Results show that simultaneous application of DLC and GR has a greater impact on reduction in power transmitted through line 13 as compared to the primary condition as well as singular GR application. As shown in Table VI, simultaneous application of DLC and GR have a greater impact on LMP in different hours and are capable of reducing LMP in some hours compared to the network in which either constraints are not considered or using GR singularly.

In other words, based on the results of this study as shown in Fig. 3, simultaneous implementation of incentive-based DR programs (DLC) and GR can significantly reduce generation cost and generation difference from the primary dispatch. Consequently, network congestion can be removed or reduced.

Moreover, utilization of these devices can change the on or off scheduling of generators so that it matches or comes closer to the mentioned schedule when network constraints are neglected.

Furthermore, the result illustrated incentive-based DR programs has been able to decrease the LMP and power transmitted in congested line by allocation incentive payment for each kWh of power decrement at overloaded periods.

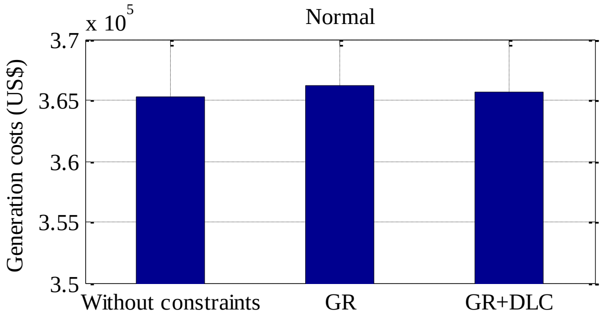

Figure 3. Generation costs during 24 hours for different states (US$)

However, congestion occurrence is usually haphazard which may happen in different hours during peak, off-peak and even low-peak hours. Likewise, the demand of responsive loads decreases in a particular period and increases in the other due to incentive payment. Thus, incentive-based DR programs mostly affect load reduction and a consequent generation cost reduction while it is limited in congestion removal. On the other hand, results show that incentive-based DR programs have a great impact on the price change in different hours and are capable of reducing it in some hours as compared to the case where network constraints are not considered.

C. Contingency analysis

In this section, the impact of GR and incentive-based DR programs on the short-term congestion management is investigated considering scenarios for different contingencies due to generator or line outages. To cover different cases for the system operation, N-1 contingency analysis is utilized for generators and lines. The selection basis of contingency scenarios for lines and generators has been described in sections III.

1) Scenario 1: Outage of a generator

In a power system, generator outage will cause other generators to automatically adjust their outputs to restore the generation-demand balance. This will leads to increasing of generation cost or congestion. In this case, the outage of generator 5 (which is located at bus 8) has the greatest impact on the network congestion during the considered hours as discussed in section III. Thus, generator 5 is selected to be out of service in the contingency analysis. Consequently, generation cost at 21:00 (which is in peak period) for scenario1 is illustrated in Fig.4.

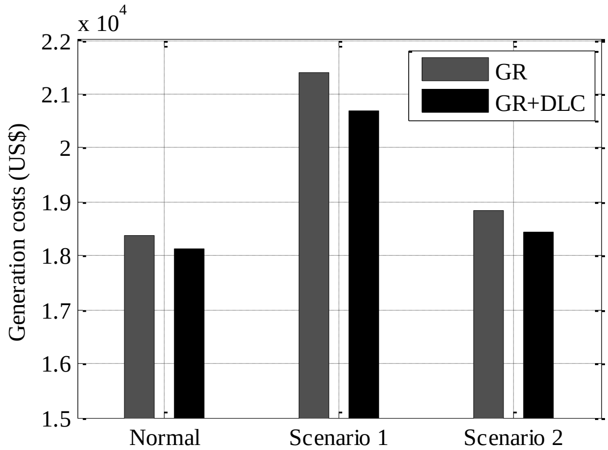

Figure 4. Generation cost at 21:00 in Normal, Scenario 1, and, Scenario 2 contingency (US$)

As shown in Fig.4, in this scenario, simultaneous implementation of DLC and GR is more effective than singular GR application in this case and it causes a greater decrease in the generation and congestion costs. Thus, simultaneous implementation of incentive-based DR programs and GR has been able to play a more effective role than singular GR application in reducing the generation cost during peak hours in case of the most sensitive generator outage.

2) Scenario 2: Outage of a line

In a power system, when a line is corrupted, its power flow will be shared among other lines of the system. This may lead some lines to be overloaded and increase the generation cost. In this case, the outage of line 19 (which is located between buses 12 and 13) has the greatest impact on the network congestion during the considered hours as discussed in section III. Thus, line 19 is selected to be disconnected in the contingency analysis. Consequently, generation cost at 21:00 (which is in peak period) for scenario2 is exhibited in Fig.4.

As shown in Fig.4, in this scenario, simultaneous implementation of DLC and GR is more effective than application of only GR, resulting in significant generation and congestion costs reduction. Thus, simultaneous implementation of incentive-based DR programs and GR has been able to play vital role in reducing generation cost during peak hours as well as reducing congestion removal or decrease cost in the considered hour during outage of most sensitive line.

