Global Journal of Engineering Science and Research Management

# A COMPREHENSIVE STUDY ON VOLTAGE STABILITY MARGIN IMPROVEMENT IN POWER SYSTEM

**Majeed Rashid Zaidan** *1, **Dr. Ali Mohammed Kathim Al-zohuari**2, **Saif Tahseen Hussain**3, **Ghanim Thiab Hasan**4, **Saber Izadpanah Toos**5
* 1 Technical Institute of Baqubah, Middle Technical University, Baghdad, Iraq.
2 Ministry of Municipalities, Baghdad, Iraq.
3 Company of Electricity Transmission, Diyala, Iraq.
4 Tikrit University, Oil and Minerals Engineering College, Tikrit, Iraq.
5 Sadjad University of Technology, Iran.

**DOI: 10.5281/zenodo.4764469**

**KEYWORDS:** FACTS devices, MLP, Shunt capacitor, STATCOM, SSSC, SVC, Tap-changing transformer, TCSC, Voltage stability.

## ABSTRACT

In a power system, the excessive voltage drop in the buses due to increasing power demand leads to voltage instability consequent voltage collapse. Hence the voltage stability is a critical concern in a power system. In this paper, the application of tap-changing transformer, shunt capacitor, Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor-Controlled Series Capacitor (TCSC), and Static Synchronous Series Compensator (SSSC) for improving voltage stability margin is studied. The Continuation Power Flow (CPF) method has been applied to the IEEE 14-bus test system to determine the Maximum Loading Point (MLP) and demonstrate the effectiveness of these devices on improving voltage stability margin. Simulation results show that these devices can increase the load ability margin of power systems and, as a result, causes voltage stability improvement. Although the performance of shunt compensation devices includes SVC, STATCOM, and shunt capacitor are better than other devices.

## INTRODUCTION

The beginning of the third millennium is characterised by ever-increasing competition and the globalisation of markets. This situation is the result of globalisation and technological development. It is no longer enough to do one's job well; it is necessary to provide a quality product and/or service that meets the needs and expectations of the customer (ISO 9000 version 2015, p.2). Surviving in this competitive environment requires the implementation of new management approaches, one of the most important of which is quality management. It therefore appears necessary, even essential for a company or institution wishing to emerge, to make quality its hobbyhorse currently, rising consumer demand and use of the power system close to their physical limits increase the possibility of system fault. In other words, the imbalance between power generation and power consumption can cause voltage instability and, as a result, a severe voltage drop in an extensive part of the power system. In this situation, the inability to quickly provide reactive power for compensating voltage drop and prevent voltage collapse can turn the power system toward blackout.

Voltage stability issues can be studied in two conditions, steady-state and transient-state. Voltage stability in steady-state addresses stability during small and low changes like gradual load variations, while in transient-state, it discusses stability in the time of large and sudden changes like fault occurrence, line outage, and sudden change in load [1]. Steady-state voltage stability can be analyzed based on power flow or CPF. Using the CPF method, the maximum loading point or voltage collapse point is determined [2], [3].

Generally, the maximum loading point and voltage stability margin will be improved by controlling the reactive power of the system. Usually, there are two solutions to control reactive power. The first solution is to control reactive power by controlling the power flow using tap-changing transformers and series-connected flexible AC transmission systems (FACTS). The second solution is to control reactive power by injecting reactive power into the network using shunt capacitors and Shunt-connected FACTS devices [3], [4].

This paper investigates the impact of tap-changing transformers, the shunt capacitor, series-connected FACTS devices, and shunt-connected FACTS devices on voltage stability margin improvement in power systems. The rest of this paper is arranged as follows; a survey of tap-changing transformers, the shunt capacitor, and FACTS devices are done in sections 2 to 4, respectively. Section 5 presents the continuation power flow. The Simulation results are provided in section 6. The paper finishes with a conclusion in the final section.

## TAP-CHANGING TRANSFORMER

Almost all electrical substations are equipped with tap-changing transformer facilities. Tap-changing transformers can eliminate or minimize the voltage instability of power systems. Generally, a transformer changes its tap position to control the voltage magnitude of a substation [5]. Many papers have studied the tap-changing transformer effect on voltage stability [5-10].

In Fig. 1, an equivalent circuit of a tap-changing transformer is shown, where $y_t$ is the admittance in p.u. based on the nominal turn ratio, and $a$ is the p.u. Off-nominal tap position that provides an adjustment in voltage of normally ±10% [11].

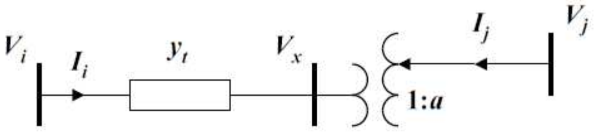


*Fig. 1. The equivalent circuit of a tap-changing transformer [11].*

The Π model illustrated in Fig. 2 presents the admittance matrix in equation (1). In the Π-model, the left side has no tap, and the right side has a tap [11].

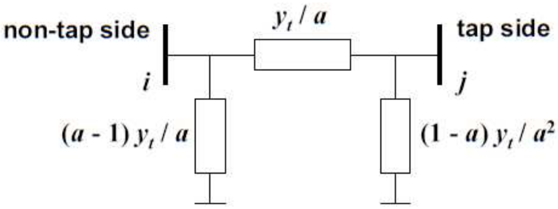


*Fig. 2. Π-equivalent model of the tap-changing transformer [11].*

$$\begin{bmatrix} I_i \\ I_j \end{bmatrix} = \begin{bmatrix} y_t & -\dfrac{y_t}{a} \\ -\dfrac{y_t}{a^*} & \dfrac{y_t}{|a^2|} \end{bmatrix} \begin{bmatrix} V_i \\ V_j \end{bmatrix} \tag{1}$$

## SHUNT CAPACITOR

Shunt capacitors are installed to provide reactive compensation, and they can improve voltage stability. However, shunt capacitors have a moderate performance for voltage regulation, but due to the low-cost of establishment and maintenance as well as ease of installation, they are plenty utilized in power systems [12], [13].

