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IMPROVEMENT OF AVAILABLE TRANSFER CAPABILITY IN A DEREGULATED POWER SYSTEM USING EFFECT OF MULTI FACTS DEVICES

[1]T V V Pavan Kumar, [2]Dr Amit Kumar Jain

[1]Assistant Professor. Global Institute of Engineering & Technology. Hyderabad.
[2]Professor. Jagan Institute of Management Studies Rohini, Delhi-110085

Abstract: In a deregulated power system structure, power producers and customers share a common transmission network for wheeling power from the point of generation to the point of consumption. All parties in this open access environment may try to produce the energy from the cheaper source for greater profit margin, which may lead to overloading and congestion of certain corridors of the transmission network. This may result in violation of line flow, voltage and stability limits and there by undermine the system security, utilities therefore need to enhance "available transfer capability (ATC)" to ensure the system reliability is maintained while serving a wide range of bilateral and multilateral transactions. This paper focuses on the enhancement ATC using multi FACTS devises i.e combination of Thyristor Controlled Series Capacitor (TCSC) and Thyristor Controlled Phase Angle Regulator (TCPAR). The optimal location of FACTS devices were determined based on Sensitivity methods. The Reduction of Total System Reactive Power Losses Method was used to determine the suitable location of TCSC and TCPAR for ATC enhancement. The effectiveness of proposed method is demonstrated on modified IEEE-9 bus system and 24 bus real time system using power world simulator 8.0

Keywords: Deregulation, Available Transfer Capability, TCSC, TCPAR, Multi FACTS devises

I. INTRODUCTION

The introduction of deregulation has brought several new entities in the electricity market place, while on the other hand redefining the scope of activities of many of the existing players. With the ongoing expansion and growth of the electric utility industry, numerous changes are continuously being introduced. Improved utilization of the existing power system is provided through the application of advanced control technologies. Power electronics based equipment, or Flexible AC Transmission Systems (FACTS), provide proven technical solutions to address these new operating challenges being presented today. Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Angle Regulator (TCPAR), Unified Power Flow Controller (UPFC) and Static VAR Compensator (SVC) are some of the commonly used FACTS controllers. In many deregulated markets, the power transaction between buyer and seller is allowed based on calculation of ATC. Low ATC signifies that the network is unable to accommodate further transaction and hence does not promote free competition. FACTS controllers like TCSC, TCPAR can help to improve ATC by allowing more power transactions. Electrical energy plays an important role in today's modern society. It is an efficient energy used widely for lighting, communication systems, transportation systems, industrial purposes and many other areas. In past, the electricity industry is in the control of government and therefore monopolistic. However over the past decade, the electric industry in many countries has undergone significant changes to reform into a free market, which is also known as deregulation.

Figure 1. Typical structure of a vertically integrated utility

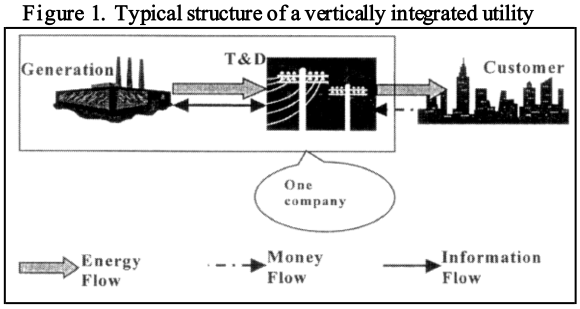

Figure 1. shows the typical structure of a vertically integrated utility where links of information flow existed only between the generators and the transmission system. Similarly, money (cash) flow was unidirectional, from the consumer to the electric utility. One of the first step in the restructuring process of the power industry is the separation of the transmission activities from the electricity generation activities. The subsequent step was to introduce competition in generation activities. An important point to note is that the restructuring process was started with the breaking up of a large vertically integrated utility which was characterized by the opening up of small municipal monopolies to competition. A system operator for the whole

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appropriately, the system operator came to be known as the Independent System Operator (ISO).

Fig.2 Typical structure of a deregulated electricity system

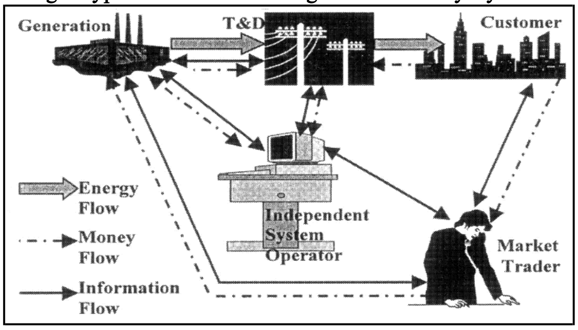


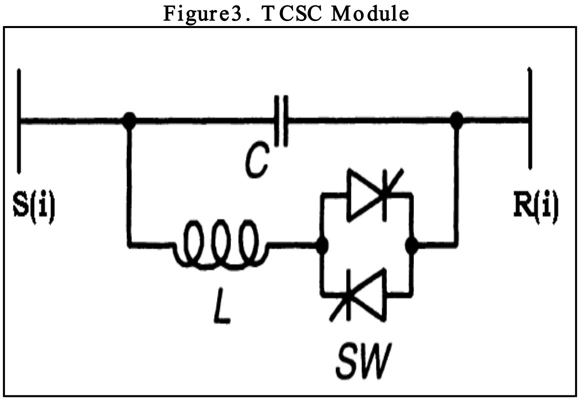
Figure 2 shows the typical structure of a deregulated electricity system with links of information and money (cash) flow between various players. The possibility of having such a complex nature of information flow has been one of the driving factors in the process of deregulation of the power sector. This has been possible due to the rapid developments in the fields of communication and information technology during the nineties decade.

