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Impact of FACTS Devices in Optimal Generation in Deregulated Power System

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ABSTRACT

A well-prepared abstract enables the reader to identify the basic content of a document quickly and accurately, to determine its relevance to their interests, and thus to decide whether to read the document in its entirety. The Abstract should be informative and completely self-explanatory, provide a clear statement of the problem, the proposed approach or solution, and point out major findings and conclusions. The Abstract should be 100 to 200 words in length. The abstract should be written in the past tense. Standard nomenclature should be used and abbreviations should be avoided. No literature should be cited. The keyword list provides the opportunity to add keywords, used by the indexing and abstracting services, in addition to those already present in the title. Judicious use of keywords may increase the ease with which interested parties can locate our article (9 pt).

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1. INTRODUCTION

The ordinary power flow or load flow problem gives the voltage at various buses, the loading of lines, how much power is generated and how much power is lost, but the main drawback of this method is that it takes both the generation and demand as fixed. This leads to a result which is only a snapshot of the system in any given instant. But the power system is a complex structure and the generation to demand ratio in it keeps changing frequently. So for a power system operator to operate the system in a more economical and feasible way instead of fixed generation the generated power needs to be adjusted according to certain criteria's. Need for economic power system operations lead way to the formulation of OPF.Eventhough in its early stages OPF was used only for economic operation of the power systems, lately its application has widened which ranges from planning of the power systems in its preliminary stages to its reliable operations.

In 1977 H.H. Happ [1], did the first comprehensive survey regarding the optimal dispatch problem. From there on many literatures have been published in the area OPF. Even though many works have been published in the past all these works considered mainly three elements of the OPF problem an objective function, control variables of that function and a constraint to which the objective function is subjected to. J. Carpentier [2] in 1985 presented a work in which different methods used for solving OPF where classified based on the algorithm used. In [3] a survey on OPF under different security constraints has been presented. OPF problem is a nonlinear problem and similarly addition of FACTS device control parameters makes the problem highly nonlinear, so it should be handled with utmost importance [4].

In a heavily loaded interconnected system under steady state operation there is an unwanted loop flow and a parallel power flow. These power flows are beyond the control of a generator regulation due to the cost associated with it. In order to regulate these issues FACTS devices can be used [5]. The importance of incorporating the FACTS device with OPF problem can be emphasized by realizing the benefits offered by those devices. The FACTS devices use high speed control elements to regulate the system under consideration. In addition to this when FACTS are incorporated with OPF it further relaxes the operating limits of and OPF problem [5-10].

This paper proposes an OPF solution method for a standard IEEE 30 bus system with three different types of FACTS devices. The rest of the paper is organized as followsbrief introduction to OPF and its formulation is given in Section II. Section III presents the FACTS devices, their advantages and various types. In section IV the test system is discussed and its modeling is described. In section V various cases of OPF for the test system is discussed and the results are presented. Section VI provides the conclusion to the work.

2. OPF AND OPF PROBLEM FORMULATION

An OPF problem needs to optimize the steady state performance of a power system in terms of an objective function subjected to equality and inequality constraints and other control variable limits and security constraints. Therefore an OPF needs to find out some or all of the control variables to optimize the objective function. Some general objectives are to reduce the fuel cost, reduce transmission line losses, to keep the equipment operating within the limits, to maximize the power transfer, to minimize the deviation from targeted allocations. In the work presented here the main objective is to minimize the power loss. Therefore the objective function for OPF in general is:

$$MinF(P_L) = f(x,u) \tag{1}$$

Where P_L is the active power loss?

Subject to satisfaction of Non-Linear Equality Constraints

$$g(x,u) = 0 \tag{2}$$

and Non-Linear Inequality Constraints

$$h(x,u) \le 0 \tag{3}$$

Where the vector *x*contains dependent variables which might be bus voltage magnitudes, phase angles, MW

and MVAr outputs of generators, MW and MVArconsumption of loads, line parameters and fixed bus voltages. Similarly the vector *u*might consists of variables such as real and reactive power generation, transformer taps, and control voltages.

