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An Optimal FACTS Device Allocation for Improving the Power Loss Factors in IEEE 9 Bus System

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Abstract. This paper deals with power quality improvement by using Unified Power Flow Controller (UPFC), Static Synchronous Series Compensator (SSSC) and Second Generation of FACTS Static Compensator (STATCOM) according to change of the reactive and real power of the load, a suitable high response compensator is needed. UPFC, (Thyristor controlled tap changer) TCTC, (Thyristor Controlled Series Capacitor) TCSC, SSSC, STATCOM and SVC are the compensators belonging to FACTS devices. this paper used UPFC (Unified Power Flow Controller), STATCOM (Static Compensator) and static synchronous Series compensator (SSSC). there are three such compensators belonging to FACTS devices. Models for the UPFC, SSSC, and STATCOM are analysis using MATLAB Simulink. The simulation results of nine bus system with UPFC, SSSC, and STATCOM are presented. MATLAB codes are utilized for the implementation of the three FACTS devices in the Newton – Raphson algorithm. Power flow control was evaluated for nine bus system.

Keywords: UPFC (Unified Power Flow Controller); Static Synchronous Series Compensator (SSSC); SECOND GENERATION OF FACTS Static Compensator (STATCOM)

1. Introduction

Power quality is becoming increasingly important to electricity users at all levels of usage. Non-linear loads and sensitive equipment are commonplace in both the domestic environment and the industrial; because of this, a heightened consciousness of power quality is developing. The sources of problems that can disturb the power quality are arcing devices, power electronic devices, large motor starting, load switching, embedded generation, sensitive equipment, storm, environment related damage, design, and network equipment. The solution to improving power quality at the load side is a great important when the production processes get complicated and require a greater liability level, which includes aims same to provide energy without ceasing, with tension regulation between very narrow margins without harmonic distortion. The devices that can fulfill these requirements are the Custom Power; a concept that could include among the FACTS. Using the static power converters in grids has improving the supply quality of the electric energy and the possibility of increasing the transmission lines capacity. These devices are FACTS (Flexible Alternating Current Transmission Systems). The FACTS technology has a collection of controllers, that can be used individually or co-ordinate with other controls installed in the network, thus permitting to gain better of the network's characteristics of control. The FACTS controllers offer a great chance to set the transmission of alternating current (AC), increasing or decreasing the power flow in certain lines and responding almost immediately to the stability problems. The potential of this technology is depending on the prospect of controlling the



route of the power flow and the capability of connecting networks that are not enough interconnected, giving the possibility of trading energy between distant agents.

2. Merits of FACTS devices

The merits of FACTS devices in electrical transmission systems can be summarized follows [1]:

- Better utilization of present transmission system assets
- Increased transmission system availability and reliability
- Increased dynamic and transient grid firmness and reduction of loop flows
- Increased quality of supply for sensitive industries
- Environmental benefits Better employment of existing transmission system assets

3. Classification

There are several classifications for the FACTS devices:

3.1. Depending on the kind of connection to the network FACTS devices can differentiate four categories

- Serial controllers
- shunt controllers
- Serial to serial controllers
- Serial-shunt controllers

3.2. Depending on technological features, the FACTS devices can split into two generations

- First generation: used thyristors with flicker controlled by gate Silicon Controlled Rectifier (SCR).
- Second generation: semiconductors with flicker and suppression controlled by the gate (Gate Turn Off GTO 's, Insulated Gate Bi-polar Transistor IGBTs, etc).

The main variance between first- and second-generation devices is the capacity to control reactive and active power.

The first-generation FACTS devices work same tap changer transformers controlled by thyristors or passive elements using impedance. The second-generation FACTS devices work like the angle and module-controlled voltage sources and without inertia, based in converters, employing electronic tension sources (three-phase inverters, synchronous voltage sources, auto-switched voltage sources, voltage source control) fast proportioned and controllable and current sources and static synchronous voltage.

4. Devices used in this paper

A. The Static compensator

The STATCOM consists of Voltage Source Converter (VSC) and shunt-connected transformer. It is the static counterpart of the rotating synchronous condenser, but it absorbs or generates reactive power at a speed rate because no moving parts are involved. In principle, it performs the like voltage regulation function as the SVC but in a more robust manner, unlike the SVC, its operation is not impaired by the presence of low voltages.

