



## Price Spikes Reduction with EDRP Program

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### Abstract

With the development of deregulated power systems and increase of prices in some hours of day and increase fuel price, demand response programs were noticed more by customers. demand response consists of a series of activities that governments or utilities design to change the amount or time of electric energy consumption, to achieve better social welfare or some times for maximizing the benefits of utilities or consumers. In this paper we try to evaluate the effect of DR programs especially EDRP on Nodal Marginal Pricing spikes reduction of Restructured Power Systems while occurs events. In order to reach to this target, EDRP program (Emergency Demand Response Program), as common demand response program, is considered. Effects of EDRP program on Nodal Marginal Pricing spikes and operation cost reduction of Restructured Power Systems are investigated using EDRP and economic load model, AC-OPF Formulation and nodal marginal price evaluation techniques.

The IEEE 9 bus Test System is used to implement comparisons of impacts with and without EDRP activity on nodal marginal pricing spikes and operation cost reduction.

According to obtained results, EDRP using lead to volatility decrease in local marginal price (LMP). It can be said that solving problems such as congestion in transmission lines, power system reliability decrease and volatility decrease in local marginal price at load network peak hours, is impossible without customer interfering in power market. In other hand Consumer participation, makes the power markets more competition and enhance its performance.

*Keywords:* Restructured Power Systems, Demand Response (DR), Emergency Demand Response Program (EDRP), Nodal Marginal Pricing, AC-OPF.

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### 1. Introduction

Participant of customers in electricity market increases competitiveness of electricity markets and reduces the severity of price spikes. Customers modifying their use when they see price volatility help reduce the magnitude of price spikes. When consumers can receive price signals and can respond to them, some consumers will shift their demand to cheaper hours when they face high prices.

Demand Response can be defined as the changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time. [1,6].

DR is divided into two basic groups and several subgroups [1, 6]:

A- Incentive-based programs:

A-1- Direct Load Control

A-2- Interruptible/curtail able service

A-3- Demand Bidding/Buy Back

A-4- Emergency Demand Response Program

A-5- Capacity Market Program

A-6- Ancillary Service Markets

B- Time-based programs:

B-1- Time-of-Use program

B-2- Real Time Pricing program

B-3- Critical Peak Pricing Program

The benefits of DR include increased static and dynamic efficiency, better capacity utilization, pricing patterns that better reflect actual costs, reduction of price spikes, decentralized mitigation of market power, and improved risk management.

A recent study estimated the prospective benefits of active demand response at \$7.5 billion by 2010 (ICF 2002). Other studies, described in GAO (2004), give further details of the benefits that have already been generated because of demand response and active retail choice [2].

The most usual demand response program while events are Emergency Demand Response program (EDRP). Emergency Demand Response program provide incentives for customers to reduce loads during reliability events, though the curtailment is voluntary. No penalty is assessed if customers do not curtail, and the rates are pre-specified, though no capacity payments are received [3].

Generally, Emergency Demand Response is not included in Internal Demand data and NERC does not collect this data for its seasonal and long-term assessments. Operators cannot easily predict load curtailment amounts, and planners do not attempt to forecast their impact in the future.

Emergency Demand Reduction Program (EDRP) is a reliability-specific day-of interpretability contract that is available for hours when there is a shortfall in reliability reserves. Customers can choose to allow the ISO to interrupt their service, for which the customer is paid a price determined through a bidding process [3].

EDRP is emergency DR programs that provide mechanisms where demand can be reduced on short notice when reserve shortfalls are forecast. EDRP is a voluntary emergency program that pays customers the greater of \$500/MWh or the prevailing real-time market price for curtailments of at least four hours long when called by the ISO [3]. Fig. 1 show effect EDRP in the price.