The constraints such as power flow equations, branch flow limits, Generation and load balances, transmission limits, active & reactive power limits and bus voltage limits can be taken into account for equality and inequality constraints.

The equality constrains and inequality constraints are well described in the works done by M.M. Al-Hulali and M.A. Abido in [11] have been taken for problem formulation.

(i)Equality Constraints

The function g represents the equality constraints which are the power flow equations as given below

$$P_{G_i} - P_{D_i} = \sum_{j=1}^{NB} V_i V_j Y_{ij}\left(FACTS\right)\cos\left(\theta_{ij}(FACTS) + \delta_j - \delta_i\right) = 0; \quad \forall i \in NB \tag{4}$$

$$Q_{G_i} - Q_{D_i} = \sum_{j=1}^{NB} V_i V_j Y_{ij}\left(FACTS\right)\sin\left(\theta_{ij}(FACTS) + \delta_j - \delta_i\right) = 0; \quad \forall i \in NB \tag{5}$$

NB is Number of Buses

$P_{G_i} - Q_{G_i}$ Are active and reactive power generations at bus i

$P_{D_i} - Q_{D_i}$ Are active and reactive power demands at bus i

V_i and δ_i are voltage magnitudes and angle at bus i

$Y_{ij}\left(FACTS\right)$ and $\theta_{ij}(FACTS)$ are magnitudes and phase angle of elements in Y-BUS matrix where the effects of FACTS have been taken into account.

(ii)Inequality Constraints

h is the system nonlinear inequality constraints that includes:

(a)Generation Constraints: The generated voltage and the real and reactive power outputs are restricted to their respective upper and lower limits as follows:

$$\begin{aligned} &V_{G_i}^{\min} \le V_{G_i} \le V_{G_i}^{\max}, where i = 1,.,.,.,.NG \\ &P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max}, where i = 1,.,.,.,.NG \\ &Q_{G_i}^{\min} \le Q_{G_i} \le Q_{G_i}^{\max}, where i = 1,.,.,.,.NG \end{aligned} \tag{6}$$

(b)Transformer Constraints: The transformers tap settings are bounded as follows:

$$T_i^{\min} \le T_i \le T_i^{\max}, where i = 1,.,.,.,.NT \tag{7}$$

(c)Security Constraints: This includes the constraints of bus voltages and line loadings as below

$$\begin{aligned} &V_{L_i}^{\min} \le V_{L_i} \le V_{L_i}^{\max}, where i = 1,.,.,.,.NL \\ &S_{L_i} \le S_{L_i}^{\max}, where i = 1,.,.,.,.nl \end{aligned} \tag{8}$$

(d) FACTS Device Constraints: The settings of SVC, TCSC and UPFC are bounded as follows:

$$\begin{aligned} &B_i^{\min} \le B_i \le B_i^{\max}, where i = 1,.,.,.,.NSVC \\ &x_{c_i}^{\min} \le x_{c_i} \le x_{c_i}^{\max}, where i = 1,.,.,.,.NTCSC \\ &\phi_i^{\min} \le \phi_i \le \phi_i^{\max}, where i = 1,.,.,.,.NUPFC \end{aligned} \tag{9}$$

3. FACTS DEVICES AND ITS TYPES

The concepts of FACTS controller was pioneered by Hingorani first in 1988 [12],[13]. These are high power electronic devices which can control the power flow and enhance the stability of a power system. These devices can control the active and reactive power flows simultaneously in a network under both normal and abnormal conditions which can help in reducing the system losses, regulating the voltage and control the power flow.

STATIC VAR COMPENSATORS

Static VAR compensators or SVC are the first generation FACTS devices that are widely used for shunt compensation.

