Re-Dispatch Approach for Congestion Relief in Deregulated Power Systems

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***Abstract*— In the competitive power market environment, congestion is an indicator for the need of transmission system reconfiguration by compensation devices or its expansion with new lines erection. Due to economic considerations, the short time solution like re-dispatch is also playing a key role in the present scenario. In some inevitable cases, moderating the congestion by load shedding is the only solution which is not good in practice. Hence this paper addresses a solution for congestion relief, i.e. re-scheduling of generators if required simultaneously with load reduction. In re-schedule method, some of the generators are required to increase/decrease their actual market schedule which causes to increase/decrease transmission losses. Simultaneously, the increase in production cost so called congestion cost. The IEEE-6 bus and IEEE 14 bus test systems are used to show the effectiveness of the proposed method.**

***Keywords*—Deregulated power system, Congestion relief, Day-Ahead electricity market, Re-dispatch, Load curtailment.**

I. Introduction

In the deregulated power system, the system operator would like to schedule more generation from the cheapest available sources with the objective of production cost minimization. But the competition among power producers causes to change their bidding methodologies frequently. The scheduling for this producer’s strategic bidding leads to allocate high MW quantity at lower price offered utility and low MW quantity at higher price offered utility. By the frequently changing schedules, the possibility unsecured state due to anyone of the transmission line overloading condition will increase. In deregulated environment, this situation is termed as congestion and can avoid with suitable techniques. In [1], the congestion management approaches have been explored significantly. Among all these approaches, the re-dispatch is one of the short-term solutions which can easily implement in the day-ahead energy market since the schedules will decide one day prior to the schedule day. Sometimes, congestion relief is not possible only with reschedule hence the load curtailment is become one of the option. In this paper, the generation schedule has been cleared by the assumption of all GENCOS are mandatory to participate pool operation and they should adjust their schedule according to the system operator signals. The system is operating as day-ahead market with single sided auction mechanism. In this mechanism, only generators will participate in the market and a common aggregate supply curve will develop based on the submitted bids.

The intersecting point with forecasted demand will decide the generation quantities for each market participants. After market schedule, the ISO will check for congestion feasibility in the system. If system is insecured due to congestion, the remedial actions will take place. This situation can happen frequently in the competitive environment. In competitive market, the GENCOS are permitted to alter their bid curves before market settling time. To obtain unconstrained cleared quantities in strategic bidding environment, ISO is always explore to get an idea about GENCOs bid curves which will change frequently with the market signal. The change in bids due to competition and real time incremental cost curves can interrelate in probabilistic manner [2].

In [3], an AC-OPF based re-dispatch problem has been proposed to alleviate congestion along with congestion cost allocation. A computationally simple method for cost efficient generation rescheduling and load shedding for congestion management is proposed in [4]. In [5], review of existing congestion management methods with their pros and cons in Spanish market based on security constrained unit commitment algorithm, and security constrained optimal power flow algorithms is presented. In [6], the comprehensive literature survey on congestion management has been given. According this survey, whatever the approach, the security margin maintenance is the major objective of the ISO.

The paper is organized as follows: After the introduction, the Day-Ahead energy market clearing mechanism under perfect mechanism is explained in Section II. The Section III explores the congestion relief by using re-dispatch and in Section IV, load curtailment are explained. In Section V, case study and later conclusions are deduction based on the results.

II. Day-Ahead Energy Market Settlement

In this paper, the DA market is organized as a sequence of twenty-four independent hourly single-sided auctions, under the uniform pricing rule. The objective function of DA settlement is:

$$Minimize\ \lambda^{*} \times P_{d} \tag{1}$$

If the market operates on a perfect completion, then the bids submitted by the GENCOs can related with incremental cost curve of that unit. Under this assumption, the schedule will decide simply economic load dispatch without transmission loss [7]. According to this concept, the market clearing price (MCP), λ^{*} and generation at a bus $P_{G,p}$ for a known demand P_d , can determine analytically as follows:

$$\lambda^{*} = \frac{P_d + \sum_{p=1}^{NG} \frac{b_p}{2a_p}}{\sum_{p=1}^{NG} \frac{1}{2a_p}} \tag{2}$$

$$P_{G,p} = \frac{\lambda^{*} - b_p}{2a_p} \tag{3}$$

Subjected to the constraint

$$\sum_{p=1}^{NG} P_{G,p} = P_d \tag{4}$$

It is required to verify the possibility of congestion in the network for the above market schedule. In general, the network loading and its security level can easily understand with performance index [8]. The real power flow based performance index is given by

$$PI = \sum_{l} \left(\frac{f_l}{f_{l,\max}} \right)^{2x} \tag{5}$$

where l is the number of transmission lines, f_l is the absolute flow of line l and $f_{l,max}$ is its MVA rating. In case studies, the x is taken as 5.

