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ENHANCEMENT OF AVAILABLE TRANSFER CAPABILITY IN DEREGULATED POWER SYSTEMS USING FACTS DEVICES IN REAL TIME SYSTEM OF ANDRA PRADESH STATE POWER GRID

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ABSTRACT

The Available Transfer Capability (ATC) of a transmission system is a measure of unutilized capability of the system at a given time. The computation of ATC is very important to the transmission system security and market forecasting. While the power marketers are focusing on fully utilizing the transmission system, engineers are concern with the transmission system security as any power transfers over the limit might result in system instability. One of the most critical issues that any engineers would like to keep an eye on is the voltage collapse. Recent blackouts in major cities throughout the world have raised concerns about the voltage collapse phenomenon. FACTS devices such as thyristor controlled series compensators and thyristor controlled phase angle regulators, by controlling the power flows in the network, can help to reduce the flows in heavily loaded lines resulting in an increased loadability of the network and improves the voltage stability. In this paper (128 bus system of Andhra Pradesh state power grid) a real time system is tested for calculating transfer capability by using various FACTS devices like TCSC and TCPAR. The results have been presented and analyzed.

Keywords: - Deregulation, Transfer capability, Repeated power flow (RPF), FACTS.

INTRODUCTION

Electricity markets throughout the world continue to be opened to competitive forces. Several countries have accepted the reasoning that deregulation will lead to cheaper electricity and better quality of service to customers and have proceeded with vast transformations of their electricity industries. Competition provides an incentive and an opportunity for transmitting power over long distances. The compulsory accommodation of the contracted (usually the least expensive) power by the transmission network is likely to aggravate parallel and loop flow problems, causing unpredictable line loading, voltage variations and stability problems. The effect of these on the reliability and security of the overall power system could be devastating. Various new technologies are becoming available that will help utilities maintain power system reliability while handling large volume of energy transactions. Flexible AC Transmission Systems (FACTS) is the application of power electronics devices to control the flows and other quantities in power systems. FACTS controllers can be effectively used to improve the utilization of the power system and improve its stability. FACTS provide the needful corrections of transmission functionality in order to fully utilize existing transmission systems. Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Angle Regulator (TCPAR) 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 [5].

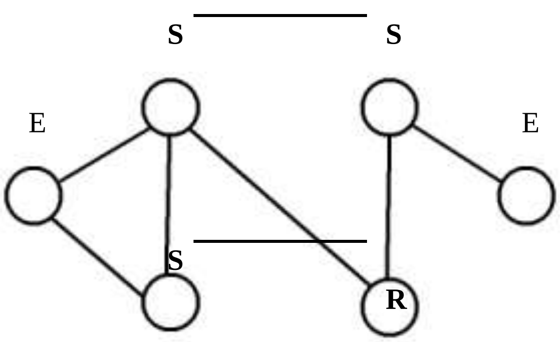
The concept of flexible AC transmission systems (FACTS) was first proposed by Hingorani [2]. FACTS devices have the ability to allow power systems to operate in a more flexible, secure, economic, and sophisticated way. Generation patterns that lead to heavy line flows result in higher losses, weakened security and stability. Such factors are economically undesirable. Further, transmission constraints make certain combinations of generation and demand unviable due to the potential of outages. In such situations, FACTS devices may be used to improve system performance by controlling the power flows in the grid. Studies on FACTS so far have mainly focused on device developments and their impacts on the power system aspects such as control, transient and small signal stability enhancement, and damping of oscillations [3, 4, 6, and 7]. With the increased presence of independent gencos in the deregulated scenario, the operation of power systems would require more sophisticated means of power control. In this aspect FACTS devices can meet those requirements. To operate the power system safely and to gain benefits of the bulk power transfer, the transfer capabilities must be calculated, so that the power transfers do not exceed the transfer capability [1,8].ATC is significantly limited by heavily loaded circuits or buses with relatively low voltages. FACTS technology makes it possible to redistribute line flow and regulate bus voltages. These can be used effectively for the enhancement of ATC.

TRANSFER CAPABILITY

Transfer capability is the measure of the ability of interconnected electric systems to *reliably* move or transfer power from one area to another over all transmission lines (or paths) between those areas under specified system conditions. The units of transfer capability are in terms of electric power, generally expressed in megawatts (MW). In this context, “area” may be an individual electric system, power pool, control area, sub-region, or a portion of any of these. Transfer capability is also directional in nature. That is, the transfer capability from Area 1 to Area 2 is *not* generally equal to the transfer capability from Area B to Area A. Transfer capability can be represented in several ways, among which the available transfer capability (ATC) and the total transfer capability (TTC) are the two most widely used ones.

