The Optimization on FACTS Devices for Network Security

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Abstract—**One of the most important indices which are used in FACTS devices placement are indices related to network security and its vulnerability. On this basis, objective function consisting of vulnerability indices of generators, lines and bus bars presented and placement is done simultaneously and non-simultaneously. For case studies, placement of a UPFC, a TCSC and a SVC in IEEE 30 bus test system are performed simultaneously and non-simultaneously. The results have shown simultaneous placement of these devices improve vulnerability indices more than non-simultaneous placement.**

Keywords-FACTS devices, TCSC, Network Security

I. INTRODUCTION

FACTS devices can reduce losses, improve voltage profiles, control transmission power flow and control power demanded from the power plants. Also, due to the expansion of power systems, network security has been more important and it is necessary to pay much more attentions on application of FACTS devices for network security indices. One of the major issues in the FACTS devices placement is optimizing a specified objective function by considering its corresponding constraints. For FACTS devices placement, in references [1 and 2] the objective function includes losses and transmitted power through transmission lines and in references [3 and 4], the placement of FACTS devices based on transmitted power sensitivity. In [5 and 6], voltage profile and transmitted power, and in [7] the optimal load flow are used for FACTS devices placement. In references [8 and 9], FACTS devices placement has been done based on the electricity market. Mentioned placement is done in [10] based on reactive power control and in [11] is done for network balancing. In references [12, 13, 14 and 15], the dynamic performance of network and in references [16 and 17], network security margin are considered as the objective function.

In this paper, since the network security margin is more important than any other system indices, network security margin and system vulnerabilities indices are considered as the objective function in placement of FACTS devices. Considered indices are the generators, lines and bus bars vulnerability indices.

II. MODELING FACTS DEVICES

The most widely used FACTS devices are: SVC, TCSC and UPFC. Models so far presented for this type of FACTS devices are in two dynamic and static models which further their static models will be examined.

A. TCSC Model

TCSC is a capacitor along with a parallel TCR is placed in series with a transmission line. Accordingly, from the viewpoint of power system, TCSC is variable impedance in series with transmission line, and according to Eq (1) leads to changes in line impedance. Also, in power flow problem, TCSC can only lead to change network impedance matrix. Fig. 1 shows the TCSC model based on the above explanation.

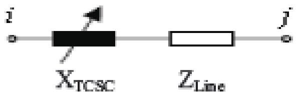

Figure 1. TCSC Model

$$X_{new,L} = X_{old,L} + X_{TCSC} \tag{1}$$

Where:

$X_{old,L}$: Transmission line reactance before TCSC installation

X_{TCSC} : Injected reactance by TCSC

$X_{new,L}$: Transmission line reactance after TCSC installations.

B. SVC Model

SVC has several models that the most used model is Fixed Capacitor Thyristor Controlled Regulator (FCTCR). In fact, according to the Fig. 2 SVC is a capacitor in parallel with a TCR which is connected in parallel with the network and can be used as compensating reactive power, hence it can be modeled as a variable reactive power source.

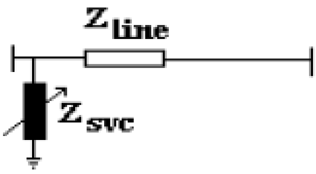

Figure 2. SVC Model

C. UPFC Model

As shown in Fig. 3-a, UPFC is combined of a series voltage source and a parallel current source. In this Figure, $V_{se}\angle\varphi_{se}$ is a series voltage source and I_{shq} is a parallel current source. From the viewpoint of power system, parallel devices can be modeled as the active and reactive power compensating. So, if the parallel part of UPFC decomposed into two sources of compensating reactive power and active power, reactive power compensating models will be similar to SVC and STATCOM and compensating active power will be equal to the series branch active power. For modeling series branch, according to Fig. 3-b, series voltage source with the line impedance will be transformed to the Norton's equivalent. Thus, according to Fig. 3-a, series branch can be considered as the active and reactive power compensating in two adjacent buses of transmission line. Series active and reactive power injection to bus i and j can be calculated using Eqs. (2)-(7).