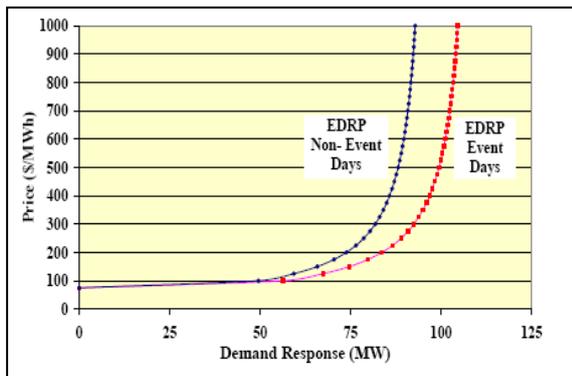


Fig.1: Effect EDRP in Price [3].

The New York Independent System Operator (NYISO) calculated that its demand response program provided substantial benefits to the market by helping the power grid recover from the August 2003 Blackout. Specifically, they estimated that on August 15, 2003, the participating DR of 593.9 MW provided \$50.8 M (US) worth of economic benefits at a cost of \$5.9 M (US).

During August 2001, higher than normal temperatures forced the NYISO to invoke emergencies on August 7, 8, and 9 (18 hours in all zones) and on August 10 (4.5 hours in New York City/Long Island and Hudson River, Zones F–K). On August 9th, a new record peak load of 30,983 MW was established. Most of the capacity shortfall occurred in the New York City/Long Island area (Zones J–K). During this time, a variety of load management programs, including the PRL<sup>1</sup> programs (EDRP, DADRP<sup>2</sup>, and ICAP), were deployed. At peak load, an estimated 1,580 MW was curtailed, of which the PRL programs contributed 605 MW (38 percent), with the balance coming from other sources. At the time the EDRP events were called, 292 participants had registered in the EDRP. Participants in the EDRP provided 70 percent of all load curtailment from all PRL programs. While 292 participants (712 MW) registered with the NYISO for EDRP, only 213 (617 MW) actually performed when emergencies were declared. Those who performed delivered only an average 418 MW per hour, or 68 percent of their registered capability. A planning consideration for future rounds of the EDRP, given that it is a voluntary program, is that more loads have to be registered than is actually required [3].

This paper investigates the impact of Emergency Demand Response program on Nodal Marginal Pricing Spikes and Operation Cost Reduction of Restructured Power Systems. The IEEE 9 bus Test System, is studied, and simulation results show that demand response can reduce local marginal pricing spikes and Operation Cost. This paper is organized in five sections. Section 2 defines the load economic model which is used to evaluate the participation in EDRP program and explains the economic analysis formulation. Local marginal price Calculations is discussed in section 3. Section 4 presents the numerical results which are tested on 9-bus IEEE and finally section 5 is dedicated to conclusions.

<sup>1</sup> Price Responsive Load

<sup>2</sup> Day-Ahead Demand Reduction Program

## 2. Demand Response Economic Model

Currently power industries in many countries are going under restructuring and deregulation. The trend is to replace the previous monolithic regulated public utilities with competitive power markets. However, the development of the restructured power systems has been accompanied by many problems, such as capacity storage, transmission congestion, wholesale electricity price volatility and reduced system reliability.

Elasticity is defined as the ratio of the relative change in demand to the relative change in price [5]:

$$E = \frac{\partial q}{\partial p} = \frac{\rho_0}{q_0} \cdot \frac{dq}{dp} \quad (1)$$

Where:

$\Delta d(t_i)$ : Demand changes in time interval  $t_i$

$\Delta \rho(t_i)$ : Price changes in interval  $t_i$

$\Delta \rho(t_j)$ : Price changes in time interval  $t_j$

According to equation (2), self elasticity and cross elasticity can be written as:

$$\xi_{ii} = \frac{\Delta d(t_i) / d_0}{\Delta \rho(t_i) / \rho_0} \quad (2)$$

$$\xi_{ij} = \frac{\Delta d(t_i) / d_0}{\Delta \rho(t_j) / \rho_0}$$

Where:

$\Delta d(t_i)$ : Demand changes in time interval  $t_i$

$\Delta \rho(t_i)$ : Price changes in interval  $t_i$

$\Delta \rho(t_j)$ : Price changes in time interval  $t_j$

Self elasticity and cross elasticity are negative and positive values, respectively. If the relative change in demand is larger than the relative change in price, the demand is said to be elastic, on the other hand, if the relative change in demand is smaller than the relative change in price, the demand is said to be inelastic.

