Application of TCSC and SVC to Enhance the Power System Static Voltage Stability

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Abstract

In this paper, the performance of two types of FACTS devices in order to enhance the power system static voltage stability has been investigated. These devices include Static Var Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC). The modeling of the Single Machine Infinite Bus (SMIB) and aforesaid devices has been made up in steady state mode with disregarding of the generator limitations. The incremental load changes will cause the voltage collapse phenomenon, load power factor decrease and load current increase. Consequently, the voltage will have more decrement and therefore voltage will collapse, and then the power system will be encountered with instability problem. This paper presents a scale of the Voltage Collapse Proximity Indicator (VCPI) for evaluation of voltage stability and its role in transmission line power flow. Application of the mentioned compensators in power system will improve the voltage stability and power flow in transmission line. The simulation results of this paper reveal the good efficiency of TCSC and SVC in reducing the voltage collapse and improving the bus voltage.

Keywords: FACTS, TCSC, SVC, VCPI, SMIB

1. Introduction

One of the main issues in the field of electric power system is power system stability that many definitions are presented about it in literatures [1−4]. Generally, recovery of power system after any kind of disturbances and release it from synchronism loss is introduced as power system stability [5]. By the way, power system stability has been dealt with form three viewpoints:

1) Steady state: inspection of the stability under small disturbance in power system.

2) Dynamical: inspection of the stability under small disturbance affected by system's controllers.

3) Transient: inspection of the stability under sever disturbance in power system.

Recent advances in the field of power electronics provided an appropriate bed in order to using of Flexible AC Transmission System (FACTS) devices in power system [6]. FACTS devices have ability to control network status in very rapid events and this particular feature increased the power system transient stability. TCSC and SVC are two prominent FACTS devices that by compensating of reactive power can play important role in controlling active power through the power network, improving voltage fluctuation and power system static voltage stability [7−9]. Furthermore, these devices can improve the flexibility of transferring the power and reliability of the power system. It is due to speed response of the devices in disturbance positions in order to diminish the sequel of backwashes. As described in literatures, the occurrence of any kind of disturbances in power system can cause the collapse of the voltage stability [10−13]. Aforesaid problem has been thoroughly investigated the studied power system. Likewise, the possible approaches to repel and eliminate the effects of these disturbances in power system will be inspected and suggested. In this paper, the scale of Voltage Collapse Proximity Indicator (VCPI) is extracted and then implemented to evaluate the voltage stability and its role in transmission line power flow. Likewise, both the TCSC and SVC will be applied to enhance the bus voltage and power system static voltage stability. Meanwhile, the

Journal of Electrical Power Systems- Vol. 1-No. 2- Autumn 2012

MATLAB software has been used to carry out the studied power system and its other relevant details. To sum up, the results of simulation reveal that by application of TCSC and SVC the static voltage stability has been significantly enhanced.

2. Modeling of the FACTS Controllers

For this study, both the series and shunt FACTS devices (TCSC and SVC) are used to deal with their roles in enhancing the bus voltage and power system static voltage stability.

2.1. SVC

Generally, SVC consists of [14]: Fixed Capacitor (FC) and Thyristor Controlled Reactor (TCR) which are connected in parallel to each other. The single line diagram of this device is shown in Fig. 1.

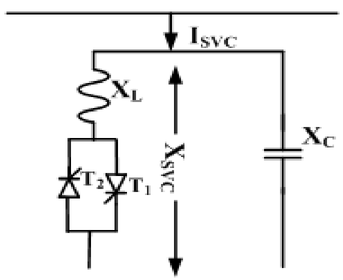

Figure 1. Equivalent circuit of SVC

TCR is a changeable inductive reactor (X_L) which is controlled by firing angle α. According to the power system position, α can be selected between $90^0$and 180^0. In fundamental frequency, the value of TCR is given by:

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

In the sequel, the final value for SVC's reactance can be presented by:

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

As for the required qualification for the power system, SVC can act as capacitor or inductance.

2.2. TCSC

The single line diagram of TCSC [8] is presented in Fig. 2.

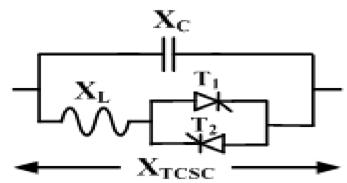

Figure 2. Equivalent circuit of SVC

Same the previous section, the final value for TCSC's reactance is considered by:

$$X_{TCSC} = -X_C \left[1 - \frac{r_X}{(r_X - 1)} \frac{(\sigma + \sin\sigma in}{\pi} + \frac{4 r_X \cos^2(\frac{\sigma}{2})}{\pi (r_X - 1)^2} \left(\sqrt{r_X} \tan \frac{\sigma \sqrt{r_X}}{2} - \tan \frac{\sigma}{2} \right) \right] \qquad (3)$$

