Congestion Management in Deregulated Power System using Price based Programs

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***Abstract*--In deregulated market environment, congestion management plays an important role in power system operation. An approach of applying Demand Response (DR) programs has been used for transmission line congestion management in a deregulated power system. In this paper DR is modelled considering Time of Use (TOU), Critical Peak Pricing (CPP) using MATPOWER software. The paper evaluates DR effects on the generating companies, consumers, merchandising surplus, power system security and operating cost in addition to the congestion management. The proposed models are implemented on IEEE-14 bus system.**

Keywords - Congestion Management, Merchandising Surplus; Demand Response, TOU, CPP, MATPOWER.

I. INTRODUCTION

The electric supply industry has been changed from vertically integrated to restructured power system. The electricity cannot be stored in bulk easily and the transportation of electricity is constrained by physical laws which have to be satisfied to maintain the reliability and security of the power system. In restructured market environment, every buyer wants to buy power from the low cost generator available. The transmission system has a limited capability to transfer power which may overload certain transmission lines. Congestion referred to as a transmission line hitting its maximum limit.

Transmission congestion occurs when the transmission capacity is insufficient to accommodate all the transactions. Congestion may occur due to the lack of coordination between generation and transmission companies in present scenario. In peak periods, the system operates near its transmission capacity limit with a reduced security margin [1]. It may not be possible to meet the demand always and to deliver all bilateral and multilateral contracts due to violation of operating constraints such as voltage and line power flow. In Maintaining the Integrity of the Specifications such cases there may be a chance of occurrence of congestion. In order to relieve that congestion, in many cases cost-free means such as network reconfiguration, operation of transformer taps and operation of flexible alternating current transmission system (FACTS) devices are used [2]. In some cases it may be advantageous to relieve congestion by some non-cost-free control methods, such as re-dispatch of generation and curtailment of loads [3-5]. Since there is a large scope of events which can lead to transmission system congestion, it is very important to manage and respond to operating conditions in which system voltages and/or power flow limits are violated[6].A congestion management method proposed in this project is based on the application of Demand Response programs [7]. In this paper programs used are TOU, CPP on IEEE-14 bus system.

II. DEMAND RESPONSE

DR is defined by Department of Energy (DOE) as:"Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized". DR is classified into two basic categories and several subgroups [8]:

1. Incentive-based programs:
   - Direct Load Control (DLC)
   - Interruptible/curtailable service (I/C)
   - Demand Bidding/Buy Back
   - Emergency Demand Response Program
   - Capacity Market Program (CAP)
   - Ancillary Service Markets (A/S)
2. Time-based programs:
   - Time-of-Use (TOU) program
   - Real Time Pricing (RTP) program
   - Critical Peak Pricing (CPP) Program

As mentioned above, in time based programs i.e. Time of Use (TOU), Real Time Pricing (RTP), and Critical Peak Pricing programs, the electricity price changes with respect to the electricity supply cost. TOU rates establish three periods that reflect hours when the system load is higher (peak), moderate (off-peak), lower (valley), and charge a higher rate during peak hours. RTP rates vary continuously during the day reflecting the wholesale price of electricity.CPP uses real-time prices at times of extreme system peak.

The incentive based programs can be classified into three main subgroups namely; voluntary, mandatory and market clearing programs.DLC and EDRP are voluntary programs in which there are no penalties for not curtailing their consumption. DLC refers to a program in which system operator shuts down the customer’s electrical equipment on short notice by providing incentive payment or bill credit. EDRP facilitate with more incentive payments to customers for reducing their loads during reliability triggered events. I/C and CAP are mandatory programs and customers who participated in that programs are subjected to penalties if they do not curtail consumption when they are called upon to do so. Customers on I/C service rates receive a rate discount or bill credit in exchange for agreeing to reduce load during

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system contingencies. In CAP, customers agreed to provide prespecified load reductions during system contingencies, and are penalized if they do not reduce the load demand. DB and A/S are market clearing programs, where large customers are encouraged to offer load reductions at a price at which they are willing to be curtailed. A/S program allows customer to bid load curtailment in electricity market as operating reserve.

