Sensitivity Index Based Load Optimization and Impact of FACTS Devices in Pool and Hybrid Electricity Market Model

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Abstract— **Congestion management process is very crucial and important for better planning and successful operation of electrical power system. Due to increase in load, power flow for the system must be calculated to ensure system stability and security. In this paper Congestion management is implemented by minimization and optimization of loads. Use of FACTS devices is also included for optimal power flow for congestion management. Nodal price based sensitivity index is also implemented for economic load dispatch using optimal power flow method. IEEE 24 RTS is simulated on PSAT for performance analysis and evaluation.**

*Keywords— **Congestion Management; FACTS; Optimal Power Flow; Pricing; Pool market; hybrid market***

I. INTRODUCTION

Sudden demand variations, equipment failure, and contingencies may cause overloads in many case that may lead to instability of the transmission system. Violations of a transmission line constraint is known as over load [1-2]. To ensure system security and stability these constraints must be alleviated up to reasonable limits for smooth and reliable transmission system operation and control [3]. The different procedures for this kind of problem are

- Generation rescheduling
- Generation rescheduling and load shedding
- Changing the parameters of some network devices as transformer ratios and reactive power injections in buses[4]

By managing load, congestion can be effectively relieved. The benefit results from reduced peak demand and reduced pressure on both electricity generation and distribution systems [5]. The amount of load curtailed should be as small as possible [6].

In this paper, optimal load curtailment strategy has been developed using DC and AC optimal power flow method [7-8]. As the FACTS devices helps in reactive power compensation, the effect of implementing these devices for optimization and minimization of load can be implemented effectively [9].

The load optimization for congestion management is available [10].

The single and multi-line congestion cases are included in the results for better planning and control. Both generator and load bids are taken for the congestion management [11]. The loads based on their bids participate for their curtailment. In this paper, a mechanism has been devised based on the sensitivity index of the nodal prices for deciding the loads for their optimal curtailment. Nodal price technique is used to calculate priced based sensitivity of FACTS integrated system [12].The study for congestion management with load optimization and minimization, several FACTS devices has been optimized and tested to increased power flow and optimal power flow. Based on physical laws of flow of electricity[13-14], all kinds of desired objectives, such as load curtailment minimization, cost minimization, total loss minimization, etc. are achieved by incorporating FACTS and corresponding control variables with system variables.

II. ESTIMATION OF SENSTIVITY INDEX BASED OPTIMAL LOAD FLOW

The objective function for optimization and minimization and to calculate price based on sensitivity index, considering network contingencies and power flow equations can be formulated as,

$$Function = Min\left(\sum_{i\in N_g} C_i(P_{Gi}) - \sum_{i\in N_d} B_i(P_{di})\right) \quad (1)$$

This objective function consist of two parts. The first part consist of fuel cost function of all the generators present in the system and the second function is the bid function. Hence the two function can be defined as

$$C_i(P_{Gi}) = a_{Pi} * P_{Gi}^2 + b_{Pi} * P_{Gi} + c_{Pi} \quad (2)$$

$$B_i(P_{di}) = a_{di} * P_{di}^2 + b_{di} * P_{di} + c_{di} \quad (3)$$

Where,

a_{pi}=Quadratic component of generator fuel cost function

b_{pi} =Linear component of generator fuel cost function

c_{pi} =Constant tem for generator fuel cost function

a_{di} =Quadratic component of demand bid function

b_{di} =Linear component of demand bid function

c_{di} =Constant component for demand bid function

Heavy congestion at the customer location side increases the per unit electricity price. Sometimes due to increase in price the customer is bound to minimize his load to meet the electricity price at the users end.so increase in electricity generation and proper congestion management of available power this increase

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in price can be minimized satisfactory. The proposed index determines per unit cost to be decreased with minimized and optimized load at increased generation.

$$\mu_{ci}=\begin{cases} 1 & (K_i \geq K_i^{Max}) \\ \frac{(K_i-K_i^{min})}{(K_i^{max}-K_i^{min})} & (K_i^{min} \leq K_i \leq K_i^{Max}) \\ 0 & (K_i \leq K_i^{min}) \end{cases} \quad (4)$$

Where,

K_i^{max} =Maximum price based on locational,

K_i^{min} =Minimum value of load that cannot be lower down further.

K_i^{max} and K_i^{min} are the maximum and minimum values of price based index, calculated without heavy congestion Such an index represents a criterion where the effectiveness measured in sensitivity is high (μ_s)[15-16].