Margin (CBM). In other words, ATC can be expressed as:

ATC = TTC – TRM – CBM (if there is no existing transmission commitment)



R – Receiving area; S – Sending area;

E – External area …transfer path

Fig.1 A simple interconnected power system

MODELING OF FACTS DEVICES

For enhancing of transfer capability using FACTS controllers, the 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 denoted as $V_i\angle\boldsymbol{\delta}_i$ and $V_j\angle\boldsymbol{\delta}_j$ respectively as shown in figure 2.

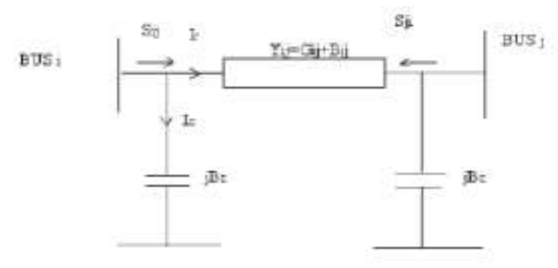


Fig.2 Model of a Transmission line

The complex power flowing from bus i to bus j can

be expressed as

$S^*_{ij} = P_{ij} – jQ_{ij} = V_i^* I_{ij} = V_i^* (I_R+I_C)$ (1)

$=V_i^* [(V_i – V_j) (G_{ij} + jB_{ij}) + V_i (jB_c)]$

$= V_i^* [V_i (G_{ij} + jB_{ij}) + V_i (jB_c) – V_j (G_{ij} + jB_{ij})]$

$= V_i^2 [G_{ij} + j (B_{ij} + B_c)] - V_i^* V_j (G_{ij} + jB_{ij})]$

$= V_i^2 G_{ij} + j [V_i^2 (B_{ij} + B_c)] – V_i V_j ((G_{ij} + jB_{ij}) \angle (\delta_j- \delta_i))$

$= V_i^2 G_{ij} + j V_i^2 (B_{ij} + B_c) - V_i V_j (G_{ij} + jB_{ij}) [Cos (\delta_j - \delta_i) + j Sin (\delta_j - \delta_i)]$

$= [V_i^2 G_{ij} - V_i V_j(G_{ij}) Cos (\delta_j - \delta_i) + V_i V_j B_{ij} Sin (\delta_j - \delta_i)] + j [V_i^2 (B_{ij} + B_c) – V_i V_j B_{ij} Cos (\delta_j - \delta_i) - V_i V_j G_{ij} Sin (\delta_j - \delta_i)]$

$= [V_i^2 G_{ij} - V_i V_j G_{ij} Cos (\delta_i - \delta_j) - V_i V_j B_{ij} Sin (\delta_i - \delta_j)] + j[V_i^2 (B_{ij} + B_c) - V_i V_j B_{ij} Cos (\delta_i - \delta_j) + V_i V_j G_{ij} Sin (\delta_i - \delta_j)]$

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

$P_{ij} = V_i^2 G_{ij} - V_i V_j G_{ij} Cos \delta_{ij} - V_i V_j B_{ij} Sin \delta_{ij}$ (2)

Where, $\delta_{ij} = \delta_i - \delta_j$

$Q_{ij} = -V_i^2 (B_{ij} + B_c) + V_i V_j B_{ij} Cos \delta_{ij} - V_i V_j G_{ij} Sin \delta_{ij}$(3)

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

$P_{ji} = V_j^2 G_{ij} - V_i V_j G_{ij} Cos (\delta_i - \delta_j) + V_i V_j B_{ij} Sin (\delta_i- \delta_j)$

(4)

$Q_{ji} = -V_j^2 (B_{ij} + B_c) + V_i V_j\ G_{ij} \text{Sin} (\delta_i - \delta_j) + V_i V_j B_{ij} \text{Cos} (\delta_i - \delta_j)$

(5)

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

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

$= V_i^2 G_{ij} - V_i V_j\ G_{ij} \text{Cos}\ \delta_{ij} - V_i V_j\ B_{ij} \text{Sin}\ \delta_{ij} + V_i^2 G_{ij} - V_i V_j\ G_{ij} \text{Cos}\ \delta_{ij} + V_i V_j\ B_{ij} \text{Sin}\ \delta_{ij}$