A schematic representation of the STATCOM and its equivalent circuit are shown in Figures 1 (a) and (b), respectively.

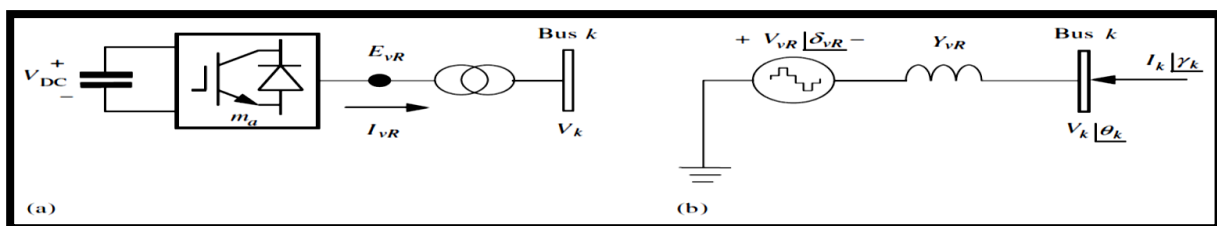


Figure 1. Static compensator (STATCOM) system: (a) voltage source converter (VSC) connected to the AC network via a shunt-connected transformer; (b) shunt solid-state voltage source.

The equivalent circuit corresponds to the Thevenin equivalent as seen from bus k , with $\hat{V}_{control}$ being the fundamental frequency component of the VSC output voltage, resulting from the product of \hat{V}_{tri} and m_a of the pulse width modulator where;

$$m_a = \frac{\hat{V}_{control}}{\hat{V}_{tri}} \quad (1)$$

$\hat{V}_{control}$ and \hat{V}_{tri} is kept constant for most practical purposes as shown in Figure 2.

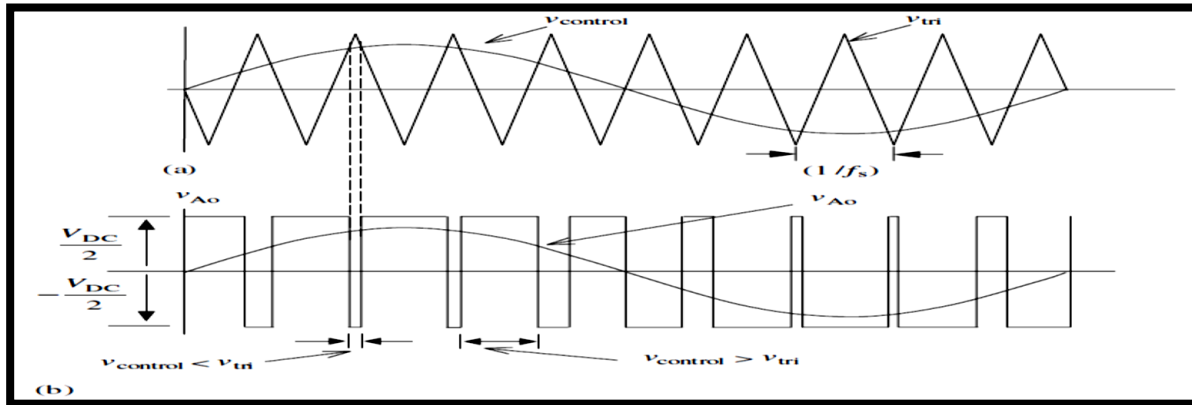


Figure 2. A pulse-width modulator: (a) comparison of a sinusoidal fundamental frequency with a high frequency triangular signal; (b) resulting train of square-wave signals.

The STATCOM may be represented in the same way as a synchronous condenser, which in most cases is the model of a synchronous generator with no active power generation. A produce a more flexible model by representing the STATCOM as a variable E_{vR} for which the phase angle and magnitude may be adjusted, using a suitable algorithm, to satisfy a specified voltage magnitude at the point of connection with the AC network. The shunt voltage source of the three-phase STATCOM may be represented by:

$$E_{vR}^{\rho} = V_{vR}^{\rho} (\cos \delta_{vR}^{\rho} + j \sin \delta_{vR}^{\rho}), \quad (2)$$

The voltage magnitude V_{vR}^{ρ} is given the minimum and maximum limits, which are a function of the STATCOM capacitor rating. However, δ_{vR}^{ρ} may take any value between 0 and 2π radians.