## FACTS DEVICES

Flexible AC Transmission Systems is a modern development in power systems that uses high-power semiconductor components in their structures. The primary duties of FACTS devices are power flow control, increasing transmission line capacity, voltage control, reactive power compensation, stability improvement, enhancing power quality, and flicker reduction [14], [15]. The classification of FACTS devices can be done in two forms [16], [17]:

1- Based on internal structure:
- Thyristor-based: SVC, TCSC, Thyristor-Controlled Phase Shifter Transformer (TCPST), and Thyristor-Controlled Reactor (TCR).
- Voltage Source Converter (VSC)-based: STATCOM, SSSC, Unified Power Flow Controller (UPFC), and Interline Power Flow Controller (IPFC).

2- Based on the connection type to power systems:
- Shunt: STATCOM and SVC.
- Series: SSSC and TCSC.
- Series-Shunt: UPFC and TCPST.
- Series - Series: IPFC.

### Static Var Compensator

Static Var Compensators have been installed as the most well-known FACTS devices in about 100 places for reactive power compensation and, as a result, controlling the voltage profile [18]. The role of the SVC for improvement in voltage stability has been investigated in numerous articles [19-23].

Commonly, an SVC structure is a combination of a fixed capacitor ($C$) in parallel with a TCR, as illustrated in Fig. 3. The variable susceptance ($B_{SVC}$), the total effective reactance ($X_{SVC}$), and TCR reactance ($X_{TCR}$) can be calculated as follows [24]:

$$B_{SVC} = -\frac{1}{X_{SVC}} \tag{2}$$

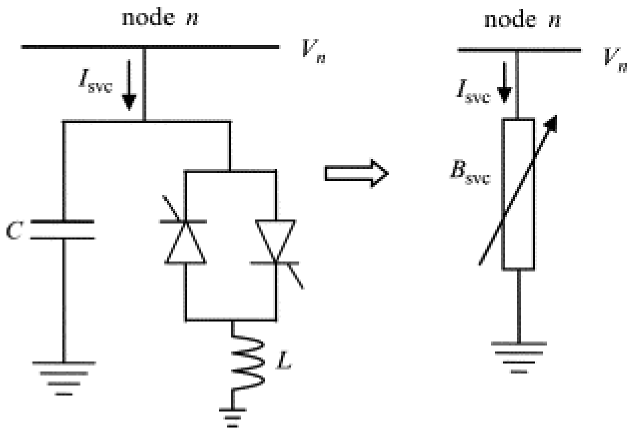
$$X_{SVC} = \frac{X_C X_{TCR}}{X_C + X_{TCR}} \tag{3}$$

$$X_{TCR} = \frac{\pi X_L}{\sigma - \sin\sigma} \tag{4}$$

Where $X_C$ is the capacitive reactance, $X_L$ is the inductive reactance, and σ is the conduction angle. The relation between the conduction angle and the firing angle ($\alpha$) of thyristors is $\sigma=2(\pi-\alpha)$. The reactive power exchanged by the SVC at the bus n can be expressed as [24]:

$$Q_{SVC} = Q_n = -B_{SVC} V_n^2 \tag{5}$$

Where $V_n$ is the voltage amplitude of the bus where the SVC is connected. If $Q_{SVC} < 0$, the SVC generates reactive power, and if $Q_{SVC} > 0$, the SVC absorbs reactive power [25].



*(a)* *(b)*

*Fig. 3. (a) Structure of the SVC, (b) Variable susceptance model of the SVC [24].*

### Static Synchronous Compensator

The function of a STATCOM is like an SVC; however, it can rapidly inject/absorb reactive power faster [24]. Generally, The STATCOM has more functional superiority than SVC, but the STATCOM is expensive and complicated to implement. In practice, SVC has been applied more often than STATCOM as a reactive power compensation device in a transmission system [26]. In various researches, the impact of the STATCOM on voltage stability has been investigated [27-31].

The configuration of a VSC-based STATCOM is shown in Fig. 4. The structure of a STATCOM can include a VSC, a magnetic circuit (MC), a shunt coupling transformer, and a shunt breaker. The presence of a DC voltage source in the capacitor causes the VSC to convert its voltage to an AC voltage source and control the bus voltage. By adjusting the output voltage range of the three-phase converter ($V_{SC}$), the reactive power exchange between the converter and the AC mains will be controlled [24], [32]. The reactive power exchanged by the STATCOM at the bus $j$ can be expressed as [24]:

$$Q_{STATCOM} = \frac{|V_j|^2}{X_{SC}} - \frac{|V_j||V_{SC}|}{X_{SC}}\cos\left(\theta_j - \delta_{SC}\right) \tag{6}$$

$$V_{SC} = |V_{SC}|\left(\cos\delta_{SC} + j\sin\delta_{SC}\right) \tag{7}$$

Where $V_j\angle\theta_j$ is the bus voltage at bus $j$, $V_{sc}\angle\delta_{sc}$ is the AC voltage at the output of the STATCOM, and $X_{sc}$ is the reactance of the line between the bus $j$ and the STATCOM. If $Q_{STATCOM} < 0$, the STATCOM injects reactive power, and if $Q_{STATCOM} > 0$, the STATCOM absorbs reactive power [25].

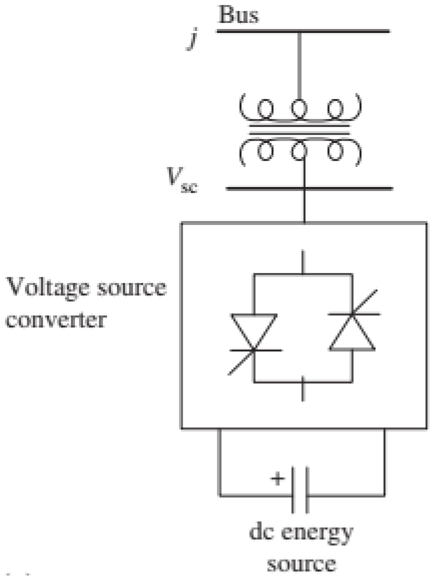


*Fig. 4. VSC-based STATCOM [24].*

### Thyristor-Controlled Series Capacitor

The series compensation can be categorized into two types fixed and variable series compensation. Generally, series compensation can enhance the power transfer capability of the line and improve the power system stability. The TCSC is a type of variable series compensation that can change line reactance by putting a Thyristor-Controlled Capacitor (TCC) in series with the transmission line [33-35]. Effects of the TCSC on voltage stability are studied in various researches [1], [36-38]. Based on Fig. 5, the structure of the TCSC uses a series capacitor connected in parallel with a TCR.