II. FACTS CONTROLLERS 2.1Thyristor

Controlled Series Compensator

Thyristor-controlled series capacitor (TCSC) is a capacitive reactance compensator, which consists of a series capacitor bank shunted by a thyristor controlled reactor in order to provide a smoothly variable series capacitive reactance. Even though a TCSC in the normal operating range is mainly capacitive, but it can also be used in an inductive mode. The power flow over a transmission line can be increased by controlled series compensation with minimum risk of subsynchronous resonance (SSR). TCSC is a second generation FACTS controller, which controls the impedance of the line in which it is connected by varying the firing angle of the thyristors. A TCSC module comprises a series fixed capacitor that is connected in parallel to a thyristor controlled reactor (TCR).

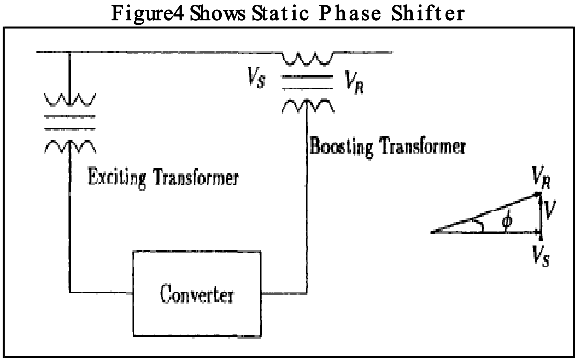
Figure3. TCSC Module



A TCR includes a pair of anti-parallel thyristors that are connected in series with an inductor. In a TCSC, a metal oxide varistor (MOV) along with a bypass breaker is connected in parallel to the fixed capacitor for overvoltage protection. A complete compensation system may be made up of several of these modules.

2.2ThyristorControlledPhaseAngleRegulator TCPAR is identical with a phase shifting transformer with a thyristor type tap changer and plays an important role in increasing loadability of the existing system and controlling the congestion in the network. FACTS device like TCPAR can be used to regulate the power flow in the tie-lines of interconnected power system. This is also known as Static Phase Shifter (SPS) and phase shift with respect to the bus voltage is achieved by adding or subtracting a variable voltage component in quadrature with the bus voltage. The quadrature voltage is injected in series with the transmission line by a boosting transformer. The basic arrangement is shown in figure 4.

Figure4 Shows Static Phase Shifter



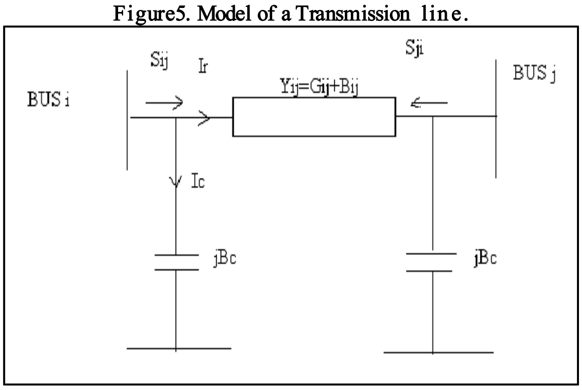
III. MODELING OF FACTS DEVICES

For enhancing of transfer capability, the static models of these controllers are considered. It is assumed that the time constants in FACTS devices are very small and hence this approximation is justified.

Analysis of Transmission Lines and its Power Flows and Loss

Let the complex voltages at bus i and bus j be enoted as $V_i \angle \delta_i$ and $V_j \angle \delta_j$ respectively.

Figure5. Model of a Transmission line.



The complex power flowing from bus i to bus j can be expressed as:

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$$S_{ij}^{*} = P_{ij} - jQ_{ij} = V_i^{*} I_{ij} = V_i^{*}(I_R + I_C)$$
(1)
$$= V_i^{*}[(V_i - V_j)(G_{ij} + B_{ij}) + V_i(jB_c)]$$
$$= V_i^{2}[G_{ij} + j(B_{ij} + B_c)] - V_i^{*}V_j(G_{ij} + B_{ij})]$$
$$= V_i^{2}[G_{ij} + j(B_{ij} + B_c)] - V_i^{*}V_j(G_{ij} + B_{ij})]$$
$$= [V_i^2 G_{ij} - V_iV_jG_{ij}\cos(\delta_j - \delta_i) + V_iV_jB_{ij}\sin(\delta_j - \delta_i)] + j[V_i^2(B_{ij} + B_c) - V_iV_jB_{ij}\cos(\delta_j - \delta_i) - V_iV_jG_{ij}\sin(\delta_j - \delta_i)]$$

The Active & Reactive power flow form bus i to bus j is,

$$P_{ij} = V_i^2 G_{ij} - V_iV_jG_{ij}\cos(\delta_{ij}) - V_iV_jB_{ij}\sin(\delta_{ij})$$
(2)
$$Q_{ij} = -V_i^2(B_{ij} + B_c) + V_iV_jB_{ij}\cos(\delta_{ij}) - V_iV_jG_{ij}\sin(\delta_{ij})$$
(3) Where $\delta_{ij} = \delta_i - \delta_j$

Similarly, Real & Reactive Power flows from bus j to bus i can be,

$$P_{ji} = V_j^2 G_{ij} - V_iV_jG_{ij}\cos(\delta_{ij}) - V_iV_jB_{ij}\sin(\delta_{ij})$$
(4)
$$Q_{ji} = -V_j^2(B_{ij} + B_c) + V_iV_jB_{ij}\sin(\delta_{ij}) + V_iV_jG_{ij}\cos(\delta_{ij}) \quad (5)$$

