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Optimal Location of FACTS Devices for Performance Enhancement of Jeddah 380 kV Power Grid

Abood AL-Dossary[(1)(2)], Khaled Sedraoui[(1)(2)], Abdulaziz Othman[(1)]

(1) Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah 21589, Saudi Arabia
(2) Center of Research Excellence in Renewable Energy and Power Systems, King Abdulaziz University, Jeddah 21589, Saudi Arabia.

Abstract: This paper focuses on the enhancement of the Jeddah 380kV power systems performance through the incorporation of the appropriate flexible AC transmission systems (FACTS) devices. The optimal locations of the FACTS devices in the network are determine through sensitivity analysis. Newton-Raphson load flow analysis incorporating the FACTS devices is performed on the Jeddah 380 kV power grid. These results are then used to investigate the effectiveness of the optimally located FACTS devices, namely Thyristor Controlled Series Capacitor (TCSC) and the Unified Power Flow Controller (UPFC), in the Jeddah grid for the enhancement of the load flow and reduce the power losses in the transmission system. The preliminary investigations reveal that the incorporation of TCSC and UPFC in appropriate location leads to significant in the reduction in the line loss and the enhancement voltage profile in the grid.

Keywords: Jeddah 380kV Power grid, FACTS devices, UPFC, TCSC, Optimal location, Sensitivity analysis.

I. INTRODUCTION

FACTS is one of the latest technologies in power electronics and are mainly based on the operations of various control transmission systems [1]. Variables such as voltages, the phase shift angle, and line impedance can result in full control of power flow in the transmission system thus making it either active or reactive. Hingorani (1988) introduced FACTS devices for the first time in the industry [2]. They are considered necessary and very important for the improvement of the reliability and capability of the power systems. The controls are defined as high power electronics used to increase the stability of the power system and enhance the power flow.

Optimum locations in the FACTS devices are determined through the application of various indices [8-12]. For the optimal controllers, their positions are determined in the same manner as the other devices. One of the main factors that must be taken into consideration in the selection of the optimal locations is sensitivity analysis which is discussed in several researches [15-18].

Singh et at. (2007), has suggested a sensitivity method to optimal location of the Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC) for enhancing the system security under different operating conditions and at optimal settings FACTS parameters.

In order to reduce power losses for either a given line or the entire system, it is important to apply various sensitivity analysis methods that decrease the loop flows [18].Leung and Chung (2011) discuss a method for solving cost and economic related problems as related to the location of FACTS devices. However, this is done with the assumption that all the lines have these devices. In this paper the optimal location of FACTS devices TCSC and UPFC is investigated for Jeddah 380kV power system to achieve the transmission capacity enhancement.

The first generation of the FACTS controllers is the Static VAR Compensator (SVC) [21]. This is a shunt device that is comprised of the thyristor-switched capacitor (TSC) or fixed capacitor (FC) in conjunction with the thyristor-controlled reactor (TCR) [20-27]. The second-generation FACTS controller is the Thyristor controlled series compensator (TCSC). This controller incorporated series reactance with the transmission line. Therefore, the purpose of the TCSC is to control efficient line reactance. The FC-TCR is connected in series with mechanical switch capacitor sections for controlling the line reactance [28-33].

Static Var Compensator (SVC) is mainly used to provide fast-acting reactive power compensation on high-voltage electricity transmission networks [34]. SVC devices are mainly of two different types which include reactors and capacitors. Specific examples of each type include the Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR) and the Thyristor Switched Capacitor-Thyristor Controlled Reactor (TSC-TCR). In terms of flexibility, the TSC-TCR is better than the FC-TCR. This can be attributed to the fact that it does not require a large rating of the reactor and hence does not generate any harmonic [35].

The Static synchronous series compensator (SSSC) controls the magnitude of the magnitude of the voltage flowing through the transmission line. This is achieved through the injection of a series of sinusoidal voltage [21-22]. The Integrated bipolar transistor (IGBT) or the gate turn-off type thyristor (GTO) are Static synchronous compensators (STATCOMs) based FACTS devices. These devices do not require large capacitive and inductive components in order to extend the transmission systems to higher levels. In addition, at lower voltage levels, the power systems are mainly based on STATCOM as a current source [23-25].

The basic structure of Unified Power Flow Controller (UPFC) includes two controllable elements, a voltage, and current source. This includes a source of current inserted in a shunt as well as a source of voltage connected in series with the transmission line [24-27]. The magnitude of the current is a controllable parameter whereas both the angle and the magnitude of inserted voltage are controllable parameters.

FACTS applications have been developed and applied in accordance with various operating configurations and can be implemented through the combination of multiple converter blocks with a lot of flexibility. Some of the most common FACTS applications are the generalized unified power flow controllers (GUPFC) and the interline power flow controller (IPFC) [32]. It has the ability to control a small subsystem rather than a single and multi-lines of bigger power flow system network by UPFC.

