Power Generation Balancing in Constrained Deregulated Power Systems using LBF

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Abstract **- Power systems are currently being transformed to become deregulated and generating stations are enhanced with fuel sources other than coal such as hydro. When such fuel sources are introduced, the quantity of the power generated is maintained as constant irrespective of demand. In this paper we consider the power loss as generators are not following the optimum operating regulations of the system. If the load on the bus is not maintained the electrical potential magnitude increases. We present the operation of a power system in deregulated condition with and without load bus to keep the electrical potential magnitude constant by the constrained power flow. By using Loss Balancing Factor, LBF, electrical power loss is assigned to the generators. After assigning the electrical power loss to the generators, it is observed that the burden on the generators and hence the loss also decreased in the constrained deregulated power system. The proposed analysis is tested on IEEE-14 bus system and analytical observations are presented. The system is run for 24 hours and the results are analyzed.**

Keywords - Constrained load flow; generator power balancing, deregulated power system.

I. INTRODUCTION

In deregulated power systems, the different types of generating sources are connecting in the system. These sources may be single phase or three phase. Such sources may disturb the system performance [2-13].

As all sources in the deregulated environment are competent to each other, there is rush at the transmission system. This condition generally called as 'congestion' [14].

In general, the fundamental aim of the electrical power system is to balance the electrical power equation such that power generation is equal to the power consumed by the consumer and loss of the system [1]. But in deregulated power systems, sometime this equation is violated. When it is violated, how power flow in the system considered in this system.

A. The Voltage Delta Bus

There are two meanings of voltage delta bus in regular power flow analysis. The first one is phase mark bus and another one is the bus which makes the power generations by the same price coefficients generators unequal. Even though the problem is there with such bus in the calculations of power flow, but it is required to consider solving the power flow problem by Newton Raphson procedure. When it is not choosing, the Jacobian matrix is not fair to allocate the power flow to the bus system of the power system. Such bus generally called as 'slack bus'.

B. Constrained Load Flow

In regular power flow, as the voltage magnitude at loads are not maintained constant. In order to maintain the quality of power flow and fair allocation of losses and hence generations, the power system has to be restructured. In restructured power system, to maintain the voltage magnitude as constant at all load buses, the capacitive devices are connected. Such power flow is named as 'constrained load flow'.

II. FORMULATION OF GENERATION BALANCING PROCEDURE

The major objective of this paper is to distribute the loss to generators under constrained deregulated environment, which are generating the power by following the rules and regulations of the electrical power system and hence the cost. Here the generating function of the generator is considered as cubic function and solved for loss balancing factor as follows:

$$F_j = a_j P_j^3 + b_j P_j^2 + c_j P_j + d_j \tag{1}$$

where F_j is the fuel cost of generator j, P_j is the power generated by j^{th} generator and a_j,b_j,c_j and d_j are cost coefficients of j^{th} generator

Incremental fuel cost of the generator is given by:

$$\frac{dF_j}{dP_j} = 3a_j P_j^2 + 2b_j P_j + c_j \tag{2}$$

But we know that:

$$\frac{dF_j}{dP_j} = \lambda \tag{3}$$

Hence from equations (2) and (3):

$$3a_j P_j^{\,2} + 2b_j P_j + c_j = \lambda$$

$$\text{or, } 3a_j P_{Gj}^{\,2} + 2b_j P_{Gj} + c_j - \lambda = 0 \tag{4}$$

The roots of equation (4) given by:

$$, P_j = \frac{-2b_j \pm \sqrt{(2b_j)^2 - 4(3a_j)(c_j - \lambda)}}{2(3a_j)} \tag{5}$$

For positive and real value of P_i equation (5) is considered as:

$$P_j = \frac{-b_j}{3a_j} + \frac{b_j}{3a_j}\left(1 - \frac{1}{2}\frac{(c_j - \lambda)}{(b_j)^2}(3a_j)\right)^{\frac{1}{2}}$$

$$\text{or} \qquad P_j = \frac{\lambda - c_j}{2b_j}$$

where P_{Gj} is the power to be generated by the generator, which is connected to the j[th] bus, hence:

$$P_{jnew} = \frac{\lambda - c_j}{2b_j} \tag{6}$$

We know that:

$$P_j = \frac{-b_j}{3a_j} + \frac{\sqrt{\left(b_j^{\,2} - 3a_j(c_j - \lambda)\right)}}{3a_j}$$

Then,

$$\sum_{i=1}^{N} P_i = \sum_{i=1}^{N}\frac{-b_i}{3a_i} + \frac{\left(\sum_{i=1}^{N} b_j\left(1 - \frac{3a_i(c_i - \lambda)}{b_i^{\,2}}\right)^{\frac{1}{2}}\right)}{\sum_{i=1}^{N} 3a_i} \tag{7}$$

