Optimal Location of Multiple FACTS Device Using Sensitivity Methods

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***Abstract*— In recent years, electric power systems, greater demands have been placed on the transmission network. Maintaining power system stability becomes difficult and challenging problem. FACTS technology have new opportunities for controlling power and enhancing the usable capacity of transmission line , FACTS Controllers to enable corresponding power to flow through such lines under normal and contingency conditions. A method to determine the optimal location of thyristor controlled series compensators (TCSC) and unified power flow control (UPFC) has been suggested based on real power performance index,reduction of total system reactive power loss and SOL index . The tested system is ieee 30 bus system.**

***Keywords*— FACTS, Power flow, TCSC (Thyristor control series capacitor), Unified power flow control(|UPFC),Transmission system, stability and loadability.**

I. INTRODUCTION

As electricity is an substantive in modern societies. In Power system delivery has a problem for insufficient transfer capability, stability and loadability etc. The secure operation is complex in power system. Introducing FACTS technology is used to controlling power and losses in transmission line.

FACTS devices can improve the stability of the power network, reduce the flows of heavily loaded lines by controlling their parameters, and maintain the bus voltages at desired levels. It may be absorb or generate a reactive power in the transmission line.

To achive minimum losses in transmission line find the optimal place of transmission line & locate the FACTS device. Sensitivity-based approach where each transmission loss calculate without FACTS device and sensitivity factor calculate with FACTS device.

TCSC is a series connected controller (connected in a line). Its major purpose is the increase in steady state power transfer. It contributes mainly control for voltage ,line reactance and active power . It consists of passive elements only.

Thyristor Controlled Series Capacitor (TCSC) is a variable impedance type FACTS device and is connected in series with the transmission line to increase the power transfer capability, improve transient stability, and reduce transmission losses[6]. The UPFC can control both the active and reactive power flow in the line. It can also provide independently controllable shunt reactive compensation

The objective is to locate the FACTS device in optimal location based on the sensitivity method.

II.OVERVIEW OF FACTS CONTOROLLERS

FACTS Controllers can be divided into four categories[1]:

- Series Controllers
- Shunt Controllers
- Combined series-series Controllers
- Combined series-shunt Controllers

A. Series Controllers:

Series Controllers inject voltage in series with the line. Even a variable impedance multiplied by the current flow through it, represents an injected series voltage in the line.

B.Shunt Controllers:

Shunt Controllers inject current into the system at the point of connection. Even a variable shunt impedance connected to the line voltage causes a variable current flow and hence represents injection of current into the line.

C.Combined series-series Controllers:

This could be a combination of separate series controllers, which are controlled in a coordinated manner, in a multiline transmission system. In which series Controllers provide independent series reactive compensation for each line but also transfer real power among the lines.

D.Combined series-shunt Controllers:

Combined shunt and series Controllers inject current into the system with the shunt part of the Controller and voltage in series in the line with the series part of the Controller. However, when the shunt and series Controllers are unified, there can be a real power exchange between the series and shunt Controllers via the power link.

E.Shunt Connected Controllers

Static Synchronous Compensator (STATCOM): A Static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output.

F.Static Var Compensator (SVC):

A shunt-connected static Var generator or absorber whose output is adjusted. to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system

G.Static Synchronous Series Compensator (SSSC):

A static synchronous generator operated without an external electric energy source as a series compensator whose output voltage is in quadrature with, and controllable independently of, the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line and thereby controlling the transmitted electric power. SSSC is also a series connected controller.

H.Thyristor Controlled Series Capacitor (TCSC):

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.

I.Unified Power Flow Controller (UPFC):

A combination of static synchronous compensator (STATCOM) and a static series compensator (SSSC) which are coupled via a common dc link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source[1].

III. MATHEMATICAL MODEL OF FACTS DEVICES

In an interconnected power system network, power flows obey the Kirchoff's laws. The resistance of the transmission line is small compared to the reactance. Also the transverse conductance is close to zero. The active power transmitted by a line between the buses i and j may be approximated by following relationships[2]:

$$P_{ij} = \left\{\frac{V_i * V_j}{X_{ij}}\right\} * \sin\delta_{ij} \qquad (1)$$

Where:

- Vi and Vj are voltages at buses i and j;
- Xij: reactance of the line;
- δij: angle between the Vi and Vj.

Under the normal operating condition for high voltage line the voltage Vi =Vj and θij is small. The active power flow coupled with θij and reactive power flow is linked with difference between the Vi-Vj. The control of Xij acts on both active and reactive power flows. The different types of FACTS devices have been choose and locate optimally in order to control the power flows in the power system network.