III. POWER FLOW CONTROL

TCSC Control

TCSC is a smooth capacitive reactance compensator that is comprised of a Thyristor-Controlled Reactor (TCR) shunted with a series capacitor bank as shown by figure 1. The performance of the TCSC is dependent on the thyristor. However, it lacks the gate turn-off capability. It is also considered as an alternative of the SSSC which is one of the FACTS controllers. The TCR is a variable reactor that is usually connected to a series reactor. Figure (a) shows a simple equivalent circuit of TCSC device installed within the transmission line.

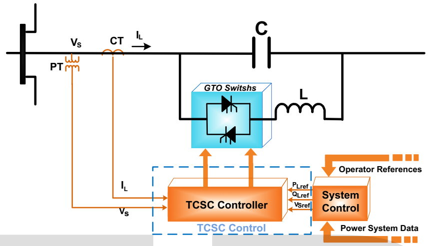

Figure 1. Typical compensation schemes with Thyristor Controlled Series Capacitor. **C** Series capacitor, **L** Parallel inductor, I_L Line current V_c Line Voltage.

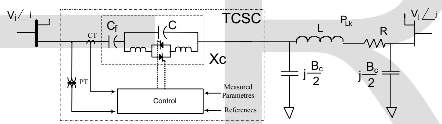

Figure 2. Series compensation using TCSC.

UPFC Control

The UPFC model is comprised of two switching converters as illustrated in figure 3. It is mainly dependent on a common DC link that is connected to voltage source converters. The shunt and series converter is coupled to the AC system through a shunt and series transformer. The series converter controls the power flow in the AC system through the adjustment of the injected voltage V_{pq}.

For the control of the active and reactive power flow in a three-phase network linking two stations, series voltages with the appropriate amplitudes and angles are to be injected. The instantaneous voltage (V_{pq}) injected can be decomposed into two voltages one in phase (V_p) and the other in quadrature phase (V_q) with respect to the source voltage. It should be noted that the UPFC is placed in the generation busbar. The network voltage at the connection point of the UPFC is used as a reference to define the pq component of the instantaneous voltage and current parameter. UPFC has four controllable parameters: the components v_p and v_q of the injected series voltage and the components i_p and i_q of the shunt current exchanged as given in Figure 3.

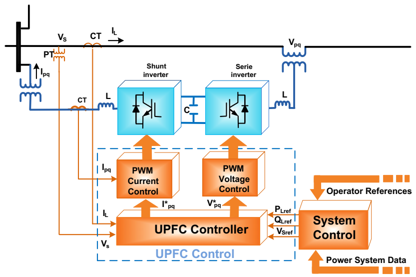

Figure 3. UPFC Control scheme of The UPFC

Figure 4(a) represent a simple equivalent circuit transmission line within installed UPFC device. Figure 4(b) shows the phasor diagram of the transmission line with UPFC compensation using the series injected voltage v_{pq}. ($0 < V_{pq} < 0.5$pu) and ($0 < \theta < 360^o$).

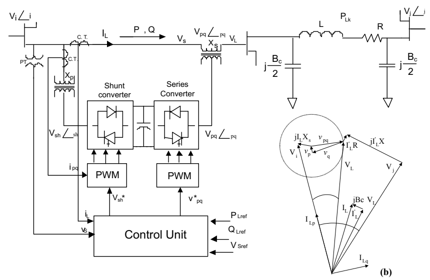

Figure 4: (a) UPFC placed on a two-machine transmission line. (b) Phasor diagram of various parameters of the transmission line with UPFC compensation.

IV. OPTIMAL LOCATION OF FACTS DEVICES

The optimal locations for FACTS controllers determining by several indices/ techniques in both unbundled and vertically integrated power systems [10-14].

Select the optimal locations for FACTS controllers depends on sensitivity analysis which have been discussed in several researches [15-18]. To reduce the real power losses for certain line or total system power, there are several sensitivity indices used to show optimal placement approach, which will also decrease loop flows. In [18], a sensitivity method based on line loss has been proposed for placement of series capacitors, static VAR compensators and phase shifters.

In [16], solving problem of the economic dispatch and the cost can do by optimal locations of FACTS devices, while making the assumption that all lines, initially, have these devices.

In [12], suggested the optimal location of the UPFC based on sensitivity analysis of real power flows and transmission line losses.

Purposed Sensitivity Method

Several approaches to the optimal placement approach of FACTS devices have been suggested in different works of literature. These techniques are mainly dependent on the objectives of the selected options. The objectives of the placement of FACTS device optimal power flow include:

- To reduce the real loss of a particular line-k (P_{Lk}).
- To reduce the total real and reactive loss of system (P_{LT})/(Q_{LT}).
- To reduce the performance index for real power flow (PI).
- To reduce the total cost of generation

In this study, the sensitivity approach has been determined to be applicable for the first objective mentioned above in the determination of the optimal locations of TCSC and UPFC.