The active and reactive Power loss in the line can be calculated as,

$$= P_{ij} + P_{ji}$$
$$P_L = V_i^2 G_{ij} - V_iV_jG_{ij}\cos(\delta_{ij}) - V_iV_jB_{ij}\sin(\delta_{ij}) - V_j^2 G_{ij} - V_iV_jG_{ij}\cos(\delta_{ij}) + V_iV_jB_{ij}\sin(\delta_{ij})$$
$$P_L = V_i^2 G_{ij} + V_j^2 G_{ij} - 2V_iV_jG_{ij}\cos(\delta_{ij})$$
(6)
$$= Q_{ij}$$
$$Q_L = -V_i^2(B_{ij} + B_c) + V_iV_jB_{ij}\cos(\delta_{ij}) - V_iV_jG_{ij}\sin(\delta_{ij}) - V_j^2(B_{ij} + B_c) + V_iV_jB_{ij}\sin(\delta_{ij}) + V_iV_jG_{ij}\cos(\delta_{ij})$$

$$Q_L = -V_i^2(B_{ij} + B_c) - V_j^2(B_{ij} + B_c) + 2V_iV_jB_{ij}\cos(\delta_{ij}) \quad (7)$$

Power Injection Model Of Thyristor Controlled Series Compensator (TCSC)

Thyristor controlled series compensators (TCSC) are connected in series with the lines. The effect of a TCSC on the network is as a controllable reactance in the related transmission line which compensates the inductive reactance of the line results in reducing the transfer reactance between the buses. This leads to an increase in the maximum power that can be transferred on that line in addition to a reduction in the effective reactive power losses. The series capacitors also contribute to an improvement in the voltage profiles.

Figure6. Model of a TCSC

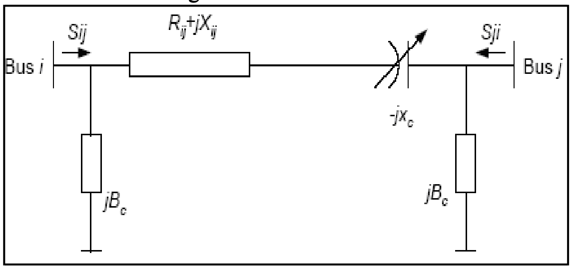

Figure 6 shows a model of a transmission line with a TCSC connected between buses i and j. The transmission line is represented by its lumped π-equivalent parameters connected between the two buses. During the steady state, the TCSC can be considered as a static reactance -jX_C. This controllable reactance, X_C is directly used as the control variable to be implemented in the power flow equation. Let the complex voltages at bus i and bus j be denoted as $V_i\angle\delta_i$ and $V_j\angle\delta_j$ respectively. The expressions for real and reactive power flows from bus i to bus j can be written as from

$$P'_{ij} = V_i^2 G'_{ij} - V_iV_j[G'_{ij}\cos(\delta_{ij}) + B'_{ij}\sin(\delta_{ij})]$$
(8)
$$Q'_{ij} = -V_i^2(B'_{ij} + B_c) - V_iV_j[G'_{ij}\sin(\delta_{ij}) + B'_{ij}\cos(\delta_{ij})]$$
(9)

Similarly, the real and reactive power flows from bus j to bus i can be expressed as,

$$P'_{ji} = V_j^2 G'_{ij} - V_iV_j[G'_{ij}\cos(\delta_{ij}) - B'_{ij}\sin(\delta_{ij})]$$
(10)
$$Q'_{ji} = -V_j^2(B'_{ij} + B_c) + V_iV_j[G'_{ij}\sin(\delta_{ij}) + B'_{ij}\cos(\delta_{ij})]$$
(11)

The active and reactive power losses in the line with TCSC are

$$P'_L = P'_{ij} + P'_{ji} = G'_{ij}(V_i^2 + V_j^2) - 2V_iV_jG'_{ij}\cos\delta_{ij}$$
(12)
$$Q'_L = Q'_{ij} + Q'_{ji} = -(V_i^2 + V_j^2)(B'_{ij} + B_c) + 2V_iV_jG'_{ij}\cos\delta_{ij}$$
(13)

Line flows

Without TCSC (-j X_c)

$$G_{ij} + jB_{ij} = \frac{r_{ij}}{r_{ij}^2 + x_{ij}^2} + j\frac{-(x_{ij})}{r_{ij}^2 + x_{ij}^2}$$

With TCSC(- j x_c)

$$G'_{ij} + jB'_{ij} = \frac{1}{r_{ij} + j(x_{ij} - x_c)} * \frac{r_{ij} - j(x_{ij} - x_c)}{r_{ij} - j(x_{ij} - x_c)}$$
$$= \frac{r_{ij} - j(x_{ij} - x_c)}{r_{ij}^2 - j(x_{ij} - x_c)^2} = \frac{r_{ij}}{r_{ij}^2 - j(x_{ij} - x_c)^2} + j\frac{-(x_{ij} - x_c)}{r_{ij}^2 - j(x_{ij} - x_c)^2}$$

Where

$$G'_{ij} = \frac{r_{ij}}{r_{ij}^2 - j(x_{ij} - x_c)}$$

and

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Hence, $\Delta G_{ij} \quad - G'_{ij}$ (without - with x_c)

$$= \frac{r_{ij}}{r_{ij}^2 + x_{ij}^2} - \frac{r_{ij}}{r_{ij}^2 - j(x_{ij} - x_c)^2}$$

$$= r_{ij} * \frac{r_{ij}^2 + (x_{ij} - x_c)^2 - r_{ij}^2 - x_{ij}^2}{(r_{ij}^2 + x_{ij}^2)\{r_{ij}^2 - j(x_{ij} - x_c)^2\}}$$

$$= r_{ij} * \frac{x_{ij}^2 + x_c^2 - 2x_{ij}x_c - x_{ij}^2}{(r_{ij}^2 + x_{ij}^2)\{r_{ij}^2 - j(x_{ij} - x_c)^2\}}$$

$$\Delta G_{ij} = \frac{x_c r_{ij}(x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)\{r_{ij}^2 - j(x_{ij} - x_c)^2\}}$$