A.Modeling of TCSC

The reactance of the line can be changed by TCSC. Hence In this project, TCSC have been selected

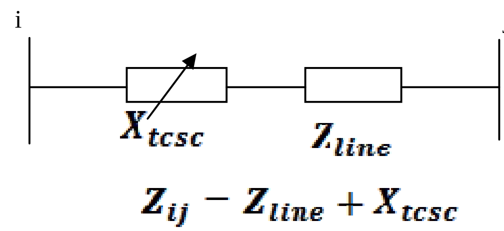

Fig.1Line with TCSC.

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[2].

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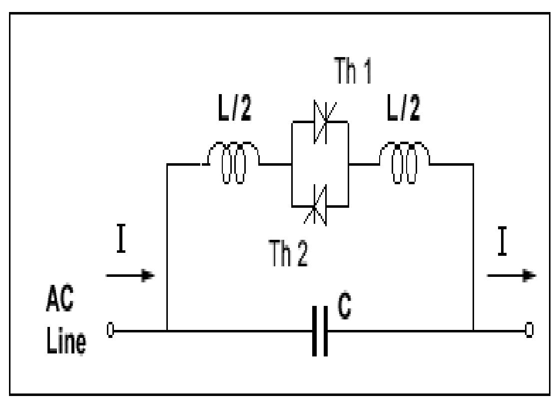

fig 2: thyristor-controlled series capacior(tcsc)

The impedence of TCSC circuit is that parallel LC circuit is given by:

$$X_{TCSC} = \frac{X_C X_l(\alpha)}{X_l(\alpha) - X_c} \qquad (2)$$

Where

$$X_{TCSC}(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin\alpha} \qquad (3)$$

α is the firing angle

X_L is the reactance of the inductor and $X_l(\alpha)$ is the effective reactance of the inductor at firing angle α and is limited thus:

$$X_L \le X_l(\alpha) \le \infty$$

The model of a transmission line with a TCSC connected between the buses i and j is shown n fig: 1. the change in the line flows due to series reactance. The real power injection at buses i and bus j (P_i (c)) and P_j (c) can be expressed as

$$P_{ic} = V_i^2 \Delta G_{ij} - V_i V_j \left[\Delta G_{ij} \cos(\delta_{ij}) + \Delta B_{ij} \sin(\delta_{ij})\right] \qquad (4)$$

$$P_{jc} = V_j^2 \Delta G_{ij} - V_i V_j \left[\Delta G_{ij} \cos(\delta_{ij}) - \Delta B_{ij} \sin(\delta_{ij})\right] \qquad (5)$$

Similarly, the reactance power injected at bus i and j (Q_i (c)) can be expressed as

$$Q_{ic} = -V_i^2 \Delta B_{ij} - V_i V_j \left[\Delta G_{ij} \sin(\delta_{ij}) - \Delta B_{ij} \cos(\delta_{ij})\right] \qquad (6)$$

$$Q_{jc} = -V_j^2 \Delta B_{ij} + V_i V_j \left[\Delta G_{ij} \sin(\delta_{ij}) + \Delta B_{ij} \cos(\delta_{ij})\right] \qquad (7)$$

Where

$$\Delta G_{ij} = \frac{x_c r_{ij}(x_c - 2x_{ij})}{\left(r_{ij}^2 + x_{ij}^2\right)\left(r_{ij}^2 + (x_{ij} - x_c)^2\right)} \qquad (8)$$

$$\Delta B_{ij} = \frac{-x_c\left(r_{ij}^2 - x_{ij}^2 + x_c x_{ij}\right)}{\left(r_{ij}^2 + x_{ij}^2\right)\left(r_{ij}^2 + (x_{ij} - x_c)^2\right)} \qquad (9)$$

B.Modelling of UPFC

To obtain UPFC injection model, it is first essential to consider the series voltage source,

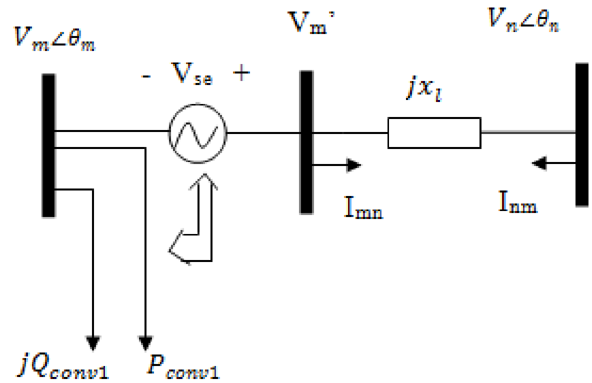

Fig. 3. The UPFC electric circuit

The reactance x_l describes a reactance seen from terminals of the series transformer and is equal to (in p.u. base on system voltage and base power) [11]:

$$x_l = x_k r_{\max}^2 \left(\frac{S_B}{S_l}\right) \qquad (10)$$

$$b_s = -\frac{1}{x_l}$$

That

x_k: The series transformer reactance.

r_{max}: The maximum value of injected voltage amplitude (p.u.).