With reference to the equivalent circuit shown in Figure 1(b), and assuming three phase parameters, the following transfer admittance equation can be written:

$$[I_k] = [Y_{vR} \quad -Y_{vR}] \begin{bmatrix} V_k \\ E_{vR} \end{bmatrix}, \quad (3)$$

Where

$$I_k = [I_k^a \angle \gamma_k^a \quad I_k^b \angle \gamma_k^b \quad I_k^c \angle \gamma_k^c]^T, \quad (4)$$

$$V_k = [V_k^a \angle \theta_k^a \quad V_k^b \angle \theta_k^b \quad V_k^c \angle \theta_k^c]^T, \quad (5)$$

$$E_{vR} = [V_{vRk}^a \angle \delta_{vRk}^a \quad V_{vRk}^b \angle \delta_{vRk}^b \quad V_{vRk}^c \angle \delta_{vRk}^c]^T, \quad (6)$$

$$Y_{vR} = \begin{bmatrix} Y_{vRk}^a & 0 & 0 \\ 0 & Y_{vRk}^b & 0 \\ 0 & 0 & Y_{vRk}^c \end{bmatrix}. \quad (7)$$

B. The static synchronous series compensator

For steady-state, the SSSC performs a similar to the static phase shifter; it injects voltage in quadrature with one of the line end voltages for regulating active power flow. However, the SSSC is the best from the phase shifter because it does not draw reactive power from the AC system; it has its own reactive power provisions in the form of a capacitor. This characteristic makes the SSSC able to regulating active and reactive power flow or nodal voltage magnitude. A schematic representation of the SSSC and its equivalent circuit are shown in Figures 3 (a) and (b), respectively.

The series voltage source of the SSSC may be represented by

$$E_{cR}^p = V_{cR}^p (\cos \delta_{cR}^p + j \sin \delta_{cR}^p) \quad \dots (8)$$

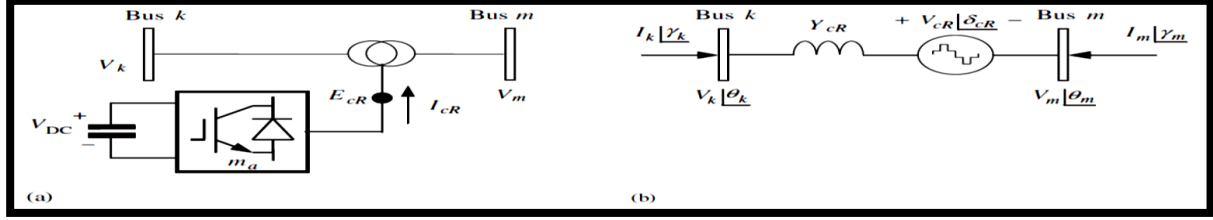


Figure 3. Static synchronous series compensator (SSSC) system: (a) voltage source converter (VSC) connected to the AC network using a series transformer and a (b) series solid state voltage source.

Like the STATCOM, minimum and maximum limits will exist for the voltage magnitude V_{cR} which are a function of the SSSC capacitor rating; the voltage phase angle δ_{cR} can take value a between 0 and 2π radians. The control capabilities of the SSSC are addressed in Section 4.

Based on the equivalent circuit shown in Figure 4, and assuming three-phase parameters, the following transfer admittance equation can be written:

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} Y_{cR} & -Y_{cR} & -Y_{cR} \\ -Y_{cR} & Y_{cR} & Y_{cR} \end{bmatrix} \begin{bmatrix} V_k \\ V_m \\ E_{cR} \end{bmatrix}. \quad (9)$$

In addition to parameters used in Equations (4)–(7) the following quantities are defined:

$$I_m = [I_m^a \angle \gamma_m^a \quad I_m^b \angle \gamma_m^b \quad I_m^c \angle \gamma_m^c]^T \quad (10)$$

$$V_m = [V_m^a \angle \theta_m^a \quad V_m^b \angle \theta_m^b \quad V_m^c \angle \theta_m^c]^T \quad (11)$$