$P_L = V_i^2 G_{ij} + V_j^2 G_{ij} - 2 V_i V_j\ G_{ij} \text{Cos}\ \delta_{ij}$

(6)

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

$Q_L = -V_i^2(B_{ij} + B_c) - V_j^2(B_{ij} + B_c) + 2 V_i V_j\ B_{ij} \text{Cos}\ (\delta_{ij})$

(7)

A.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 can be seen as a controllable reactance inserted in the related transmission line that compensates for the inductive reactance of the line. This reduces the transfer reactance between the buses to which the line is connected. 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.

Figure 3 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.

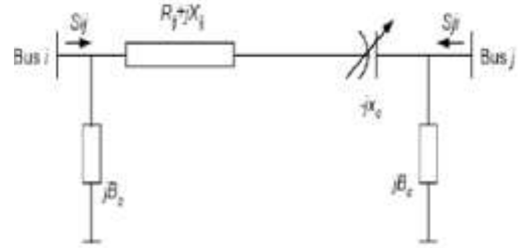


Fig. 3: Model of a TCSC

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 eqn. 1 and 2:

$P^c_{ij} = V_i^2 G_{ij}' - V_i V_j\ (G_{ij}'\ \text{Cos}\ \delta_{ij} + B_{ij}'\ \text{Sin}\delta_{ij})$ (8)

$Q^c_{ij} = -V_i^2\ (B_{ij}' + B_c) - V_i V_j\ (G_{ij}'\ \text{Sin}\delta_{ij} - B_{ij}'\ \text{Cos}\delta_{ij})$ (9)

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

$P^c_{ji} = V_j^2 G_{ij}' - V_i V_j\ (G_{ij}'\ \text{Cos}\delta_{ij} - B_{ij}'\ \text{Sin}\delta_{ij})$ (10)

$Q^c_{ji} = -V_j^2\ (B_{ij}' + B_c) - V_i V_j\ [G_{ij}'\ \text{Sin}(\delta_{ij}) + B_{ij}'\ \text{Cos}\delta_{ij}]$ (11)

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

$P^c_{LK} = P_{ij} + P_{ji}$

$P^c_{LK} = V_i^2 G_{ij}' + V_j^2 G_{ij}' - 2 V_i V_j G_{ij}' \text{Cos}\delta_{ij}$ (12)

$Q^c_{LK} = Q_{ij} + Q_{ji}$

$= -V_i^2(B_{ij} + B_c) - V_j^2(B_{ij} + B_c) + 2V_iV_jG_{ij} \cos (\delta_i - \delta_j)$ (13)

The change in line flows as,

If without TCSC ($-j X_c$)

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

If with (- j x_c)

$$G_{ij}' + jB_{ij}' = \frac{1}{r_{ij} + j(x_{ij} - x_c)}$$

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

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

Where $G_{ij}' = \frac{r_{ij}}{r_{ij}^2 + (x_{ij} - x_c)2}$ &

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

Hence, $\Delta G_{ij} = G_{ij} - G_{ij}'$ (without X_c – with X_c)

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

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

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

$$\Delta G_{ij} = \frac{x_c r_{ij}(x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)\,r_{ij}^2 + (x_{ij} - x_c)2} \quad (14)$$

$$\Delta B_{ij} = \frac{-x_c\,(r_{ij}^2 - x_{ij}^2 + x_c\,x_{ij})}{(r_{ij}^2 + x_{ij}^2)\,r_{ij}^2 + (x_{ij} - x_c)2} \quad (15)$$

The real Power injection at bus 'i'

$P_{ic} = V_i^2\,\Delta G_{ij} - V_i V_j\,[\Delta G_{ij} \cos\boldsymbol{\delta}_{ij} + \Delta B_{ij} \sin\boldsymbol{\delta}_{ij}$(16) $P_{jc} = V_j^2\,\Delta G_{ij} - V_i V_j\,[\Delta G_{ij} \cos\boldsymbol{\delta}_{ij} + \Delta B_{ij} \sin\boldsymbol{\delta}_{ij}]$ (17) $Q_{ic} = -V_i^2\,\Delta B_{ij} - V_i V_j\,[\Delta G_{ij} \sin\boldsymbol{\delta}_{ij} - \Delta B_{ij} \cos\boldsymbol{\delta}_{ij}]$ (18) $Q_{jc} = -V_j^2\,\Delta B_{ij} + V_i V_j\,[\Delta G_{ij} \sin\boldsymbol{\delta}_{ij} + \Delta B_{ij} \cos\boldsymbol{\delta}_{ij}]$ (19)