S_B: The system base power.

I_{nm}

$S_l = S_{conv\ 2}$: The nominal rating power of the series converter.

Voltage source connected in series is modeled with an ideal series voltage (Vs) the amplitude and phase is controlled.

$$0 \le r \le r_{\max}^2$$

$$V_s = rV_m e^{j\gamma}$$

$$0 \le \gamma \le 2\pi$$

That

r: The value of injected voltage amplitude (p.u.).

γ: The value of injected voltage angle.

The equations of the UPFC injection model (Fig.) are given as [8]:

$$P_{lm} = -rb_l V_m V_n \sin(\theta_m - \theta_n + \gamma) \qquad (11)$$

$$Q_{lm} = -rb_l V_m^2 \cos(\gamma) + Q_{conv1} \qquad (12)$$

$$P_{ln} = rb_l V_m V_n \sin(\theta_m - \theta_n + \gamma) \qquad (13)$$

$$Q_{ln} = rb_l V_m V_n \cos(\theta_m - \theta_n + \gamma) \qquad (14)$$

$$P_{m1} = -r\,b_l V_m V_n \sin(\theta_m - \theta_n + \gamma) - b_l V_m V_n \sin(\theta_m - \theta_n)$$
$$Q_{m1} = -r\,b_l V_m^2 \cos(\gamma) + Q_{conv1} - b_l V_m^2 + b_l V_m V_n \sin(\theta_m - \theta_n)$$
$$P_{n1} = r\,b_l V_m V_n \sin(\theta_m - \theta_n + \gamma) + b_l V_m V_n \sin(\theta_m - \theta_n)$$
$$Q_{n1} = r\,b_l V_m V_n \cos(\theta_m - \theta_n + \gamma) - b_l V_n^2 + b_l V_m V_n \cos(\theta_m - \theta_n)$$

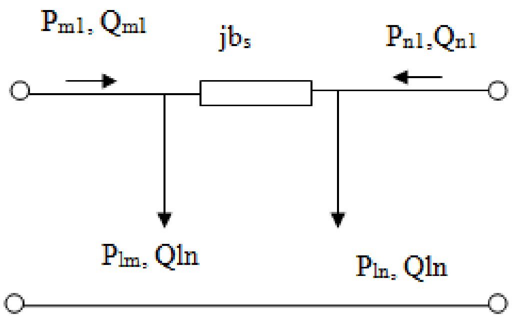

Fig.4. Injection model of the UPFC

The admittance Y_m^u and Y_n^u can be written by [9],

$$Y_m^u = \frac{P_{mi}^u - jQ_{mi}^u}{(V_m^u)^2} \qquad Y_n^u = \frac{P_{ni}^u - jQ_{ni}^u}{(V_n^u)^2}$$

IV.REDUCTION OF TOTAL SYSTEM REACTIVE POWER LOSS

Here we look at a method based on the sensitivity of the total system reactive power loss with respect to the control variable of the TCSC. For TCSC placed between buses i and j we consider net line series reactance as a control parameter[3]. Loss sensitivity with respect to control parameter of TCSC placed between buses i and j can be written as

$$aij = \left[V_i^2 - V_j^2 - 2V_iV_j\cos\delta_{ij}\right]\frac{r_{ij}^2 - x_{ij}^2}{\left(r_{ij}^2 + x_{ij}^2\right)^2} \quad (15)$$

V. REAL POWER FLOW PERFORMANCE INDEX SENSITIVITY INDICES

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index as given below.

$$PI = \sum_{m=1}^{NL} \frac{W_m}{2n}\left(\frac{P_{LM}}{P_{LM}^{max}}\right)^{2n} \quad (16)$$

Where

P_{Lm} is the real power flow

P_{Lm}^{max} is the rated capacity of line-m & n is the exponent

W_m a real non-negative weighting coefficient which may be used to reflect the importance of lines.