III. Congestion Market Modelling

In this market, the power producers may submit their incremental and decremented bidding prices in a real-time balancing market to relieve congestion. These can then be implemented in the scheduling problem to required change in the generator outputs. [9]. In order to achieve the social welfare maximization, ISO selects bids from the submitted bids and decides the amount of deviations from the preferred schedule. The objective function for the congestion management problem can be formulated as,

$$\text{Minimize } C_p = \sum_{p=1}^{NG} \left(\lambda_p^{+} \Delta P_p^{+} - \lambda_p^{-} \Delta P_p^{-} \right) \tag{6}$$

Subjected to balance equation:

$$\sum_{p=1}^{NG} P_{G,p} = \sum_{p=1}^{ND} P_{D,p} \tag{7}$$

$$P_{G,p}^{\min} \le P_{G,p} \le P_{G,p}^{\max} \tag{8}$$

where $P_{D,p}$ is the power taken at node p and C_p is the total congestion cost, λ_p^{+} and λ_p^{-} are vectors of incremental and decremented bids submitted by the generators at node i for re-dispatch during congestion, ΔP_p^{+} and ΔP_p^{-} are be the changes in preferred schedule and NG is the total generators in the system.

IV. LOAD CURTAILMENT APPROACH

In this approach, the system load will reduce until system constraints to satisfy. In order to maintain, power factor as constant, the real and reactive powers both are reduced simultaneously. The Newton-Raphson load flow considered to simulate the system. According to load flow problem, the changes in injection powers at all the buses can be linearized with the following equations:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = [J] \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \quad (9)$$

$$\Delta P = P_p^{sp} - P_p^{cal} = P_{G,p} - \left(\alpha P_{D,p}\right) - P_p^{cal} \quad (10)$$

$$\Delta Q = Q_p^{sp} - Q_p^{cal} = Q_{G,p} - \left(\alpha Q_{D,p}\right) - Q_p^{cal} \quad (11)$$

where

ΔP and ΔQ	residual power injections
P_p^{sp} and Q_p^{sp}	specified power injections
P_p^{cal} and Q_p^{cal}	calculated powers
$P_{G,p}$ and $Q_{G,p}$	real and reactive generations
$P_{D,p}$ and $Q_{D,p}$	real and reactive loads
α	load reduction factor

The load is reduced on the system up to congestion relieved. This step needs load flow solution repeatedly.

V. RESULTS & DISCUSSIONS

A. *Test System – IEEE 6 Bus System*

The case study has been performed on IEEE 6 bus system [10]. In this test system, 11 transmission lines and the buses 1, 2 and 3 are the generator buses and they treated as GENCOs in the system. The buses 4, 5 and 6 are load buses and they considered as DISCOs in the system. By assuming single sided market action, the DISCOs are not participant in the system. The total load on every hour is considered as required market clearing quantity. The total load on the system is about 210 MW. The load is shared among the generators using Market clearing DA mechanism. Incremental cost of delivered power (system lambda) = 11.898949 $/MWh and the optimal dispatch of generation: PG1=50.0000MW; PG2= 88.0736 and PG3= 71.9264 MW. Total generation cost = 3046.41 $/h. The market schedule suffers a loss of 5.777 MW and among 11 transmission lines, 3 lines are being overloaded. The system performance index is about 5.1425. In order to overcome this situation, the possibilities are:

Case 1: Increment/decrement generation at bus-1 by decrement/increment at bus-2.
Case 2: Increment/decrement generation at bus-1 by decrement/increment at bus-3.
Case 3: Increment/decrement generation at bus-2 by decrement/increment at bus-3.
Case 4: Load reduction on system.

For all the above cases, the schedule and system performance is given in Table–1.