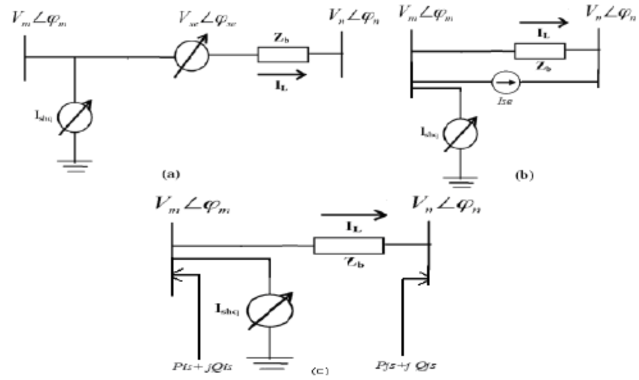

Figure 3. UPFC Model

$$P_{ise} = P_{sh} \tag{2}$$

$$I_{se} = \frac{V_{se}}{Z_l} \tag{3}$$

$$P_{ise} = \mathrm{Re}\left\{V_i \times I_{se}^{*}\right\} = -\mathrm{Re}\left\{V_i \times \left(\frac{V_{se}}{Z_l}\right)^{*}\right\} \tag{4}$$

$$Q_{ise} = \mathrm{Im}\,ag\left\{V_i \times I_{se}^{*}\right\} = -\mathrm{Im}\,ag\left\{V_i \times \left(\frac{V_{se}}{Z_l}\right)^{*}\right\} \tag{5}$$

$$P_{jse} = \mathrm{Re}\left\{V_j \times I_{se}^{*}\right\} = \mathrm{Re}\left\{V_j \times \left(\frac{V_{se}}{Z_l}\right)^{*}\right\} \tag{6}$$

$$Q_{jse} = \mathrm{Im}\,ag\left\{V_j \times I_{se}^{*}\right\} = \mathrm{Im}\,ag\left\{V_j \times \left(\frac{V_{se}}{Z_l}\right)^{*}\right\} \tag{4}$$

In which:

P_{sh} : Active power injected by the parallel branch

P_{ise} : Active power injected into the ith bus by FACTS devices

I_{se} : Injected current by the series branch

V_{se} : Voltage injected by the series branch

Z_l : Line impedance

V_i : ith bus voltage

Q_{ise} : Reactive power injected into ith bus by FACTS devices

P_{jse} : Active power injected into jth bus by FACTS devices

V_j : jth bus voltage

Q_{jse} : Reactive power injected into jth bus by FACTS devices

Similarly, parallel branch of UPFC can be regarded as a parallel reactive power source connected to the ith bus.

III. OBJECTIVE FUNCTION

In this paper, in order to consider the three indices of security margin, an objective function equation according to Eq (8) is considered.

$$VI_{sys} = VI_{bus} + VI_{line} + VI_{gen} \tag{8}$$

In which:

VI_{sys} : System vulnerability index

VI_{bus} : Bus bars' vulnerability index

VI_{line} : Lines' vulnerability index

VI_{gen} : Generators' vulnerability index.

Further, modeling abovementioned indices will be explained.

IV. MODELING SYSTEM VULNERABILITY INDICES

System vulnerability indices can be extracted from the security margin indices. Modeling system security margin indices can be done for different purposes. In this paper, for FACTS devices placement, network security indices are regarded in three parts; lines, bus bars and generators security margins.

A. Lines Security Margin Index

The vulnerability and security margins of a transmission line in power systems can be depended on the line transmitted power and the phase displacement of the adjacent buses. Therefore, for modeling it, some indices can be presented as follows:

$$VI_{LS} = \sqrt{\sum_{i=1}^{NL}\left(\frac{S_i}{S_{i,\max}}\right)^2} \tag{9}$$

$$VI_{L\delta} = \sqrt{\sum_{i=1}^{NL}\left(\frac{\Delta\delta_i}{\Delta\delta_{i,\max}}\right)^2} \tag{10}$$

Where:

VI_{LS} : Line vulnerability index due to the transmitted power through it

$VI_{L\delta}$: Line vulnerability index due to the phase displacement of the adjacent buses

S_i : ith bus power

$\Delta\delta_i$: Phase displacement between adjacent buses connected via ith line

$S_{i,\max}$: Capacity of transmitted power through ith line

$\Delta\delta_{i,\max}$: The maximum phase displacement between adjacent power lines connected to the ith line

NL: Number of system lines

Therefore, the line vulnerability indices are obtained, totally, by the lines transmitted power vulnerability and the phase displacement between adjacent busses as Eq. (11).

$$VI_L = W_L \bullet VI_{LS} + W_{L\delta} \bullet VI_{L\delta} \qquad (11)$$

In which, $W_{L\delta}$, W_{LS} are weighting coefficients of $VI_{L\delta}$, VI_{LS} , respectively, and their values can be determined based on any of the indices. Of course, since in this paper minimizing the Eq. (8) is our object, therefore the vulnerability index is used in FACTS devices placement. While if the goal was maximizing the objective function, system security margin indices could be utilized.