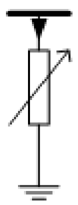

Figure.1, Model of SVC

When a SVC is connected to a bus it can control and regulate the voltage magnitude of that particular bus. This is done by injecting capacitive vars and inductive vars to make the voltage of the bus higher and lower respectively. That is under low loading inductive vars are injected and during high loading capacitive vars are injected. It either consists of a combination of fixed capacitors or thyristor switched capacitors in conjunction with thyristor controlled reactors. The maintenance of these type of devices are easy.

THYRISTOR CONTROLLED SERIES CAPACTIORS
TCSC is a series compensation device[14], which increases the steady state power transfer. TCSC can be considered as a second generation FACTS devices.

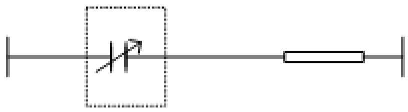

Figure.2, TCSC Model

TCSC can be viewed as a series reactance which controls the effective line reactance by connecting variable line reactance in series with a line.

UNIFIED POWER FLOW CONTROLLER
The basic concepts and structure of UPFC are presented and explained by Gyugi. An UPFC consists of two elements, both these elements are controllable. One of the elements is a voltage source inserted in series with the line and the other one is a current source connected in shunt with a line. In case of the voltage source both the angle and the magnitude of the inserted voltage are controllable, but in case of the current source only the magnitude of the current is controllable parameter [15], [16].

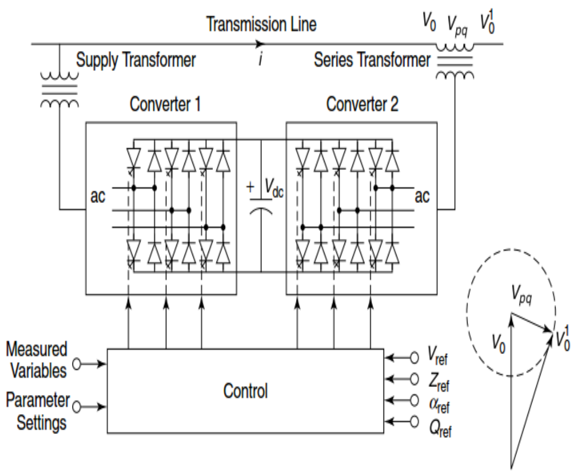

Figure.3 UPFC Model

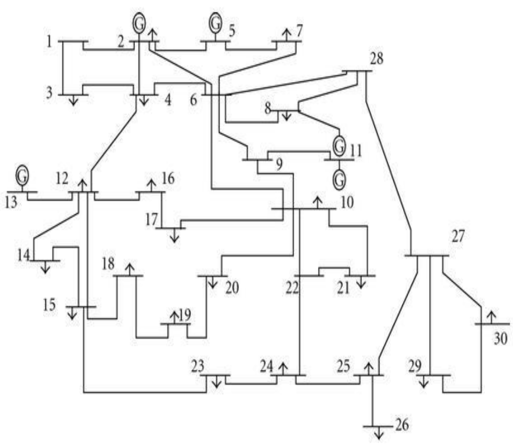

Figure. 4, IEEE 30 bus system

4. METHODOLOGY

The previous works in this field have considered active power loss minimization subjected to constraints such as line loadings, generation minimum and maximum constraints, their active power outputs and reactive power outputs. However dynamic limitation of generators, transformer tap settings, Facts device controller dynamics etc is not considered. In addition existing methods mostly aims at single objective of either loss minimisation or cost minimisation. Proposed paper include all practical constrains in all three segments of power system i.e generation, transmission & distributions. It also takes into account the influence of various controllers such as AVR, Governors, Voltage regulators for transformers, FACTS devices etc. Proposed method uses linear programing to solve the problem which results in rapid convergence. This work also considers three different loading conditions namely minimum loading (50% of total load) average loading (75% of Total load) and peak loading (100% of Total Load) The IEEE 30 bus system considered is presented in Figure. 4.