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

B.FACTS DEVICES LOCATION

The main goal of the enhancement of ATC is to perform a best utilization of the existing transmission lines. In this aspect, the FACTS Devices are located in order to maximize the system loadability while observing thermal and voltage constraints. The best utilization is possible only when the FACTS Devices are located optimally.

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

The static conditions are considering 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

For the first three objectives, methods based on the sensitivity approach may be used. If the objective of FACTS device placement is to provide maximum relief of congestion, the devices may be placed in the most congested lines or, alternatively, in locations determined by trial-and-error.

Reduction of total system VAR power loss

Here it is looked at 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 three devices considered it is considered that following control parameters:

· 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,

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}} \qquad (20)$$

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

$$b_{ij} = \frac{\partial Q_L}{\partial \theta_{ij}} \qquad (21)$$

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:

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}} = \left[V^2_i + V^2_j - 2V_iV_j\cos(\delta_i - \delta_j)\right]\frac{-R^2_{ij} - X^2_{ij}}{(R^2_{ij} + X^2_{ij})^2}$$

$$b_{ij} = \frac{\partial Q_L}{\partial \theta_{ij}} = -2aV_iV_jB_{ij}\sin\theta_{ij}$$

The sensitivity index values of other lines are calculated similarly. 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}.

RESULTS AND DISCUSSIONS

In this paper a 128 bus system is tested for the calculation of ATC by using Power world simulator to compute the power flow of each transfer case. Because every step of increase in power will need to be solved, the Newton-Raphson power flow solution is best suited with the fast iterations. This method is less prone to divergence with ill-conditioned problems. Also the number of iterations required is independent of the system size.

The limit for enhancing the ATC is the voltage collapse point with variation in load. In most systems, there are many practical and operational reasons why a simple constraint on the voltage magnitude is a more significant and limiting constraint.

In this paper, an IEEE-9, IEEE-14 and IEEE-30,AP power grid 128 Bus systems have been analyzed in this paper using Power World Simulator software.

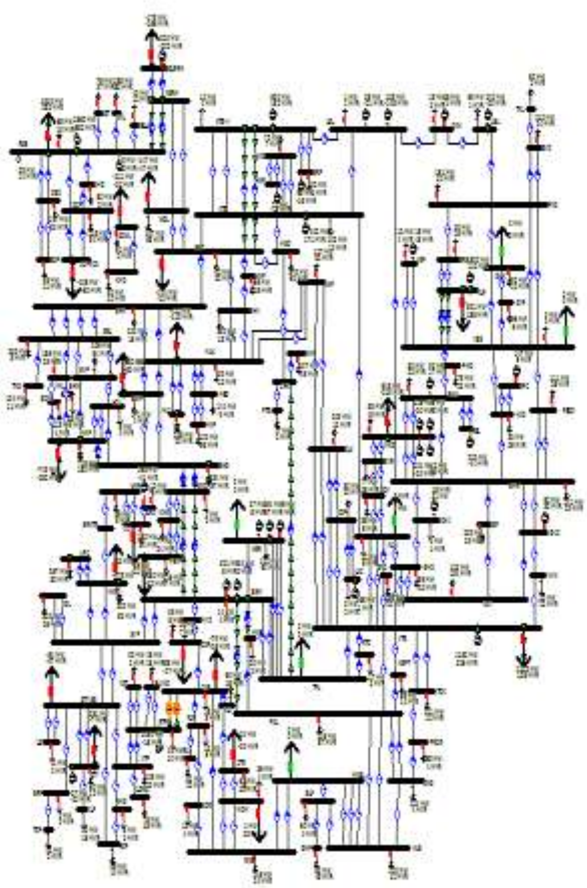


Figure 4: Single Line Diagram of IEEE-128 Bus system

The figures 4, indicates the single Line Diagrams of the128 Bus systems drawn in power world simulator Sensitivity Index of 128 bus system is calculated from the formulas.