Then,

$$\lambda = \frac{\dfrac{\sum_{i=1}^{N} P_i + \sum_{i=1}^{N}\frac{b_i}{3a_i}}{\sum_{i=1}^{N}\frac{1}{3a_i}} - \sum_{i=1}^{N} b_i + \sum_{i=1}^{N}\frac{3a_i(c_i)}{2b_i}}{\sum_{i=1}^{N} 3a_i} \tag{8}$$

We know that, $\sum_{i=1}^{N} P_i = P_D + P_L$, Where P_L is the power Loss:

$$P_{jnew} = \frac{\sum_{i=1}^{N}\frac{b_i}{3a_i} + P_D + P_L}{2b_j\left(\sum_{i=1}^{N} 3a_i\right)\left(\sum_{i=1}^{N}\frac{1}{3a_i}\right)} - \frac{\sum_{i=1}^{N} b_i}{2b_j\sum_{i=1}^{N} 3a_i} + \frac{\sum_{i=1}^{N}\frac{3a_i c_i}{2b_i}}{2b_j\sum_{i=1}^{N} 3a_i} - \frac{c_i}{2b_j}$$

where P_D is the power scheduled at generator 'j' that is: P_{Gjsch}

$$P_D = P_{jsch}$$

$$P_{jnew} = \frac{P_{jsch}}{2b_j\left(\sum_{i=1}^{N} 3a_i\right)\left(\sum_{i=1}^{N}\frac{1}{3a_i}\right)} + \frac{P_L}{2b_j\left(\sum_{i=1}^{N} 3a_i\right)\left(\sum_{i=1}^{N}\frac{1}{3a_i}\right)} + \frac{\sum_{i=1}^{N}\frac{b_i}{3a_i}}{2b_j\left(\sum_{i=1}^{N} 3a_i\right)\left(\sum_{i=1}^{N}\frac{1}{3a_i}\right)} - \frac{\sum_{i=1}^{N} b_i}{2b_j\sum_{i=1}^{N} 3a_i} + \frac{\sum_{i=1}^{N}\frac{3a_i c_i}{2b_i}}{2b_j\sum_{i=1}^{N} 3a_i} - \frac{c_j}{2b_j} \tag{9}$$

A. Loss Balancing Factor

From equation (9) loss balancing factor of j[th] generator is given by [15]

$$LBF_j = \frac{1}{2b_j\left(\sum_{i=1}^{N} 3a_i\right)\left(\sum_{i=1}^{N}\frac{1}{3a_i}\right)} \tag{10}$$

III. IMPLIMENTATION METHODOLOGY

Step1. The power generated by the generators is fixed constant and changed for every four hours.

Step2. Economic load dispatch issue is solved without loss and power flow problem is solved by using NR method and power at each bus is determined hence the loss

Step3. Find loss balancing factor for each generator by using equation (10)

Step4. Update the generation of the generator i.e.:

$P_{new} = P_{schedule} + P_{loss} * LBF$

Step5. Run the load flow with the above generations

Step6. Repeat the above for 24 hours

IV. RESULTS AND ANALYSIS

When the above theory is tested on IEEE-14 bus system, the results and analysis of results are as follows. Figure 1 gives the IEEE- 14 bus system []. It is observed that 1,2,3,6,8 buses are generator buses. Hence the power generated by those stations are considered as Pg1, Pg2, Pg3, Pg6 and Pg8. Figure 2 describes the load profile for 24 hours of IEEE-14 bus system, which is real time load taken from internet.

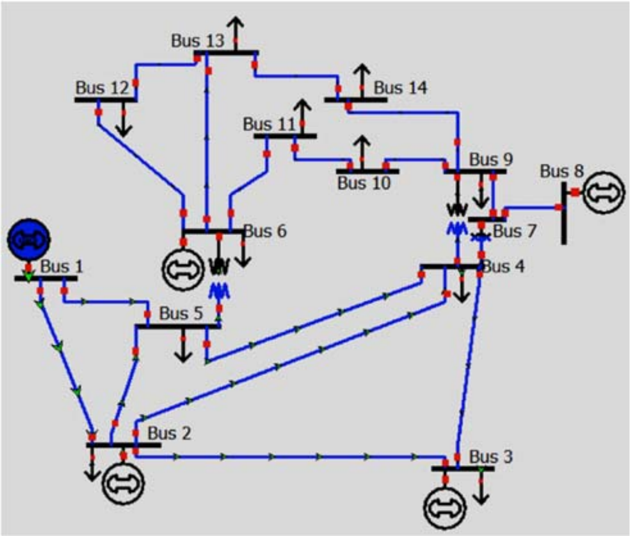

Figure 1. IEEE-14 bus system.