V. CONCLUSION

Congestion management and generation cost minimization are vital issues in deregulated power systems. In this study, a multi-stage model is proposed based on the combination of incentive-based DR and GR programs to investigate efficiency of incentive-based DR programs in short-term transmission congestion management as well as minimizing generation cost under contingency. For the purpose, the effects of N-1 contingency analysis application are investigated. To bring it closer to reality, issues such as no- load cost, start-up cost, shut-down cost, uptime, downtime, ramp up, ramp down, network load for 24 hours, change in power consumption of participants in incentive-based DR programs are considered as well. The results illustrate DLC (incentive-based DR programs) are able to decrease LMP besides reducing power transmitted in congested line by allocating incentive payment for each KWh of power decrement at overloaded periods. Results exhibit that although, DLC (incentive-based DR programs) have significant effect in congestion management as well as generation cost alleviation due to load reduction but they are more effective in generation cost minimization as compared to congestion management. Moreover, results also depict that simultaneous implementation of DLC (incentive-based DR) and GR programs are able to play a paramount role as compared to singular GR application, in generation cost reduction during peak hours and mitigating congestion during normal operation as well as most sensitive generator or line outage contingency.

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APPENDIX

TABLE (A-I)
TRANSMISSION LINES DATA

Line No.	From bus	To bus	$x\ (p.u.)$	S^{max} (MAV)
1	1	2	0.05917	50
2	1	5	0.22304	50
3	2	3	0.19797	85
4	2	4	0.17632	50
5	2	5	0.17388	50
6	3	4	0.17103	80
7	4	5	0.04211	75
8	4	7	0.20912	60
9	4	9	0.55618	30
10	5	6	0.25202	80
11	6	11	0.19890	50
12	6	12	0.25581	30
13	6	13	0.13027	30
14	7	8	0.17615	100
15	7	9	0.11001	50
16	9	10	0.08450	40
17	9	14	0.27038	30
18	10	11	0.19207	50
19	12	13	0.19988	20
20	13	14	0.34802	40

TABLE (A-II)
DATA RELATED TO NETWORK GENERATORS

Generator number	1	2	3	4	5
Bus number	1	2	3	6	8
Minimum generation capacity (MWh)	17	12	10	14	11
Maximum generation capacity (MWh)	200	150	100	140	120
Maximum ramp-up rate (MW/h)	140	120	70	90	80
Maximum ramp-down rate (MW/h)	100	70	50	78	62
No-load cost (US$)	300	300	600	300	300
Start-up cost (US$)	60	69	30	150	90
Shut-down cost (US$)	15	18	9	30	24
Minimum up-time (h)	4	3	2	5	4
Minimum down-time (h)	3	3	2	4	3
Initial generation (MWh)	80	60	0	50	40
Initial ON duration (h)	3	14	0	17	9
Initial OFF duration (h)	0	0	9	0	0

Table (A-III)
DATA RELATED TO GENERATION BIDS

Generator No.	Generation bid (MWh)			Price bid ($/MWh)		
	$Block_1$	$Block_2$	$Block_3$	$Block_1$	$Block_2$	$Block_3$
1	80	70	50	64.80	73.80	81
2	60	50	40	53	58.50	63
3	40	40	20	73.20	79.60	84.40
4	50	45	45	41	42.90	44.70
5	55	35	30	56.65	59.35	61.30

NOTATION:

A_t	Incentive payment for each kWh load reduction in DR programs
$CF_{n_{dr}}$	Participation factor of consumer n_{dr} in DR programs
E_{t,t_2}	Cross-price elasticity of demand for hours *t* and t_2
$E_{t,t}$	Self-elasticity of demand at hour *t*
f_k^0	Power flow in line *k* before outage
L_G	Number of blocks offered by generators
N	Number of system buses
N_D	Number of demands
N_{DR}	Number of demands participating in DR programs
N_G	Number of generation units
NLC^{n_g}	No- load cost of unit n_g
$P^{n_1,n_2,t}$	Active power flow in the line between bus n_1 and bus n_2 at hour *t*
${P_d}^{n_d,t}$	Active load of consumer n_d at hour t
${P_{dr}}^{n_{dr},t}$	Active load of consumer n_d at hour *t*, after participation in DR programs
${P_g}^{n_g,l_g,t}$	Active power generated by unit n_g in block l_g at hour *t*
ρ_t	Electricity price at hour *t*
ρ_{0_t}	initial electricity price at hour *t*
${\rho_{Pg}}^{n_g,l_g,t}$	Price offered by unit n_g to generate in block l_g at hour *t*
$Q^{n_1,n_2,t}$	Reactive power flow in the line n_1n_2 at hour *t*
${Q_d}^{n,t}$	Reactive load of consumer n_d at hour t
${Q_g}^{n_g,t}$	Reactive power generation by unit n_g at hour *t*
ref	Slack bus at hour *t*
S	TCSC capacity (MVar)
${S^{max}}_{n_1,n_2}$	Maximum transmissible power flows through the line n_1n_2
SDC^{n_g}	Shut-Down cost of unit n_g
$sd^{n_g,t}$	Binary variable representing “Shut-Down” state of unit n_g at hour *t*
SUC^{n_g}	Start-up cost of unit n_g
$su^{n_g,t}$	Binary variable representing “Start-Up” state of unit n_g at hour *t*
T	Time duration of the market implementation
$u^{n_g,t}$	Binary variable representing “ON/OFF” state of unit n_g at hour *t*
$V^{n,t}$	Voltage amplitude of bus *n* at hour *t*
${V^{max}}_n$	Maximum voltage amplitude of bus *n*
${V^{min}}_n$	Minimum voltage amplitude of bus *n*
$X_{n_1,k}$	Element (n_1,*k*) of reactance matrix in DC power flow
X_{n,n_1}	Element (n,n_2) of reactance matrix in DC power flow
x_k, x_l	Reactance of line *k* and *l* respectively
Y^{n,n_2}	Amplitude of element (n, n_2) in network admittance matrix
Δf_l	Power flow change in line *l*
Δp_k	Power injection change in bus *k*
$\delta^{n,t}$	Voltage phase angle of bus *n* during hour *t*
θ^{n,n_2}	Phase angle of element (n, n_2) in network admittance matrix

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