(14)

$$\Delta B_{ij} = \frac{-x_c(r_{ij}^2 - x_{ij}^2 + x_c x_{ij})}{(r_{ij}^2 + x_{ij}^2)\{r_{ij}^2 - j(x_{ij} - x_c)^2\}}$$

(15)

Hence, the Change in line flows due to Series Capacitance,

The real Power injection at bus 'i'

$$P_i' = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos(\delta_{ij}) + \Delta B_{ij} \sin(\delta_{ij})]$$

(16)

$$P_j' = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos(\delta_{ij}) + \Delta B_{ij} \sin(\delta_{ij})]$$

(17)

$$Q_i' = -V_i^2 \Delta B_{ij} - V_i V_j [\Delta G_{ij} \sin(\delta_{ij}) - \Delta B_{ij} \cos(\delta_{ij})]$$

(18)

$$Q_j' = -V_j^2 \Delta B_{ij} + V_i V_j [\Delta G_{ij} \sin(\delta_{ij}) + \Delta B_{ij} \cos(\delta_{ij})]$$

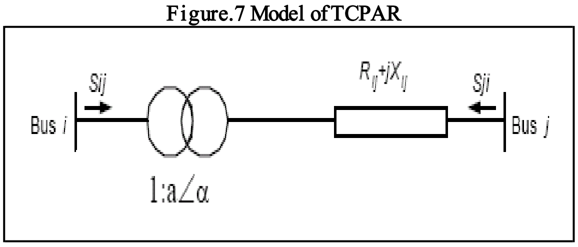
(19)

These equations are used to model the TCSC to Enhance the Power Transfer Capability.

3 .3 Power Injection of Thyristor Controlled Phase Angle Regulator (TCPAR)

In a Thyristor controlled phase angle regulator, the phase shift is achieved by introducing a variable voltage component in perpendicular to the phase voltage of the line. The static model of a TCPAR having a complex tap ratio of 1:a∟α and a transmission line between bus i and bus j is Shown in Figure5

Figure.7 Model of TCPAR



The real and reactive power flows from bus i to bus j can be expressed as

$$S_{ij}^* = P_{ij} - jQ_{ij}$$

$$= V_i^* [(V_i - V_j)Y_{ij}] \qquad (20)$$

$$S_{ij}^* = V_i^* [a^2 V_i - a^* V_j] Y_{ij}$$

$$= V_i^* [a^2 V_i - a^* V_j][G_{ij} + jB_{ij}]$$

$$= V_i^* a^2 V_i (G_{ij} + jB_{ij}) - V_i^* V_j a^* (G_{ij} + jB_{ij})$$

$$= V_i^2 a^2 (G_{ij} + jB_{ij}) - V_i V_j a (G_{ij} + jB_{ij}) ∟(\delta_j - \delta_i - \alpha)$$

$$= V_i^2 a^2 G_{ij} + jV_i^2 a^2 B_{ij} - V_i V_j a (G_{ij} - jB_{ij}) \cos(\delta_j - \delta_i - \alpha) - jV_i V_j a (G_{ij} + jB_{ij}) \sin(\delta_j - \delta_i - \alpha)$$

$$= V_i^2 a^2 G_{ij} - jV_i^2 a^2 B_{ij} - V_i V_j a G_{ij} \cos(\delta_j - \delta_i - \alpha) - jV_i V_j a B_{ij} \cos(\delta_j - \delta_i - \alpha) - jV_i V_j a G_{ij} \sin(\delta_j - \delta_i - \alpha) + V_i V_j a B_{ij} \sin(\delta_j - \delta_i - \alpha)$$

$$= [V_i^2 a^2 G_{ij} - V_i V_j a G_{ij} \cos[-(\delta_i - \delta_j + \alpha)] + V_i V_j a B_{ij} \sin[-(\delta_i - \delta_j - \alpha)]] - j[V_i^2 a^2 B_{ij} - V_i V_j a B_{ij} \cos[-(\delta_i - \delta_j + \alpha)] - V_i V_j a G_{ij} \sin[-(\delta_i - \delta_j + \alpha)]]$$

$$= [V_i^2 a^2 G_{ij} - V_i V_j a G_{ij} \cos(\delta_i - \delta_j - \alpha) - V_i V_j a B_{ij} \sin(\delta_i - \delta_j + \alpha)] + j[V_i^2 a^2 B_{ij} - V_i V_j a B_{ij} \cos(\delta_i - \delta_j + \alpha) + V_i V_j a G_{ij} \sin(\delta_i - \delta_j + \alpha)]$$

(21)

The real and reactive power flows from bus i to bus j are

Complex power, $S_{ij} \quad P_{ij} + jQ_{ij}$

$$P_{ij} \quad Re[s_{ij}^*] = Re\{V_i^* [a^2 V_i - a^* V_j] Y_{ij}\}$$

$$P_{ij} = V_i^2 a^2 G_{ij} - V_i V_j a G_{ij} \cos(\delta_i - \delta_j + \alpha) - V_i V_j a B_{ij} \sin(\delta_i - \delta_j + \alpha)$$

(22)

$$Q_{ij} \quad -Im[s_{ij}^*] = Im\{V_i^* [a^2 V_i - a^* V_j] Y_{ij}\}$$

$$-[V_i^2 a^2 B_{ij} - V_i V_j a B_{ij} \cos(\delta_i - \delta_j - \alpha) + V_i V_j a G_{ij} \sin(\delta_i - \delta_j + \alpha)]$$

$$Q_{ij} = -V_i^2 a^2 B_{ij} + V_i V_j a B_{ij} \cos(\delta_i - \delta_j + \alpha) - V_i V_j a G_{ij} \sin(\delta_i - \delta_j + \alpha) \quad (23)$$