TABLE I
SYSTEM PERFORMANCE FOR VARIOUS CASE STUDIES

Case #	PG1	PG2	PG3	Loss	SPI	State
Base	50.000	88.07	71.93	5.78	5.1425	Alert
1	138.06	0	71.93	9.081	3.8944	Alert
2	121.93	88.07	0	9.448	17.261	Alert
3	50.000	0	160.00	7.423	33.312	Alert
	50.000	160.00	0	7.739	29.356	Alert
4	50.000	73.754	54.746	4.634	2.6297	Safe

In case 1, the decrement of generation bus-2 is not overcome the congestion problem. And for the increment, the severity is further increasing. The same situation is happens to the case 2 and case 3 also. Hence for this schedule, the re-dispatch is not suitable for congestion relief. So the last option is load curtailment or reduction up to system comes to normal or safe zone.

For the 15% of load reduction the market schedule is as follows:

Incremental cost of delivered power (system lambda) = 11.644340 $/MWh and the optimal dispatch of generation: PG1=50.0000 MW, PG2= 73.7537 MW and PG3= 54.7463 MW. Total generation cost = 2675.61 $/h. The cost of opportunity loss = 3046.41-2675.61 =370.8 $/h.

B. Test System – IEEE 14 Bus System

In IEEE 14 bus system, the total transmission lines are 20 and generator buses are 5 (i.e. 1, 2, 3, 6 and 8) and the remaining buses are load buses. The bus data and line data can be found in [10]. The cost coefficients of each generator have been given in Table-2. Each GENCO has been assumed to submit bids in proportion to its $P_{G,p}^{\max}$ limit. The bids are of 10%, 20%, 30% and 40% of its maximum limit. The generator bidding parameters are assumed to be constant for the entire day.

TABLE III
IEEE 14 BUS SYSTEM COST COEFFICIENTS

Gen #	a_p	b_p	$P_{G,p}^{\min}$	$P_{G,p}^{\max}$
1	0.0200	2.00	10	250
2	0.0175	1.75	10	200
3	0.0625	1.00	05	65
4	0.0083	3.25	05	50
5	0.0250	3.00	05	60

The expected load on the system over a period of 24 hours in the next day has been given in Fig.1. For each trading interval (in this work, we have considered one hour), the demand has been cleared as explained in Section II. The SMP or MCP of the system over a period of 24 hours is illustrated in Fig.2. We can observe that the system marginal price or market clearing price is 3.85 \$/MWh. The total production cost will be 804.745 \$. With this schedule, the transmission losses of the system has been computed using Newton Raphson load flow method and are equal to 3.463MW. The transmission system is also under normal operating condition. The line loadings can be observed in Fig.3.

The similar procedure has been performed for the peak hour also. The system load is equal to 386.99MW. We can observe that the system marginal price or market clearing price is 4.55 \$/MWh. The total production cost will be 1760.805 \$. With this schedule, the transmission losses of the system have been computed using Newton-Raphson load flow method and are equal to 6.488MW. The transmission system is subjected to over loading condition. The line loadings can be observed in Fig 4.