III. PROBLEM FORMULATION

The costs may be defined as polynomials or as piecewise linear functions of generator output. Generator cost functions are represented as quadratic functions

$$MS = \sum_i \lambda_i \cdot P_{Li} - \sum_i \lambda_i \cdot P_{Gi} = E_{total} - R_{total}$$

Where PG is the produced power a, b and c are cost coefficients. OPF can be formulated in the following form [9]:

$$\min \sum C_i(P_{Gi})$$

The generation dispatch is in such a way that the above function should be minimised.In Deregulated Power System, because of the congestion, the Locational Marginal Prices (LMP) (λi) are different at various buses.Hence, the money paid by the loads (E_{total}) is greater than the money paid to the generators (R_{total}) *i.e.* there will always be a Merchandising Surplus (MS*)* that the ISO collects.

$$MS = \sum_i \lambda_i \cdot P_{Li} - \sum_i \lambda_i \cdot P_{Gi} = E_{total} - R_{total}$$

Run the OPF after implementing the DR programs using the following methodology, then find the revenue of generators, loads payment and observe the LMPs at different buses. Thereafter find the MS. In order to manage the congestion MS should be low.

TOU: In TOU, the price is lower in valley period, medium in off peak period and high in peak period, so that the consumers reduce their power consumption in peak periods and shift to other periods. In order to meet the demand in peak periods, the expensive generators are used [10]. In low and off peak periods cheaper generators are sufficient to supply the load. Based on the MS value, the congestion is compared under different conditions. In order to implement this TOU in MATPOWER, need to follow some steps which are mentioned below.

Steps for Procedure:

1. According to the load curve, divide the load into valley, off peak and peak periods.
2. Observe the variation of prices in different periods which is low in valley, moderate in off peak and high in peak periods.
3. Now create congestion for that system. The prices will be different at various buses and also high.
4. In order to implement TOU in MATPOWER assume some dispatchable loads and set the marginal benefit for that loads.
5. If the price is above that marginal benefit, the load will be curtailed using price sensitive load concept.
6. Then there will be a congestion relief, which is represented by approximately equal and decrement of LMPs at all the buses.
7. Thereafter calculate the revenue of generators, loads payment, SR and MS.
8. Compare the above terms under normal, congested and after curtailment of load conditions.

CPP: In CPP, the price is very high in critical peak period, in which the duration of the period is less compared to TOU. Same as TOU, divide the load into two periods i.e. in critical peak period and normal period.CPP is a dynamic pricing where the prices are set before a day under critical contingencies. In MATPOWER due to operation of very expensive generators the price is very high in critical peak periods than the price in peak periods in TOU.

Steps for Procedure:

1. According to the load curve, the load is divided into normal and critical peak periods.
2. Observe the variation of prices in both periods which is low and very high respectively.
3. Now create congestion for that system. The prices will be different at various buses and also high.
4. In order to implement CPP assume some dispatchable loads and set the marginal benefit for that loads.
5. Then by using price sensitive load concept in MATPOWER, the load will be curtailed if the price is above the marginal benefit.
6. Now observe the congestion relief by equal LMPs and also decrement of LMPs at all the buses.
7. Thereafter calculate the revenue of generators, loads payment, SR and MS for all the conditions.
8. Compare the above terms under normal, congested and after curtailment of load conditions.

In the below pages results are projected which are implemented on an IEEE-14 bus systems. The tables are shown which are the OPF results where the LMPs can be observed and the bar graphs are represented the comparison between the different conditions for the two program.