Table 1: VAR loss sensitivity index of 128 Bus System

From Number	To Number	Circuit	TCSC	TCPAR
28	1	1	-0.108	-0.0114
28	1	2	-0.108	-0.0114
6	10	1	-0.206	-0.0517
16	6	1	-0.193	-0.0526
6	16	2	-0.193	-0.0526
19	6	1	-0.187	-0.0509
19	6	2	-0.187	-0.0509
19	6	3	-0.187	-0.0509
19	6	4	-0.187	-0.0509
9	20	1	-0.13	-0.0476
9	20	2	-0.13	-0.0476
9	39	1	-0.118	-0.0414
9	39	2	-0.118	-0.0414
42	9	1	-0.123	-0.0445
42	9	2	-0.123	-0.0445
15	16	1	-1.057	-0.0533
15	21	1	-0.168	-0.0559
30	19	1	-0.108	-0.0253
20	21	1	-0.137	-0.054
20	21	2	-0.168	-0.0561
23	21	1	-0.168	-0.0561
21	47	1	-0.081	-0.0559
21	47	2	-0.081	-0.0559
27	28	1	-0.047	-0.0132
27	28	2	-0.047	-0.0132
37	28	1	-0.046	-0.0127
28	37	2	-0.046	-0.0127
29	30	1	-0.036	0
29	30	2	-0.036	0
29	32	1	-0.036	-0.0001
29	32	2	-0.036	-0.0001
33	30	1	-0.031	-0.0011
30	36	1	-0.296	-0.0098
30	87	1	-0.018	-0.0001
101	31	1	-0.444	-0.0001

31	113	1	-0.056	0
33	34	1	-0.026	-0.0023
33	34	2	-0.026	-0.0023
35	36	1	-0.026	-0.0123
37	35	1	-0.052	-0.0134
37	35	2	-0.052	-0.0134
35	38	1	-0.041	-0.0136
42	35	1	-0.076	-0.0238
36	40	1	-0.021	-0.019
38	42	1	-0.081	-0.0324
89	39	1	-0.055	-0.0188
89	39	2	-0.055	-0.0188
40	84	1	-0.071	-0.0099
47	46	1	-0.067	-0.0263
47	46	2	-0.067	-0.0263
49	46	1	-0.134	-0.0031
49	46	2	-0.134	-0.0031
54	46	1	-0.079	0
82	46	1	-0.075	-0.0106
84	46	1	-0.123	-0.0007
84	46	2	-0.123	-0.0007
46	120	1	-0.087	-0.0089
56	48	1	-0.153	-0.0022
56	48	2	-0.153	-0.0022
121	48	1	-0.153	-0.0027
49	50	1	-0.148	-0.0126
49	50	2	-0.148	-0.0126
49	52	1	-0.151	-0.0049
49	52	2	-0.151	-0.0049
50	57	1	-0.135	-0.0136
50	61	1	-0.152	-0.0188
61	50	2	-0.152	-0.0188
52	121	1	-0.155	-0.0033
84	54	1	-0.08	-0.0007
84	54	2	-0.08	-0.0007
84	54	3	-0.08	-0.0007
128	56	1	-0.159	-0.001
72	57	1	-0.166	-0.0041
72	57	2	-0.166	-0.0041
66	67	1	-0.076	-0.0388

66	71	1	-0.073	-0.0364
66	72	1	-0.168	-0.0136
66	72	2	-0.168	-0.0136
75	67	1	-0.022	-0.0512
71	78	1	-0.035	-0.0398
71	78	2	-0.035	-0.0398
81	77	1	-0.043	-0.0258
81	82	1	-0.014	-0.0223
81	82	2	-0.014	-0.0223
125	81	1	-0.029	-0.0205
85	82	1	-5E-04	-0.0117
94	82	1	-0.002	-0.0229
82	120	1	0.0248	-0.0206
83	85	1	-0.008	-0.0012
83	85	2	-0.008	-0.0012
83	125	1	-0.024	-0.0111
85	84	1	**0.0616**	-0.0007
90	84	1	**0.1158**	-0.0023
85	86	1	-0.002	-0.0003
85	87	1	-8E-04	-0.0001
85	87	2	-8E-04	-0.0001
85	90	1	0.0542	-0.0016
85	94	1	-0.001	-0.0112
95	85	1	-4E-04	-0.0013
85	99	1	-4E-04	-0.0013
86	87	1	-0.003	-0.0004
87	92	1	-6E-04	0
87	92	2	-6E-04	0
95	87	1	-0.001	-0.0001
92	93	1	-0.005	0.001
92	93	2	-0.005	0.001
100	93	1	0.0037	**0.0009**
93	100	2	0.0037	**0.0009**
96	95	1	0.0086	0
95	98	1	0.0062	-0.0024
98	95	2	0.0062	-0.0024
101	96	1	0.0181	-0.0001
97	98	1	0.0149	-0.0028
97	99	1	0.008	-0.0017
101	97	1	0.0176	-0.0005