Similarly, the real and reactive power flows from bus j to bus i are

$$\quad = Re\{V_i^* [V_j - aV_i] Y_{ij}\}$$

$$P_{ji} = V_j^2 G_{ij} - V_i V_j a G_{ij} \cos(\delta_i - \delta_j + \alpha) + V_i V_j a B_{ij} \sin(\delta_i - \delta_j + \alpha)$$

(24)

And $\quad = -Im\{V_i^* [V_j - aV_i] Y_{ij}\}$

$$Q_{ji} \quad -V_j^2 B_{ij} + V_i V_j a B_{ij} \cos(\delta_i - \delta_j + \alpha) + V_i V_j a G_{ij} \sin(\delta_i - \delta_j + \alpha)$$

(25)

The real and reactive power loss in the line having a TCPAR can be expressed as

$$= P_{ij} + P_{ji}$$

$$P_L = V_i^2 a^2 G_{ij} + V_j^2 G_{ij} - 2V_i V_j a G_{ij} \cos(\delta_i - \delta_j + \alpha)$$

(26)

$$Q_L = Q_{ij} + Q_{ji}$$

$$Q_L = -V_i^2 a^2 B_{ij} - V_j^2 B_{ij} + 2V_i V_j a B_{ij} \cos(\delta_i - \delta_j + \alpha)$$

(27)

This mathematical model makes the Y-bus asymmetrical. In order to make the Y-bus symmetrical, the TCPAR can be simulated by augmenting the existing line with additional power injections at the two buses. The injected active and reactive powers at bus i (ΔP_i, ΔQ_i) and bus j (ΔP_j, ΔQ_j) are given as:

$$\Delta P_i = -a^2 V_i^2 G_{ij} - aV_i V_j [G_{ij} \sin(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j)]$$

(28)

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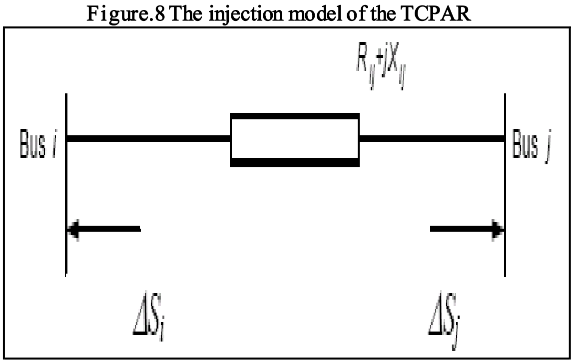
$$\Delta P_j = -aV_iV_j\left[G_{ij}\sin(\delta_i-\delta_j) - B_{ij}\cos(\delta_i-\delta_j)\right]$$
(29)

$$\Delta Q_i = a^2V_i^2B_{ij} + aV_iV_j\left[G_{ij}\cos(\delta_i-\delta_j) - B_{ij}\sin(\delta_i-\delta_j)\right]$$
(30)

$$\Delta Q_j = -aV_iV_j\left[G_{ij}\cos(\delta_i-\delta_j) - B_{ij}\sin(\delta_i-\delta_j)\right]$$
(31)

These equations will be used to model the TCPAR in the Enhancement of transfer capability

Figure.8 The injection model of the TCPAR



IV. OPTIMAL LOCATION BASED ON SENSITIVITY APPROACH FOR TCSC AND TCPAR DEVICES

The static conditions are considered here for the placement of FACTS devices in the power system. The objectives for device placement may be one of the following:

1. Reduction in the real power loss of a particular line
2. Reduction in the total system real power loss
3. Reduction in the total system reactive power loss
4. Maximum relief of congestion in the system

Reduction of total system VAR power loss

Here, a method based on the sensitivity of the total system reactive power loss (Q_L) with respect to the control variables of the FACTS devices For each of the two devices considered in Section 2.1 and 2.2, the following describes control parameters considered:

- Net line series reactance (X_{ij}) for a TCSC placed between buses i and j,
- Phase shift (α_{ij}) for a TCPAR placed between buses i and j.

The reactive power loss sensitivity factors with respect to these control variables may be given as follows:

1. Loss sensitivity with respect to control parameter X_{ij} of TCSC placed between buses i and j,

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}} \qquad (32)$$

2. Loss sensitivity with respect to control parameter θ_{ij} of TCPAR placed between buses i and j,

$$b_{ij} = \frac{\partial Q_L}{\partial \theta_{ij}} \qquad (33)$$

These factors can be computed for a base case power flow solution. Consider a line connected between buses i and j and having a net series impedance of X_{ij}, that includes the reactance of a TCSC, if present. In that line θ_{ij} is the net phase shift in the line and includes the effect of the TCPAR. The loss sensitivities with respect to X_{ij} and θ_{ij} can be computed as:

$$a_{ij} = \frac{\partial Q_L}{\partial x_{ij}} = \left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i-\delta_j)\right]\frac{R_{ij}^2 - X_{ij}^2}{(R_{ij}^2+X_{ij}^2)^2}$$
(34)

$$b_{ij} = \frac{\partial Q_L}{\partial \theta_{ij}} = \left[-2aV_iV_jB_{ij}\sin\theta_{ij}\right]$$
(35)

Selection of optimal placement of FACTS devices

Using the loss sensitivities as computed in the previous section, the criteria for deciding device location might be stated as follows:

1. TCSC must be placed in the line having the most positive loss sensitivity index a_{ij}.
2. TCPAR must be placed in the line having the highest absolute value of loss sensitivity index b_{ij}.

V. RESULTS AND DISCUSSIONS:

Case studies are conducted on a 5 number of systems – IEEE 9, IEEE 24 rts .bus systems.

