and combination of different non-linear membership functions have used to cluster the real and reactive loads and ransform the input variables into fuzzy domains in first and second stages, respectively.

Static Synchronous Compensator (STATCOM) is other shunt FACTS device which has used to voltage stability analysis in [8-10]. In [8], for power flow control, a novel controller based on Neural Networks (NNs) has suggested for STATCOM. Peak value, fall value and settle time of injected current and active and reactive powers have been used as comparison criteria. Comparison of STATCOM results based on Multilayer Perceptron (MLP) controller with classic PI and PID controller illustrate the ability of MLP controller in better power flow control. Zhang et al. performed the power flow and voltage stability analysis in the presence of STATCOM using a power injection model (PIM) of STATCOM. The proposed model can also take into account the steady-state losses of STATCOM. The proposed approach has been tested on IEEE 30-bus and 300-bus [9].

In this paper, three types of FACTS controllers, i.e. SVC, STATCOM and UPFC are used to enhance stability of power systems. Therefore, a 33-bus network test system has been used for simulation in PSAF. Simulation results show that FACTS controllers which are installed in other buses than the weakest bus could have better results in terms of voltage stability. Also, in a power system with several voltage levels, voltage stability with FACTS controllers installed in a bus which has the highest voltage will has a better outcome

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although it may has no loads even it would be more useful.

## II. FACTS CONTROLLERS

### A. SVC

This compensator is existing in several different types which two of the most well known are TCR and TSC. In the simplest case, the SVC is composed of a TCR in parallel with a capacitor. In fact, the SVC is a variable reactance connected in parallel to the network and can absorb/produce reactive power at the connecting point. Controlling Thyristor firing angle make SVC to respond to the network in almost every instant. For SVC, $X_v$ is the controllable part of the TCR obtained as

$$X_V = \frac{\pi}{2\pi - 2\alpha + \sin 2\alpha} \tag{1}$$

where, $\alpha$ is Thyristor firing angle and. B as the effective susceptance of the TCR is obtained as

$$B = \frac{X_V}{X_V X_C} \tag{2}$$

Which $X_c$ is capacitor reactance in parallel with TCR..

### B. STATCOM

STATCOM, similar to the SVC, can absorb/generate reactive power, but STATCOM has the characteristic curve better than SVC. From the viewpoint of the power system SVC and STATCOM are variable reactive power sources.

### C. UPFC

Fig 1 shows the UPFC models. The model is used extensively in research and impact studies of UPFC in the power systems. In this arrangement because both the amplitude and angle of the voltage is controllable, therefore it can exchange the active power as well as reactive power with transmission line.

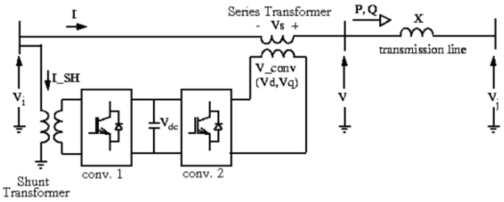

Fig. 1.UPFC model.

## III. VOLTAGE STABILITY

The ability of a power system to maintain acceptable steady voltages at all system buses, both in normal operation mode and in the disturbance mode, is voltage stability. The main reason for voltage instability is the system inability to supply the reactive power demand.

### A. Voltage Collapse

Voltage collapse occurs when consumer voltages (load) in the power system are much smaller than the nominal values, and despite switching the reactive power sources into the power system, voltage cannot be returned to the nominal value or cannot be damped due to the lack of oscillations. If there is not a balance between consumption and production of reactive power, voltage collapse will be happened. This may be partial or total collapse and included the whole system. Although the capacitor banks cause voltage stabilization, they can be cut off from the circuit in the voltage reduction and may cause voltage collapse.

### B. The Weakest Bus

The weakest bus is referred to any of the buses which most likely are going to the voltage collapse.

## IV. VOLTAGE STABILITY ANALYSIS

The methodology used in this paper for voltage stability analysis is the continuing power flow (CPF). In this method, P-V curves are plotted to determine voltage collapse point and the system maximum loading. This method is similar to regular power flow with the difference that in this method load variations are considered by small changes in the power flow equations constantly. As in Fig. 2, power flow is started with a known amount and the next estimation is done according to the next parameter value. Then this estimation is corrected to obtain the precise solution.