Line loss sensitivity indices for TCSC

Fig.2 shows a simple transmission line represented by its π equivalent parameters connected between bus-i and bus-j. Let complex voltages at bus-i and bus-j are $V_i(\delta_i)$ and $V_j(\delta_j)$ respectively.

The sensitivity S_k^c of transmission line loss (P_{Lk}) on a series compensated line-k connected between bus-i and bus-j with respective complex voltages $V_i(\delta_i)$ and $V_j(\delta_j)$ and impedance$Z = R + jX$, for series TCSC reactance (X_C), is calculated as follows [14]:

$$S_k^c = \frac{\partial P_{Lk}}{\partial X_C}\bigg|_{X_C=0} = \text{Line loss sensitivity with TCSC} \quad (1)$$

Therefore connected the real power loss (P_{Lk}) between bus-i and bus-j in line-k is;

$$P_{Lk} = G'_{ii}\left(V_i^2 + V_j^2\right) + 2G'_{ij}\left(V_iV_j cos\delta_{ij}\right)$$
$$= -G'_{ij}\left(V_i^2 + V_j^2 - 2V_iV_j cos\delta_{ij}\right) = -G'_{ij}\left|V_i - V_j\right|^2 \quad (2)$$

Where,

$$G'_{ii} = -G'_{ij} = \frac{R}{R^2+(X+X_C)^2}\ ,\ G'_{ij} = -\frac{R}{R^2+(X+X_C)^2} \quad (3)$$

$$\delta_{ij} = \delta_i - \delta_j \quad (4)$$

From equations (1)-(3), can expressed as,

$$S_k^c = \frac{\partial P_{Lk}}{\partial X_C}\bigg|_{X_C=0} = -\left(V_i^2 + V_j^2 - 2V_iV_j cos\delta_{ij}\right)\frac{\partial G'_{ij}}{\partial X_C} \quad (5)$$

Where,

$$\frac{\partial G'_{ij}}{\partial X_C}\bigg|_{X_C=0} = \frac{2R(X+X_C)}{(R^2+(X+X_C)^2)^2} \quad (6)$$

This leads to,

$$S_k^c = \frac{\partial P_{Lk}}{\partial X_C}\bigg|_{X_C=0} = -2\left(V_i^2 + V_j^2 - 2V_iV_j cos\delta_{ij}\right)\frac{R(X+X_C)}{(R^2+(X+X_C)^2)^2} \quad (7)$$

Line loss sensitivities Indices for UPFC

The sensitivities $S_{\mathrm{k}}^{V_{pq}}$ and $S_{\mathrm{k}}^{\delta_{pq}}$ of transmission line loss (P_{Lk}) on the compensated line-k connected between bus-i and bus-j with respective complex voltages $V_i(\delta_i)$ and $V_j(\delta_j)$ and impedance $Z = R + jX$, with respect to UPFC injected voltage amplitude V_{pq} and angle δ_{pq}, are defined as follows (fig. 4). The calculation of these factors can be as follows:

$$S_{\mathrm{k}}^{V_{pq}} = \frac{\partial P_{Lk}}{\partial V_{pq}}\bigg|_{V_{pq}=0} \quad \text{Line loss sensitivity with respect to } V_{pq} \quad (8)$$

$$S_{\mathrm{k}}^{\delta_{pq}} = \frac{\partial P_{Lk}}{V_s\, \partial \delta_s}\bigg|_{\delta_{pq}=0} \quad \text{Line loss sensitivity with respect to } \delta_{pq} \quad (9)$$

The power flow equations from bus-j to bus$-i$ are as follows,

$$S_{ji} = P_{ji} + jQ_{ji} = V_jI_{ji}^* = V_j(Y'_{ji}(V_i + V_{pq}) + Y'_{jj}V_i)^* \quad (10)$$

The a active and reactive power flows of the line with UPFC are,

$$P_{ji} = G'_{ji}\left(V_jV_i cos\delta_{ji} + V_jV_{pq} cos\delta_{jpq}\right) + G'_{jj}V_j^2 - B'_{ji}\left(V_jV_i sin\delta_{ji} + V_jV_{pq} sin\delta_{jpq}\right) \quad (11)$$

$$Q_{ji} = -G'_{ji}\left(V_jV_i sin\delta_{ji} + V_jV_{pq} sin\delta_{jpq}\right) + B'_{jj}V_j^2 + B'_{ji}\left(V_jV_i cos\delta_{ji} + V_jV_{pq} cos\delta_{jpq}\right) \quad (12)$$