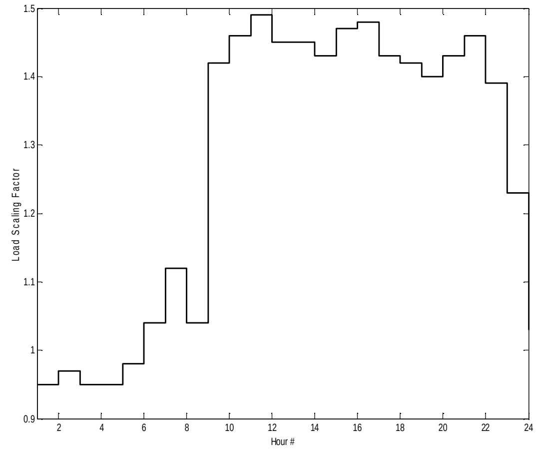

Fig. 1. Forecasted Load Curve of the Scheduled Day

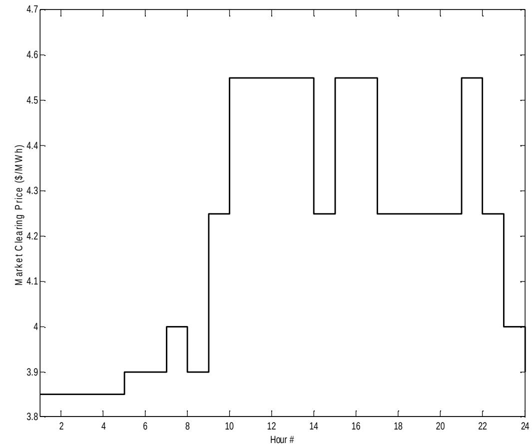

Fig. 2. MCP or SMP of the system for the period of 24 hours

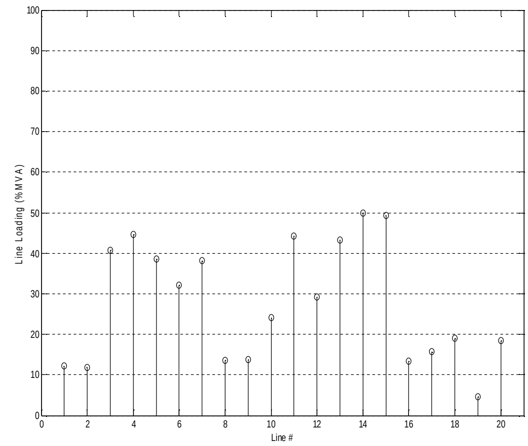

Fig. 3. Percentage of Line loadings for Hour 1

From figure, the line # 14 has been hit its thermal limit. In deregulated environment, this situation is termed as transmission congestion. In order to relief this condition, the system operator will follow certain market rules and regulations. These rules will dependent on market type and country.

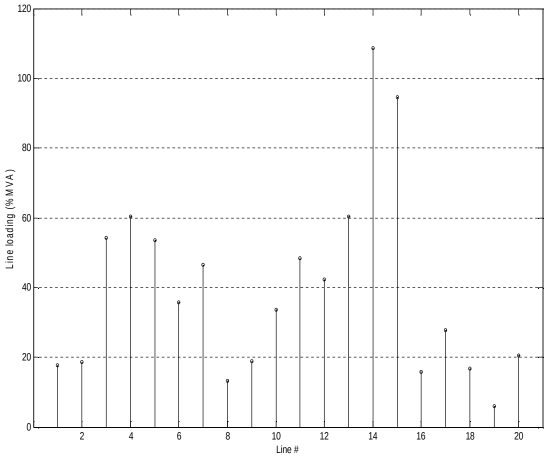

Fig. 4. Percentage of Line loadings for the Peak load

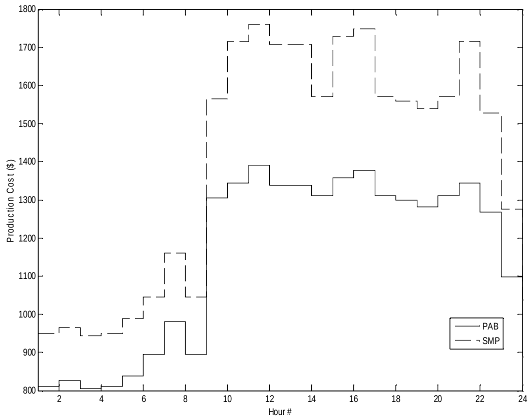

Fig. 5. Production cost as per SMP and PAB

The MCP of each trading hour has been illustrated in Figure 5. Depending upon load quantity, the generators schedules are different for each interval. If the market operates with Pay-As-Bid policy, then the production cost will be different. The difference between MCP and PAB for the entire day can be observed in Fig. 5. The important thing is that the suppliers will get more profit in SMP compare with PAB. So in order to encourage market participants, most of the systems are operating with SMP only.

As long as system is under safe conditions, the market will run under economic and competitive conditions. If system is under congestion, the economics will deviate and causes to market power. In order to avoid the market price hikes during peak hours and under unexpected disturbances, the need of system strength should be increased by integrating the advanced technologies like Flexible AC Transmission System (FACTS) devices, Distributed Generation etc.

VI. CONCLUSION

This paper has been explored the Day-Ahead market scheduling under normal as well as congestion states. The re-schedule and load curtailment approaches have been applied to the congestion relief. The case studies once again revels that the re-dispatch is not possible in all the cases. Under this mode, only load reduction will be the alternative solution which is not good in practice. In order to keep reliability and security, the need of transmission system loadability enhancement is also understandable from this paper.

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