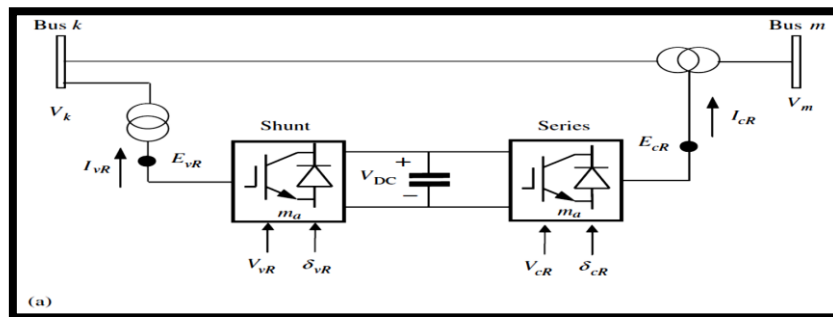
$$E_{cR} = [V_{cR}^a \angle \delta_{cR}^a \quad V_{cR}^b \angle \delta_{cR}^b \quad V_{cR}^c \angle \delta_{cR}^c]^T \quad (12)$$

$$Y_{cR} = \begin{bmatrix} Y_{cRk}^a & 0 & 0 \\ 0 & Y_{cRk}^b & 0 \\ 0 & 0 & Y_{cRk}^c \end{bmatrix}. \quad (13)$$

C. The unified power flow controller

A schematic representation of the UPFC is given in Figure 4 (a), together with its equivalent circuit, in Figure 4 (b).

The UPFC let simultaneous control of reactive power flow, voltage magnitude at the UPFC terminals, and active power flow. The controller may be set to control one or more of these parameters in any combination or to control none of them.



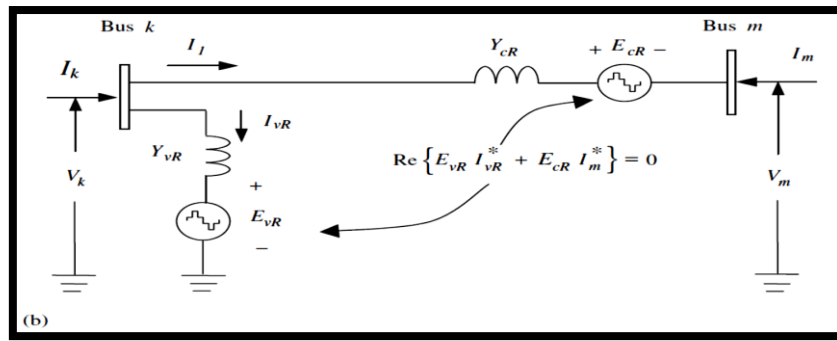


Figure 4. (a) Configuration of UPFC (b) equivalent circuit.

The active power claim by the series converter is drawn by the shunt converter from the AC network and supplied to bus m through the DC link. The output voltage of the series converter is joined to the nodal voltage, at say bus k, to improvement the nodal voltage at bus m. The voltage magnitude of the output voltage V_{cR} provides voltage regulation, and the phase angle δ_{cR} determines the mode of power flow control.

Providing a supporting role in the active power exchange that takes place between the series converter and the AC system, the shunt converter can also generate or absorb reactive power to provide independent voltage magnitude regulation at its point of connection with the AC system.

The UPFC equivalent circuit shown in Figure 4 (b) consists of a series-connected voltage source, an active power bands equation, which links the two voltage sources and a shunt-connected voltage source, the two voltage sources are connected to the AC system through inductive reactance representing the VSC transformers. From Equations (2) and (8) in a three-phase UPFC, the suitable term for the two voltage sources and bands equation would be:

$$\text{Re}\{-E_{vR}^\rho I_{vR}^{*\rho} + E_{vR}^\rho I_m^{*\rho}\} = 0. \quad (14)$$

Comparable to the shunt and series voltage sources used to represent the STATCOM and the SSSC, respectively, the voltage sources used in the UPFC application would also have limits.

UPFC is connected between two buses k and m in the power system. Based on the equivalent circuit shown in Figure (4b), assuming applying the Kirchhoff's current and three-phase parameters and voltage laws for the network in Figure (4 b) gives the following transfer entry equation:

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} (Y_{cR} + Y_{vR}) & -Y_{cR} & -Y_{cR} & -Y_{vR} \\ -Y_{cR} & Y_{cR} & Y_{cR} & 0 \end{bmatrix} \begin{bmatrix} V_k \\ V_m \\ E_{cR} \\ E_{vR} \end{bmatrix}, \quad (15)$$

Power flow analysis involves the calculation of power flows in lines/voltages of a power system for a given set of bus bar loads and active power generation list and particular bus voltage magnitude at generating buses, transformers. Such calculations are widely used in the analysis and design of fixed state operation as well as the dynamic performance of the system.