Hence, from equations (10),(11) and (12), the real power loss (P_{Lk}) between bus-i and bus-j in line-k is;

$$P_{Lk} = G'_{ii}(V_i^2 + V_iV_{pq}\cos\delta_{ipq}) + G'_{jj}V_j^2 + G'_{ij}(2V_iV_j\, cos\delta_{ij} + V_jV_{pq} cos\delta_{jpq}) + G'_{sh}V_iV_{sh} cos\delta_{ipq} - B'_{ii}V_iV_{pq} sin\delta_{ipq} + B'_{ji}(V_iV_j sin\delta_{ji} + V_jV_{pq} sin\delta_{jpq} - B'_{sh}V_iV_{pq} sin\delta_{ish} \quad (13)$$

Where,

$$Y'_{ii} = G'_{ii} + jB'_{ii} = \frac{Y_{ii}}{1++Y_{ii}Z_s}, Y'_{ii} = G'_{jj} + jB'_{ii} = Y_{jj} - \frac{Y_{ij}Y_{ji}Z_{pq}}{1+Y_{ii}Z_{pq}} \quad (14)$$

$$Y'_{ij} = Y'_{ji} = G'_{ij} + jB'_{ij} = \frac{Y_{ij}}{1+Y_{ii}Z_{pq}} \text{ and } Y'_{sh} = \frac{1}{Z_{sh}} \quad (15)$$

$$Y_{ii} = Y_{jj} = G_{ii} + jB_{ii} = Y + j\frac{B_C}{2} \text{ and}$$
$$Y_{ij} = Y_{ji} = Y'_{ii} = G_{ij} + jB_{ij} = -Y \quad (16)$$

Where $Y = \frac{1}{Z}$ and $Z = R + jX$ = Transmission Line impedance

$$Y'_{sh} = \frac{1}{Z_{sh}} \quad (17)$$

$$\delta_{jpq} = \delta_j - \delta_{pq} \quad (18)$$

$$\delta_{ipq} = \delta_i - \delta_{pq} \quad (19)$$

δ_{pq} ; The angle of injected series voltage
δ_{sh} ; The angle of injected shunt voltage
V_{sh}; The voltage of inserted shunt voltage

So the sensitivity indexes are:

$$S_{\mathrm{k}}^{V_{pq}} = \frac{\partial P_{Lk}}{\partial V_{pq}}\bigg|_{V_{pq}=0} = G'_{ii}V_i\cos\delta_{ipq} + G'_{ij}V_j\cos\delta_{jpq} - B'_{ii}V_i sin\delta_{ipq} - B'_{ji}V_j sin\delta_{jpq} \quad (20)$$

$$S_{\mathrm{k}}^{\delta_{pq}} = \frac{\partial P_{Lk}}{V_{pq}\, \partial \delta_{pq}}\bigg|_{\delta_{pq}=0} = -G'_{ii}V_i sin\delta_{pq} - G'_{ij}V_j sin\delta_{pq} + B'_{ii}V_i\cos\delta_{pq} + B'_{ji}V_j\cos\delta_{pq} \quad (21)$$

V. JEDDAH NETWORK IMPLEMENTATION

The TCSC and UPFC devices are placed randomly to show the effectiveness of these devices on the real power losses and system performance. Thereafter, the selected optimal locations for the TCSC and UPFC devices are analyzed using Sensitivity analysis method [15].

Before connecting the FACTS devices to the system, it is important to select the sensitive lines that are dependent on sensitivity factors. The TCSC and UPFC placed in the lines that has the most positive loss sensitivity index S^cinductive mode. However, in order to place UPFC in a line$k$, it was considered that the line should have sensitivity indices for phase angles δ_{pq} with the largest absolute value and most negative sensitivity index for V_{pq} , $S^{V_{pq}}$.The final placement of FACTS depends on different sensitivity indices.

As shown in Figure 5, Jeddah 380 kV transmission network is comprised of 21 substations.

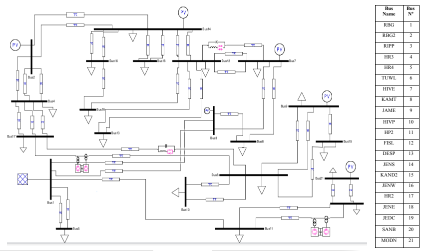

Figure 5. Jeddah 380 KV Network

VI. RESULTS AND DISCUSSION

From Table 1, to placement the TCSC devices must be selected the lines have most positive loss sensitivity index.

For objective 1, the aim of selected lines 37 and 39; the sensitivity index for line 37 and line 39 are more positive than other also lines 3, 17, 33 and 34 maybe select.

While connected TCSC device to Jeddah 380KV system with lines 37 & 39 with a range of reactance between 70% to +20% with reactance of transmission line and with series compensation of 30% , the line loss in 37 & 39 reduced from 29.293 MW to 16.573 also the loss for each lines are reduced. Moreover, the line power flows reduce.

From Table 2, the lines having the most negative loss $\boldsymbol{S_1^{Vs}}$and the highest absolute values of sensitivity indices $\boldsymbol{S_1^{\delta s}}$ are considered for the placement of the UPFC devices for UPFC objective.