Numericalstudies:

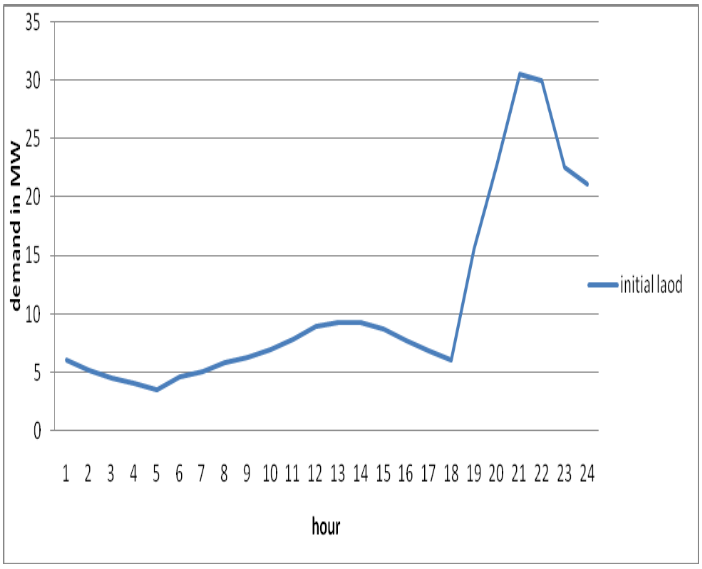

Fig.1. Daily load curve

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TOU: In an IEEE-14 bus system case, the network embraces two generator, three synchronous condenser and eleven load buses. There are five sources which can meet the load where the 1,2,3 are least expensive and 6,8 generators are more expensive. The generator cost data can be found in appendix.

According to TOU the price is low for off peak periods, very low for valley periods and high for peak periods. Assumed 1 to 8 hrs. as valley, 9 to 18hrs as off peak and 19 to 24hrs as peak period shown in fig1. Table 1, 2, 3 represents OPF results for valley, off peak and peak periods where we can observe that the prices are low under valley Period, moderate in off peak period and high in peak period. The cheaper generators are unable to meet the increased load demand in peak periods. So more expensive generators are used in the peak periods which are quick start to meet the load.

Table-1: OPF for IEEE-14 bus system during valley period

Bus	V (volts)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)	λ_P ($/MWh)
1	1.012	33.12	0.00	-	-	22.850
2	1.005	6.06	-19.51	3.25	1.90	23.031
3	1.003	0.00	0.01	14.13	2.85	23.292
4	1.008	-	-	7.17	-0.58	23.212
5	1.007	-	-	1.14	0.24	23.155
6	1.060	0.00	-6.00	1.68	1.13	23.154
7	1.046	-	-	-	-	23.209
8	1.035	0.00	-6.00	-	-	23.209
9	1.059	-	-	4.42	2.49	23.208
10	1.058	-	-	1.35	0.87	23.218
11	1.059	-	-	0.53	0.27	23.198
12	1.058	-	-	0.91	0.24	23.209
13	1.057	-	-	2.02	0.87	23.227
14	1.056	-	-	2.23	0.75	23.283

Table-2: OPF for IEEE-14 bus system during off peak period

Bus	V (volts)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)	λ_P ($/MWh)
1	1.029	66.62	0.00	-	-	25.733
2	1.020	12.27	-7.44	6.51	3.81	26.133
3	1.008	0.00	1.97	28.26	5.70	26.724
4	1.014	-	-	14.34	-1.17	26.539
5	1.013	-	-	2.28	0.48	26.409
6	1.060	0.00	-6.00	3.36	2.25	26.404
7	1.046	-	-	-	-	26.537
8	1.036	0.00	-6.00	-	-	26.537
9	1.058	-	-	8.85	4.98	26.536
10	1.056	-	-	2.70	1.74	26.558
11	1.057	-	-	1.05	0.54	26.508
12	1.056	-	-	1.83	0.48	26.530
13	1.054	-	-	4.05	1.74	26.572
14	1.051	-	-	4.47	1.50	26.708