The power flow problem is formulated as a set of nonlinear equations. Many calculation methods have been suggesting disbanding this problem. Among them, the Newton-Raphson (NR) method and fast-decoupled load flow method are two very active methods. In general, the decoupled power flow methods are only good for a weakly loaded network with large X/R ratio network. For system conditions with large angles across lines (heavily loaded network) and with private control devices (FACTS devices such as UPFC) that highly impact reactive and active power flows.

From the circuit shown in Figure 4, the UPFC voltage sources given in equations (2) and (8), V_{vR} and δ_{vR} are the controllable magnitude ($V_{vR \min} \leq V_{vR} \leq V_{vR \max}$) and phase angle ($0 \leq \delta_{vR} \leq 2\pi$) of the voltage source representing the shunt converter. The magnitude V_{cR} and phase angle δ_{cR} of the voltage source representing the series converter are controlled between limits ($V_{cR \min} \leq V_{cR} \leq V_{cR \max}$) and ($0 \leq \delta_{cR} \leq 2\pi$) respectively.

The phase angle of the series- injected voltage determines the mode of power flow control.

If δ_{cR} is in quadrature with respect to θ_k , it controls active power flow, expressible as a phase shifter. If δ_{cR} is in phase with the nodal voltage angle θ_k , the UPFC regulates the terminal voltage. If δ_{cR} is in quadrature with the line current angle then it controls active power flow, expressible as a variable series compensator. At any other value of δ_{cR} , the UPFC operates as a mix of voltage regulator, variable series compensator, and phase shifter. The magnitude of the series-injected voltage determines the amount of power flow to be controlled.

Based on the equivalent circuit shown in Figure (4 b) and Equations (2) and (8), the active and reactive power equations are:

At bus k:

$$P_k = V_k^2 G_{kk} + V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)] \\ + V_k V_{cR} [G_{km} \cos(\theta_k - \delta_{cR}) + B_{km} \sin(\theta_k - \delta_{cR})] \\ + V_k V_{vR} [G_{vR} \cos(\theta_k - \delta_{vR}) + B_{vR} \sin(\theta_k - \delta_{vR})], \quad (16)$$

$$Q_k = -V_k^2 B_{kk} + V_k V_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] \\ + V_k V_{cR} [G_{km} \sin(\theta_k - \delta_{cR}) - B_{km} \cos(\theta_k - \delta_{cR})] \\ + V_k V_{vR} [G_{vR} \sin(\theta_k - \delta_{vR}) + B_{vR} \cos(\theta_k - \delta_{vR})], \quad (17)$$

At bus m:

$$P_m = V_m^2 G_{mm} + V_m V_k [G_{mk} \cos(\theta_m - \theta_k) + B_{mk} \sin(\theta_m - \theta_k)] \\ + V_m V_{cR} [G_{mm} \cos(\theta_m - \delta_{cR}) + B_{mm} \sin(\theta_m - \delta_{cR})], \quad (18)$$

$$Q_m = -V_m^2 B_{mm} + V_m V_k [G_{mk} \sin(\theta_m - \theta_k) - B_{mk} \cos(\theta_m - \theta_k)] \\ + V_m V_{cR} [G_{mm} \sin(\theta_m - \delta_{cR}) - B_{mm} \cos(\theta_m - \delta_{cR})]; \quad (19)$$

Series converter:

$$P_{cR} = V_{cR}^2 G_{mm} + V_{cR} V_k [G_{km} \cos(\delta_{cR} - \theta_k) + B_{km} \sin(\delta_{cR} - \theta_k)] \\ + V_{cR} V_m [G_{mm} \cos(\delta_{cR} - \theta_m) + B_{mm} \sin(\delta_{cR} - \theta_m)], \quad (20)$$

$$Q_{cR} = -V_{cR}^2 B_{mm} + V_{cR} V_k [G_{km} \sin(\delta_{cR} - \theta_k) - B_{km} \cos(\delta_{cR} - \theta_k)] \\ + V_{cR} V_m [G_{mm} \sin(\delta_{cR} - \theta_m) - B_{mm} \cos(\delta_{cR} - \theta_m)]; \quad (21)$$