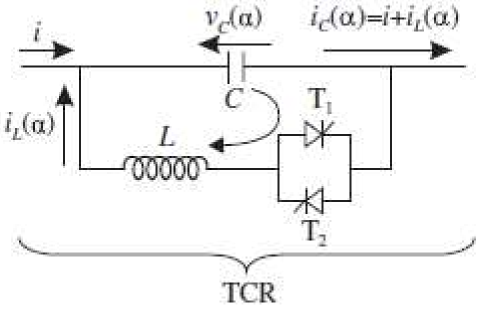


*Fig. 5. The structure of the TCSC [32].*

The TCSC inserts in a transmission line a variable capacitive reactance ($X_{TCSC}$) that is related to the firing angle ($\alpha$) of the thyristor [39]:

$$X_{TCSC}(\alpha)=\frac{X_C X_L(\alpha)}{X_L(\alpha)-X_C}=-j\frac{1}{\omega C-\frac{1}{\omega L}} \qquad (8)$$

$$X_L(\alpha)=X_L\frac{\pi}{\pi-2\alpha-\sin\alpha}\quad (X_L\le X_L(\alpha)\le\infty) \qquad (9)$$

Where $X_C$ is the impedance of the capacitor, $X_L$ is the impedance of the reactor, and $X_L(\alpha)$ is the controlled reactor impedance.

**Static Synchronous Series Compensator**

The SSSC is a type of variable series compensation that can be considered as an advanced TCSC. An SSSC has more advantages than a TCSC, such as higher speed, more comprehensive control range, and no use of bulky capacitors and reactors. However, a TCSC is cheap and has no complexity; therefore, it has a higher practical application [24], [40], [41]. Improving voltage stability by the SSSC is examined in [42-45].

Like the STATCOM, an SSSC uses a VSC, but it is connected in series with the transmission line by a coupling transformer, Fig. 6 [32]. An SSSC presents the series compensation by injecting the controllable voltage ($V_q$) in series with the transmission line. $V_q$ is in quadrature with the line current ($I$) and emulates an inductive or a capacitive reactance [46].

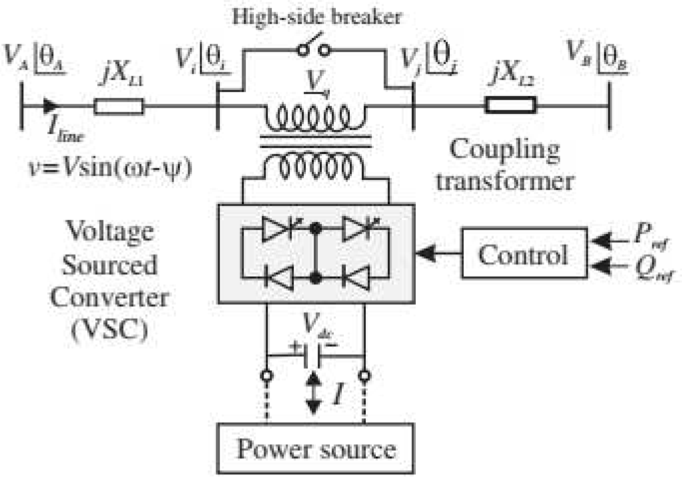


*Fig. 6. The structure of the SSSC [32].*

The injected voltage ($V_q$) can be written as [47]:

$$V_q = \left| \overline{V}_q \right| \tag{10}$$

where

$$\overline{V}_q = V_q \left\{ \overline{I} \big/ \left| \overline{I} \right| \right\} e^{\mp j\,90^\circ} \tag{11}$$

## CONTINUATION POWER FLOW

The continuation power flow method is a valuable technique in detecting the maximum loading point (MLP) at the critical point or voltage collapse point. Mathematically, the CPF method investigates the stability of a power system by changing a system parameter, which is the same loading parameter ($\lambda$) in static and dynamic analysis of voltage stability. As shown in Fig. 7, In the CPF method, the predictor-corrector steps are employed to solve the PV curve [48].

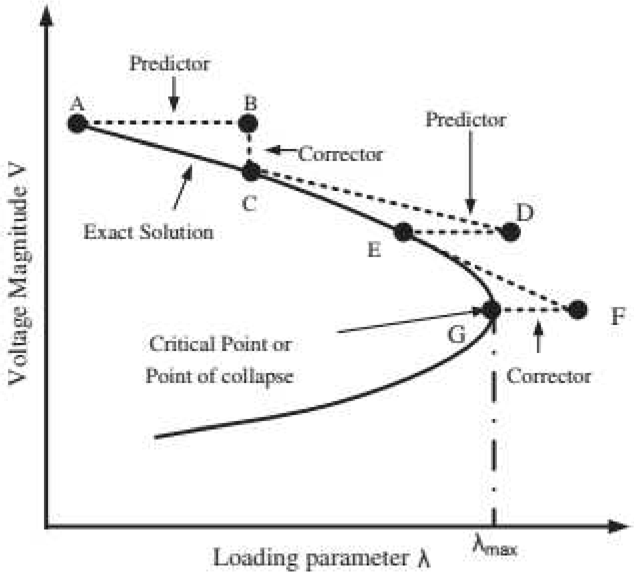


*Fig. 7. The CPF method [48].*

## SIMULATION RESULTS

A single line diagram of the IEEE 14-bus test system is shown in Fig. 8. The system consists of five synchronous machines, including three synchronous compensators employed only for reactive power compensation. Also, it includes 16 transmission lines, four transformers, and 11 loads [49]. The minimum and maximum voltage limits at load buses are considered 0.9 p.u. and 1.1 p.u., respectively.