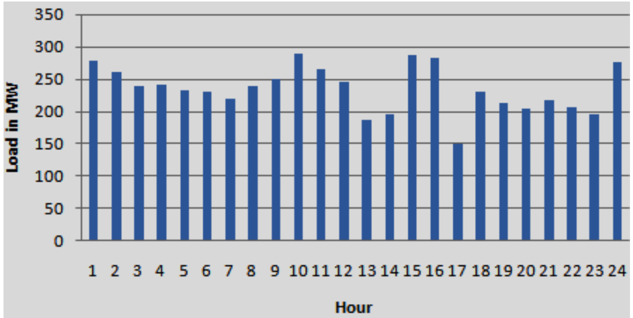

Figure 2. Load profile of IEEE 14 bus system for 24 hours.

Table I gives the results of load flow solution with losses for deregulation case. From this we observed that, the generators 2, 3 and 6 are generating the power without regulations. Hence the burden is more on generator 1 and 8. As the first bus is voltage magnitude bus, hence the total power loss is allocated to the first bus. The negative power generation is meant that, the generator not generating power but utilizing electrical power.

TABLE I. POWER GENERATION OF THE GENERATORS OVER THE 24 HOURS

Hour	Power generation by the generators in MW					Total Generation in MW
	Pg1	Pg2	Pg3	Pg6	Pg8	
1	64.30561	60	60	60	49.00325	293.3089
2	53.31134	60	60	60	40.25225	273.5636
3	39.23269	60	60	60	28.9045	248.1372
4	41.52791	60	60	60	30.7055	252.2334
5	28.60696	65	65	65	18.2004	241.8074
6	27.45651	65	65	65	17.2005	239.657
7	21.67097	65	65	65	11.7506	228.4216
8	31.63445	65	65	65	21.4012	248.0356
9	30.20584	70	70	70	19.3008	259.5066
10	53.06407	70	70	70	38.8518	301.9159
11	35.05247	70	70	70	27.30215	272.3546
12	24.96866	70	70	70	17.95235	252.921
13	-4.06902	75	75	75	-19.0485	201.8825
14	-7.03118	75	75	75	-15.0977	202.8711
15	42.75529	75	75	75	30.5027	298.258
16	36.60518	75	75	75	28.40405	290.0092
17	-26.4708	72	72	72	-33.2455	156.2837
18	26.20113	72	72	72	7.0789	249.28
19	8.382293	72	72	72	-2.4414	221.9409
20	0.870086	72	72	72	-5.792	211.0781
21	23.14168	62	62	62	15.8271	224.9688
22	13.66458	62	62	62	9.4519	209.1165
23	13.35861	62	62	62	4.6506	204.0092
24	56.6354	62	62	62	44.3006	286.936
Total generation over the day (MW)	**635.0808**	**1616**	**1616**	**1616**	**385.416**	**5868.497**

Figure 3, 4 indicates the variation of generations of generator 1 and 8 with respective to the hour of day. Generator 1 takes the power during 13th, 14th and 17th hour while Generator 8 takes electrical power during

13th, 14th, 17th, 19th and 20th hours of the day.This is only because of deregulation of power system. Figure 5, 6 and 7 indicates the variation of power during the day of generator 2,3 and 6 respectively, which are generating irrespective of the load.

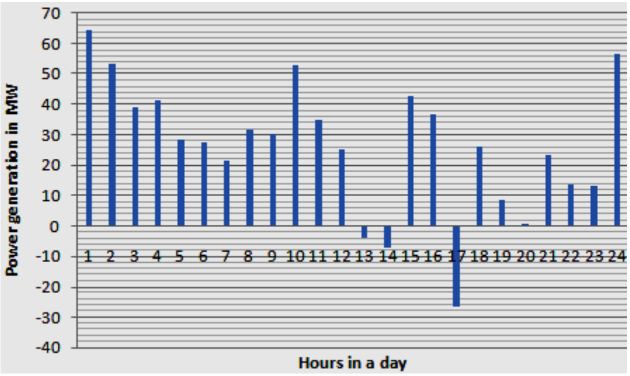

Figure 3:The variation of power generated by the generator 1 under deregulated condition over the day.

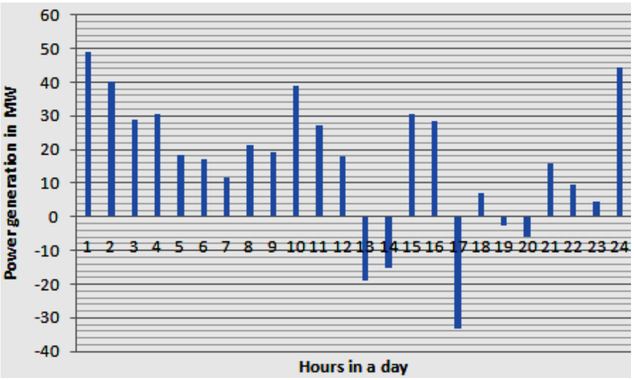

Figure 4:The variation of power generated by the generator 8 under deregulated condition over the day.