Shunt converter:

$$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR} V_k [G_{vR} \cos(\delta_{vR} - \theta_k) + B_{vR} \sin(\delta_{vR} - \theta_k)], \quad (22)$$

$$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR} V_k [G_{vR} \sin(\delta_{vR} - \theta_k) - B_{vR} \cos(\delta_{vR} - \theta_k)]. \quad (23)$$

The UPFC converters are supposed loss-less converter valves in this voltage sources model, this implies that there is no absorption or generation of active power by the two converters for its losses and the active power claim by the series converter at its output is outfitted from the AC Power system by the shunt converters via the common D.C link. The DC link capacitor voltage V_{dc} remains constant. Hence the active power outfitted to the shunt converter, P_{vR} equals the active power claim by the series converter, P_{cR} . Then the following equality constraint has to be secured,

$$\Delta P_{bb} = P_{vR} + P_{cR} = 0. \quad (24)$$

Furthermore, if the coupling transformers are supposed to contain no resistance then the active power at bus k matches the active power at bus m. accordingly,

$$P_{vR} + P_{cR} = P_k + P_m = 0. \quad (25)$$

The UPFC power equations, in linearized form, are common with those of the AC network.

For the case when the UPFC controls the following parameters: (1) active power flow from bus m to bus k, (2) reactive power injected at bus m, and taking bus m to be a PQ bus and (3) voltage magnitude at the shunt converter terminal (bus k), the linearized system of equations is as follows:

$$\begin{bmatrix} \Delta P_k \\ \Delta P_m \\ \Delta Q_k \\ \Delta Q_m \\ \Delta P_{mk} \\ \Delta Q_{mk} \\ \Delta P_{bb} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial \theta_m} & \frac{\partial P_k}{\partial V_{vR}} V_{vR} & \frac{\partial P_k}{\partial V_m} V_m & \frac{\partial P_k}{\partial \delta_{cR}} & \frac{\partial P_k}{\partial V_{cR}} V_{cR} & \frac{\partial P_k}{\partial \delta_{vR}} \\ \frac{\partial P_m}{\partial \theta_k} & \frac{\partial P_m}{\partial \theta_m} & 0 & \frac{\partial P_m}{\partial V_m} V_m & \frac{\partial P_m}{\partial \delta_{cR}} & \frac{\partial P_m}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_m} & \frac{\partial Q_k}{\partial V_{vR}} V_{vR} & \frac{\partial Q_k}{\partial V_m} V_m & \frac{\partial Q_k}{\partial \delta_{cR}} & \frac{\partial Q_k}{\partial V_{cR}} V_{cR} & \frac{\partial Q_k}{\partial \delta_{vR}} \\ \frac{\partial Q_m}{\partial \theta_k} & \frac{\partial Q_m}{\partial \theta_m} & 0 & \frac{\partial Q_m}{\partial V_m} V_m & \frac{\partial Q_m}{\partial \delta_{cR}} & \frac{\partial Q_m}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial P_{mk}}{\partial \theta_k} & \frac{\partial P_{mk}}{\partial \theta_m} & 0 & \frac{\partial P_{mk}}{\partial V_m} V_m & \frac{\partial P_{mk}}{\partial \delta_{cR}} & \frac{\partial P_{mk}}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial Q_{mk}}{\partial \theta_k} & \frac{\partial Q_{mk}}{\partial \theta_m} & 0 & \frac{\partial Q_{mk}}{\partial V_m} V_m & \frac{\partial Q_{mk}}{\partial \delta_{cR}} & \frac{\partial Q_{mk}}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial P_{bb}}{\partial \theta_k} & \frac{\partial P_{bb}}{\partial \theta_m} & \frac{\partial P_{bb}}{\partial V_{vR}} V_{vR} & \frac{\partial P_{bb}}{\partial V_m} V_m & \frac{\partial P_{bb}}{\partial \delta_{cR}} & \frac{\partial P_{bb}}{\partial V_{cR}} V_{cR} & \frac{\partial P_{bb}}{\partial \delta_{vR}} \end{bmatrix} \begin{bmatrix} \Delta \theta_k \\ \Delta \theta_m \\ \frac{\Delta V_{vR}}{V_{vR}} \\ \frac{\Delta V_m}{V_m} \\ \Delta \delta_{cR} \\ \frac{\Delta V_{cR}}{V_{cR}} \\ \Delta \delta_{vR} \end{bmatrix}, \quad (26)$$