Where, $(\pi - \alpha)$, $\sigma = r_x = {}^{X_C}/_{X_L}$

3. Voltage Stability Evaluation Results

In fact, an electric power system is comprised of generators, transmission lines, loads and voltage controllers. A single line diagram of a transmission line in an interconnected power system is given as follows:

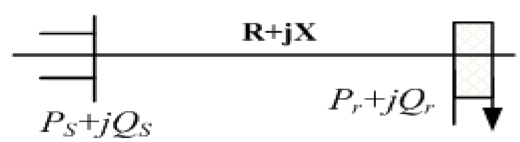

Figure 3. Transmission line schematic in an interconnected power system

To inspect and calculate the static voltage stability, the VCPI index has been taken into account for this study. The single line diagram of Single Machine Infinite Bus (SMIB) power system which is considered for this study is given as follows:

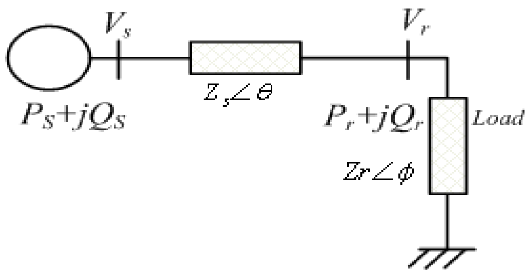

Figure 4. SMIB power system with its relevant parameters

It is assumed that load impedance is varied and φ is fixed. This assumption will not reduce the accuracy of analysis rather it simplifies the manual computation. In experimental action, the value of power factor is constant. Increasing the load (Z_L) will cause dropping of the load voltage (V_r) and increase of load current as well as collapse of the voltage stability.

$$V_r = Z_r I \qquad (4)$$

$$\mathrm{I}=\frac{\mathrm{V_S}}{\sqrt{[(\mathrm{Z_S}\cos\theta+\mathrm{Z_r}\cos\varphi)^2+(\mathrm{Z_S}\sin\theta+\mathrm{Z_r}\sin\varphi)^2]}} \qquad (5)$$

Thus, the receiving active and reactive powers can be presented by:

$$Q_{\mathrm{r}} = \mathrm{V_r}\,\mathrm{I}\sin\varphi \qquad (6)$$

$$P_{\mathrm{r}} = \mathrm{V_r}\,\mathrm{I}\cos\varphi \qquad (7)$$

Finally, Eqs. 8 and 9 which are given as follows have been extracted from above mentioned equations.

$$Q_{\mathrm{r}} = \frac{(V_s)^2/Z_s}{1+(\frac{Z_r}{Z_s})^2+2(\frac{Z_r}{Z_s})\cos(\theta-\varphi)}\frac{Z_r}{Z_s}\sin\varphi \qquad (8)$$

$$P_{\mathrm{r}} = \frac{(V_s)^2/Z_s}{1+(\frac{Z_r}{Z_s})^2+2(\frac{Z_r}{Z_s})\cos(\theta-\varphi)}\frac{Z_r}{Z_s}\cos\varphi \qquad (9)$$

Maximum active and reactive powers can be transferred to the consumption spot which can be elicit via $(\partial P_r)/(\partial Z_r)=0$ and $Z_r/Z_s=1$.

$$\mathrm{Q_{r(max)}} = \frac{(V_s)^2}{Z_s}\frac{\sin\varphi}{4\cos^2\frac{(\theta-\varphi)}{2}} \qquad (10)$$

$$P_{\mathrm{r(max)}} = \frac{(V_s)^2}{Z_s}\frac{\cos\varphi}{4\cos^2\frac{(\theta-\varphi)}{2}} \qquad (11)$$

In this study, the VCPI index which is based on permissive maximum active/reactive power has been taken into account for evaluation of static voltage stability.

$$\mathrm{VCPI}(2) = \frac{\mathrm{Q_r}}{\mathrm{Q_{r(max)}}} \quad (12) \qquad \mathrm{VCPI}(1) = \frac{\mathrm{P_r}}{\mathrm{P_{r(max)}}} \quad (13)$$

Both the VCPI (1) and VCPI (2) give same value as scale of the voltage collapse which is as follows:

$$\mathbf{VCPI}(\mathbf{1}) = \mathbf{VCPI}(\mathbf{1}) = \frac{\frac{\mathbf{Z_s}}{\mathbf{Z_r}}\left\{\mathbf{1}+\left(\frac{\mathbf{Z_r}}{\mathbf{Z_s}}\right)^{\mathbf{2}}+\mathbf{2}\left(\frac{\mathbf{Z_r}}{\mathbf{Z_s}}\right)\mathbf{cos}(\boldsymbol{\theta}-\varphi)\right\}}{\mathbf{4cos}^{\mathbf{2}}\frac{(\boldsymbol{\theta}-\varphi)}{\mathbf{2}}} \qquad (14)$$

This part of the paper inspects the effects of both the SVC and TCSC on voltage improvement and VCPI index.