For each system, the enhancements of ATC and voltage profile at buses are determined with individual FACTS devices placed in turn and multi type FACTS devices. The following subsections describe the models and study conducted in detail. The calculation of ATC is carried out by using Power world simulator to compute the power flow of each transfer case. The optimal power flow under normal and at contingency conditions has been carried out. The static models of the FACTS controllers as given in Section 2.1, .2.2 are considered. TCSC is represented as a static reactance and TCPAR is considered as a transformer with a complex tap ratio. The optimal locations for placing each of these devices are determined by sensitivity analysis.

Case Study -1-IEEE 9 Bus system

System Model

This system consists of 9 buses, 9 line sections, 3 generator buses and 3 load buses.

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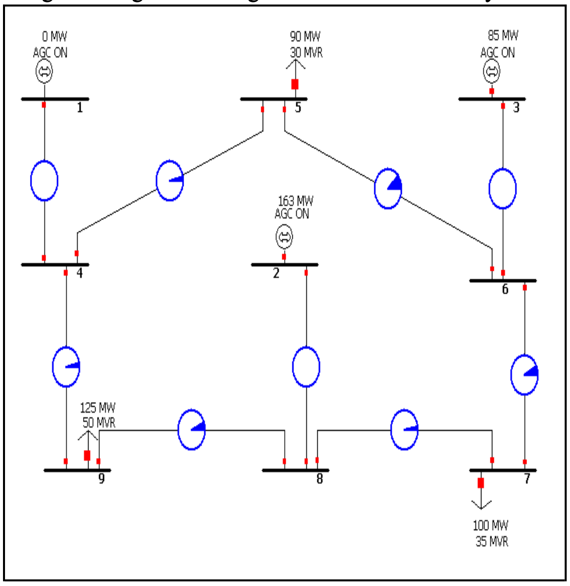
Figure .8Single line diagram of IEEE 9 bus System



Sensitivity Index

TABLE1:VAR loss sensitivity index of IEEE-9 Bus System

Line No(k)	From-To Bus	Loss Sensitivities	
		TCSC(a_{ij})	TCPAR (b_{ij})
1	1-4	-0.5771	1.441
2	8-2	-2.765	-3.26
3	3-6	-0.721	**1.696**
4	4-5	**-0.095**	0.588
5	9-4	-0.258	-0.752
6	5-6	-0.334	-1.19
7	6-7	**-0.0785**	0.4486
8	7-8	-0.58	-1.513
9	8-9	-0.711	**1.679**

For this system, from Table1, three cases have been considered

1.A TCSC is placed in lines 4(4-5) and 7(6-7), operated with an inductive reactance of 75% and 20% of the line reactance;

2.A TCPAR is placed in the lines 3(3-6), 9(8-9) operated with a phase shift of 2.9, 4.5 degrees and unity tap ratio;

3.For Multi type FACTS (i.e. combination of TCSC & TCPAR), TCSC is placed in line 7(6-7) with 20% of the line reactance and TCPAR is placed in line 3(3-6) with a phase shift of 2.9 degrees respectively.

ATC Enhancement

Table 2: Available Transfer Capability for an IEEE 9-Bus System [without Contingency]

From-To Bus	ATC (MW)						
	Without FACTS	With TCSC	% Enhancement	With TCPAR	% Enhancement	With TCSC-TCPAR	% Enhancement
1-4	170.4	170.4	N.E	170.9	0.251	171.4	0.583
2-8	124	124	N.E	124	N.E	124	N.E
3-5	112.9	121.6	7.103	113.0	0.044	122.9	**8.13**
3-8	135.6	135.9	0.228	142.6	4.920	145.6	6.865

It is observed from the Table 2, the enhancement of ATC is of **8.13%** with Multi type FACTS which is more than that due to placement of individual FACTS devices.

Table 3: Available Transfer Capability for an IEEE 9-Bus System [with Contingency]

From-To Bus	ATC (MW)						
	Without FACTS	With TCSC	% Enhancement	With TCPAR	% Enhancement	With TCSC-TCP	% Enhancement
1-4	169.95	170.0	0.058	171.3	0.822	172.9	**1.74**
2-8	87	87	N.E	87	N.E	87	N.E
3-5	166.45	166.5	0.036	166.5	0.048	167.4	0.591
3-8	166.45	166.5	0.036	166.5	0.048	167.4	0.591

It is observed from the Table 3, the percentage enhancement of ATC is of **1.740%** with Multi type FACTS which is more than that due to placement of individual FACTS devices under contingency condition at line 8 (i.e line between bus 7 and bus 8 disconnected).

Voltage Profiles

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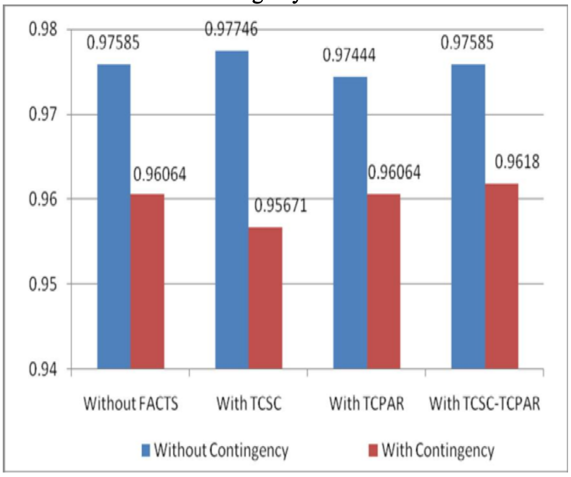
Fig 8. Comparision of voltages with and without FACTS under normal and contingency condition at bus 5