Table-3: OPF for IEEE-14 bus system during peak period

Bus	V (volts)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)	λ_P ($/MWh)
1	1.054	80.00	1.16	-	-	57.778
2	1.046	30.00	6.07	11.94	6.99	58.664
3	1.038	50.00	8.84	51.81	10.45	59.384
4	1.027	-	-	26.29	-2.15	60.298
5	1.026	-	-	4.18	0.88	59.988
6	1.060	3.73	-6.00	6.16	4.13	60.075
7	1.054	-	-	-	-	60.258
8	1.047	0.00	-3.74	-	-	60.258
9	1.060	-	-	16.23	9.13	60.234
10	1.055	-	-	4.95	3.19	60.525
11	1.052	-	-	10.93	0.99	60.841
12	1.043	-	-	13.36	0.88	61.612
13	1.049	-	-	7.43	3.19	60.885
14	1.045	-	-	8.20	2.75	61.175

The results mentioned above are without any line limits. From the above tables we can observe that price is high in peak periods and very low in valley periods. For that system the limits are set in such a way of congestion is created in the line 6-13 by 1MW. Table4 represents the OPF results for congested system where the prices are different at all the buses and are high.

In order to remove this congestion, it is assumed that consumers at 9,10and 13 buses are participating in DR program whom marginal benefit is 40$.MWh. To tackle this high prices, the load at these buses are reduced to zero using matpower dispatchable load concept and the prices at all buses come to original and congestion is It removed which is shown in table-5.It is observed that the load curtailment of the elastic loads at the particular buses are with respect to the marginal benefit.

Table-4: OPF for IEEE-14 bus system during congestion

Bus	V (volts)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)	λ_P ($/MWh)
1	0.980	80.00	0.00	-	-	69.275
2	0.969	30.00	-8.53	11.94	6.99	70.698
3	0.964	50.00	4.95	51.81	10.45	72.235
4	0.963	-	-	26.29	-2.15	73.970
5	0.959	-	-	4.18	0.88	71.570
6	0.998	2.23	-6.00	6.16	4.13	60.045
7	1.020	-	-	-	-	80.043
8	1.060	1.89	24.00	-	-	80.038
9	1.015	-	-	16.23	9.13	83.205
10	1.006	-	-	4.95	3.19	79.753
11	0.996	-	-	10.93	0.99	70.911
12	0.982	-	-	13.36	0.88	104.510
13	0.989	-	-	7.43	3.19	148.300
14	0.993	-	-	8.20	2.75	112.536

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Table-5: OPF for IEEE-14 bus system after load curtailment

Bus	V (volts)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)	λ_P ($/MWh)
1	1.027	80.00	0.00	-	-	38.843
2	1.017	30.00	-3.99	11.94	6.99	39.515
3	1.004	25.08	5.56	51.81	10.45	40.503
4	1.008	-	-	26.29	-2.15	40.437
5	1.007	-	-	4.18	0.88	40.253
6	1.051	0.00	-6.00	6.16	4.13	40.472
7	1.046	-	-	-	-	40.305
8	1.035	0.00	-6.00	-	-	40.305
9	1.060	-	-	0.15*	0.09*	40.234
10	1.057	-	-	0.00*	0.00*	40.378
11	1.048	-	-	10.93	0.99	40.768
12	1.037	-	-	13.36	0.88	41.424
13	1.047	-	-	0.00*	0.00*	40.696
14	1.045	-	-	8.20	2.75	40.865

Table-6: Comparison of results in different conditions

System	Cost ($/hr)	Revenue of Generators ($/hr)	Loads Payment ($/hr)	SR (MW)	MS ($/hr)
A	7595.91	12506.75	12669.17	198.9	162.42
B	7656.8	14491.21	16091.22	198.4	1600
C	6352.63	8242.49	8357.78	235.9	115.29

The table-6 represents the comparison made between the normal, congested and curtailment of load conditions i.e. A,B,C respectively in which the MS value is very much high than the two conditions. In economical point of view also, the revenue of generators, loads payment are high compared to others.SR is represented as the security point of view which is high in the case of curtailment of load. From the above comparison it is observed that due to curtailment of load it is beneficial to the customers in terms of cost and also for the utility providers in view of congestion.