III. OPTIMAL POWER FLOW WITH PLACEMENT OF FACTS

For the congestion management and minimization of load several research have been applied earlier [17].Load buses where the loads are to be minimized are selected based on the price based index method at the corresponding load bus. Here in the pool model we are selecting the load buses where the sensitivity factor (μ_s) is higher [18]. The nodal price sensitivity factor for pool model is given in Table I and its values at each bus are shown in Fig.1.The results obtained for various buses for minimization of load shows that the bus numbers from 4 to 14, excluding bus numbers 7 and 13 have higher values for this index, considering that buses numbers 11 and 12 does not have connected load. Hence the bus numbers having higher value of sensitivity factor are taken in to consideration for the optimization and minimization of load. Similarly for hybrid market model, the sensitivity factors are shown in Table II and Fig 2.From the results obtained it is clear that nodal price sensitivity is higher at buses 4, 6, and 8 and is selected for load model. Although there are higher sensitivity at other buses can also be selected for load model.

IV. RESULTS AND DISCUSSION

From the results obtained, FACTS contribution in Pool Market Model is given in Table I, Table II and Table III. It also shows the load minimization by a variety of FACTS controllers like STATCOM, UPFC, IPFC, and GUPFC. The comparison of compensation offered by FACTS and without FACTS (WOF) with total power generated and power loss is also presented. It is also seen that due to change in the schedule of power generation, the load minimization by FACTS controllers is lower, so as to allow the total power flow through the lines. Total 7 load buses selected for load minimization and for optimized power flow. Loads at buses 4 and 6 participated for congestion management with UPFC, IPFC and GUPFC. The minimum and optimized load is obtained with the placement of GUPFC. Optimal power generation is given in Table IV and is shown in Fig.3 and Fig.4. The real power losses are shown in Fig. 5. It is evident from the results that with the placement of FACTS controllers, losses are reduced, however, with GUPFC, the losses are found to increase due to the increase in power flows in few lines.

Total minimized and optimized load for congestion management with and without placement of FACTS devices is presented in Fig. 6. The comparison of compensation offered by FACTS and without FACTS (WOF) with total power generated and power loss is also presented. Total 7 load buses selected for load minimization and for optimized power flow. For hybrid model, load buses at 4, 6, and 8 are selected based on their nodal price sensitivity factors for load curtailment. The load is curtailing only at two buses 4 and 6 without and with STATCOM and SSSC. With only the load at bus 6 participate for congestion management. With IPFC and GUPFC, there is no load curtailment. Total power generation and load minimized with losses is presented in Table V for hybrid market. Similarly power generation with FACTS devices in hybrid market is also presented in Table VI.Fig.7-8, presents output in terms of power generation with power loss, after implementation of FACTS devices for hybrid market model.

TABLE I. SENSITIVITY FACTORS FOR POOL MARKET MODEL

Bus Numbers	**Base case**	**Congestion case**	**Sensitivity factor**
1	25.37	25.919	0.090037
2	25.369	25.943	0.094332
3	25.897	25.812	-0.01395
4	26.243	26.902	1
5	26.036	26.763	1
6	26.24	27.139	1
7	20.15	20.137	0
8	25.96	27.027	1
9	25.853	26.55	1
10	25.903	26.787	1
11	25.801	27.113	1
12	25.755	26.452	1
13	25.252	26.044	0.12999
14	25.675	27.944	1
15	25.039	23.379	-0.27233
16	25.077	25.062	-0.0024
17	24.603	17.678	0
18	24.462	18.976	0
19	25.294	25.328	0.005596
20	25.252	25.326	0.012178
21	24.383	20.157	-0.69368
22	23.762	18.651	0
23	25.142	25.238	0.01581
24	25.607	24.497	-0.18221

Figure 1.Sensitivity factor analysis in Pool Market

TABLE II. SENSITIVITY FACTORS FOR HYBRID MARKET MODEL

Bus Number	Base case	Congestion case	Sensitivity factor
1	25.374	25.477	0.87483
2	25.371	25.477	0.87472
3	25.895	25.973	0.95627
4	26.24	26.354	1
5	26.031	26.151	0.98537
6	26.212	26.36	1
7	20.15	20.137	0
8	25.936	26.317	1
9	25.848	25.963	0.95453
10	25.892	26.023	0.96437
11	25.801	25.94	0.95079
12	25.754	25.871	0.93951
13	25.249	25.356	0.85487
14	25.677	25.842	0.93471
15	25.039	25.015	0.79885
16	25.077	25.265	0.83987
17	24.603	23.825	0.60352
18	24.462	23.882	0.6129
19	25.295	25.417	0.86487
20	25.253	25.318	0.84873
21	24.384	23.979	0.62881
22	23.762	23.23	0.50582
23	25.141	25.177	0.82547
24	25.608	25.618	0.89787