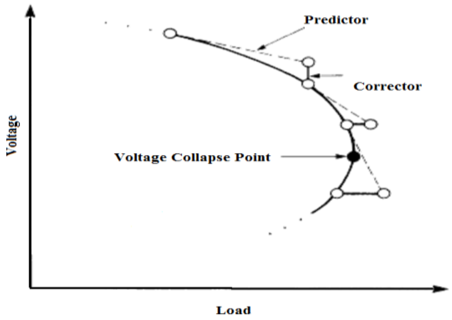

Fig. 2. Continuity power flow steps

The flowchart of FACTS controllers modeling and continuous power flow is illustrated in the Fig. 3.

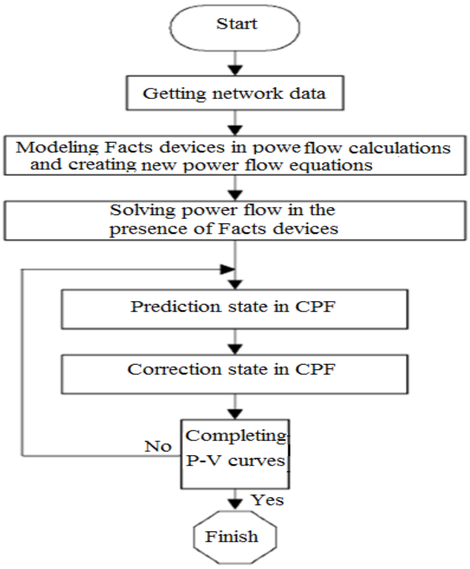

Fig. 3. Continuous power flow (CPF) in the presence of FACTS controllers

## V. POWER FLOW FORMULATION

Power flow formulation is given using following equations:

$$\text{Minimize } \lambda \tag{3}$$

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |U_i||U_j|(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}) = 0 \tag{4}$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} |U_i||U_j|(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}) = 0 \tag{5}$$

$$|U_i|_{\min} \le |U_i| \le |U_i|_{\max} \tag{6}$$

$$S_{ij} \le S_{ij}^{\max} \tag{7}$$

Which, $\lambda$ is numeric parameter which represents load increase or bus generation, $P_{Gi}$ and $Q_{Gi}$ are active and reactive power generation in *ith* bus respectively, $n$ is the number of system buses, $|U_i|$ and $|U_j|$ are voltage amplitudes in *ith* and *jth* bus, $\delta_{ij}$ is phase displacement between *ith* and *jth* voltage buses, $S_{ij}$ is apparent power between the *ith* and *jth* line buses. In the power flow equations, $P_{Gi}$, $P_{Di}$ and $Q_{Di}$ are equals to:

$$P_{Gi} = P_{Gi}^{\circ}(1 + \lambda K_{Gi}) \tag{8}$$

$$P_{Di} = P_{Di}^{\circ}(1 + \lambda K_{Di}) \tag{9}$$

$$Q_{Di} = Q_{Di}^{\circ}(1 + \lambda K_{Di}) \tag{10}$$

Which, $P^0_{Gi}$, $P^0_{Di}$ and $Q^0_{Di}$ are active power generation and active as well as reactive power consumptions in *ith* bus. $K_{Di}$ and $K_{Gi}$ are constants used as the production or consumption rates for changes for $\lambda$ changes.

## VI. THE EFFECT OF ON THE MAXIMUM LOADING

Without considering the frequency, generally, static load model is as follows

$$Pd_i^0 = Pd_i^{norm}(a_{i0} + a_{i1}V_i + a_{i2}V_i^2) \tag{11}$$

$$Qd_i^0 = Qd_i^{norm}(b_{i0} + b_{i1}V_i + b_{i2}V_i^2) \tag{12}$$

Which, $i$ is the bus number, $Pd_i^{norm}$ and $Qd_i^{norm}$ are active and reactive power at rated voltage, respectively. $\alpha_{i0}$ and $b_{i0}$ are constants of power components, respectively. $\alpha_{i1}$ and $b_{i1}$ are constants of current components. $\alpha_{i2}$ and $b_{i2}$ are constant of impedance components. The following equations should be satisfied,

$$a_{i0} + a_{i1} + a_{i2} = 1 \tag{13}$$

$$b_{i0} + b_{i1} + b_{i2} = 1 \tag{14}$$

## VII. SIMULATION RESULTS AND DISCUSSION

For the simulation case studies, according to the Fig. 4, a 33-bus network test system selected which include six voltage levels; 13.8, 69, 86, 120, 308 and 735 kV and seven generators and two reactors. Whole simulation was carried out in six stages, which are described below.