The sensitivity index for line 37 and line 39 are observed to be more negative than others and these are selected for the possible best locations of UPFC.Similarly, lines 3, 17, 33 and 34 may also be selected.

The results for line flows and real power losses with and without the incorporation of the FACTS device in lines 37, 39, 17 and 33 are shown in Table 3. From the table, it can be observed that the loss for each line is reduced.

The Line loss in lines 37 and 39 are reduced from 29.293 MW to 15.635MW.The line loss in line 17 is reduced from 0.366 MW to 0.189 MW and that in line 33 is reduced from 0.011 MW to 0.005 MW also the loss for each line are reduced. In addition, the total line losses is observed to be reduced from 125.85 MW to 65.135MW.

Table 1. Sensitivity Indices for Jeddah 380KV system using TCSC

LINE	From-To	Real Line Loss MW	Line Flows MW	S_k^c TCSC
1	RABG-HR4	0.312	200.31	-0.000160
2	RABG-HR4	0.312	200.31	-0.000160
3	HIVE-FISL	0.366	789.11	0.000091
4	HR3-RABG2	2.129	-721.57	-0.000343
5	HR3-RABG2	2.129	-721.57	-0.000343
6	HR3-RBG2	2.129	-721.57	-0.000343
7	HR2-HR3	5.054	-699.24	-0.004040
8	RBG2-JENS	0.744	164.46	-0.000741
9	RBG2-JENS	0.744	164.46	-0.000741
10	JENS-JENW	0.047	281.3	0.000068
11	JENS-JENW	0.047	281.3	0.000068
12	JENS-JENE	0.044	213.04	0.000076
13	*RBG-SANB	0.141	30.092	-0.000007
14	JENS-JENE	0.044	213.04	0.000076
15	JENS-FISL	0.044	-250.63	0.000087
16	JENS-FISL	0.044	-250.63	0.000087
17	HIVE-FISL	0.366	789.11	0.000821
18	HIVE-FISL	0.366	789.11	-0.000021
19	RIPP-TUWL	7.89	1099.52	-0.002706
20	RIPP-HIVE	12.019	1099.52	-0.011616
21	TUWL-HIVE	4.213	887.63	-0.000952
22	JEDC-FISL	0.188	-621.5	-0.000001
23	DESP-FISL	0.105	-259	-0.000001
24	DESP-FISL	0.105	-259	-0.000001
25	JEDC-JENW	0.005	294.99	0.000034
26	KAMT-JAME	0.034	170.66	0.000023
27	KAMT-JAME	0.034	170.66	0.000023
28	KAND2-JAME	0.188	-486.06	-0.000003
29	KAMT-KAND2	0.209	402.15	-0.000225
30	RIPP-RBG	7.441	-969.93	-0.007657
31	SANB-MODN	0.943	-275.06	-0.000187
32	SANB-MODN	0.943	-275.06	-0.000187
33	SANB-HP2	0.011	90.057	0.000024
34	SANB-HP2	0.011	90.057	0.000024
35	KAMT-HIVP	0.193	357.69	-0.000002
36	KAMT-HIVP	0.193	357.69	-0.000002
37	KAMT-HR2	29.293	-453.23	0.002368
38	RIPP-RBG	7.441	-969.93	-0.007657
39	KAMT-HR2	29.293	-453.23	0.002368
40	HR2-HR3	5.054	-699.24	-0.004040
41	R2-HR3	5.054	-699.24	-0.004040

The results for line flows and real power losses with and without the incorporation of the FACTS device in lines 37, 39, 17 and 33 are shown in Table 3. From the table, it can be observed that the loss for each line is reduced. The Line loss in lines 37 and 39 are reduced from 29.293 MW to 15.635MW.The line loss in line 17 is reduced from 0.366 MW to 0.189 MW and that in line 33 is reduced from 0.011 MW to 0.005 MW also the loss for each line are reduced. In addition, the total line losses is observed to be reduced from 125.85 MW to 65.135MW.

From figures 6, 7 it is evident that the voltage profile of load buses gets improved by a substantial margin. The total real loss of the system gets reduced by 47 % from a value of 125.85 MW to 65.135 MW.