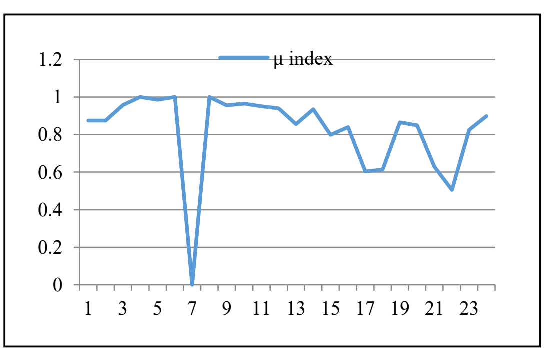

Figure 2. Sensitivity factor analysis in Hybrid Market

TABLE III. FACTS IMPLEMENTATION IN POOL MARKET MODEL

(p.u)	WOF	STATCOM	SSSC	UPFC	IPFC	GUPFC
Load curtailed	1.235	1.665	1.232	1.333	1.197	1.115
Total power generation	28.562	28.431	28.419	27.851	27.856	28.05
Real power losses	0.721	0.668	0.394	0.583	0.564	0.637

TABLE IV. POWER GENERATION FOR POOL MARKET WITH FACTS

Generat or buses	WOF	STATC OM	SSSC	UPFC	IPFC	GUPFC
Gen1	1.92	1.92	1.92	1.92	1.92	1.92
Gen 2	1.92	1.92	1.92	1.92	1.92	1.92
Gen 7	0.335	0.679	1.851	0.609	0.657	0.366
Gen 13	4.734	4.420	3.003	4.661	4.801	5.353
Gen 15	2.15	2.15	2.15	2.15	2.15	2.15
Gen 16	1.55	1.55	1.55	1.55	1.55	1.55
Gen 18	3.521	3.517	3.468	3.549	3.349	3.472
Gen 21	4	4	4	4	4	4
Gen 22	3	3	3	3	3	3
Gen 23	4.330	4.373	4.555	4.491	4.508	4.299