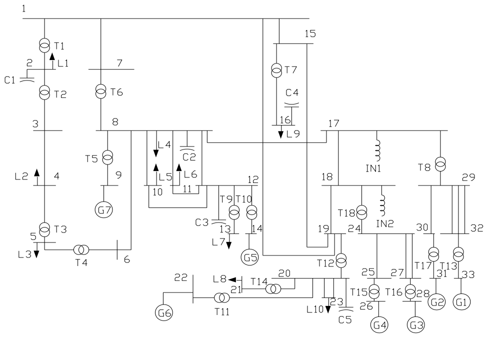

Fig. 4. 33 bus networks test system

### A. Without FACTS Controllers

Simulation results show that the network security margins in terms of the voltage instability is 0.71 (p.u.) in the weakest bus (bus 23). P-V curve for this case is shown in Fig. 5.

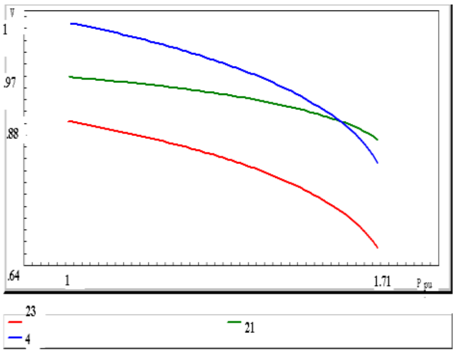

Fig. 5. P-V curve for the weakest bus without FACTS controllers

### B. With FACTS Controllers

FACTS controllers' impacts for different places are shown in Figs .6-14.

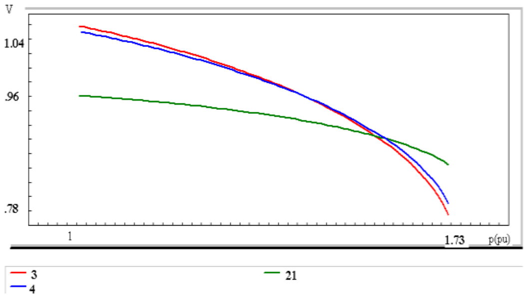

Fig. 6. P-V curve by installing SVC at the weakest bus (bus 23)