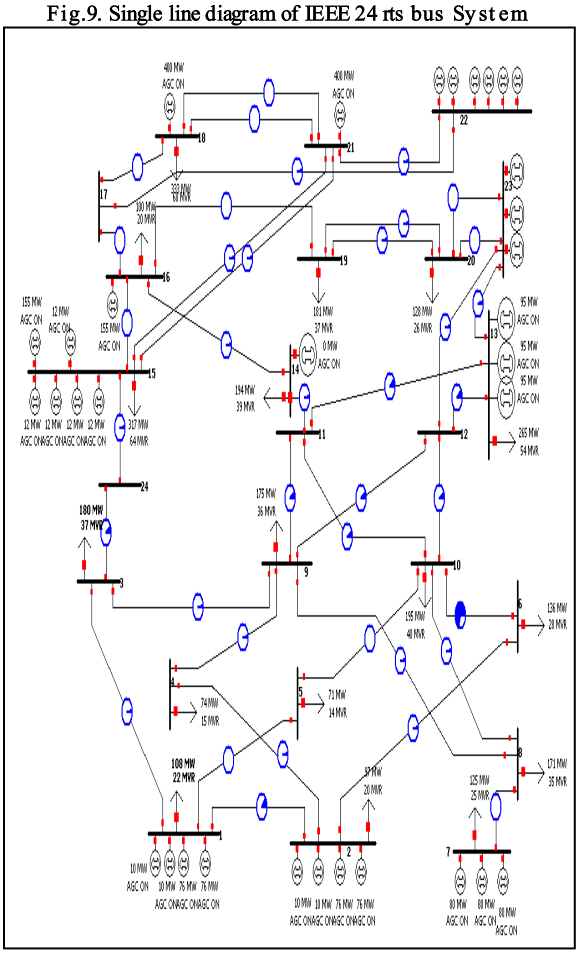
It is also observed from the Fig 8 that with multi-type FACTS devices the voltage at bus 5 is increased from 0.96064p.u to 0.9618 p.u under contingency conditions compared to individual FACTS devices

Case Study -2-IEEE 24 rts Bus system

System Model

This systemconsists of 24 buses, 38 line sections, 11 generator buses and 17 load buses.

Fig.9. Single line diagram of IEEE 24 rts bus System



Sensitivity Index

Table 4: VAR loss sensitivity index of IEEE-24 rts Bus System

Line No(k)	From-To Bus i-j	Loss sensitivities	
		TCSC(a_{ij})	TCPAR(b_{ij})
1	1-2	-0.01232	0.2421
2	1-3	-0.0474	-0.256
3	1-5	-0.2897	1.227
4	2-4	-0.154	0.6933
5	2-6	-0.3001	1.149
6	3-9	-0.0756	0.5534
7	3-24	-4.898	-4.33
8	4-9	-0.1096	-0.7256
9	5-10	-0.06604	-0.129
10	6-10	-1.0578	-2.146
11	7-8	-1.1189	2.218
12	8-9	-0.1122	-0.738
13	8-10	-0.116	-0.3062
14	9-11	-1.164	-2.1447
15	9-12	-0.01225	-2.44029
16	10-11	-2.922	-3.1667
17	10-12	-3.176	-3.4889
18	11-13	-0.877	-1.638
19	11-14	-3.322	-3.614
20	12-13	-0.368	-1.185
21	12-23	-4.986	-4.608
22	13-23	-4.72	-4.5339
23	14-16	-13.67	-7.308
24	15-16	-1.3055	2.351
25	15-21	-4.47	-4.2029
26	15-21	-4.47	-4.2029
27	15-24	-4.575	4.151
28	16-17	-9.865	-6.384
29	16-19	-1.409	2.421
30	17-18	-3.43	-3.594
31	17-22	-1.76	-2.825
32	18-21	-0.328	-1.233
33	18-21	-0.328	-1.233
34	19-20	-0.214	-0.571
35	19-20	-0.214	-0.571
36	20-23	-1.0022	-1.8325
37	20-23	-1.0022	-1.8325
38	21-22	-2.218	-3.201

For this system, from Table 4, three cases have been considered (from Section 3.4.2)

1. A TCSC is placed in lines 1(1-2) and 15(9-12), operated with an inductive reactance of 75% and 20% of the line reactance;
2. A TCPAR is placed in the lines 23(14-16), 28(16-17) operated with a phase shift of 2.5, 4.5 degrees and unity tap ratio;
3. For Multi type FACTS (i.e. combination of TCSC & TCPAR), TCSC is placed in line 15(9-12) with 20% of the line reactance and TCPAR is placed in line 23(14-16) with a phase shift of 2.5 degrees respectively.

ATC Enhancement

Table 5: Available Transfer Capability for an IEEE 24 rts Bus System
[without Contingency]

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From-To Bus	ATC (MW)						
	Without FACTS	With TCSC	% Enhancement	With TCPAR	% Enhancement	With TCSC-TCPAR	% Enhancement
1-5	155.0	155.8	0.50	157.9	1.81	158.3	2.046
23-15	817.2	821.2	0.49	817.2	N.E	827.2	1.208
13-21	917.9	938.6	2.20	927.6	1.04	947.6	3.135
16-21	1118.3	1123.8	0.49	1118.3	N.E	1183.5	**5.511**
22-19	332.4	332. 4	N.E	332.4	N.E	337.4	1.493