So the elasticity coefficients can be arranged in a 24 by 24 matrix E [4].

$$E = \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \cdots & \xi_{1,23} & \xi_{1,24} \\ \xi_{2,1} & \xi_{2,2} & \cdots & \xi_{2,23} & \xi_{2,24} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \xi_{23,1} & \xi_{23,2} & \cdots & \xi_{23,23} & \xi_{23,24} \\ \xi_{24,1} & \xi_{24,2} & \cdots & \xi_{24,23} & \xi_{24,24} \end{bmatrix} \quad (3)$$

The detailed process of modelling and formulating how the EDRP program effects on the electricity demand is discussed in [6]. Accordingly the final responsive economic model is presented by (4):

$$d(i) = \left\{ d_0(i) + \sum_{j=1}^{24} E_0(i, j) \cdot \frac{d_0(i)}{\rho_0(j)} \times A(j) \right\} \cdot \left\{ 1 + \frac{E(i)[\rho(i) - \rho_0(i) + A(i)]}{\rho_0(i)} \right\} \quad i = 1, 2, \dots, 24. \quad (4)$$

The above equation shows how much should be the customer's demand in order to achieve maximum benefit in a 24-hours interval.

Time varying loads for 24 hours within one day are considered in this paper. Time period is assumed to be one hour.

### 2.1 Modelling of EDRP

The final response of the economic model is presented by (4). The modified model for showing the effect of EDRP is as follows:

For  $i = \text{EDRP Non-Event Hours}$

$$d(i) = \left\{ d_0(i) + \sum_{j=14}^{18} E_0(i, j) \cdot \frac{d_0(i)}{\rho_0(j)} \times A(j) \right\} \quad (5)$$

For  $i = \text{EDRP Event Hours}$

$$d(i) = \left\{ d_0(i) + \sum_{j=14}^{18} E_0(i, j) \cdot \frac{d_0(i)}{\rho_0(j)} \times A(j) \right\} \cdot \left\{ 1 + \frac{E(i) \times A(i)}{\rho_0(i)} \right\} \quad (6)$$

## 3. Local Marginal Price Calculation

Local marginal price use the Lagrange function as shadow prices. Local marginal price can be depicted by the optimization problem of optimization equations. Obviously, to maintain the stability of the system, the generation must be equal to the load; the operation of this system can thus be formulated as the following constrained optimization problem:

$$\text{Min} \sum^n (C_{pi}(P_{gi})) \quad (7)$$

Subject to

$$P_{gi} - P_{di} = P_i(\theta, V) \quad i = 1, \dots, n \quad (8)$$

$$Q_{gi} - Q_{di} = Q_i(\theta, V) \quad i = 1, \dots, n \quad (9)$$

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \quad (10)$$

$$Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max} \quad (11)$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (12)$$

$$|S_{ij}^f(\theta, V)| \leq S_{ij}^{\max} \quad (12)$$

To have a symbolic representation of the Lagrange function,  $C(x)$ ,  $m(x)$  and  $n(x)$  are defined as the objective function, equality constraints and inequality constraints respectively. The form of

equality constraints and inequality constraints should be given by (13) and (14).

$$m_i(x) = 0 \quad i = 1, \dots, n \quad (13)$$

$$n_j(x) = 0 \quad j = 1, \dots, m \quad (14)$$

The Lagrange function of equations (13) to (14) can be depicted by (15).

$$L(z) = C(x) + \lambda^T \cdot m(x) + \mu^T \cdot n(x) \quad (15)$$

Where  $\lambda^T = [\lambda_1 \quad \lambda_2 \quad \dots \quad \lambda_n]$  and  $\mu^T = [\mu_1 \quad \mu_2 \quad \dots \quad \mu_m]$ .

