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Transfer Capability Enhancement Employing Static Var Compensator

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Abstract—This research focuses on the evolution of the impact of FACTS control on Available Transfer Capability (ATC) of SVC. For relieve congestion and outage, one of the best solution is to compensate the reactive power. This paper deals with reactive power compensation by enhancement of Available Transfer Capability using Static Var Compensator. In this paper, the variable shunt susceptance model is used for modeling of Static Var Compensator and Newton-Rapson load flow with IEEE-39 bus system is used. The results of Available Transfer Capability without SVC and with SVC connected at different busses discussed.

Keywords- FACTS devices, Compensation methods, SVC modeling; ATC enhancement.

I. INTRODUCTION

Increased reliance on electrical energy is a result of rising industry and urbanization of lifestyle. As a result, the development of power systems has accelerated. There aren't many uncertainties as a result of this quick expansion. Power interruptions and isolated power outages are among the biggest issues that have an impact on every nation's economy. Transmission systems are being forced to operate closer to their stability limits and at the same time reaching their thermal constraints as a result of the increased power delivery, which contrasts with the rapid changes in technologies and the power needed by these technologies. The following are the main issues that the electricity industries confront in matching supply and demand:

- Transmission & Distribution; supply the electric demand without exceeding the thermal limit.
- • Stability issues in major power systems lead to power outages and blackouts, which result in significant losses. The type of power that is delivered is impacted by these limitations. However, by improving power system control, these restrictions can be avoided. FACTS gadgets are one of the finest ways to lessen these restrictions. Flexible AC Transmission Systems (FACTS) devices have been suggested and utilized in power systems due to the rapid growth of power electronics. Devices made with FACTS can be used to regulate power distribution and improve system stability. The use of FACTS devices in the operation and control of power systems is becoming more popular, especially with the deregulation of the electricity market. Utilizing the current power systems more effectively to boost their Available Transfer Capability (ATC) and Total Transfer CapabilityAll these can be done using high speed power electronics controllers call FACTS controllers.

The static VAR compensator (SVC) is generally used as a voltage controller in power systems. It can help maintain the voltage magnitude at the bus it is connected to at a desired value during load variations. The SVC can both absorb as well as supply reactive power at the bus it is connected to by

control of value of susceptance. It is continuously controllable over the full reactive operating range as determined by the component ratings. We can model the SVC as a variable reactive power source.
Available Transfer Capability (ATC) is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses. Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM). ATC can be expressed as [2]:

ATC = TTC – TRM – Existing Transmission Commitments (including CBM)

The ATC between two areas provides an indication of the amount of additional electric power that can be transferred from one area to another for a specific time frame for a specific set of conditions. ATC can be a very dynamic quantity because it is a function of variable and interdependent parameters. These parameters are highly dependent upon the conditions of the network. Consequently, ATC calculations may need to be periodically updated. Because of the influence of conditions throughout the network, the accuracy of the ATC calculation is highly dependent on the completeness and accuracy of available network data.

Total Transfer Capability (TTC) is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre- and post-contingency system conditions.

Transmission Reliability Margin (TRM) is defined as that amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under a reasonable range of uncertainties in system conditions.

Capacity Benefit Margin (CBM) is defined as that amount of transmission transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements.

II. FUNDAMENTALS OF FACTS DEVICES

A. Various Compensation Methods
(1) Without Compensation
(2) Series Compensation
(3) Shunt Compensation

- Without Compensation

AC system mainly consists of inductive load so it requires reactive power for its operation and hence, the source must supply it, increasing the current from the generator and through power lines, Fig-1 shows the representation of AC system. If reactive power is supplied near the load, the line current can be reduced or minimized resulting into lower losses and improving voltage regulation at the load terminals. Fig-2 shows the phasor diagram of the system without compensation, the phase angle of the current has been related to the load side, which means that the active current IP is in phase with the load voltage V2 [3].

- Series Compensation

The conventional Series compensators employ switches to add inductive or capacitive reactance in transmission line. The conventional compensator emulates a static flow controller by means of mechanical switching [4]. Series compensation can also be implemented by injecting a voltage source in series with transmission line as shown in Fig-3. The voltage source can inject voltage of controllable magnitude and phase. When the injected voltage is in phase quadrature leading to line current, series compensation emulates like an inductor, similarly when injected voltage is lagging to line current it emulates a capacitor. The results obtained with the series compensation through a voltage source, which has been adjusted again to have unity power factor operation at V2 as shown in Fig-4. In this case, voltage VCOMP has been added between the line and the load to change the angle of V2, which is now the voltage at the load side. As it can be seen from the phasor diagram of Fig-4, VCOMP generates a voltage with opposite direction to the voltage drop in the line inductance because it lags the current IP [3].