101	97	2	0.0176	-0.0005
105	98	1	0.0186	-0.0024
101	105	1	0.0213	-0.0001
102	116	1	0.0432	-0.0002
106	116	1	0.0405	-0.0002
108	111	1	0.0523	0.0001
113	111	1	0.0507	0

The lines having the most positive loss sensitivity index is chosen for placement of the TCSC devices. Hence lines 85to84 and 90 to 84 are selected from Table 1. TCSC devices in the inductive mode of operation are connected in series with these two lines, with inductive reactance of 75% and 20% of the line reactance respectively have been considered [9]. Similarly the lines having the highest absolute value of loss sensitivity index can be chosen for placement of the TCPAR devices. Hence, TCPAR as a Transformer with a complex tap ratio 1:a∟**α** is placed in the lines 93 to 100 of two circuits from table 1, operated with a phase shift of **α**= 2.9 and 4.5 degrees and unity tap ratio.

Enhancement of ATC with and without FACTS devices of 128bus system

Here, the ATC is calculated for 128 bus systems. In each case, one of the two FACTS controllers, viz. TCSC and TCPAR is included in the problem formulation. The static models of these devices are considered, i. e. a TCSC is represented as static impedance, a TCPAR as a transformer with a complex tap ratio. The optimal locations for placing each of these devices are determined by sensitivity analysis and the values are shown in table 1.

It is observed that from Table 2 the comparison between the data obtained for enhance the ATC with and without FACTS devices in the system.

Table 2: Available Transfer Capability for 128-Bus System

S. No.	From Area	To Area	ATC in MW					
			Without FACTS	With TCSC	% Enhancement	With TCPAR	% Enhancement
1	2	1	528.42	531.37	0.55	529.7	0.253
2	3	1	733.65	733.65	N.E	733.6	N.E
3	3	2	1019.4	1019.8	0.43	1019	0.28
4	4	1	607.48	609.28	2.53	610.4	2.74
5	4	2	636.15	639.35	3.21	641.1	4.1

N. E = No Enhancement

It is observed that from the Table 2, the enhancement of ATC of an 128 bus system is maximum i.e. 3.21% between area 4 to area 2, when the TCSC is placed in lines, with inductive reactance of 75% and 20% respectively. Similarly from the Table 3, the enhancement of ATC of an 128 bus system is maximum 4.2% between the area 4 to area 2, when the TCPAR is located in lines, with a Transformer operated with a phase shift of **α**= 2.9 and 4.5 degrees and unity tap ratio.

The comparison of the enhancement of ATC of an 128 bus system among four areas for without FACTS Devices and With FACTS devices i.e. TCSC and TCPAR are shown. Also observed that the enhancement of ATC is more in between the area 4 to area 2 than other areas, when the TCSC is placed in lines, with inductive reactance of 75% and 20% respectively considered and when the TCPAR is placed in lines, with a Transformer operated with a phase shift of **α**= 2.9 and 4.5 degrees and unity tap ratio respectively is considered.

CONCLUSION

With the history of more than three decades and widespread application in recent years, FACTS controllers have established itself as a proven and mature technology. The operational flexibility and controllability that, FACTS have to offer will be one of the most important tools for the system operator in the changing utility environment. In view of the various power system limits, FACTS provides the most reliable and efficient solution. Application of FACTS for improvement of ATC, also help to better utilization of the existing transmission resources, where the utilities are facing the problem of transmission expansion, because of the more stringent environmental constraints. This all indicates that there is a great potential for its application in the years to come. The sensitivity index is proposed to determine the optimal location of FACTS devices in deregulated power system. Two different types of devices like TCSC, TCPAR have been presented and analyzed to enhance the Available Transfer Capability. The simulation results show that, the determination optimal location gives the best results. Further, these methods are practical and easy to be implemented in the deregulated power system

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