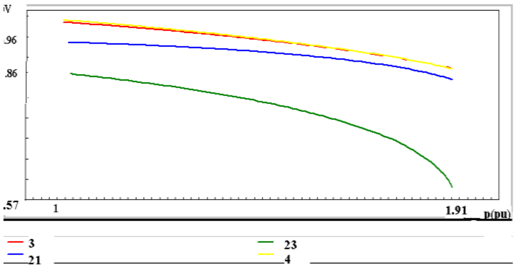

Fig. 7. P-V curve by installing SVC in bus 1

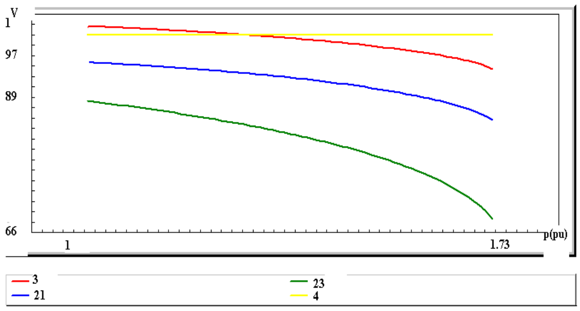

Fig. 8. P-V curve by installing SVC in bus 4

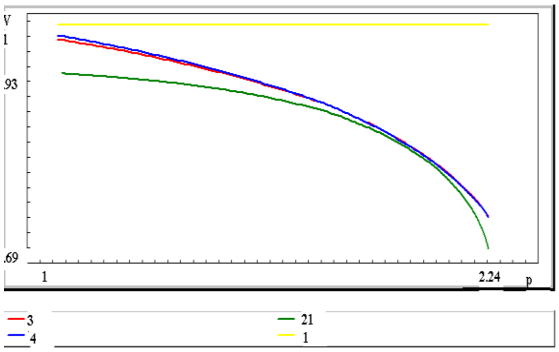

Fig. 9. PV curve by installing SVC in buses 1 and 23

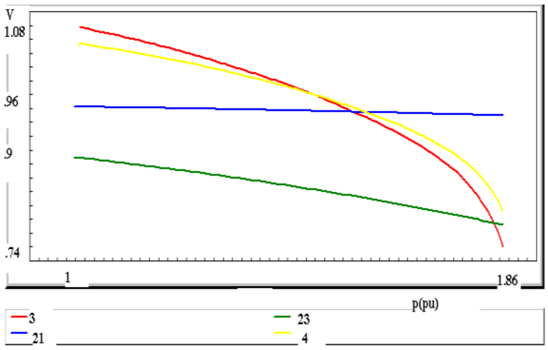

Fig. 10. P-V curve by installing STATCOM in bus 23

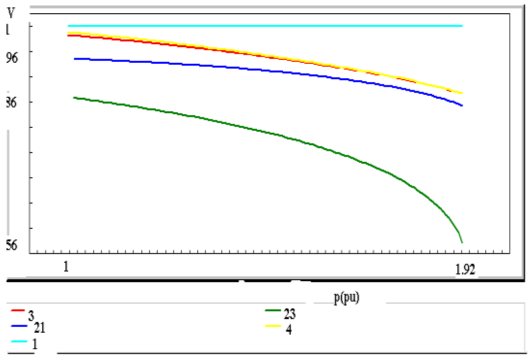

Fig. 11. P-V curve by installing STATCOM in bus 1

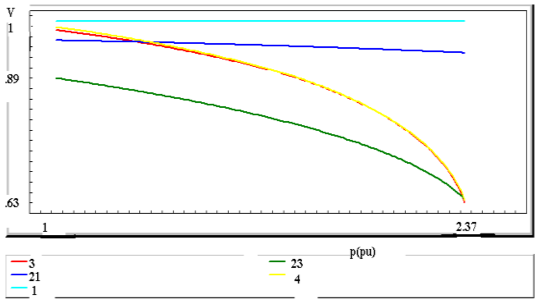

Fig. 12. PV curve by installing STATCOM in buses 1, 23

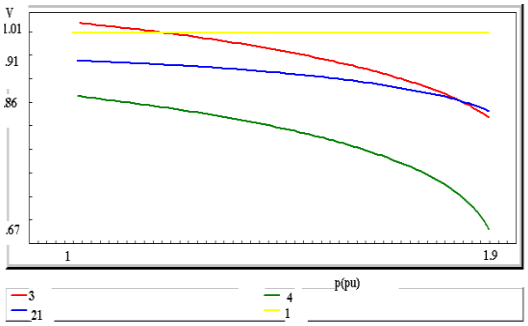

Fig. 13. PV curve by installing the UPFC in bus 23

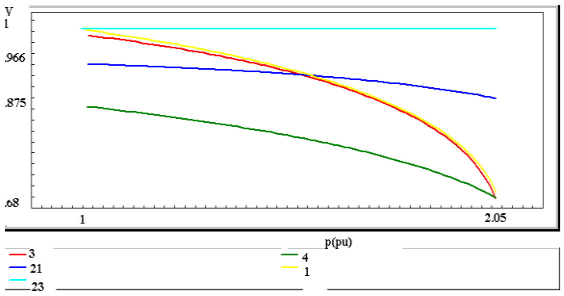

Fig. 14. PV curve by installing the UPFC in bus 1

For the comprehensive understanding, the simulation results of SVC, UPFC and STATCOM are given in Table I, II and III, respectively.

TABLE I: SVC INSTALLATION RESULTS

| SVC @ bus | Maximum loading in the weakest bus (p.u.) | Loading margins security in the weakest bus (p.u.) | The weakest bus |
|---|---|---|---|
| - | 1.71 | 0.71 | 23 |
| 23 | 1.73 | 0.73 | 3 |
| 3 | 1.74 | 0.74 | 23 |
| 4 | 1.85 | 0.85 | 23 |
| 1 | 1.91 | 0.91 | 23 |
| 1 and 23 | 2.24 | 1.24 | 21 |