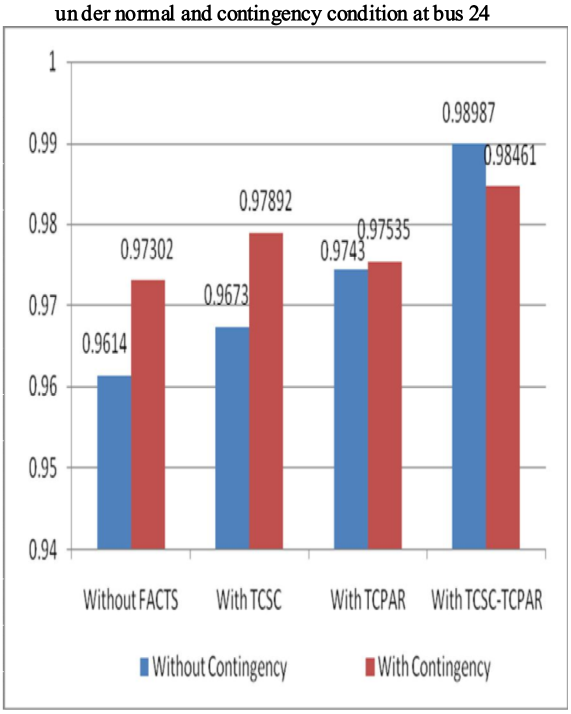
It is observed from the Table .5, the Enhancement of ATC is of **5.511%** with Multi type FACTS which is more than that due to placement of individual FACTS devices. It is observed from the Table 6, the percentage enhancement of ATC is of **5.66%** with Multi type FACTS which is more than that due to placement of individual FACTS devices under contingency condition at line 10 (i.e line between bus 6 and bus 10 disconnected).

Table .6: Available Transfer Capability for an IEEE 24 rts Bus System [with Contingency at line10 (6-10)

From-To Bus	ATC (MW)						
	Without FACTS	With TCSC	% Enhancement	With TCPAR	% Enhancement	With TCSC-TCPAR	% Enhancement
1-5	212.31	212.31	N.E	215.5	1.48	224.2	5.32
23-15	846.5	846.5	N.E	846.5	N.E	862.5	1.86
13-21	1007.7	1101.0	8.47	1037.5	2.87	1068.2	**5.66**
16-21	1159.7	1185.0	2.13	1159.7	N.E	1228.1	5.56
22-19	322.66	322.66	N.E	322.66	N.E	326.9	1.31

Voltage Profiles

Fig 10. Comparision of voltages with and without FACTS under normal and contingency condition at bus 24



It is observed from the Fig10 that with multi-type FACTS devices the voltage at bus 24 is increased from 0.97302p.u to 0.98461 p.u under contingency conditions compared to individual FACTS devices.

CONCLUSIONS

It is observed that the enhancement of Available Transfer Capability comparison between various buses of an IEEE-9, 24rts, bus systems. Also observed that the enhancement of ATC using Multi type FACTS devices is more than individual FACTS devices like TCSC, TCPAR by placing optimally with sensitivity approach. It is observed that the enhancement of ATC is not only for IEEE test systems but also for Indian utility system with and without FACTS devices under normal and contingency conditions. Also observed the voltages with and without FACTS devices while enhancing the Available Transfer Capability. This indicates that the system is more voltage stable while enhancing ATC with multi type FACTS devices than with individual FACTS devices under contingency conditions.

Nomenclature

P_{ij}	Real power flow from bus i to j
Q_{ij}	Reactive power flow from i to j
P_L	Real power losses in the line.
Q_L	Reactive power losses in the line.
$P_{i_1}^{1}$	Real power injection at bus i
Q_i	Reactive power injection at bus i
P_{ij}^{1}	Real power flow from bus i to j with TCSC
Q_{ij}^{1}	Reactive power flow from bus i to j with TCSC

P_L^1 Real power losses in the line with TCSC
Q_L^1 Reactive power losses in the line with TCSC
$V_i \angle \delta_i$ Complex voltage at bus i
$V_j \angle \delta$ Complex voltage at bus j

REFERENCES

[1] North American Electric Reliability Council, "Available Transfer Capability Definitions and Determination", NERC June 1996.
[2] Hingorani, N.G, Gyugyi, L, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems", Institute of Electrical and Electronic Engineers Press, New York, 2000.
[3] Ying Xiao, Y. H. Song, Chen-Ching Liu, and Y. Z. Sun, "Available Transfer Capability Enhancement Using FACTS Devices", IEEE Transactions On Power Systems, Vol. 18, No. 1, February 2003
[4] Bairavan Veerayan Manikandan, Sathiasamuel Charles Raja, Paramasivam Venkatesh, "Enhancement of Available Transfer Capability with Facts Device in the Competitive Power Market", Engineering, Scientific Research, 2, 337-343, 2010.
[5] J. Vara Prasad,I. Sai Ram,B. Jayababu, "Genetically Optimized FACTS Controllers for Available Transfer Capability Enhancement", International Journal of Computer Applications (0975 – 8887) Volume 19– No.4, April 2011
[6] K. Narasimha Rao, J. Amarnath And K. Arun Kumar, "Voltage Constrained Available Transfer Capability Enhancement With Facts Devices", ARPN Journal Of Engineering And Applied Sciences, Vol. 2, No. 6, December 2007
[7] Ch.Rambabu, Dr.Y.P.Obulesu, Dr.Ch.Saibabu, "Improvement of Voltage Profile and Reduce Power System Losses by using Multi Type Facts Devices", International Journal of Computer Applications (0975 – 8887)Volume 13– No.2, January 2011
[8] Claudio A. Ca~nizares ,Alberto Berizzi ,Paolo Marannino, "Using FACTS Controllers to Maximize Available Transfer Capability", Bulk Power Systems Dynamics and Control IV{Restructuring, August 24-28, 1998, Santorini, Greece
[9] H O Bansal, H P Agrawal, S Tiwana, A R Singal And L Shrivastava, "Optimal Location of FACT Devices to Control Reactive Power", International Journal of Engineering Science and Technology Vol. 2(6), 2010, 1556-1560
[10] Yajing Gao, Ming Zhou, Jin Yang, "Available Transfer Capability Calculation Based on Contingency Selection", 5th IEEE Conference on Industrial Electronics and Applicationsis, 2010.
[11] G. MadhusudhanaRao, P. Vijaya Ramarao, T. Jayanth kumar, "Optimal Location of TCSC and SVC for Enhancement of ATC in a De-Regulated Environment using RGA", IEEE Transactions on Power Systems,2010.