Table 2. Sensitivity Indices for Jeddah 380 kV system

LINE	From-To	Real Line Loss MW	Line Flows MW	UPFC $S_1^{V_S}$	UPFC $S_1^{\delta_S}$
1	RBG-HR4	0.312	200.31	1.221022	45.38818
2	RBG-HR4	0.312	200.31	1.221022	45.38818
3	HIVE-FISL	0.366	789.11	18.77862	64.48201
4	HR3-RBG2	2.129	-721.57	2.144146	54.54700
5	HR3-RBG2	2.129	-721.57	2.144146	54.54700
6	HR3-RBG2	2.129	-721.57	2.144146	54.54700
7	HR2-HR3	5.054	-699.24	0.809663	40.40687
8	RBG2-JENS	0.744	164.46	0.757587	38.01982
9	RBG2-JENS	0.744	164.46	0.757587	38.01982
10	JENS-JENW	0.047	281.3	15.61615	62.73836
11	JENS-JENW	0.047	281.3	15.61615	62.73836
12	JENS-JENE	0.044	213.04	10.41777	60.63827
13	*RBG-SNB	0.141	30.092	8.174807	60.80216
14	JENS-JENE	0.044	213.04	10.41777	60.63827
15	JENS-FISL	0.044	-250.63	15.63751	62.42292
16	JENS-FISL	0.044	-250.63	15.63751	62.42292
17	HEVE-FISL	0.366	789.11	18.77862	64.48201
18	HEVE-FISL	0.366	789.11	18.77862	64.48201
19	RIPP-TUWL	7.89	1099.52	1.443711	46.93143
20	RIPP-HIVE	12.019	1099.52	0.774355	37.54307
21	TUWL-HIVE	4.213	887.63	1.741504	49.82970
22	JEDC-FISL	0.188	-621.5	18.70802	-64.4409
23	DESP-FISL	0.105	-259	7.224113	60.57779
24	DESP-FISL	0.105	-259	7.224113	60.57779
25	JEDC-JENW	0.005	294.99	8.504272	59.05898
26	KAMT-JAME	0.034	170.66	9.011267	62.31685
27	KAMT-JAME	0.034	170.66	9.011267	62.31685
28	KAND2-JAME	0.188	-486.06	8.898792	61.05069
29	KAMT-KAND2	0.209	402.15	0.190748	53.658684
30	RIPP-RBG	7.441	-969.93	1.096697	37.09306
31	SANB-MODN	0.943	-275.06	3.19427	47.70014
32	SANB-MODN	0.943	-275.06	3.19427	47.70014
33	SANB-HP2	0.011	90.057	17.71125	66.45722
34	SANB-HP2	0.011	90.057	17.71125	66.45722
35	KAMT-HIVP	0.193	357.69	5.491016	62.39686
36	KAMT-HIVP	0.193	357.69	5.491016	62.39686
37	KAMT-HR2	29.293	-453.23	50.42532	-68.5694
38	RIPP-RBG	7.441	-969.93	1.096697	37.09306
39	KAMT-HR2	29.293	-453.23	50.42532	-68.5694
40	HR2-HR3	5.054	-699.24	0.809663	40.40687
41	HR2-HR3	5.054	-699.24	0.809663	40.40687

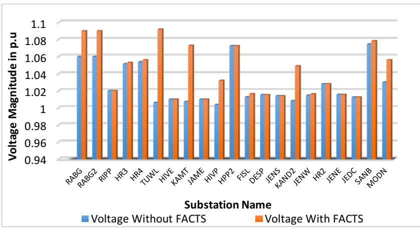

Figure 6: Effect of FACTS devices on Bus Voltage magnitude

Table 3: Effect of FACTS devices on Line Flows and Real line Losses

LINE	From-To	Line Flows MW Without FACTS	Line Flows MW With FACTS	Real Line Loss MW Without FACTS	Real Line Loss MW With FACTS
1	RBG-HR4	200.31	200.31	0.312	0.312
2	RBG-HR4	200.31	200.31	0.312	0.312
3	HIVE-FISL	789.11	789.11	0.366	0.363
4	HR3-RBG2	-721.57	-721.57	2.129	2.12
5	HR3-RBG2	-721.57	-721.57	2.129	2.12
6	HR3-RBG2	-721.57	-721.57	2.129	2.12
7	HR2-HR3	-699.24	-699.24	5.054	4.462
8	RBG2-JENS	164.46	164.46	0.744	0.744
9	RBG2-JENS	164.46	164.46	0.744	0.744
10	JENS-JENW	281.3	281.3	0.047	0.047
11	JENS-JENW	281.3	281.3	0.047	0.047
12	JENS-JENE	213.04	213.04	0.044	0.044
13	*RBG-SNB	30.092	30.092	0.141	0.057
14	JENS-JENE	213.04	213.04	0.044	0.044
15	JENS-FISL	-250.63	-250.63	0.044	0.043
16	JENS-FISL	-250.63	-250.63	0.044	0.043
17	HEVE-FISL	789.11	789.11	0.366	0.189
18	HEVE-FISL	789.11	789.11	0.366	0.120
19	RIPP-TUWL	1099.52	1099.52	7.89	5.88
20	RIPP-HIVE	1099.52	1099.52	12.019	11.36
21	TUWL-HIVE	887.63	887.63	4.213	4.086
22	JEDC-FISL	-621.5	-621.5	0.188	0.188
23	DESP-FISL	-259	-259	0.105	0.105
24	DESP-FISL	-259	-259	0.105	0.105
25	JEDC-JENW	294.99	294.99	0.005	0.005
26	KAMT-JAME	170.66	170.66	0.034	0.034
27	KAMT-JAME	170.66	170.66	0.034	0.034
28	KAND2-JAME	-486.06	-486.06	0.188	0.188
29	KAMT-KAND2	402.15	402.15	0.209	0.209
30	RIPP-RBG	-969.93	-969.93	7.441	7.107
31	SANB-MODN	-275.06	-275.06	0.943	0.792
32	SANB-MODN	-275.06	-275.06	0.943	0.792
33	SANB-HP2	90.057	90.057	0.011	0.005
34	SANB-HP2	90.057	90.057	0.011	0.005
35	KAMT-HIVP	357.69	357.69	0.193	0.193
36	KAMT-HIVP	357.69	357.69	0.193	0.193
37	KAMT-HR2	-453.23	-79.848	29.293	15.015
38	RIPP-RBG	-969.93	-969.93	7.441	7.107
39	KAMT-HR2	-453.23	-79.848	29.293	15.015
40	HR2-HR3	-699.24	-695.96	5.054	4.462
41	HR2-HR3	-699.24	-695.96	5.054	4.462