5. SYSTEM CONSIDERED

In order to test the effectiveness of the proposed method, standard IEEE 30 bus system is used. Different loading conditions such as 50% loading, 75% loading and 100% loading are considered. For all these three cases the power loss is found using four more cases namely without facts devices, with SVC, With TCSC and finally UPFC. The line flow for different cases is also considered. Therefore in total 12 different scenarios are considered and their results are presented in the next section.

CASE DEFINITIONS

(i). Without FACTS: In this case the control variables are the bus voltage magnitudes, transformer taps and line flows.
(ii). With SVC: In this case the bus voltage magnitudes are considered and then the SVC is placed on a three bus with weaker bus voltage profiles namelyBUS 4, BUS 7 and BUS 13
(iii). With TCSC: The TCSC is placed between the buses BUS 5&BUS 2 and
(iv). With UPFC: The UPFC is placed in BUS 3.

6. SIMULATION AND RESULTS

CASE (i): The total system is considered to be loaded for only 50% (i.e. 141.7 MW) and based on this an OPF solution is developed for without facts devices and with different types of FACTS devices. The active power loss is calculated and presented below. It can be seen that

Table 1 Comparison of Active Power Loss In 50% Loading

DEVICE TYPE	Generation Cost	ACTIVE POWER LOSS UNDER 50% LOADING IN MW
WITOUT FACTS	4.89	4.89
WITH SVC	4.76	4.76
WITH TCSC	4.3	4.3
WITH UPFC	4.12	4.12

Table 2. Power Flow Under 50% Loading

S. NO.	FROM BUS	TO BUS	POWER FLOW (IN MW)			
			WITHOUT FACTS DEVICES	WITH SVC	WITH TCSC	WITH UPFC
1	1	3	34.06	33.98	30.09	28.45
2	10	24	19.35	19.35	17.43	16.84
3	2	4	34.96	35.46	31.09	29.73
4	2	1	32.21	30.03	31.82	29.45
5	5	2	52.85	53.78	48.34	47.23
6	5	7	26.66	26.45	23.65	22.84
7	4	3	32.08	31.09	29.82	23.84
8	15	23	26.33	25.88	23.45	21.57
9	29	30	22.49	22.19	19.87	18.65

CASE (ii): The total system is considered to be loaded for only 75% (i.e. 212.55 MW) and based on this a OPF solution is developed for without facts devices and with different types of FACTS devices. The active power loss is calculated and presented below. It can be seen that