CPP: In CPP, at critical peak times the price is very high.The marginal benefit is assumed as 40$/MWh. The duration of the period of the critical peak period is very less i.e.20 to 23hrs. This program is used where the system is under critical conditions. In this case the load is increased, so in order to meet the load in that period the most expensive generators comes into the operation which leads to high prices. It dynamically varies according to the load.Table-7 represents the system under normal condition where the prices are normal.

Table-7: OPF for IEEE-14 bus system under normal condition

Bus	V (volts)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)	λ_P ($/MWh)
1	1.060	152.89	0.00	-	-	33.158
2	1.044	28.64	13.57	14.71	8.61	34.318
3	1.020	0.00	15.77	63.87	12.88	36.076
4	1.023	-	-	32.41	-2.64	35.531
5	1.024	-	-	5.15	1.08	35.146
6	1.060	0.00	-3.75	7.59	5.09	35.157
7	1.055	-	-	-	-	35.533
8	1.060	0.00	3.03	-	-	35.533
9	1.057	-	-	20.00	11.25	35.534
10	1.052	-	-	6.10	3.93	35.603
11	1.054	-	-	2.37	1.22	35.462
12	1.050	-	-	4.14	1.08	35.543
13	1.048	-	-	9.15	3.93	35.671
14	1.041	-	-	10.10	3.39	36.082

Table-8: OPF for IEEE-14 bus system during critical peak

Bus	V (volts)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)	λ_P ($/MWh)
1	1.027	27.11	-	-	-	59.522
2	1.023	21.36	-7.49	6.97	4.08	59.755
3	1.025	50.00	2.64	30.26	6.10	59.535
4	1.016	-	-	25.35	-1.25	60.801
5	1.014	-	-	2.44	0.51	60.591
6	1.060	25.56	-5.98	13.60	2.41	60.511
7	1.047	-	-	-	-	60.840
8	1.036	0.00	-6.00	-	-	60.840
9	1.057	-	-	9.47	5.33	60.860
10	1.054	-	-	2.89	1.86	61.072
11	1.052	-	-	11.12	0.58	61.354
12	1.047	-	-	11.96	0.51	61.835
13	1.053	-	-	4.33	1.86	61.093
14	1.050	-	-	4.78	1.61	61.346

Table-8 represents the system under critical peak condition where the load is increased at 4, 11, 12 buses. In order to meet that load there is more generation dispatch from the expensive source the price is high.Table-9 represents the system under congested condition and the congestion is created same as TOU where the prices are very high especially from the buses 7 to 14. Now to mitigate this congestion the load curtailment is used which is shown in table-10.At 9,10 and 13 buses the load is curtailed and the congestion is removed represented by equal and reduced prices at all buses. The curtailment of the load is based on the assumed marginal benefit and the price at that particular bus.

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Table-9: OPF for IEEE-14 bus system with congestion

Bus	V (volts)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)	λ_P ($/MWh)
1	0.970	27.11	-	-	-	71.109
2	0.964	21.36	-7.49	6.97	4.08	71.606
3	0.970	50.00	2.64	30.26	6.10	71.834
4	0.969	-	-	25.35	-1.25	73.957
5	0.965	-	-	2.44	0.51	71.820
6	1.017	21.02	-5.98	13.60	2.41	60.420
7	1.029	-	-	-	-	80.096
8	1.060	4.74	-6.00	-	-	80.095
9	1.030	-	-	9.47	5.33	83.223
10	1.024	-	-	2.89	1.86	79.690
11	1.015	-	-	11.12	0.58	71.028
12	1.004	-	-	11.96	0.51	103.603
13	1.011	-	-	4.33	1.86	144.620
14	1.016	-	-	4.78	1.61	110.413