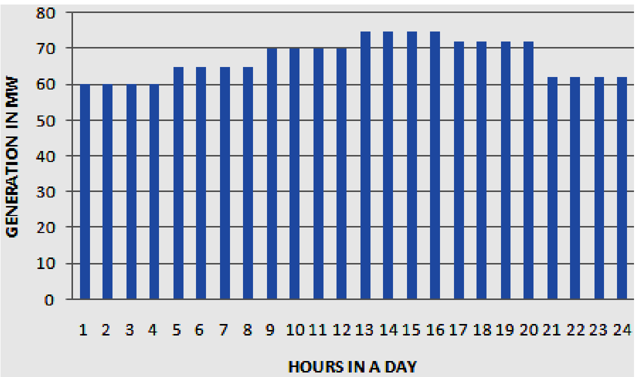

Figure 5:The variation of power generated by generator 2 under normal condition and constrained condition.

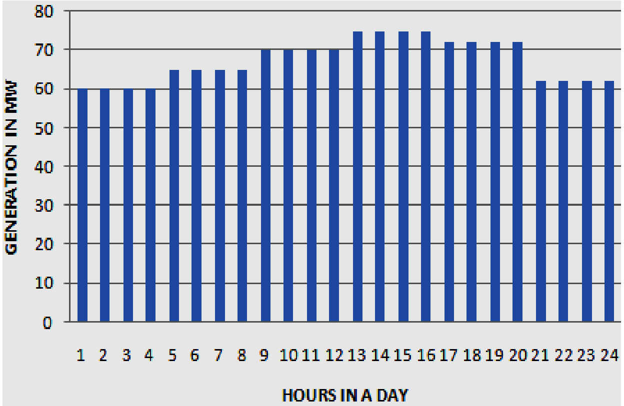

Figure 6:The variation of power generated by generator 3 under normal condition and constrained condition.

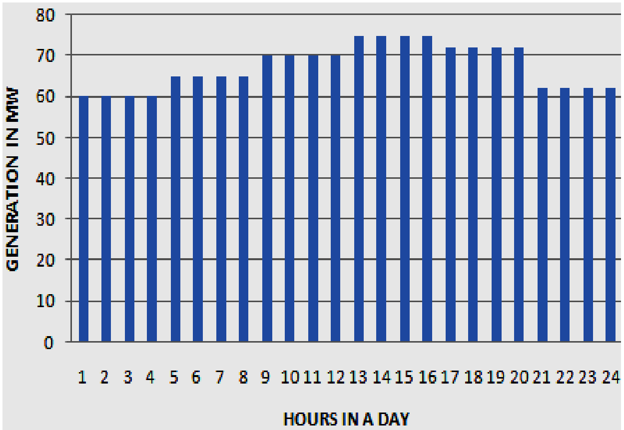

Figure 7:The variation of power generated by generator 6 under normal condition and constrained condition.

Table II indicates the list of loss balancing factors which are calculated from equation (10).

Table II: Loss balancing factors

S.No.	Generator	Loss balancing factor
1	Pg1	0.1977
2	Pg8	0.276

Table III, next page, indicates the loss of the system over the day. During the 19th hour, the loss of the system is maximum and is minimum during 22nd hour of the day.

Table III. The loss generated by the IEEE-14 bus system for 24 hours of the day under deregulated power flow case.

Hour	LOSS in MW
1	15.30236
2	13.05909
3	10.32819
4	10.82241
5	10.40656
6	10.25601
7	9.920369
8	10.23325
9	10.90504
10	14.21227
11	7.750323
12	7.016308
13	14.97948
14	8.066519
15	12.25259
16	8.201131
17	6.774745
18	19.12223
19	10.82369
20	6.662086
21	7.314581
22	4.212679
23	8.708007
24	12.3348
Total loss over the day in MW	**249.6647**

Figure 8 indicates the variation of the loss over the day.