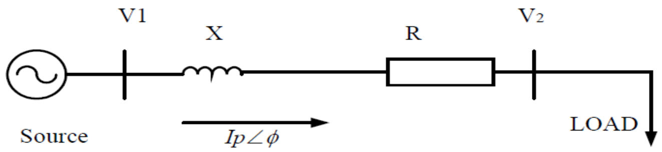


Fig-1 Representation of AC system

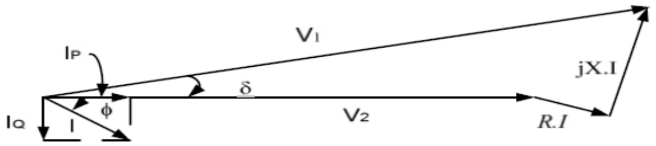


Fig-2 Phasor diagram without compensation

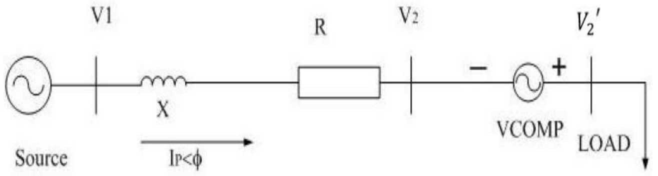


Fig-3 Representation of AC system with series compensation

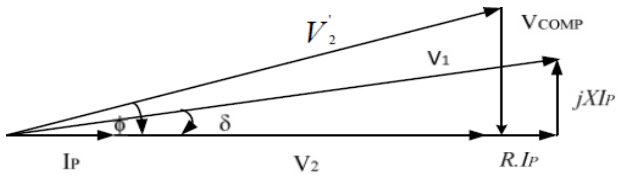


Fig-4 Phasor diagram with series compensation

- Shunt Compensation

Shunt compensation is used to influence the natural electrical characteristics of the transmission line to increase the steady-state transmittable power and to control the voltage profile along the line. The shunt compensator like STATCOM can be operated either to provide capacitive or inductive compensation depending on the specific requirement. The impedance of the shunt controller, which is connected to the line voltage, causes a variable current flow, and hence represents an injection of current into the line. As long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes variable reactive power. The ultimate objective of applying reactive shunt compensation in a transmission system is to increase the transmittable power capability from the generator to the load, which is required to improve the steady-state transmission characteristic as well as the stability of the system [5].

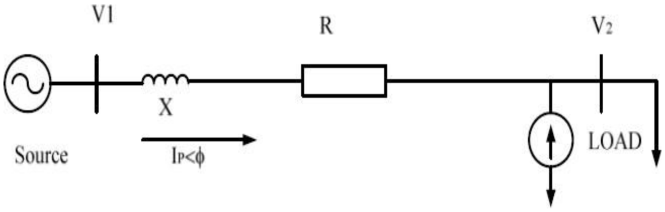


Fig-5 Representation of AC system with Shunt compensation

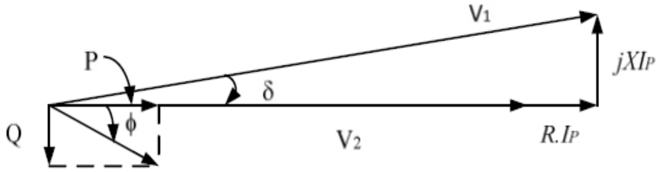


Fig-6 Phasor diagram of AC sytem with shunt compensation

The shunt capacitive compensator is used to improve the power factor, most of the practical loads are inductive and results into lagging power factor. To compensate, a shunt capacitor is connected which draws current leading the source voltage. The net result is improvement in power factor. The shunt inductive compensator is used either when charging the transmission line, or, when there is very low load at the receiving end. To compensate, shunt inductors are connected across the transmission line. In Fig-5. a current source device is being used to compensate the reactive component of the load current (IQ). As a result, the system voltage regulation is improved and the reactive current component from the source is reduced or almost eliminated as shown in Fig-6 . Also a current source or a voltage source can be used for inductive shunt compensation[3].

The main purpose of shunt compensation is to provide the following:
- Steady state and dynamic voltage control.
- Reactive power control of dynamic loads.
- Damping of active power oscillations.
- Improvement of system stability.