Table-10: OPF for IEEE-14 bus system after curtailment of load

Bus	V (volts)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)	λ_P ($/MWh)
1	1.012	27.11	0.00	-	-	58.793
2	1.007	21.36	-14.13	6.97	4.08	59.015
3	1.010	50.00	0.51	30.26	6.10	58.762
4	1.005	-	-	25.35	-1.25	60.003
5	1.003	-	-	2.44	0.51	59.916
6	1.052	8.87	-6.00	13.60	2.41	60.177
7	1.045	-	-	-	-	59.843
8	1.034	0.00	-6.00	-	-	59.843
9	1.060	-	-	0.00*	0.00*	59.760
10	1.057	-	-	0.00*	0.00*	59.989
11	1.049	-	-	11.12	0.58	60.602
12	1.041	-	-	11.96	0.51	61.411
13	1.050	-	-	0.00*	0.00*	60.402
14	1.050	-	-	4.78	1.61	60.404

Table-11 is a comparison of system under different conditions. The results clearly shows that, when the customers reduce their load under critical conditions then their loads payment is less and also they have a chance to shift their loads from peak to off peak periods. The above table also resembles the congestion relief in terms of MS. In condition 'C' the MS is low compared to the congested case which is our requirement.

Table-11: Comparison of results in different conditions

System	Cost ($/hr)	Revenue of Generators ($/hr)	Loads Payment ($/hr)	SR (MW)	MS ($/hr)
A	9521.56	13465.81	13720.79	194.5	254.98
B	9626.32	14751.03	16098.84	194.2	1347.81
C	7274.25	12378.6	12630.51	217.4	251.91

Graphical Representation:

The above shown results are all the optimal power flow results where the generation dispatch and LMPs are given at all the buses. Those LMPs are represented in graphs. Fig2 and fig3 represents the comparison of LMP under normal, congested and load curtailment conditions when implemented TOU and CPP. The LMPs are high in congested case and they decreased after curtailment of load. Particularly, the LMPs are high at buses nearer to the congested area. Now by curtailment of load at the dispatchable load buses the LMP at that buses are decreased.

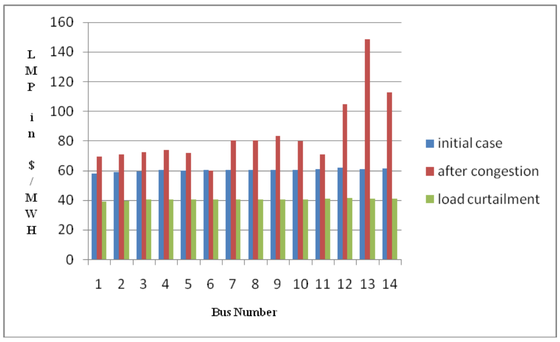

Fig.2. Comparison of LMP in TOU

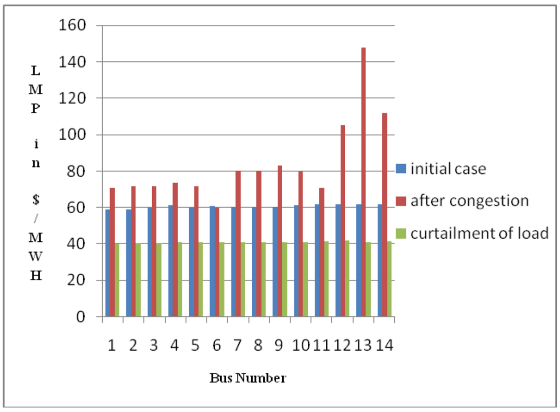

Fig.3. Comparison of LMP in CPP

Fig.4 and fig.5 represents the comparison of MS using TOU and CPP programs for an IEEE-14 bus system. From the bar graphs shown below we can observe that the MS value under congested is high and is less when there is curtailment of load. By this comparison we can clearly state that the congestion is removed when the consumers reduced their load.