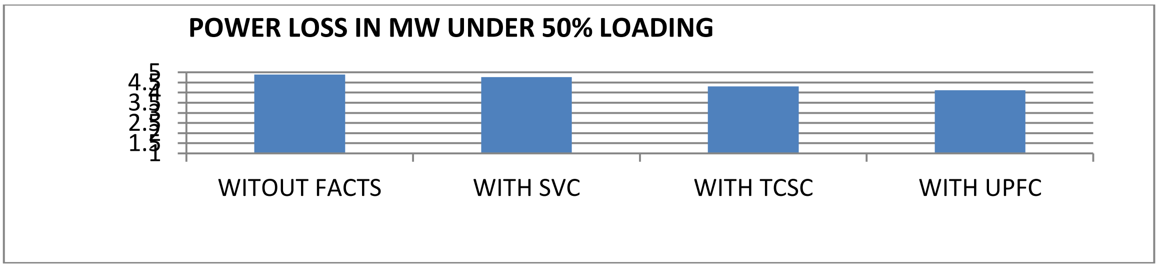

Figure 4. Power loss in 50% loading

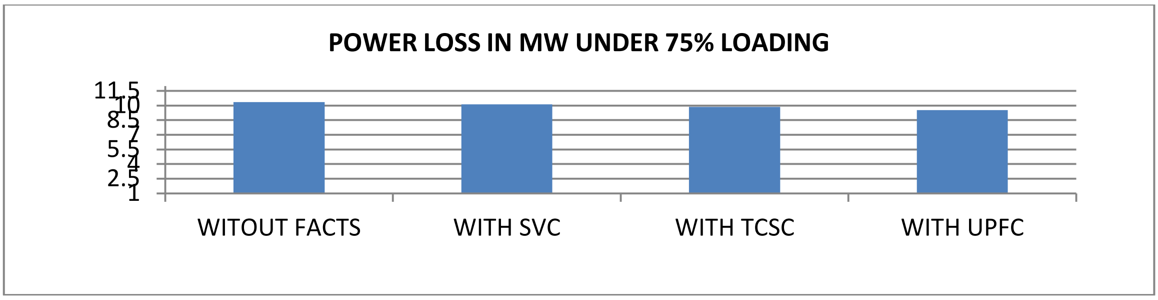

Figure 5, Power loss in 75% loading

Table 3. Comparison of Active Power Loss In 75% Loading

DEVICE TYPE	ACTIVE POWER LOSS UNDER 75% LOADING IN MW
WITOUT FACTS	10.355
WITH SVC	10.12
WITH TCSC	9.87
WITH UPFC	9.54

Table 4. Power Flow Under 75% Loading

S. NO.	FROM BUS	TO BUS	POWER FLOW (IN MW)			
			WITHOUT FACTS DEVICES	WITH SVC	WITH TCSC	WITH UPFC
1	1	3	63.91	63.45	62.23	61.84
2	10	24	4.41	4.39	4.28	4.09
3	2	4	56.46	54.34	51.87	45.84
4	2	1	63.91	63.78	57.82	54.92
5	5	2	125.13	123.21	120.46	117.97
6	5	7	57.74	55.45	49.25	44.89
7	4	3	43.77	42.12	40.19	39.05
8	15	23	54.46	53.36	52.49	49.34
9	29	30	33.26	32.24	29.06	25.56

CASE (iii) The total system is considered to be loaded for 100% (i.e. 283.4MW) and based on this a OPF solution is developed for without facts devices and with different types of FACTS devices. The active power loss is calculated and presented below. It can be seen that

Table 5 Comparison Of Active Power Loss In 100% Loading

DEVICE TYPE	ACTIVE POWER LOSS UNDER 100% LOADING IN MW
WITOUT FACTS	20.064
WITH SVC	19.24
WITH TCSC	18.78
WITH UPFC	18.49

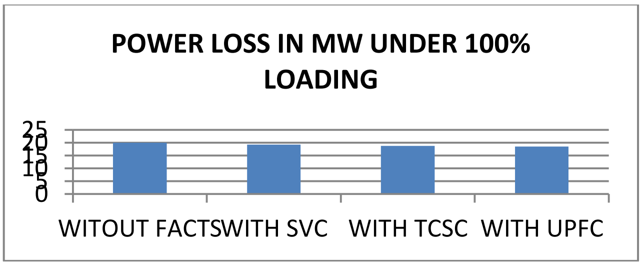

Figure 6. Power Loss Under 100% Loading

Table 6. Power Flow Under 100% Loading

S. NO.	FROM BUS	TO BUS	100% LOADING (IN MW) WITHOUT FACTS DEVICES	WITH SVC	WITH TCSC	WITH UPFC
1	1	3	85.60	85.23	81.67	78.43
2	10	24	5.90	5.43	4.87	3.95
3	2	4	75.71	75.34	73.61	71.43
4	2	1	85.60	85.12	81.90	75.09
5	5	2	182.74	179.23	176.87	171.34
6	5	7	80.72	78.26	73.11	72.82
7	4	3	57.29	56.83	54.23	49.75
8	15	23	75.33	74.34	71.39	68.42
9	29	30	45.03	44.92	41.87	37.06

7. CONCLUSION

Optimal Power Flow solution to minimize the loss in a deregulated environment with FACTS is attempted with all practical constraints for IEEE 30bus system. Studies are carried out for various loading condition with various FACTS devices namely SVC, TCSC and UPFC and all these results are compared. Proposed methodology provides the optimal solution compared with existing methods even with nonlinearities from Deregulated environment and FACTS controllers.

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