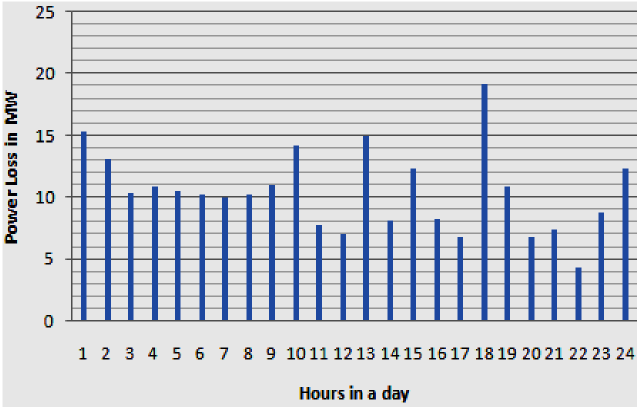

Figure 8: The variation of power loss under deregulated condition for a day.

Table 4 describes the result IEEE-14 bus system, after balancing the load with loss balancing factor for 24 hours. The observation from this table is the burden on voltage magnitude and phase angle bus is shared by generator 1 and generator 8. Figure 9and Figure 10 describes the variation of generations of generator 1 and generator 8. Both generators take the power from the system during 13th, 14th, 17th and 20th hours. Table 6 is the result of variation loss of the system over the day. The loss generated by the system is minimum during 22nd hour and maximum during 18th hour.

TABLE IV: POWER GENERATIONS BY THE GENERATORS AFTER BALANCING THE LOSSES OVER THE DAY

Hour	Pg1 in MW	Pg2 in MW	Pg3 in MW	Pg6 in MW	Pg8 in MW	TotGen in MW
1	54.77151	60	60	60	57.91994	292.6915
2	45.21087	60	60	60	47.86178	273.0727
3	32.88218	60	60	60	34.92274	247.8049
4	34.86132	60	60	60	37.01172	251.873
5	22.20061	65	65	65	24.2643	241.4649
6	21.14533	65	65	65	23.17668	239.322
7	15.57146	65	65	65	17.5312	228.1027
8	25.33986	65	65	65	27.36411	247.704
9	23.48019	70	70	70	25.65517	259.1354
10	44.22102	70	70	70	47.13329	301.3543
11	30.30907	70	70	70	31.81826	272.1273
12	20.68667	70	70	70	22.04075	252.7274
13	-13.3234	75	75	75	-10.32	201.3566
14	-11.9249	75	75	75	-10.3973	202.6778
15	35.19834	75	75	75	37.64228	297.8406
16	31.58924	75	75	75	33.18285	289.7721
17	-30.6011	72	72	72	-29.2979	156.101
18	14.28688	72	72	72	18.22142	248.5083
19	1.806821	72	72	72	3.865566	221.6724
20	-3.1773	72	72	72	-1.91	210.9127
21	18.78801	62	62	62	20.08931	224.8773
22	11.11628	62	62	62	11.90663	209.0229
23	8.036273	62	62	62	9.724756	203.761
24	49.05699	62	62	62	51.48809	286.5451
Total generation over the day (MW)	**481.5323**	**1616**	**1616**	**1616**	**530.8956**	**5860.428**

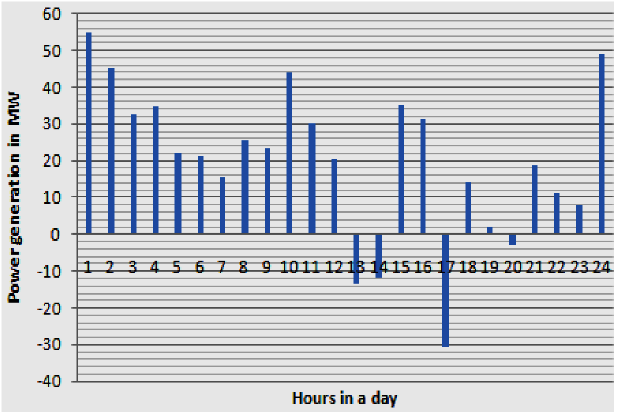

Figure 9:The variation of power generated by the generator 1 under deregulated condition with LBF over the day

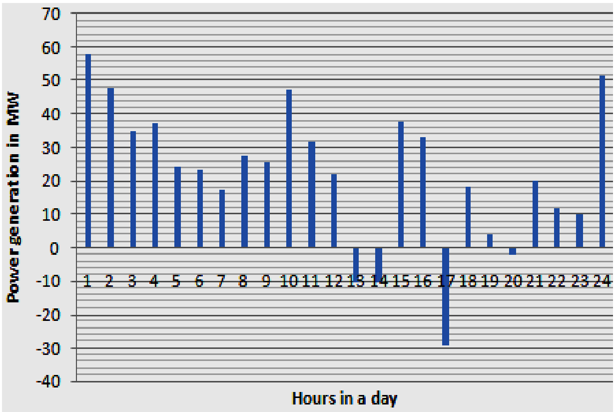

Figure 10: The variation of power generated by the generator 8 under deregulated condition with LBF over the day.