B. Classification of FACTS devices

Facts devices are classified by following three ways:
(1) Depending Type of Connection
(2) Depending on Technological Features
(3) Depending on Cost

- Depending Type of Connection

Depending type of connection FACTS controllers can be divided into three categories:[6]

-The Series controllers (TCSC, SSSC, FSC…) works on principle variation of line Impedance, and having strong (maximum) control on Stability. But poor on load flow and voltage quality.
-The Shunt controllers (STATCOM and SVC) works on principle voltage control, having strong (maximum) control on Voltage quality and medium control on Stability.
-The Combined series-shunt controllers such as UPFC having strong control on load flow ,voltage quality and Stability.

- Depending on Technological Features

Depending on technological features the FACTS devices can divided into two generations [6].
(1) First Generation: In it thyristors with ignition controlled by gate (SCR) used.
-Static Var Compensator (SVC): Voltage control and stability, compensation of VAR´s. muffling of oscillations.
-Thyristor Controlled Series Compensations (TCSC): Current control, muffling of oscillations, dynamics and of voltage stability, limitation of fault current.
-Thyristor Controlled Phase Shifting Transformer (TCPST):Control of active power, muffling of oscillations, transitory, dynamics and of voltage stability.
(2) Second Generation: Semiconductors with ignition and extinction controlled by gate (GTO´s , MCTS , IGBTS , IGCTS , etc).
-Synchronous Static Compensator (STATCOM): Voltage control, compensation of VAR´s, muffling of oscillations, stability of voltage.
-Static Synchronous Series Compensator (SSSC): Current control, muffling of oscillations, transitory, dynamics and of voltage stability.
-Unified Power Flow Controller(UPFC): Control of active and reactive power, voltage control, compensation of VAR´s, muffling of oscillations, dynamics and of voltage stability, limitation of fault current.

- Depending on Cost

The cost comparison of different conventional FACTS Device is given in below Table-1[6].

FACTS Controllers	Cost (US$)
Shunt Capacitor	8/kVar
Shunt Capacitor	20/kVar
SVC	40/kVar controlled portions
TCSC	40/kVar controlled portions
STATCOM	50/kVar
UPFC Series Portion	50/kVar through power
UPFC Shunt Portion	50/kVar controlled

Table-1 Cost wise comparison of FACTS devices

From the above comparison of FACTS devices it is seen that, the Static Var Compensator is best solution for reactive power compensation because of its simplest construction and lowest cost. So, here the Static Var Compensator is used for reactive power compensation and enhancement of Available Transfer Capability (ATC).

III. MODELLING OF STATIC VAR COMPENSATOR

Conventional and advanced power flow models of SVCs are presented in this section. The advanced models depart from the conventional generator-type representation of the SVC and are based instead on the variable shunt susceptance concept. In the latter case, the SVC state variables are combined with the nodal voltage magnitudes and angles of the network in a single frame of reference for unified, iterative solutions using the Newton–Raphson method. Two models are presented in this category namely, [7]

(1) The variable shunt susceptance model

(2) The firing-angle model

- The variable shunt susceptance model

In practice the SVC can be seen as an adjustable reactance with either firing-angle limits or reactance limits. The equivalent circuit shown in Fig-7 is used to derive the SVC nonlinear power equations and the linearised equations required by Newton’s method.

With reference to Fig-7, the current drawn by the SVC is

$I_{SVC}=j\,B_{SVC}\,V_{k},$ ………(1)

and the reactive power drawn by the SVC, which is also the reactive power injected at bus k,is

$$Q_{SVC}=Q_k=-V_k^2 B_{SVC}$$

____[2]

The linearised equation is given by Equation, where the equivalent susceptance BSVC is taken to be the state variable:

$$\begin{bmatrix}\Delta P_k\\ \Delta Q_k\end{bmatrix}^{(i)}=\begin{bmatrix}0 & 0\\ 0 & Q_k\end{bmatrix}^{(i)}\begin{bmatrix}\Delta\theta_k\\ \Delta B_{SVC}/B_{SVC}\end{bmatrix}^{(i)}.$$

-------[3]

At the end of iteration (i), the variable shunt susceptance BSVC is updated according to,

Fig-7 Variable shunt susceptance

$$B_{SVC}^{(i)}=B_{SVC}^{(i-1)}+\left(\frac{\Delta B_{SVC}}{B_{SVC}}\right)^{(i)}B_{SVC}^{(i-1)}$$

____[4]

The changing susceptance represents the total SVC susceptance necessary to maintain the nodal voltage magnitude at the specified value. Once the level of compensation has been computed then the thyristor firing angle can be calculated. However, the additional calculation requires an iterative solution because the SVC susceptance and thyristor firing angle are nonlinearly related.