TABLE II: UPFC INSTALLATION RESULTS

| UPFC @ bus | Maximum loading in the weakest bus (p.u.) | Loading margins security in the weakest bus (p.u.) | The weakest bus |
|---|---|---|---|
| - | 1.71 | 0.71 | 23 |
| 23 | 1.9 | 0.90 | 4 |
| 3 | 1.88 | 0.88 | 23 |
| 4 | 1.96 | 0.96 | 23 |
| 1 | 2.05 | 1.05 | 23 |
| 1 and 23 | 2.31 | 1.31 | 21 |

TABLE III: STATCOM INSTALLATION RESULTS

| STATCOM @ bus | Maximum loading in the weakest bus (p.u.) | Loading margins security in the weakest bus (p.u.) | The weakest bus |
|---|---|---|---|
| - | 1.71 | 0.71 | 23 |
| 23 | 1.86 | 0.86 | 3 |
| 3 | 1.79 | 0.79 | 23 |
| 4 | 1.87 | 0.87 | 23 |
| 1 | 1.92 | 0.92 | 23 |
| 1 and 23 | 2.24 | 1.24 | 21 |

## VIII. CONCLUSION

Today, by increasing the power system networks, network instability is considered as one of the security indices. If the balance between consumption and generation of reactive power does not be established or load sudden changes are occurred, the voltage collapse would be happened. This may be of partial or total collapse and even can include the whole system. With different methods, voltage instability can be prevented. One of the ways is install the FACTS controllers in the optimal places. In this paper, a 33-bus network test system is simulated in PSAF software. In this simulation, voltage instability in the network by installing FACTS controllers in the weakest bus and other buses has been analyzed. Simulation results showed that the impact of FACTS controllers in large networks has increased the voltage stability. Also, the UPFC performance in increasing voltage stability is better than the STATCOM and SVC.

## REFERENCES

[1] D. Mostafa Tobnaghi, P.Farhadi, B.Najafi, M.Karimi, and M. Toloei, Damping Power System Oscillation in Critical Condition using UPFC, Proceedings of the IASTED International Conference November 24 - 26, 2010 Phuket, Thailand Power and Energy Systems (AsiaPES 2010).

[2] M.Z El-Sadek, M Dessouky, G.A Mahmoud, W.I Rashed, *Series capacitors combined with static VAR compensators for enhancement of steady-state voltage stabilities*, Electric Power Systems Research, Volume 44, Issue 2, February 1998, Pages 137–143

[3] M. Karimi, P.Farhadi, M. Bagher Ahmadi, T. Sojoudi and D. Mostafa Tobnaghi, *Statistical Analysis of Shunt FACTS Devices Impact on Power Flow Control*, Research Journal of Applied Sciences, Engineering and Technology [in press].

[4] L. Battistelli, D. Lauria and D. Proto, *Reactive control in a deregulated environment with static VAr compensators improving voltage stability*, IET Proc-GTD, vol. 150, no. 1, 2003, pp.113-118.

[5] RM Monteiro Pereira, Adelino JC Pereira, CM Machado Ferreira e FP Maciel Barbosa, "Series Capacitor Compensation Strategy to Improve the Dynamic Voltage Stability of an Electric Power Network", The Second International Conference on Electrical Engineering (CEE'07), College of Engineering of Coimbra / DEE (ISEC), Coimbra, Portugal. November 26-28, 2007..

[6] C.S. Chang, J.S. Huang, *Optimal SVC placement for voltage stability* reinforcement, Electric Power Systems Research, Volume 42, Issue 3, September 1997, Pages 165–172.

[7] P.K. Modi, S.P. Singh, J.D. Sharma, *Fuzzy neural network based* voltage *stability evaluation of power systems with SVC*, Applied Soft Computing, Volume 8, Issue 1, January 2008, Pages 657–665.

[8] E. Kazemi Abharian, M. Karimi, and P. Farhadi, *STATCOM Controller* Design *Based on MLP for Power Flow Control*, International Journal of Modeling and Optimization, Vol. 1, No. 4, 2011, pp.328-334.

[9] Yankui Zhang, Yan Zhang, Bei Wu, Jian Zhou, *Power injection model of STATCOM with control and operating limit for power flow and voltage stability analysis*, Electric Power Systems Research, Volume 76, Issue 12, August 2006, Pages 1003–1010.

[10] P.K. Modi, S.P. Singh, J.D. Sharma, *Voltage stability evaluation of power system* with *FACTS devices using fuzzy neural network*, Engineering Applications of Artificial Intelligence, Volume 20, Issue 4, June 2007, Pages 481–491.

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