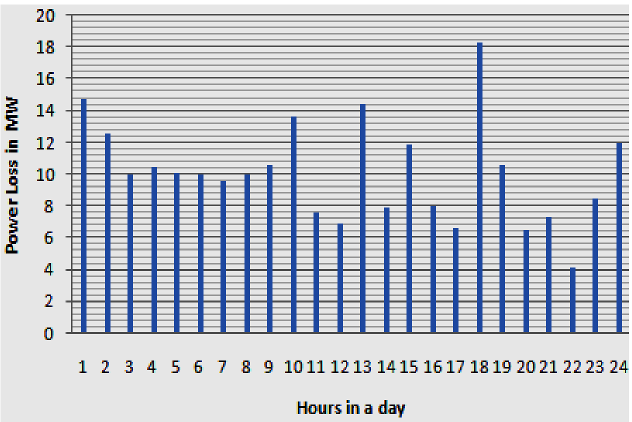

Figure 11:The variation of power loss under deregulated constrained power flow condition for a day

TABLE VI: LOSS GENERATED BY THE SYSTEM AFTER BALANCING THE LOSS UNDER DEREGULATED POWER FLOW CONDITION

HOUR	LOSS in MW
1	14.68495
2	12.56815
3	9.995915
4	10.46204
5	10.06411
6	9.921012
7	9.601456
8	9.901573
9	10.53376
10	13.65071
11	7.523032
12	6.82272
13	14.45364
14	7.873219
15	11.83522
16	7.963994
17	6.592018
18	18.3505
19	10.55519
20	6.496702
21	7.223119
22	4.119108
23	8.459829
24	11.94388
Total loss over the day in MW	**241.5959**

Table VII, next page, gives the results of load flow solution with losses for deregulated constrained power flow case. From this we observed that, the generators 2, 3 and 6 are generating the power without regulations. Hence the burden is more on generator 1 and 8. As the first bus is voltage magnitude bus, hence the total power loss is allocated to the first bus. The negative power generation is meant that, the generator is taking the power from the system.

TABLE VII. POWER GENERATION OF THE GENERATORS OVER THE 24 HOURS UNDER CONSTRAINED POWER FLOW

Hour	Power generation by the generators in MW					Total Generation in MW
	Pg1	Pg2	Pg3	Pg6	Pg8	
1	62.53523	60	60	60	49.00325	291.5385
2	51.97587	60	60	60	40.25225	272.2281
3	38.33756	60	60	60	28.9045	247.2421
4	40.56669	60	60	60	30.7055	251.2722
5	27.82269	65	65	65	18.2004	241.0231
6	26.69653	65	65	65	17.2005	238.897
7	21.01603	65	65	65	11.7506	227.7666
8	30.77289	65	65	65	21.4012	247.1741
9	29.28361	70	70	70	19.3008	258.5844
10	51.56408	70	70	70	38.8518	300.4159
11	34.48641	70	70	70	27.30215	271.7886
12	24.55842	70	70	70	17.95235	252.5108
13	-5.21832	75	75	75	-19.0485	200.7332
14	-7.31283	75	75	75	-15.0977	202.5895
15	41.71087	75	75	75	30.5027	297.2136
16	36.0551	75	75	75	28.40405	289.4591
17	-26.6648	72	72	72	-33.2455	156.0897
18	24.1612	72	72	72	7.0789	247.2401
19	7.799574	72	72	72	-2.4414	221.3582
20	0.652935	72	72	72	-5.792	210.8609
21	22.82944	62	62	62	15.8271	224.6565
22	13.47311	62	62	62	9.4519	208.925
23	12.98606	62	62	62	4.6506	203.6367
24	55.47857	62	62	62	44.3006	285.7792
Total generation over the day (MW)	**615.5669**	**1616**	**1616**	**1616**	**385.416**	**5848.983**

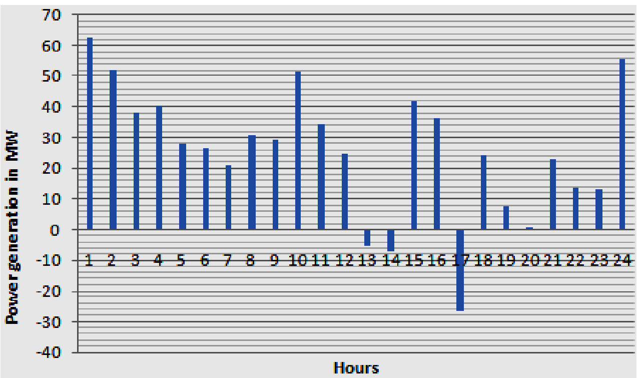

Figure 12. The variation of power generated by the generator 1 under deregulated constrained power flow condition over the day