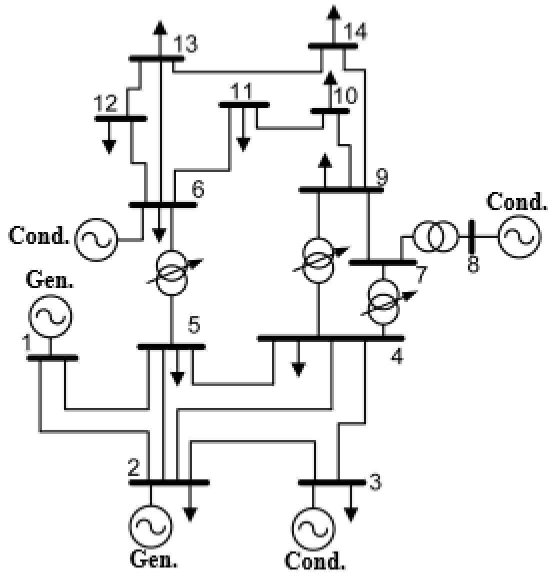


*Fig. 8. Single line diagram of the IEEE 14- bus test system.*

The Power System Analysis Toolbox (PSAT) and MATLAB codes are used for simulation purposes. The results of power flow and CPF are presented in Table 1. For the base case, the tap ratio of tap-changing transformers is $Tap_{4\text{-}7}=0.978$, $Tap_{4\text{-}9}=0.969$, and $Tap_{5\text{-}6}=0.932$.

*TABLE 1. Power flow and CPF results.*

| | Power Flow | | CPF |
|---|---|---|---|
| **Bus No.** | **Amplitude (p.u.)** | **Phase (Deg.)** | **Critical voltage (p.u.)** |
| 1 | 1.06 | 0 | 1.06 |
| 2 | 1.045 | -4.99 | 1.045 |
| 3 | 1.01 | -12.74 | 1.01 |
| 4 | 1.014 | -10.26 | 0.69 |
| 5 | 1.017 | -8.77 | 0.67 |
| 6 | 1.07 | -14.42 | 1.07 |
| 7 | 1.05 | -13.26 | 0.78 |
| 8 | 1.09 | -13.26 | 1.09 |
| 9 | 1.033 | -14.83 | 0.68 |
| 10 | 1.032 | -15.04 | 0.71 |
| 11 | 1.047 | -14.85 | 0.87 |
| 12 | 1.053 | -15.72 | 0.97 |
| 13 | 1.047 | -15.74 | 0.92 |
| 14 | 1.021 | -16.4 | 0.67 |
| | **Total Losses**: | 13.55 MW<br>31.17 MVar | **MLP** ($\lambda_{max}$) = 4.03 p.u. |

According to Table (1), buses 4, 5, 9, and 14 are the four weakest buses. The weakest bus is defined as the bus which has a higher desire for experiencing voltage collapse [12]. The P-V curves for the weakest buses are shown in Fig. 9.

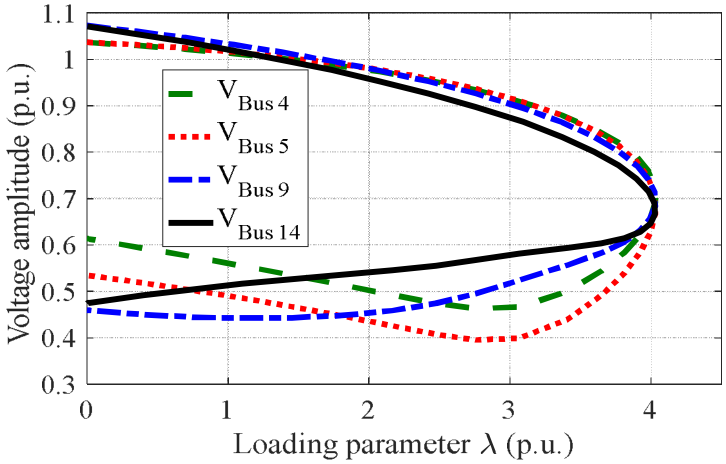


*Fig. 9. The P-V curves for the weakest buses.*

**Impact of Tap-changing Transformer**

Based on [50], the tap ratio has been considered between 0.9 and 1.1 with a step size of 0.00625 to find the highest MLP. For each step size, the CPF is run, and the loading parameter is calculated. After running 35937 iterations, the highest MLP has been obtained equal to 4.057 p.u. for $Tap_{4\text{-}7}=0.9$, $Tap_{4\text{-}9}=0.9$, and $Tap_{5\text{-}6}=0.9$. In other words, a 0.67% increase in MLP is obtained. In Fig. 10, the highest MLP is shown in the 3D scatter-plot.

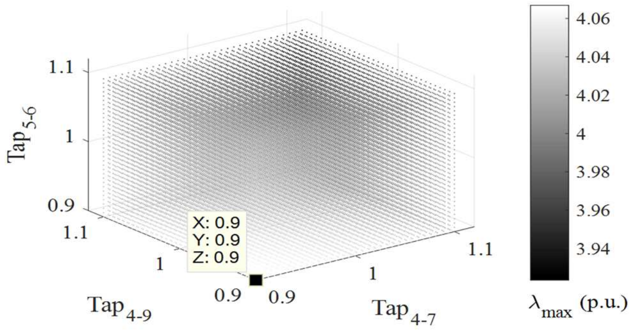


*Fig. 10. 3D scatter-plot for tap ratio variations.*

The voltage amplitude in the base case and adjusted tap-changing transformers is shown in Fig. 11. The results show the voltage stability is improved

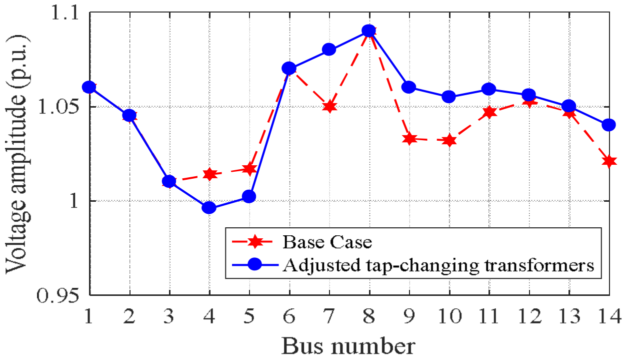


*Fig. 11. Comparison of the voltage amplitude (base case and adjusted tap-changing transformers).*

Active and reactive power losses are 13.88 MW and 32.52 MVar, respectively. The results reveal a minor increase in losses.