3.1. Evaluation of SVC role in SMIB power system

In this section, the role of SVC in order to enhance the static voltage stability and improve the load voltage has been well dealt with. The system response is presented in Figs. 5 and 6. These figures unveil that with presence of SVC the scale of voltage collapse has been significantly reduced, and also the voltage bus has been dramatically improved.

Journal of Electrical Power Systems- Vol. 1-No. 2- Autumn 2012

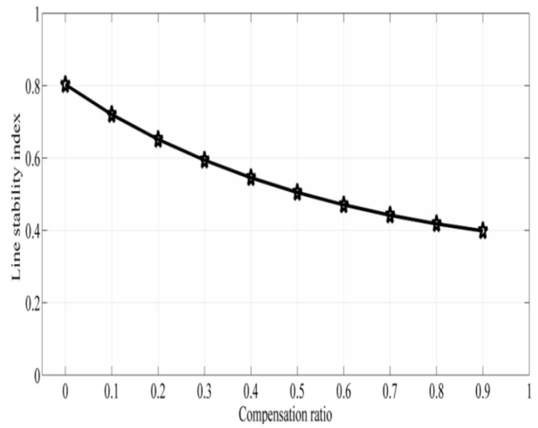

Figure 5. VCPI's diagram with compensation by SVC

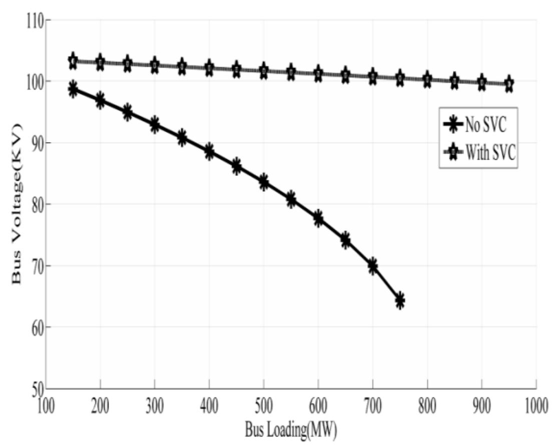

Figure 6. Bus voltage's diagram under different loading

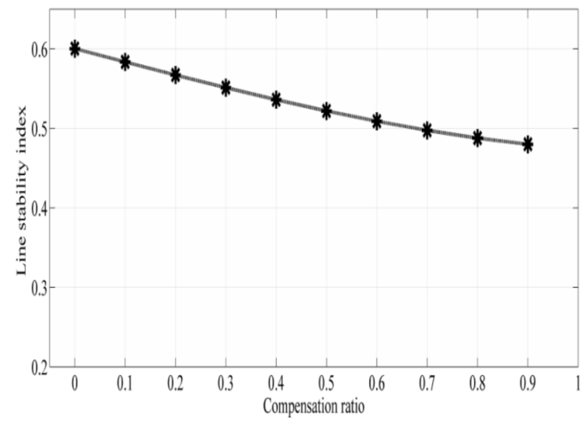

Figure 7. VCPI's diagram with compensation by SVC

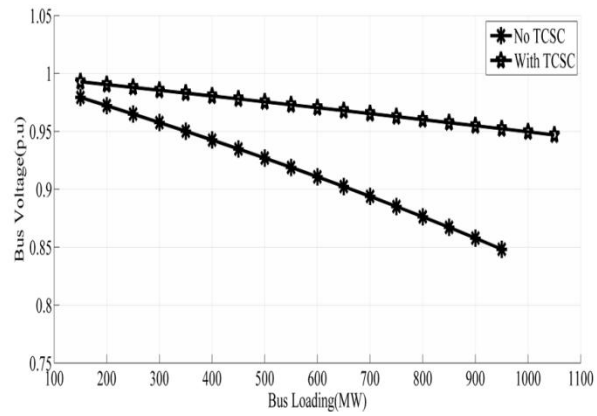

Figure 8. Bus voltage's diagram under different loading

3.2. Evaluation of TCSC role in SMIB power system

In this section, same the previous section the role of TCSC in upgrading the static voltage stability and improving the load voltage has been perfectly evaluated. The system response is presented in Figs. 7 and 8. These figures reveal that with presence of TCSC the scale of voltage collapse has been significantly reduced, and also the voltage bus has been dramatically improved.

4. Conclusion

FACTS are robust controllable devices which can play key role in controlling active power through the power network, improving voltage fluctuation and power system static voltage stability. In this paper, both the Thyristor Controlled Series Capacitor (TCSC) and Static Var Compensator (SVC) are engaged to unveil the problem of the power system static voltage stability. By the way, the scale of the Voltage Collapse Proximity Indicator (VCPI) is taken into account for appraising the voltage stability. A Single Machine Infinite Bus (SMIB) power system has been selected for this study. The modeling of the SMIB power system and TCSC and SVC has been made up in steady state with disregarding of the generator limitations.

Voltage improvement and VCPI index reduction has been perfectly investigated with presence of both the TCSC and SVC. The results of simulation reveal that with application of these devices and increase of compensation rate, the bus voltage has been well improved and also VCPI index has been significantly reduced.

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