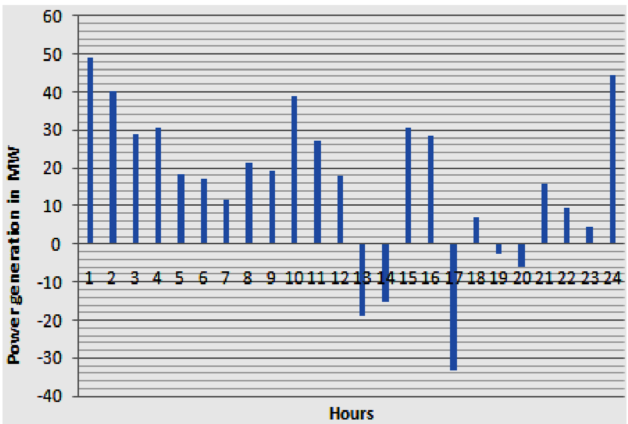

Figure 13. The variation of power generated by the generator 8 under deregulated constrained power flow condition over the day

Table VIII, next page, indicates the loss of the system over the day under deregulated constrained power flow condition. During the 18th hour, the loss of the system is maximum and is minimum during 22nd hour of the day.

TABLE VIII. TOTAL LOSS

Hour	LOSS in MW
1	13.53198
2	11.72362
3	9.433061
4	9.861185
5	9.622291
6	9.496034
7	9.265426
8	9.371687
9	9.982806
10	12.71228
11	7.184261
12	6.606067
13	13.83018
14	7.78487
15	11.20817
16	7.65105
17	6.580674
18	17.0823
19	10.24097
20	6.444935
21	7.002344
22	4.02121
23	8.335462
24	11.17797
Total loss over the day in MW	**230.1508**

Figure 14 indicates the variation of the loss over the day.

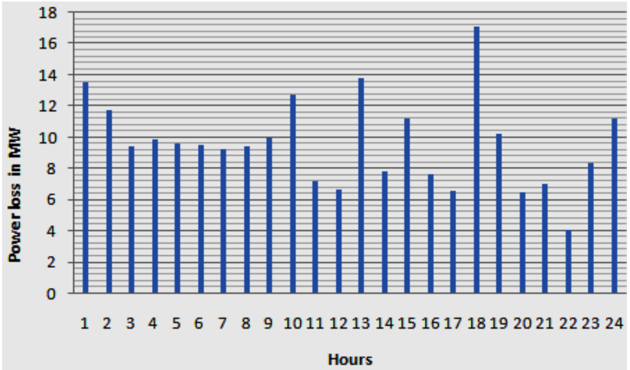

Figure 14: The variation of power loss under deregulated constrained power flow condition for a day after balancing the power loss with LBF

Table IX describes the result IEEE-14 bus system, after balancing the load with loss balancing factor for 24 hours under deregulated constrained power flow condition. It is observed that, the loss of the system is shared by generator 1 and generator 8. Figures 15 and 16, next page, describe the variation of generations of generator 1 and generator 8 during the day under deregulated constrained power flow condition. Both generators take the power from the system during 13th, 14th, 17th and 20th hours. Table X, next page, is the result of variation loss of the system over the day. The loss generated by the system is minimum during 22nd hour and maximum during 18th hour.

TABLE IX. POWER GENERATIONS BY THE GENERATORS AFTER BALANCING THE LOSSES OVER THE DAY UNDER CONSTRAINED DEREGULATED POWER FLOW CONDITION

Hour	Pg1 in MW	Pg2 in MW	Pg3 in MW	Pg6 in MW	Pg8 in MW	TotGen in MW
1	54.13173	60	60	60	56.88834	291.0201
2	44.72932	60	60	60	47.0836	271.8129
3	32.55565	60	60	60	34.40114	246.9568
4	34.51185	60	60	60	36.45161	250.9635
5	21.93763	65	65	65	23.80731	240.7449
6	20.89064	65	65	65	22.73384	238.6245
7	15.35534	65	65	65	17.14956	227.5049
8	25.03014	65	65	65	26.86208	246.8922
9	23.15336	70	70	70	25.11778	258.2711
10	43.68862	70	70	70	46.25924	299.9479
11	30.10062	70	70	70	31.48842	271.589
12	20.55813	70	70	70	21.8017	252.3598
13	-13.6321	75	75	75	-10.9897	200.3782
14	-12.0095	75	75	75	-10.5615	202.429
15	34.8211	75	75	75	37.0337	296.8548
16	31.38602	75	75	75	32.86232	289.2483
17	-30.6603	72	72	72	-29.4109	155.9288
18	13.6147	72	72	72	17.03276	246.6475
19	1.623173	72	72	72	3.526016	221.1492
20	-3.24858	72	72	72	-2.03654	210.7149
21	18.66683	62	62	62	19.90737	224.5742
22	11.04344	62	62	62	11.79506	208.8385
23	7.913365	62	62	62	9.507674	203.421
24	48.62208	62	62	62	50.814	285.4361
Total generation over the day (MW)	**474.7833**	**1616**	**1616**	**1616**	**519.5249**	**5842.308**