**Impact of Shunt Capacitor**

According to [23], the best location of the SVC for regulating voltage levels is bus 9, as well as since bus 9 is weak, hence SVC, STATCOM, and shunt capacitor will be installed at bus 9. For a fair comparison, the reactive power injection constraint for shunt-connected devices is considered ±50 MVar. The shunt capacitor is connected to bus 9 in the base case ($Tap_{4\text{-}7}=0.978$, $Tap_{4\text{-}9}=0.969$, $Tap_{5\text{-}6}=0.932$), and reactive power injection by shunt capacitor will change to determine the highest MLP. According to the result, the highest MLP is obtained equal to 4.104 p.u. when 50 MVar reactive power is injected by shunt capacitor. The voltage amplitude without/with shunt capacitor is shown in Fig. 12.

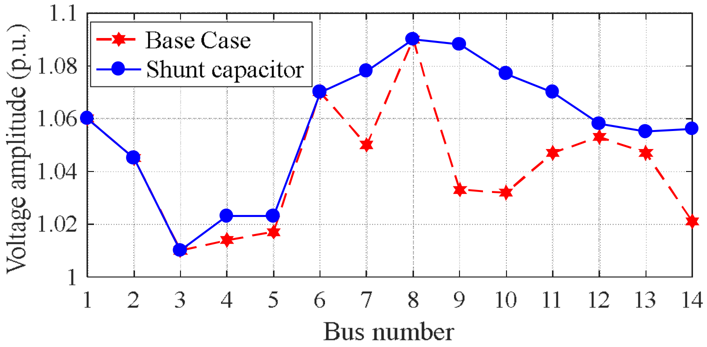


*Fig. 12. Comparison of the voltage amplitude (base case and shunt capacitor).*

The results show the shunt capacitor has a significant effect on voltage stability improvement. Also, after installing a shunt capacitor, active and reactive power losses are 13.47 MW and 30.36 MVar, respectively; hence, as can be seen, the shunt capacitor can decrease losses.

**Impact of SVC**

The SVC has been connected to bus 9 in the base case. Then parameters are set so that the maximum reactive power (i.e., 50 MVar) is injected into the bus. The CPF result shows the MLP is equal to 4.15 p.u. which has been improved a 2.98% from the base case. According to Fig. 13, the SVC can improve the voltage amplitude compared to the base case. Also, as can be seen, the SVC and shunt capacitor have similar results in voltage amplitude.

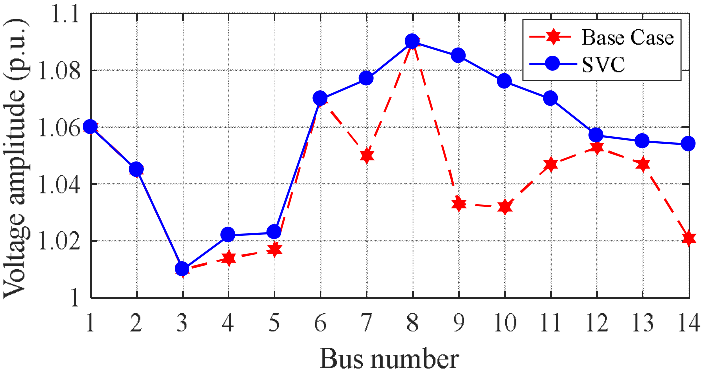


*Fig. 13. Comparison of the voltage amplitude (Base case and SVC).*

Active and reactive power losses are 13.45 MW and 30.25 MVar, respectively, representing a reduction in losses.

**Impact of STATCOM**

After installing the STATCOM to bus 9 in the base case, parameters are adjusted to inject 50 MVar reactive power into the bus. According to results, so far, the highest MLP, i.e., 4.282 p.u., is provided by STATCOM.

Comparing the voltage amplitude of buses without synchronous machines is shown in Fig. 14. The results show that Shunt-connected devices include SVC, STATCOM, and shunt capacitor, have the same function in improving the voltage amplitude. Notice, if a shunt capacitor with a higher reactive power injection is used, it can cause some buses to violate the maximum voltage limit.

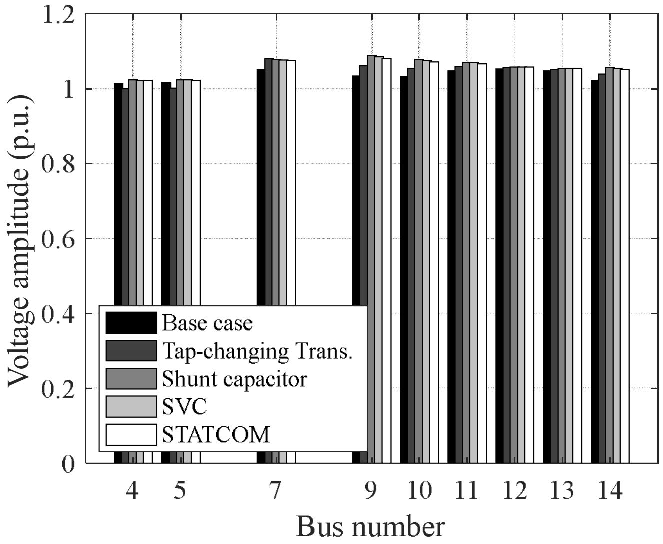


*Fig. 14. Comparison of the voltage amplitude.*

For further investigation, a comparison between the MLP, the critical voltage of the four weakest buses at the MLP, and losses are shown in Fig. 15 to Fig. 17, respectively.