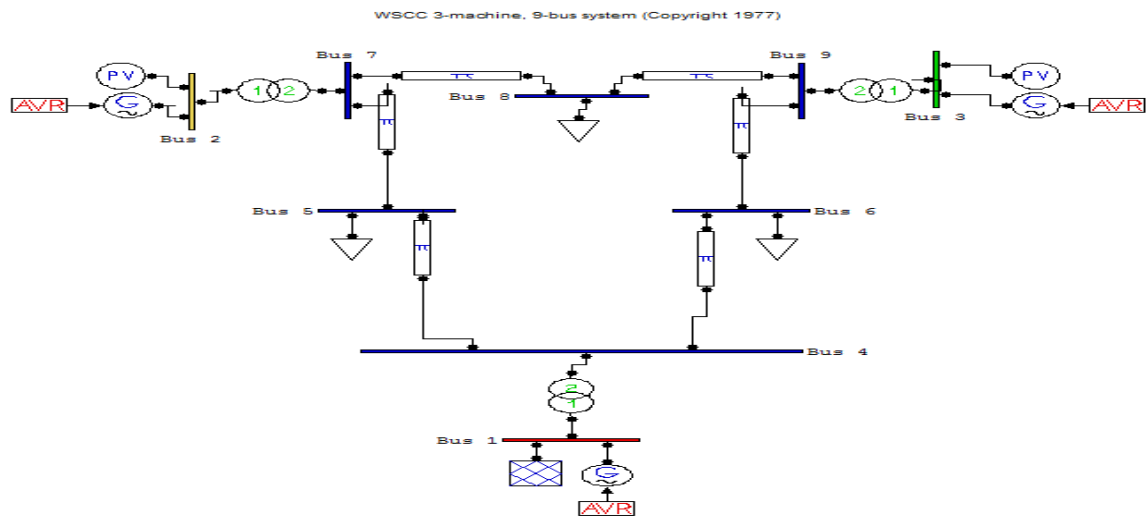
If voltage control at k is damaged, the third column of Equation (26) is replaced by partial derivatives of the bus and UPFC mismatch powers with respect to the bus voltage magnitude V_k . So, the voltage magnitude increase of the shunt source, $\Delta V_{vR}/V_{vR}$ is replaced by the voltage magnitude increment at bus k, $\Delta V_k/V_k$. If both buses, k and m, are PQ the linearized system of equations is as follows:

$$\begin{bmatrix} \Delta P_k \\ \Delta P_m \\ \Delta Q_k \\ \Delta Q_m \\ \Delta P_{mk} \\ \Delta Q_{mk} \\ \Delta P_{bb} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial \theta_m} & \frac{\partial P_k}{\partial V_k} V_k & \frac{\partial P_k}{\partial V_m} V_m & \frac{\partial P_k}{\partial \delta_{cR}} & \frac{\partial P_k}{\partial V_{cR}} V_{cR} & \frac{\partial P_k}{\partial \delta_{vR}} \\ \frac{\partial P_m}{\partial \theta_k} & \frac{\partial P_m}{\partial \theta_m} & \frac{\partial P_m}{\partial V_k} V_k & \frac{\partial P_m}{\partial V_m} V_m & \frac{\partial P_m}{\partial \delta_{cR}} & \frac{\partial P_m}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_m} & \frac{\partial Q_k}{\partial V_k} V_k & \frac{\partial Q_k}{\partial V_m} V_m & \frac{\partial Q_k}{\partial \delta_{cR}} & \frac{\partial Q_k}{\partial V_{cR}} V_{cR} & \frac{\partial Q_k}{\partial \delta_{vR}} \\ \frac{\partial Q_m}{\partial \theta_k} & \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial V_k} V_k & \frac{\partial Q_m}{\partial V_m} V_m & \frac{\partial Q_m}{\partial \delta_{cR}} & \frac{\partial Q_m}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial P_{mk}}{\partial \theta_k} & \frac{\partial P_{mk}}{\partial \theta_m} & \frac{\partial P_{mk}}{\partial V_k} V_k & \frac{\partial P_{mk}}{\partial V_m} V_m & \frac{\partial P_{mk}}{\partial \delta_{cR}} & \frac{\partial P_{mk}}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial Q_{mk}}{\partial \theta_k} & \frac{\partial Q_{mk}}{\partial \theta_m} & \frac{\partial Q_{mk}}{\partial V_k} V_k & \frac{\partial Q_{mk}}{\partial V_m} V_m & \frac{\partial Q_{mk}}{\partial \delta_{cR}} & \frac{\partial Q_{mk}}{\partial V_{cR}} V_{cR} & 0 \\ \frac{\partial P_{bb}}{\partial \theta_k} & \frac{\partial P_{bb}}{\partial \theta_m} & \frac{\partial P_{bb}}{\partial V_k} V_k & \frac{\partial P_{bb}}{\partial V_m} V_m & \frac{\partial P_{bb}}{\partial \delta_{cR}} & \frac{\partial P_{bb}}{\partial V_{cR}} V_{cR} & \frac{\partial P_{bb}}{\partial \delta_{vR}} \end{bmatrix} \begin{bmatrix} \Delta \theta_k \\ \Delta \theta_m \\ \frac{\Delta V_k}{V_k} \\ \frac{\Delta V_m}{V_m} \\ \Delta \delta_{cR} \\ \frac{\Delta V_{cR}}{V_{cR}} \\ \Delta \delta_{vR} \end{bmatrix}, \quad (27)$$