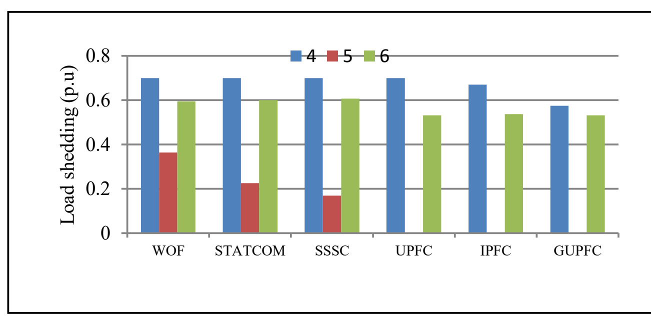

Figure 3. Optimization of load with and without FACTS

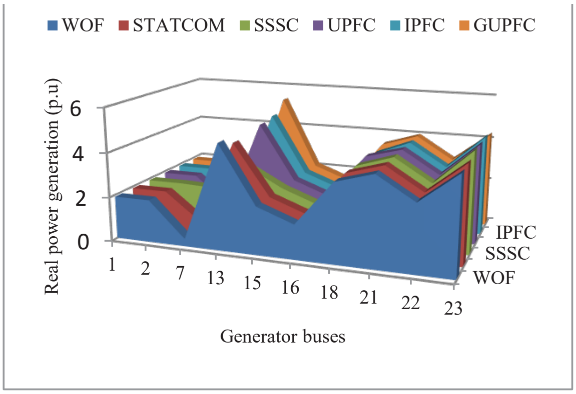

Figure 4. Power generation with FACTS in pool market

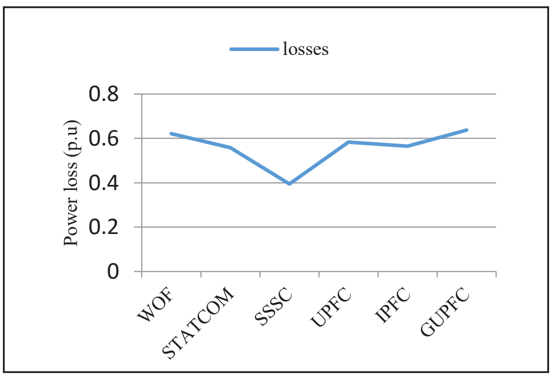

Figure 5. Real power loss with FACTS devices for pool market

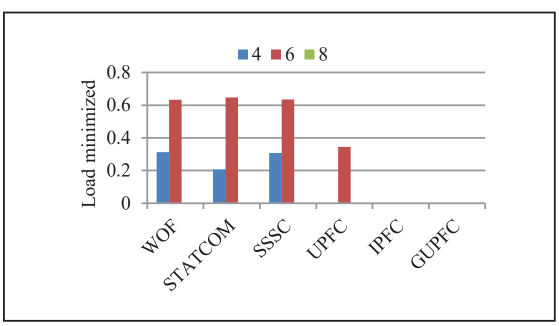

Figure 6. Load minimization with and without FCATS device

TABLE V. FACTS IMPLEMENTATION IN HYBRID MARKET MODEL

(p.u) Values	**WOF**	**STATCOM**	**SSSC**	**UPFC**	**IPFC**	**GUPFC**
Load minimized	0.947	0.853	0.941	0.345	0	0
Total power generation	28.187	28.282	28.192	28.730	28.837	28.930
Real power losses	0.635	0.636	0.6340	0.658	0.3371	0.431

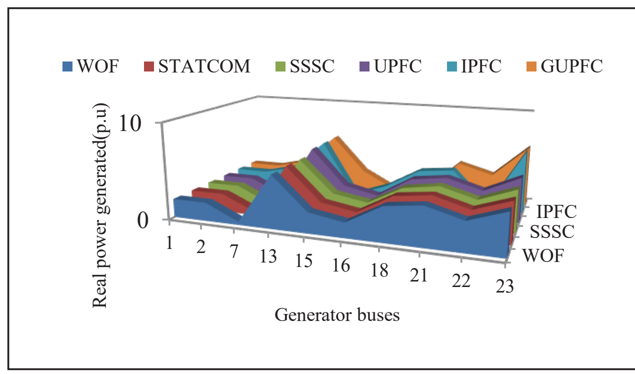

Figure 7. Power generation with FACTS in hybrid market

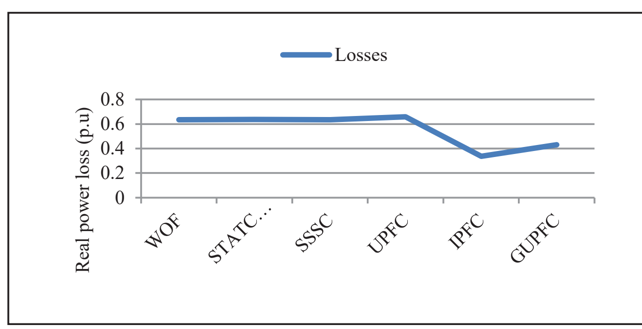

Figure 8. Real power loss with FACTS devices for hybrid market

Table VI. POWER GENERATION IN HYBRID MARKET WITH FACTS

Generator buses	WOF	STATCOM	SSSC	UPFC	IPFC	GUPFC
Gen 1	1.92	1.92	1.92	1.92	1.92	1.92
Gen 2	1.92	1.92	1.92	1.92	1.92	1.92
Gen 7	0.332	0.367	0.329	0.24	2.7499	2.735
Gen13	5.488	5.539	5.459	5.91	5.91	5.91
Gen15	2.15	2.15	2.15	2.15	0.24	2.15
Gen16	1.55	1.55	1.55	1.376	1.55	0.273
Gen18	3.556	3.564	3.468	3.520	3.604	0.68
Gen21	4	4	4	4	4	4
Gen22	3	3	3	3	0.3425	3
Gen23	4.270	4.270	4.394	4.693	6.6	6.341

V. CONCLUSION

In this paper, sensitivity index with economic load dispatch based approach has been presented and implemented for IEEE 24 RTS using nodal price based sensitivity index. On the basis of the results obtained it is evident that selection of loads based on their response to the nodal prices at the respective buses rather than considering only bids from all loads for load dispatch by the independent system operator. The impact of the various FACTS devices namely STATCOM, SSSC, UPFC, IPFC, GUPFC also have been studied and incorporated to see their impact on the optimal load and power flow optimization. The placement and performance of FACTS devices is tested for pool and hybrid electricity market model to make more versatile use in the electricity market. The FACTS devices play a key role in power flow control and thereby reducing the amount of load curtailment in the system. Nodal prices in future markets can play an important role for demand side management as well for better planning and control of the integrated systems.

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