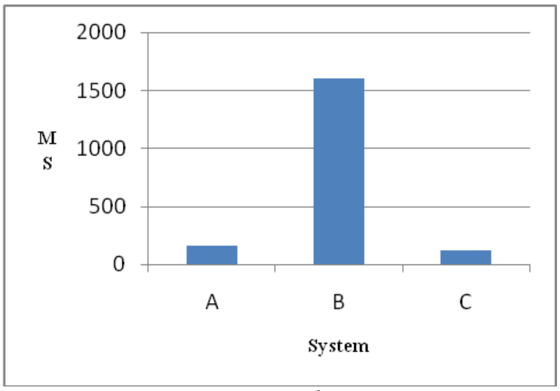

Fig. 4. Comparison of MS in TOU

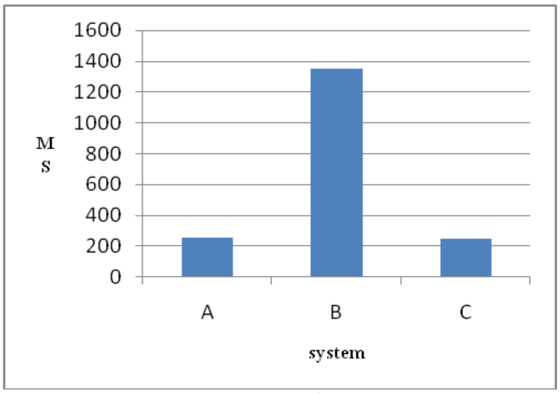

Fig.5. Comparison of MS in CPP

CONCLUSIONS:

In this paper, a new model is introduced for congestion management using demand response programs. It is observed that by applying DR programs MS is reduced which is a measure of the congestion. Without any installation of new transmission corridors and using the concept of FACTS the load is reduced using DR programs. By using the proposed model consumers having the property of price elasticity get benefited in terms of reduced loads payment by curtailment of load.

Appendix:

Table-12: Generator Cost Data

Generator	a[$/hr]	b[$/MWhr]	c[$/MW^{2}hr]
1	0	20	0.043
2	0	20	0.25
3	0	40	0.01
6	0	60	0.01
8	0	80	0.01

REFERENCES:

[1] Christie RD, Wollenberg BF, Wangen steen I, Transmission in the deregulated environment, Proc IEEE 2000;88:170-95.
[2] Acharya N, Mithulanathan. N. Locating series FACTS devices for congestion management in deregulated electricity markets Electr. Power Syst. Res 2007;77;352-60.
[3] Tuan LA, Bhattacharya K, Daalder J. Transmission congestion management in bilateral markets: an interruptible load auction solution. Electr power Syst Res 2005;74:379-89
[4] Bombard E, CarpentonE, Chicco G, Gross G. The role of load demand elasticity in congestion management and pricing. In: Power Engineering Society Summer Meeting, IEEE2000, vol , 4;2000, p.2229-34.
[5] Singh K, Padhy NP, Sharma J, Congestion management considering hydro thermal combined operation in a pool based electricity market, Int J Electr Power Energy Syst 2011; 33;1513-9.
[6] Kumar A, Srivastava SC, Singh SN, Congestion management in competitive power market; a bibliographical survey. Electr Power Syst Res 2005; 76;153-64.
[7] Yousefi , T.T. Nguye, H. Zareipour, O.P. Malik," Congestion management using demand response and FACTS devices" Accepted 5 December 2011.
[8] M. Parsa Moghaddam , A. Abdollahi , M. Rashidinejad, ."Flexible demand response programs modeling in competitive electricity markets", Accepted 23 February 2011, ELSEVIER, Applied Energy 88 (2011) 3257–3269.
[9] Shahram Jadid, and Nahid Aslani Amoli, "Factoring the Price Elasticity of Demand in the Optimal Power Flow", The 8th International Power Engineering Conference (IPEC 2007).
[10] Yudong Tang, Hongkun Song, Funain Hu, Yun Zou, Investigation on TOU pricing principles", 2005 IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China.