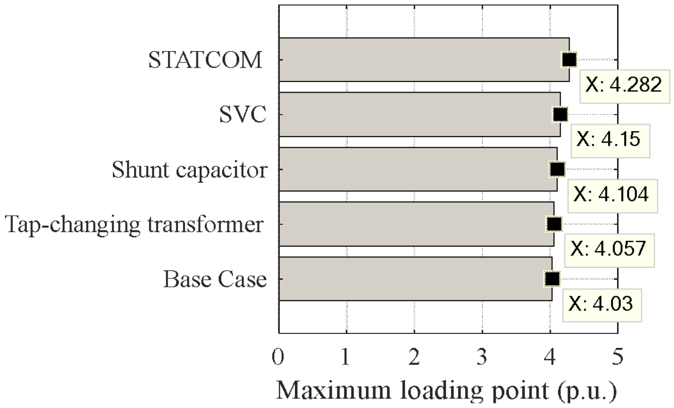


*Fig. 15. Comparison of the MLP.*

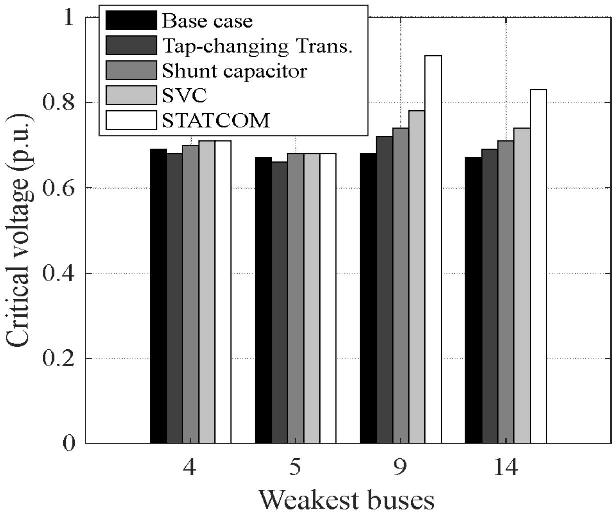


*Fig. 16. Comparison of critical voltage of four weakest buses at MLP.*

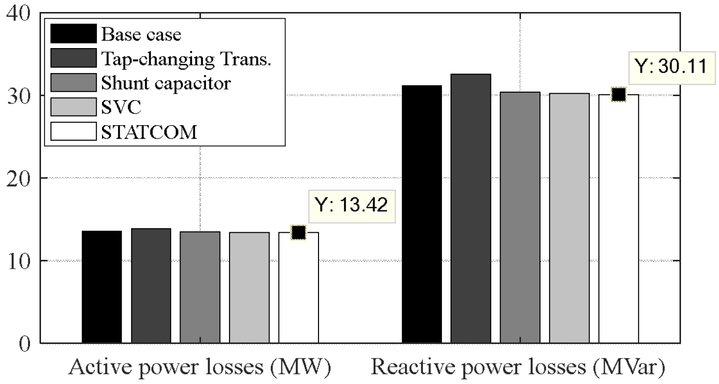


*Fig. 17. Comparison of losses.*

According to the results, the STATCOM has the best performance; however, it is expensive compared to other shunt reactive power compensators.

**Impact of TCSC and SSSC**

In the base case, a TCSC is placed in branch number 17 (from bus 9 to bus 14), then it is removed and replaced with an SSSC. The parameters of these two devices will be adjusted to achieve the highest MLP.

For a 90 percent of series compensation, the MLP is calculated 4.071 p.u. for both devices. Also, they have the same active and reactive power losses, which are 13.36 MW and 30.81 MVar, respectively. Fig. 18 and Fig. 19 show the voltage amplitude of buses and the critical voltage of the four weakest buses at the MLP, respectively.

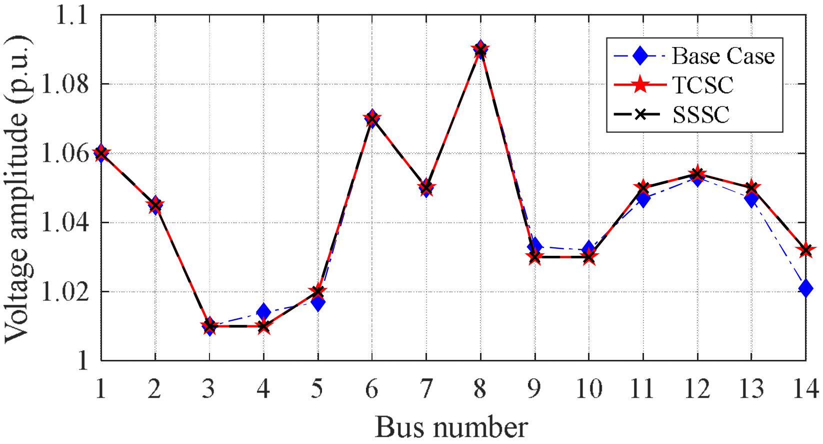


*Fig. 18. Comparison of the voltage amplitude (Base case, TCSC, SSSC).*

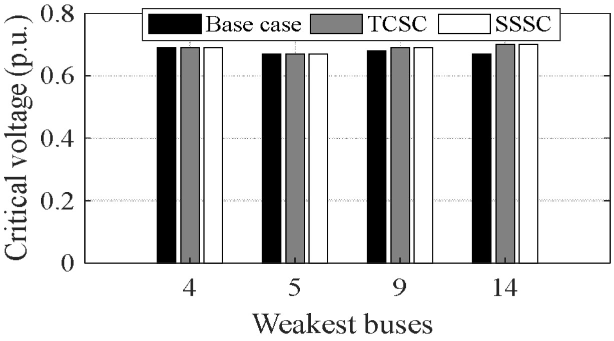


*Fig. 19. Comparison of critical voltage of four weakest buses at MLP.*

As can be seen, the effectiveness of the SSSC and TCSC is minor on voltage amplitude and critical voltage, and they have similar performance on voltage stability.