B. Bus bars Security Margin Indices

In any power networks, vulnerability and security margin of any bus bars is dependent to its voltage. Therefore, for modeling, an index is regarded as follows:

$$VI_{BV} = \sqrt{\sum_{i=1}^{NB} \left(V_{i,pu} - V_{ref,pu}\right)^2} \qquad (12)$$

Where:

VI_{BV} : Vulnerability index of bus bars due to the bus bars' voltage

$V_{i,pu}$:ith bus voltage in per unit

$V_{ref,pu}$:ith bus desired voltage in per unit

NB: Number of system bus bars.

Therefore, the vulnerability index of bus bars due to the bus bars' voltage vulnerability can be obtained according to Eq. (13):

$$VI_B = W_{BV} \bullet VI_{BV} \qquad (13)$$

In which W_{BV} is the weighting coefficient of VI_{BV} and can be determined based on the importance of each index.

C. Generators Security Margin Index

The vulnerability indices of generators can be measured based on the maximum production of generator active and reactive power separately. Of course, instead of the generator security margin, we can use optimal load flow to reduce production cost, but considering the importance of generators security, in this paper, as following equations, we use security or vulnerability indices.

$$VI_{gQ} = \sqrt{\sum_{i=1}^{Ng} \left(\frac{Q_{gi}}{Q_{i.\max}}\right)^2} \qquad (14)$$

$$VI_{gP} = \sqrt{\sum_{i=1}^{Ng} \left(\frac{P_{gi}}{P_{i.\max}}\right)^2} \qquad (15)$$

Where:

VI_{gQ} : Generators' vulnerability index for reactive power production or absorption

VI_{gP} : Generators' vulnerability index for active power production

Q_{gi} : Reactive power production or absorption by the ith generator

$Q_{i.\max}$: Maximum reactive power production or absorption by the ith generator

P_{gi} : Active power production or absorption by the ith generator

$P_{i.\max}$: Maximum active power production or absorption by the ith generator

Ng: Number of generators.

Therefore, the vulnerability index of generators, totally, is obtained by the vulnerability indices VI_{gQ} , VI_{gP}, according to Eq. (16):

$$VI_{gen} = W_{gQ} \bullet VI_{gQ} + W_{gP} \bullet VI_{gP} \qquad (16)$$

In which, W_{gP}, W_{gQ} are weighting coefficients corresponding to the VI_{gP}, VI_{gQ} indices, respectively. And these coefficients can be determined based on importance of each indicator.

Total vulnerability index of system, according to Eq (8) is consisting of the lines, bus bars and FACTS devices vulnerability indices.

V. PLACEMENT ALGORITHM

In this paper, placement is done in two ways: simultaneously and individually (firstly SVC, and then TCSC and finally UPFC). Placement algorithm can be expressed as Fig. 4. However, in non-simultaneous placement, firstly SVC and then TCSC and finally UPFC will be placed separately.

VI. NUMERICAL STUDIES

For numerical studies, IEEE 30-buses test system is used. Given that, usually the installation of more than one FACTS device is not feasible for electrical power companies, so this paper assumes that the number of FACTS devices is determined by electrical power companies based on their type, and its placement is done by algorithm genetic only to maximize the network security margin indices. Therefore, it is assumed that the target will be the optimal placement of a UPFC, a TCSC and a SVC. Placement is done in two ways, once simultaneously and other time non-simultaneously (firstly SVC, then TCSC and finally UPFC).

Series voltage source and the angle of UPFC are modeled by the amplitude in range of (0-0.1) pu and $\pm\pi$ rad, respectively which this modeling is done according to Eqs. (4) to (7) as sources of active and reactive power injected adjacent to the bus transmission line in which UPFC is installed. Active and reactive powers injected at any stage of load flow iterations, according to the voltages obtained from the previous step are corrected. Compensating reactive power; UPFC and SVC are regarded as a source in operating range of ±100MVAr. Also, TCSC is modeled as the variable impedance with working range (-0.7-+0.2) X L. Simulation results for simultaneous and non-simultaneous placement are as the Tables (1) to (3).