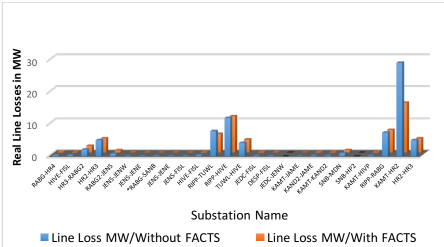

Figure 7: Effect of FACTS devices on Line Loss

VII- CONCLUSION

This paper has discussed the application of TCSC and UPFC in the improvement of the magnitude if the voltage as well as the minimization of the power losses in the transmission network. The sensitivity analysis approach has been used to find the optimal placement of single and multiple FACTS devices. This method has been applied on Jeddah 380KV power system. The results obtained show significant improvements in the voltage profile of load buses. The total real loss of system has also significant reduced.

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REFERENCES

[1] Hingorani, N.G., Gyugyi, L.: 'Understanding FACTS concepts and technology of flexible AC transmission systems' (IEEE Press, New York, 1999)

[2] Hingorani NG, «Flexible AC Transmission», IEEE Spectrum, p. 40-45, April 1993.

[3] J. Carpentier, "Contribution to the economic dispatch problem," Bulletin de la Societe Francoise des Electriciens, vol. 3, no. 8, pp. 431–447, 1962-OPF

[4] Dommel, H. W. and Tinney, W. F. "Optimal Power Flow Solutions," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-87, October 1968, pp. 1866-1876.

[5] 12. Sun, D. I. Ashley, B. Brewer, B. Hughes, A. and Tinney, W. F "Optimal Power Flow by Newton Approach," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-103, October 1984, pp. 2864-2880.

[6] 15. Lai, L. L. "Intelligent System Applications in Power Engineering, Evolutionary Programming and Neural Networks" New York, Wiley 1998.

[7] Yuryeich, J. and Wong, K.P. "Evolutionary Programming Based Optimal Power Flow Algorithm," IEEE Transactions on Power System, Vol. 14, No.4, November 1999, pp.1245-1250.

[8] PrakashBurade, JagdishHelonde., Optimal Location of FACTS Device on Enhancing System Security,International Journal of Scientific & Engineering Research. Volume 3, Issue 5, May-2012.

[9] Aswini kumar, "Optimal location of UPFC and comparative Analysis of Maximum loadability with FACTS in Competitive Electricity Markets," 7 th WSEAS international conference on Electric Power System, Nov., 2007.

[10] Mohd Wazir Mustafa,Wong Yan Chiew, Optimal placement of SVC using Genetic Alogorithm, V- 10., Faculty of Electrical Engineering, 2008

[11] Lijun cai and georgios stamtsis,yicheng luo, "Optimal choice and allocation of FACTS device in deregulated electricity market using Genetic Algorithm"

[12] T. Jibiki, E. Sakakibara, S. Iwamoto, "Line flow sensitivities of line reactances for congestion management", Proceedings of the IEEE Power Engineering Society General Meeting, pp. 1–6, 2007.

[13] Abouzar Samimi, Peyman Naderi, "A New method for optimal placement of TCSC based on sensitivity analysis for congestion management, SGRE. 2012.

[14] H. C. Leung and T. S. Chung, "Optimal Placement of FACTS Controller in Power System by a Genetic-Based Algorithm," Proceedings of the IEEE International Con-ference on Power Electronics and Drive Systems, 27-29 July 1999, pp. 833-836.