## CONCLUSION

This paper presents a comprehensive study on voltage stability margin improvement using tap-changing transformers, shunt capacitor, SVC, STATCOM, TCSC, and SSSC. The continuation power flow method has been used to examine the effectiveness of devices on voltage stability margin improvement in power systems. The results show all devices can increase the maximum loading point and voltage stability margin; however, SVC and STATCOM as shunt-connected FACTS devices provide better performance in terms of loss reduction and improving voltage profile, and it is evident that the STATCOM has the best function. It should be noted that SVC and STATCOM are expensive when compared to the shunt capacitor.

## REFERENCES

1. M. R. Zaidan, S. Izadpanah Toos, and S. T. Hussain, “Impact of Using TCSC on Power System Stability,” World Journal of Engineering Research and Technology (WJERT), vol. 6, no. 6, pp. 238-251, 2020.
2. M. R. Aghamohammadi, S. Hashemi, and M. S. Ghazizadeh, "Improving Voltage Stability Margin Using Voltage Profile and Sensitivity Analysis by Neural Network", Iranian Journal of Electrical & Electronic Engineering, vol. 7, no. 1, pp. 33-41, 2011.
3. M. A. Kamarposhti, and H. Soltani, "The study of maximum loading point in investigation of capacitor performance with power electronic shunt devices," International Conference on Electrical and Electronics Engineering (ELECO), pp. I-326-I-330, 2009.

4. A. Chakrabarti and S. Halder, Power System Analysis, Operation and Control, 3rd Edition, PHI Learning Private Ltd., New Delhi, 2010.
5. P. L. Swe, W. Swe, and K. M. Lin, “Effects of Tap Changing Transformer and Shunt Capacitor on Voltage Stability enhancement of Transmission Networks,” World Academy of Science, Engineering and Technology, vol. 5, no. 3, pp. 268-271, 2011.
6. M. S. Calovic, "Modeling and Analysis of Under-Load Tap-Changing Transformer Control Systems," IEEE Transactions on Power Apparatus and Systems, vol. PAS-103, no. 7, pp. 1909-1915, 1984.
7. C.-C. Liu, and K. T. Vu, "Analysis of tap-changer dynamics and construction of voltage stability regions," IEEE Transactions on Circuits and Systems, vol. 36, no. 4, pp. 575-590, 1989.
8. M. Z. El-Sadek, G. A. Mahmoud, M. M. Dessouky, and W. I. Rashed, “Tap changing transformer role in voltage stability enhancement,” Electric Power Systems Research, vol. 50, no. 1, pp. 115-118, 1999.
9. D. Thukaram, L. Jenkins, H. P. Khincha, G. Yesuratnam, and B. R. Kumar, "Monitoring the effects of on-load tap changing transformers on voltage stability," International Conference on Power System Technology (POWERCON), vol. 1, pp. 419-424, 2004.
10. M. R. Shakarami, R. Sedaghati, “A Study on Integrated Performance of Tap-Changing Transformer and SVC in Association with Power System Voltage Stability,” World Academy of Science, Engineering and Technology, vol. 8, no. 7, pp. 1181-1188, 2014.
11. Hadi Saadat, Power Systems Analysis, 2nd ed., McGraw-Hill, 2002.
12. A. Sode-Yome, and N. Mithulananthan, "Comparison of shunt capacitor, SVC and STATCOM in static voltage stability margin enhancement," International Journal of Electrical Engineering Education, Vol. 41, No. 2, pp. 158-171, 2004.
13. H. Omidi, B. Mozafari, A. Parastar, and M. A. Khaburi, "Voltage stability margin improvement using shunt capacitors and active and reactive power management," IEEE Electrical Power & Energy Conference (EPEC), pp. 1-5, 2009.
14. V.K. Sood, HVDC and FACTS controllers: applications of static converters in power systems. Kluwer Academic Publishers, 2004.
15. M. Jourabian, G. B. Gharehpetian, and D. Mirabassi, Flexible AC Transmission Systems, Concepts and Applications. Chamran University Publication, 2nd Edition, 2010 (in Persian).
16. Y. H. Song and A. T. Johns, Flexible AC Transmission Systems (FACTS). London, U.K., IEE Press, 1999.
17. S. Chawla, S. Garg, and B. Ahuja, "Optimal location of series-shunt FACTS device for transmission line compensation," International Conference on Control, Automation, Communication and Energy Conservation, pp. 1-6, 2009.
18. F. M. Albatsh, S. Mekhilef, S. Ahmad, H. Mokhlis, and M. Hassan, "Enhancing power transfer capability through flexible AC transmission system devices: A review", Frontiers of Information Technology & Electronic Engineering, vol. 16, no. 8, pp. 658-678, 2015.
19. S. Sakthivel, D. Mary, R. Vetrivel, and V. S. Kannan, “Optimal Location of SVC for Voltage Stability Enhancement under Contingency Condition through PSO Algorithm,” International Journal of Computer Applications, vol. 20, no. 1, pp. 30-36, 2011.
20. S. Dixit, L. Srivastava, and G. Agnihotri, “Optimal placement of SVC for minimizing power loss and improving voltage profile using GA,” International Conference on Issues and Challenges in Intelligent Computing Techniques (ICICT), pp. 123-129, 2014.
21. P. Balachennaiah, P. H. Reddy, and U. N. K. Raju, “A novel algorithm for voltage stability augmentation through optimal placement and sizing of SVC,” IEEE International Conference on Signal Processing Informatics Communication and Energy Systems (SPICES), pp. 1-5, 2015.
22. P. Choudekar, S. K. Sinha, and A. Siddiqui, “Optimal location of SVC for improvement in voltage stability of a power system under normal and contingency condition,” International Journal of System Assurance Engineering and Management, vol. 8, pp. 1312–1318, 2017.
23. M. R. Zaidan, and S. Izadpanah Toos, "Optimal Location of Static Var Compensator to Regulate Voltage in Power System," IETE Journal of Research, 2021.
24. D. Mondal, A. Chakrabarti, and A. Sengupta, Power System Small Signal Stability Analysis and Control. Academic Press, second Edition, 2020.