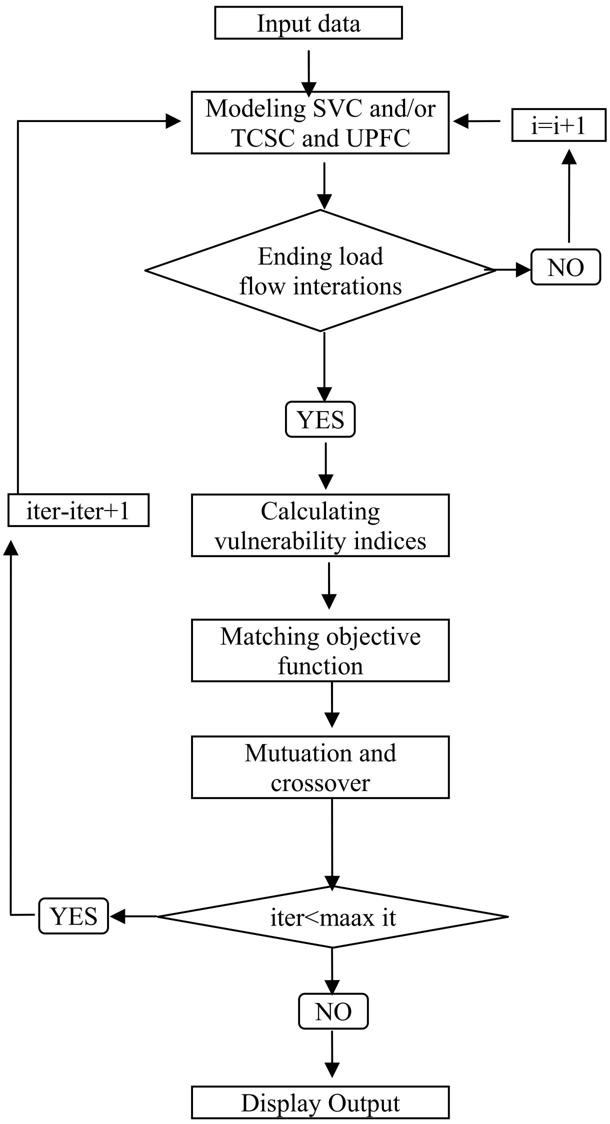

TABLE I. TABLE RESULTS OF FACTS DEVICES PLACEMENT

Index	simultaneous placement	Non-simultaneous placement	Without FACTS devices
VI_{sys}	2.0785	2.2255	3.4529
VI_{gen}	0.9168	1.8104	2.3885
VI_{bus}	0.2903	0.2180	0.199
VI_{line}	0.8826	0.9378	0.8654

TABLE II. FACTS DEVICES CHARACTERISTICS IN SIMULTANEOUS PLACEMENT

Type of equipment	Location	inserted Q (MVAr)	X_{se} (pu)	V_{se} (pu)	φ_{se} (rad)
TCSC	Line 7-6	--	0.0943	---	---
UPFC	Lines 22-21	70=-Qsh Psh=0	---	0.096	1.6965
SVC	Bus 5	-70	---	---	---

TABLE III. FACTS DEVICES CHARACTERISTIC IN NON-SIMULTANEOUS PLACEMENT

Type of equipment	Location	inserted Q (MVAr)	X_{se} (pu)	V_{se} (pu)	φ_{se} (rad)
TCSC	Line 7-6	--	0.18	---	---
UPFC	Lines 8-6	Qsh=-34 Psh=0	---	0.1	1.4451
SVC	Bus 28	-92	---	---	---

The results show that by non-simultaneous placement of a UPFC, a TCSC and SVC, vulnerability of a system decreases from 3.4529 to 2.2255 (without FACTS devices installations). Also, voltage profiles are improved according to the Fig. 5. With the simultaneous placement of the FACTS devices, system vulnerabilities decrease from 2.2255 to 2.0785 (in the non-simultaneous placement). Also, voltage profiles are improved in some bus bars.

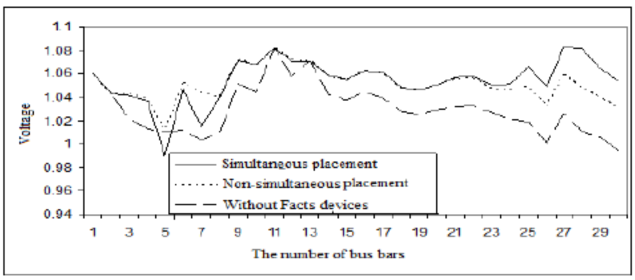

Figure 4. Voltage profiles of the bus bars

VII. CONCLUSION

In this paper, an objective function consisting of generators, bus bars and lines vulnerability indices for optimal placement of facts devices including UPFC, SVC and TCSC has been presented. To calculate the vulnerability and network security indices, an appropriate model of mentioned devices to solve the load flow calculation is used. Also, in this paper, the optimal placement of facts devices has been done by two ways. In the first case, placement and installation of them is performed individually and in the next state the placement of these devices have been done simultaneously. For the case studies, IEEE 30-buses test system is selected and a UPFC, SVC and a TCSC are placed in the system simultaneously and non-simultaneously. Results show that these devices have better influences in the simultaneous placement mode than the non-simultaneous mode, and could improve voltage profile and network security margin.

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