[15] W. F. Tinney and C. E. Hart, "Power Flow Solution by Newton's Method," in IEEE Transactions on Power Apparatus and Systems, vol. PAS-86, no. 11, pp. 1449-1460, Nov. 1967.

[16] H. Saadat, Power system analysis, 3rd ed. United States: PSA Pub., 2011.

[17] CIGRE TF 38-01-06 on Load Flow Control, "Load Flow Control in High Voltage Systems Using FACTS Controllers", October 1995.

[18] GeorgantzisGJ, LeonidakiEA,HatziargyriouND,Vlachogiannis JG, "Investigation of the Effect of FACTS Devices on the Steady-state Operation of the Hellenic Transmission System", CIGRE Symposium "Working Plant and Systems Harder", London, UK, 7-9 June 1999.

[19] Ghahremani, E., Kamwa, I.: 'Optimal placement of multiple-type FACTS devices to maximize power system loadability using a generic graphical user interface', IEEE Trans. Power Syst., 28, (2), pp. 764–778, 2013

[20] Ghahremani,E.,Kamwa, I.: 'Maximizing transmission capacity through a minimum set of distributed multi-type FACTS'. Proc. IEEE PES General Meeting , 22–29, pp. 523–528, July 2012

[21] Hingorani, N.G., Gyugyi, L.: 'Understanding FACTS concepts and technology of flexible AC transmission systems' (IEEE Press, New York, 1999).

[22] Sedraoui K., Fnaiech F., AL Haddad K., "Solutions for Power Quality Using the Advanced UPFC- Control Strategy and Case Study-"International Review of Electrical Engineering (I.R.E.E.), September-October 2008, Vol. 3, n. 5, pp 811-819.

[23] Sedraoui K., Olivier G., AL Haddad K., "Flicker Compensation in Arc Furnace Power systems Using UPFC " Published and presented in the, IEEE International Symposium on Industrial Electronics (ISIE 2006), Montreal, CA. 9-13 Jul. 2006, Vol.3 pp.1864 - 1868.

[24] Sedraoui K. "A Practical Approach of Instantaneous Power to Control the Unbalanced and Non-Sinusoidal Three phase system" Presented and published in the Power Systems Conference and Exposition, (IEEE PSCE2004), 10-13 October 2004, NY, USA.

[25] Sedraoui K., Olivier G., AL Haddad K., Chandra A., "A new Approach for the Dynamic Control of Unified Power Flow Controller (UPFC) " Presented and published in the IEEE Power Engineering Society summer Meeting 15-19 July 2001, Vancouver, CA.

[26] Singh, S.N., Erlich, I.: 'Locating unified power flow controller for enhancing power system loadability'. Proc. 2005, IEEE Int. Conf. Future Power Systems, pp. 1–5, 18–21 November 2005

[27] Sharma, N.K., Ghosh, A., Varma, R.K.: 'A novel placement strategy for FACTS controllers', IEEE Trans. Power Deliv., pp. 982–987, 2003

[28] Sharma, A., Chanana, S., Parida, S.: 'Combined optimal location of FACTS controllers and loadability enhancement in competitive electricity markets using MILP'. Proc. 2005, IEEE Power Engineering Society General Meeting (PES'05), vol. 1, pp. 670–677, 12–16 July 2005

[29] Chang, R.W., Saha, T.K.: 'Maximizing power system loadability by optimal allocation of SVC using mixed integer linear programming'. Proc. 2010, IEEE Power and Energy Society General Meeting, pp. 1–7, 25–29 July 2010

[30] M. Kowsalya, K. K. Ray and D. P. Kotheri,"Positioning of SVC and STATCOM in a Long Transmission Line", International journal of Recent Trends in Engineering, Vol. 2, No. 5,2009

[31] M. A.Talebi, A. Kazemi, A. Gholami and M. Rajabi,"Optimal placement of static var compensators in distribution feeders for load balancing by genetic algorithm," International Conference on electricity Distribution, Turin, Italy, pp. 1-6, 6-9 June 2005.

[32] K.R.Padiyar,"FACTs Controllers in Power Transmission and Distribution", Anshan Publishers, New Delhi, 1st edition, 2009.

[33] X. Jiang, J.H. Chow, A.A. Edris, B. Fardanesh, E. Uzunovic, "Sensitivity methods in the dispatch and sitting of FACTS controllers", IEEE Transactions on Power Systems, Vol. 21, pp. 713–720, 2009.

[34] Singh,J.G.,S.N.Singh and S.C Srivastava,2007.Enhancement of power system security through optimal placement of TCSC and UPFC. Proceedings of the power Engineering Society General Meeting,June 24-28,2007,Tampa,FL.,PP:1-6

[35] X. Jiang, J.H. Chow, A.A. Edris, B. Fardanesh, E. Uzunovic, "Sensitivity methods in the dispatch and sitting of FACTS controllers", IEEE Transactions on Power Systems, Vol. 21, pp. 713–720, 2009.