The real power flow PI sensitivity factors with respect to the parameters of TCSC can be defined as

$$bk = \left.\frac{\partial PI}{\partial xck}\right|_{xck=0} \quad (17)$$

The sensitivity of PI with respect to TCSC parameter connected between bus-i and bus-j can be written as:

$$\frac{\partial PI}{\partial xck} = \sum_{m=1}^{NL} W_m P_{lm}^3 \left(\frac{1}{P_{lm}^{max}}\right)^4 \frac{\partial Plm}{\partial xck} \quad (18)$$

The real power flow in a line –m can be represesnted in terms of real power injection using DC powerflow equations where is slack bus,as

$$Plm = \begin{cases} \sum_{m=1,\, n\neq s}^{N} S_{mn} P_n & \text{for m} \neq \text{k} \\ \sum_{m=1,\, n\neq s}^{N} S_{mn} P_n + P_j & \text{for m = k} \end{cases} \quad (19)$$

$$\frac{\partial Plm}{\partial xck} = \begin{cases} \left(S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mj}\frac{\partial P_j}{\partial x_{ck}}\right) & \text{for m} \neq k \\ \left(S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mi}\frac{\partial P_j}{\partial x_{ck}}\right) + \frac{\partial P_j}{\partial x_{ck}} & \text{for m} = k \end{cases} \quad (20)$$

The term,

$$\left.\frac{\partial Pi}{\partial xck}\right|_{xck=0} = \left.\frac{\partial Pic}{\partial xck}\right|_{xck=0}$$

$$= -2(V_i^2 - V_i V_j \cos\delta_{ij}) \frac{r_{ij} x_{ij}}{\left(r_{ij} + x_{ij}\right)^2} - V_i V_j \sin\delta_{ij} \frac{\left(x_{ij}^2 - r_{ij}^2\right)}{\left(r_{ij} + x_{ij}\right)^2} \quad (21)$$

$$\left.\frac{\partial \mathrm{P_j}}{\partial \mathrm{xck}}\right|_{xck = 0} = \left.\frac{\partial \mathrm{P_{jc}}}{\partial \mathrm{xck}}\right|_{xck = 0}$$

$$= -2(V_i^2 - V_i V_j \cos\delta_{ij}) \frac{r_{ij} x_{ij}}{\left(r_{ij} + x_{ij}\right)^2} + V_i V_j \sin\delta_{ij} \frac{\left(x_{ij}^2 - r_{ij}^2\right)}{\left(r_{ij} + x_{ij}\right)^2} \quad (22)$$

Criteria for optimal location

The FACTS device should be placed on the most sensitive line. With the sensitivity indices computed for TCSC[2], following criteria can be used for its optimal placement

1. In reactive power loss reduction method TCSC should be placed in a line having the most positive loss sensitivity index.
2. In performance index method TCSC should be placed in a line having most negative sensitivity index.

In our project reactive power loss reduction method is used to calculate the sensitivity index of a line and TCSC is placed in line with most positive loss sensitivity index as mentioned above.

VI.SEVERITY OF OVER LOADABILITY INDEX (SOL) COMPUTATION:

The location of FACTS devices in this work is decided based on the severity of overloading of that particular branch in which the device is incorporated. The process of ranking the branch in which the device is incorporated. The process of ranking the branches based on their load ability in the order of their severity involves the following .

Step1:Establish the criterion to be considered in formulating the ranking

Step2:For the criterion established in (step1), define a scalar mathematical function which has a larger value of branch load that which stress the system relative to that criterion, and a small value for those which do not this function is called a "SOL index".

The SOL index is such that contingencies resulting in system conditions yielding large valued over load indices are considered more severe than system conditions with smaller overload indices.In overload ranker,the SOL index is defined as[7],

$$SOL = \sum_{i=1}^{N} \left(\frac{P_i}{P_{i\max}} \right)^2 \quad (23)$$

Where,

P_i is the real power flow in line "I",

$P_{i,max}$ is maximum of active power transfer over the i^{th} line and

N is set of monitored lines contributing to SOL

VII.RESULT

Line	Ak	Pixck	Pjxck
1	-141.2484	-77.3487	-411.9166
2	-60.8319	-39.3644	13.9461
3	-77.4711	7.3287	-35.0484
4	-1.0939e+003	-886.6861	123.0955
5	-84.1094	-18.5428	5.4814
6	-3.5744	-18.0363	-35.3064
7	-1.0906e+003	-731.0757	192.7788
8	-63.2670	-7.6149	-96.4295
9	-260.4326	-182.4450	36.0841
10	-224.1931	-689.2616	-90.0753
11	-98.1041	-2.5948	2.5948
12	-7.4304	3.4063	-3.4063
13	-0.0222	-9.3383014	9.3383e-014
14	-184.9690	-90.6967	90.6967
15	-6.5417	9.7881	-9.7881
16	-0.0095	-2.0527e-013	2.0527e-013
17	-6.3098	-20.8218	-7.2711
18	-26.6258	-78.8880	-27.1848
19	-4.6805	-33.1941	-17.0316