In this case, V_{vR} is maintained at a fixed value within prescribed limits, $V_{vR \min} \leq V_{vR} \leq V_{vR \max}$

5. Simulation results

A 9-bus system network is tested with UPFC, SSSC, and STATCOM, to check the two cases. In the first case without inserting the facts devices. In the second case for the same network with inserting the facts devices UPFC, SSSC, and STATCOM. So, the second case three stages for each stage we put a specific device and the location of the device on all transmission lines or buses, and we will notice the difference in the results of adding or not adding the facts devices as well as the location of the facts devices as shown in the tables below.

**Figure 5.** IEEE 9-bus bar system**Table 1.** Real and Reactive power loss with and without UPFC

	No Line	Real Power Losses [p.u.]	Reactive Power Losses [p.u.]
System without UPFC	-----	0.046410	-0.92160
	Line 1	0.046146	-0.68907
	Line 2	0.04195	-0.76652
System with UPFC	Line 3	0.031105	-0.54831
	Line 4	0.020935	-0.62681
	Line 5	0.043818	-0.73281
	Line 6	0.044886	-0.74673

Table 2. Real and Reactive power loss with and without SSSC

	No Line	Real Power Losses [p.u.]	Reactive Power Losses [p.u.]
System without SSSC	-----	0.046410	-0.92160
	Line 1	0.046093	-0.6926
	Line 2	0.041697	-0.77878
System with SSSC	Line 3	0.029239	-0.57022
	Line 4	0.018555	-0.66854
	Line 5	0.043521	-0.74189
	Line 6	0.044841	-0.75013

Table 3. Real and Reactive power loss with and without STATCOOM

	No bus	Real Power Losses [p.u.]	Reactive Power Losses [p.u.]
System without STATCOOM	0.046410	-0.92160
	Bus 1	0.046410	-0.92160
	Bus 2	0.046410	-0.92160
	Bus 3	0.046410	-0.92160
System with STATCOOM	Bus 4	0.046410	-0.92160
	Bus 5	0.046410	-0.92160
	Bus 6	0.046410	-0.92160
	Bus7	0.046410	-0.92160
	Bus 8	0.046410	-0.92160
	Bus 9	0.046410	-0.92160

6. Conclusion

The result explained that UPSC is the best facts devices that make the system with high performance and best device reduces losses. From IEEE 9-bus bar system simulation by power flow is run under loading condition using PSAT (power system analysis toolbox). While SSSC has a weak effect on controlling power losses than UPFC instillation, and the STATCOM has no effect in improving power losses. The result was illustrated that optimal location for FACTS devices in the system so the total power losses of the system are calculated for each change in the FACTS devices location and It's noticed that when FACTS placed in line 4, a decrease in the total system losses is much more if compared with the other positions

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