- The firing-angle model

An alternative SVC model, which circumvents the additional iterative process, consists in handling the thyristor- controlled reactor (TCR) firing angle α as a state variable in the power flow formulation. The variable α will be designated here as α svc, to distinguish it from the TCR firing angle α used in the TCSC model.

The positive sequence susceptance of the SVC, given by Equation:

$$Q_k = \frac{-V_k^2}{X_C X_L}\left\{X_L - \frac{X_C}{\pi}\left[2(\pi - \alpha_{\mathrm{SVC}}) + \sin(2\alpha_{\mathrm{SVC}})\right]\right\}. \quad \text{- [5]}$$

From Equation , the linearised SVC equation is given as

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{2V_k^2}{\pi X_L}\left[\cos(2\alpha_{\mathrm{SVC}}) - 1\right] \end{bmatrix}^{(i)} \begin{bmatrix} \Delta\theta_k \\ \Delta\alpha_{\mathrm{SVC}} \end{bmatrix}^{(i)}.$$

[6]

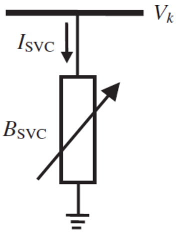
At the end of iteration (i), the variable firing angle α svc is updated according to

$$\alpha_{\mathrm{SVC}}^{(i)} = \alpha_{\mathrm{SVC}}^{(i-1)} + \Delta\alpha_{\mathrm{SVC}}^{(i)}.$$

-------[7]

IV. AVAILABLE TRANSFER CAPABILITY

Available Transfer Capability (ATC) is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses. Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM). ATC can be expressed as: [2]



ATC = TTC – TRM – Existing Transmission Commitments (including CBM)

- ATC Principles:

The following principles identify the requirements for the calculation and application of ATCs[2]. ATC calculations must produce commercially viable results. ATCs produced by the calculations must give a reasonable and dependable indication of transfer capabilities available to the electric power market.

Configuration	Total losses		Total load		Total generation		Available Transfer Capability	
	MW	MVar	MW	MVar	MW	MVar	MW	MVar
Without SVC	5.2595	141.18	6097.100	1409.100	6102.360	1550.283	337.640	289.717
With SVC at bus-4	4.3454	57.5823	6097.100	1409.100	6101.446	1466.682	338.554	373.318
With SVC at bus-34	4.6577	65.3874	6097.100	1409.100	6101.785	1474.787	338.242	365.513

Table-2 MATLAB M-file Results for Available Transfer Capability

1. ATC calculations must recognize time-variant power flow conditions on the entire interconnected transmission network. In addition, the effects of simultaneous transfers and parallel path flows throughout the network must be addressed from a reliability viewpoint.
2. ATC calculations must recognize the dependency of ATC on the points of electric power injection, the directions of transfers across the interconnected transmission network, and the points of power extraction.
3. ATC calculations must conform to NERC, Regional, sub- regional, power pool, and individual system reliability planning and operating policies, criteria, or guides. Appropriate system contingencies must be considered.
4. The determination of ATC must accommodate reasonable uncertainties in system conditions and provide operating flexibility to ensure the secure operation of the interconnected network.

- Steps for ATC Program :

To converts impedances data to admittances and obtains the bus admittance matrix (Y-bus).

To calculate the Newton-Rapson power flow. It required the bus data and the line data including load and generation in MW and Mvar, bus voltages in pu, and angle in
degrees.

To produce the bus output result. The bus output result includes the voltage magnitude and angle, real and reactive power of generator and total loads.

To display the active and reactive power flow entering the line terminal and line losses as well as net power at each bus.

To display the total losses at the system and total generation of the system. At this part to key-in the value of the total transfer capability and transmission reliable margin of system before the ATC value can be calculated.

RESULTS AND DISCUSSION

In this paper SVCs variable shunt susceptance model is used for IEEE-39 bus system with Newton-

Rapson load flow and the ATC find without SVC and with SVC at different bus is also presented. For that MATLAB M-file software is used. The M-file ATC results Without SVC and With SVC at different buses of IEEE-39 bus system are shown in Table-2. From the Table-2 seen that the value of Available Transfer Capability is enhanced using Static Var Compensator. It is also seen that the location of SVC is important for Enhancement of Available Transfer Capability.

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