20	**0.0093**	-18.1215	-18.2265
21	-1.6085	--31.7929	-21.2364
22	-3.9122	-26.5030	-13.7056
23	-0.8709	-65.4540	-54.9249
24	-4.3529	-195.3437	-239.9259
25	-8.8400	-30.7418	-10.1872
26	-2.6515	-148.8372	-115.7430
27	-19.8060	-220.5335	-130.0649
28	-4.3927	-54.7626	-33.9967
29	-0.1814	-1.8167e+003	-1.8441e+003
30	-1.8556	-29.3605	-19.4837
31	-1.3513	-34.8394	-27.2749
32	-0.2006	-14.9306	-12.4460
33	-0.5961	-7.6724	-10.5332
34	-0.3212	-7.4053	-5.7374
35	-2.7444	-16.8746	-27.5789
36	-23.2216	4.3266	-4.3266
37	-3.4701	-7.069	-1.9753
38	-3.6955	-2.4689	-0.2429
39	-1.5470	-5.8314	-2.466
40	-0.0634	-18.9648	-21.1737
41	-94.4030	-330.6767	-54.4531

Table 1.Loss sensitivity index

The Sensitive loss reduction method line 20 is more sensitive Lines TCSC should placed in that line.

Line no	SOL INDEX	Line no	SOL Index
1.	0.2503	23.	0.0025
2.	0.0452	24.	0.0128
3.	0.0452	25.	0.0517
4.	**0.9998**	26.	0
5.	0.0101	27.	0.0122
6.	0.0067	28.	0
7.	**0.8067**	29.	0.0005
8.	0.0918	30.	0.0053
9.	0.2006	31.	0.0063
10.	**0.3460**	32.	0
11.	0.0004	33.	0.0021
12.	0.0048	34.	0
13.	0	35.	0.0016
14.	0.1345	36.	0
15.	0.0101	37.	0.0074
16.	0	38.	0.0029
17.	0.0151	39.	0.0039
18.	0.0656	40.	0.0001
19.	0.0125	41.	0.1469
20.	0.0003		
21.	0.0040		
22.	0.0104		

Table 2. Severity of load index

In the Severity of over load index computation method line 4,7,10 has maximum loadability, TCSC should placed in that line.

Without FACTS device		With TCSC	
MW	MVAR	MW	MVAR
17.599	22.244	17.979	14.145

Table 3.simulation lose result TCSC

Without FACTS device		With UPFC	
MW	MVAR	MW	MVAR
17.599	22.244	17.551	21.951

Table 4.simulation lose result UPFC

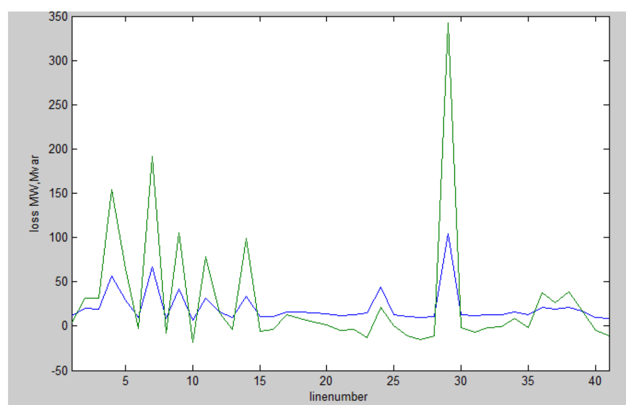

Fig 5. Effect of UPFC in power loss

The effect of UPFC in Inductive and Capacitive mode is shown in Fig.7 and Fig.8. With UPFC the total power losses in a transmission line will be reduced.

VIII.CONCLUSION:

In the powersystem has transmission loss will occur while transmiting the power, it is important to reduce the losses.FACTS device such as TCSC by controlling the network can help to reduce the flows in heavily loaded lines.

Here two methods are considered sensitivity loss method and severity of over load index method.It is used to determine the optimal placement of FACTS device in transmission line.

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