25. M. R. Zaidan, "Improvement of Transient Voltage Stability in Power System using Shunt-Connected FACTS devices," Solid State Technology, vol. 63, no. 6, pp. 22923-22932, 2020.
26. D. Lijie, L. Yang, and M. Yiqun, “Comparison of High Capacity SVC and STATCOM in Real Power Grid,” International Conference on Intelligent Computation Technology and Automation (ICICTA), pp. 993-997, 2010.
27. N. K. Hasanah, L. M. Putranto, S. P. Hadi, and F. M. R. Aditya, "Impact of STATCOM Installation on Power System’s Voltage Stability Performance," 4th International Conference on Information Technology, Information Systems and Electrical Engineering (ICITISEE), pp. 435-439, 2019.
28. M. Shaygan, S. Gh. Seifossadat, and M. Razaz, “Study the Effects of STATCOM on the Static Voltage Stability Improvement and Reduction of Active and Reactive Losses,” International Review of Electrical Engineering (I.R.E.E.), vol. 6, no. 4, pp. 1862-1869, 2011.
29. Q. Wang, B. Wang, W. Xu, and J. Xu, "Research on STATCOM for reactive power flow control and voltage stability in microgrid," 13th IEEE Conference on Industrial Electronics and Applications (ICIEA), pp. 2474-2479, 2018.
30. G. Choudhary, N. Singhal, and K. S. Sajan, "Optimal placement of STATCOM for improving voltage profile and reducing losses using crow search algorithm," International Conference on Control, Computing, Communication and Materials (ICCCCM), pp. 1-6, 2016.
31. Whei-Min Lin, Kai-Hung Lu, Cong-Hui Huang, Ting-Chia Ou, and Yuan-Hui Li, "Optimal location and capacity of STATCOM for voltage stability enhancement using ACO plus GA," IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 1915-1920, 2009.
32. M. Eremia, C.-C. Liu, and A.-A. Edris, Advanced Solution in Power Systems: HVDC, FACTS, and Artificial Intelligence, Wiley-IEEE Press, 2016.
33. A. Ahmadi, F. H. Gandoman, B. Khaki, A. M. Sharaf and J. Pou, "Comprehensive review of gate-controlled series capacitor and applications in electrical systems", IET Generation, Transmission & Distribution, vol. 11, no.5, pp. 1085-1093, 2017.
34. Al-Zohuariali M. Kathim and Majeed R. Zaidan, "Use Series Compensation in Distribution Networks 33 KV", International Journal of Science and Research (IJSR), vol. 6, no. 6, pp. 2579-2583, 2017.
35. R. N. Nayak, Y. K. Sehgal and S. Sen, "Series Compensation on 400 kV Transmission Line - A Few Design Aspects", National Power Systems Conference (NPSC), pp. 206-211, 2004.
36. L. Srivastava, S. Dixit, and G. Agnihotri, "Optimal location and size of TCSC for voltage stability enhancement using PSO-TVAC," POWER AND ENERGY SYSTEMS: TOWARDS SUSTAINABLE ENERGY, 2014.
37. A. Sheth, C. D. Kotwal, and S. Pujara, "Optimal placement of TCSC for improvement of static voltage stability," 5th Nirma University International Conference on Engineering (NUiCONE), pp. 1-6, 2015.
38. M. Amroune, A. Bourzami, and T. Bouktir, " Voltage Stability Limit Enhancement using Thyristor Controlled Series Capacitor (TCSC)," International Journal of Computer Applications (IJCA), vol. 72, no. 20, pp. 46-50, 2013.
39. N. G. Hingorani, and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems, Wiley-IEEE Press, 2000.
40. L. Qing, W. Zengping, and Z. Zhenhua, "Study and Simulation of SSSC and TCSC Transient Control Performance," Joint International Conference on Power System Technology and IEEE Power India Conference, pp. 1-6, 2008.
41. J. Morsali, K. Zare, and M. T. Hagh, "Performance comparison of TCSC with TCPS and SSSC controllers in AGC of realistic interconnected multi-source power system", Ain Shams Engineering Journal, vol. 7, no. 1, pp. 143-158, 2016.
42. D.A. Ingole, and V.N. Gohokar, "Voltage Stability Improvement In Multi-bus System Using Static Synchronous Series Compensator", Eenrgy Procedia, vol. 117, pp. 999-1006, 2017.
43. H. Taheri, S. Shahabi, S. Taheri, and A. Gholami, "Application of Synchronous Static Series Compensator (SSSC) on enhancement of voltage stability and power oscillation damping," IEEE EUROCON, pp. 533-539, 2009.
44. C. Anitha, and P. Arul, "Enhancement of voltage stability in transmission system using SSSC," International Conference on Circuits, Power and Computing Technologies (ICCPCT), pp. 30-33, 2014.

45. I. G. Adebayo, D. O. Aborisade, and K. A. Oyesina, "Steady State Voltage Stability Enhancement using Static Synchronous Series Compensator (SSSC); A Case Study of Nigerian 330kV Grid System Grid System," Research Journal in Engineering and Applied Sciences, vol. 2, no. 1, pp. 54-61, 2013.
46. S. C. Swain, S. Panda, and S. Mahapatra and, "A multi-criteria optimization technique for SSSC based power oscillation damping controller design", Ain Shams Engineering Journal, vol. 7, no. 2, pp. 553-565, 2016.
47. L. Gyugyi, C. D. Schauder, and K. K. Sen, "Static synchronous series compensator: a solid-state approach to the series compensation of transmission lines," IEEE Transactions on Power Delivery, vol. 12, no. 1, pp. 406-417, 1997.
48. M. Aman, G. Jasmon, A. Bakar, and H. Mokhlis, "Optimum network reconfiguration based on maximization of system loadability using continuation power flow theorem", International Journal of Electrical Power & Energy Systems, vol. 54, pp. 123–133, 2014.
49. Power Systems Test Case: IEEE 14 Bus Power Flow Test Case, University of Washington, 2003. Available: http://labs.ece.uw.edu/pstca/pf14/pg_tca14bus.htm.
50. H. Xu, A. D. Domínguez-García, and P. W. Sauer, "Optimal Tap Setting of Voltage Regulation Transformers Using Batch Reinforcement Learning," IEEE Transactions on Power Systems, vol. 35, no. 3, pp. 1990-2001, 2020.