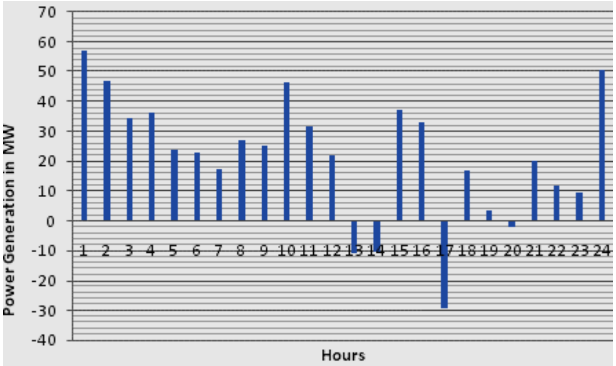

Figure 15. The variation of power generated by the generator 1 under deregulated constrained power flow condition with LBF over the day

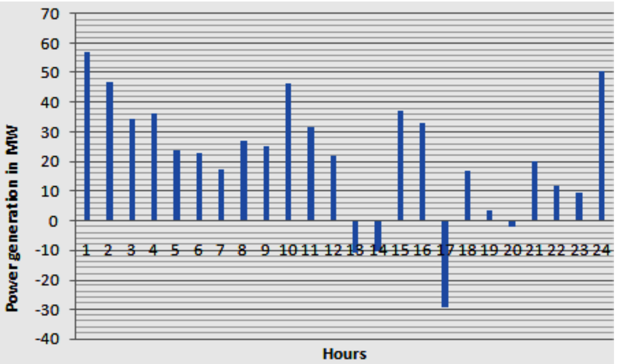

Figure 16. The variation of power generated by the generator 8 under deregulated constrained power flow condition with LBF over the day

TABLE X. LOSS GENERATED BY THE SYSTEM AFTER BALANCING THE LOSS UNDER DEREGULATED CONSTRAINED POWER FLOW CONDITION

Hour	Loss in MW
1	13.01357
2	11.30842
3	9.147785
4	9.552458
5	9.344139
6	9.223477
7	9.003699
8	9.089823
9	9.669544
10	12.24426
11	6.984739
12	6.455133
13	13.47521
14	7.624354
15	10.8494
16	7.440242
17	6.41983
18	16.48966
19	10.03199
20	6.298884
21	6.919996
22	3.934703
23	8.119839
24	10.83488
Total loss over the day in MW	**223.476**

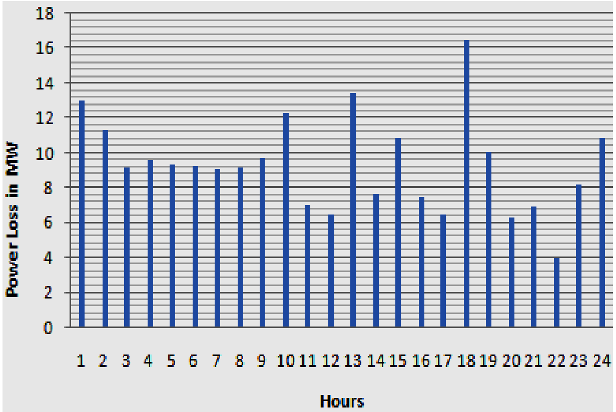

Figure 17: The variation of power loss deregulated constrained power flow condition for a day

From the results the following observations are made as followsThe generation burden on the system is decreased.

a. The total loss of the system is decreased by **241.5959-223.476=18.1199MW.**
b. The burden on each generator also decreased as follows
i. At generator1 the burden is decreased by **481.5323-474.7833=6.749 MW**
ii. At generator 8 the burden is decreased by **530.8956-519.5249=11.3707 MW**

V. CONCLUSIONS

In this paper, the power system is considered as restructured deregulated power system. The meaning of deregulated power system for this case is generation of electrical power irrespective of load conditions. When such system maintains the voltage magnitudes at their load bus then it is considered as restructured deregulated power system. Such system is considered as constrained system in this paper. When regular power system is constrained, then the analysis of constrained load flow is done by a comparison with the regular power flow. In our proposed method, the system benefits from a reduction of burden on generators at mainly the same price coefficients for the same amount of power. When constrained power system is compared with regular power system, the total loss in the system is decreased.

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