The local marginal prices of real powers at node are the marginal cost of load supply at the optimal solutions of (16).

$$LMP_i = \frac{\partial L}{\partial P_{di}} \quad (16)$$

The local marginal prices of real powers at each node considering Emergency Demand Response Program are the marginal cost of load supply at the optimal solutions of the following equations:

$$\text{Min} \sum_{i=1}^{ng} (C_{pi}(P_{gi})) + \sum_{i=1}^{nD} (C_{pi}(P_{EDRPi})) \quad (17)$$

Subject

$$P_{gi} - P_{di} + P_{EDRPi} = P_i(\theta, V) \quad i = 1, \dots, n \quad (18)$$

$$Q_{gi} - Q_{di} + Q_{EDRPi} = Q_i(\theta, V) \quad i = 1, \dots, n \quad (19)$$

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \quad (20)$$

$$Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max} \quad (21)$$

$$P_{EDRPi}^{\min} \leq P_{EDRPi} \leq P_{di} \quad (22)$$

$$Q_{EDRPi}^{\min} \leq Q_{EDRPi} \leq Q_{di} \quad (23)$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (24)$$

$$|S_{ij}^f(\theta, V)| \leq S_{ij}^{\max} \quad (25)$$

$$LMP_i = \frac{\partial L}{\partial P_{di}} \quad (26)$$

#### 4. Numerical Results

A case study based on the IEEE 9-bus system is presented in this section, in order to show the effect of EDRP program on nodal marginal pricing spikes and operation cost reduction of restructured power systems.

The amount of incentive in EDRP program formulation is assumed to be equal to 500 \$/MWh (existing incentive in New York market). The elasticity of the load is shown in Table.1 [6].

Table.1  
Self and Cross Elasticities

	Peak	Off-Peak	Low
Peak	-0.02	0.0032	0.0024
Off-Peak	0.0032	-0.02	0.002
Low	0.0024	0.002	-0.02

Firstly it is desired to evaluate the impact of demand response program on nodal marginal price spikes and cost operation reduction of a restructured power system.

Load curve of Mid-Atlantic region New York network was selected for testing and analyzing the effect of EDRP program, Fig. 2 [3]. The load curve is divided into three intervals: low load period (12:00 p.m. to 9:00 a.m.), off-peak period (10:00 a.m. to 13:00 p.m. and 19:00 p.m. to 12:00 p.m.) and peak period (14:00 p.m. to 18:00 p.m.).

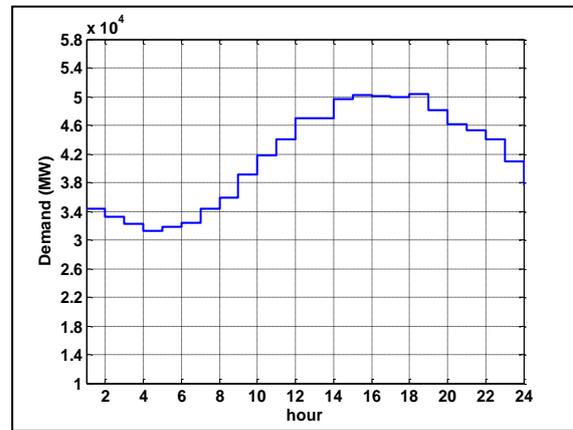


Fig. 2: Load curve of Mid-Atlantic region New York network

The load curves before and after implementations of demand response program are represented in Fig.3. As it can be seen, by implementation of demand response program, based on the difference between elasticities in different periods, loads are transferred from peak periods to valley periods. Without demand response programs, the system peak load is 315 MW; considering demand response programs, however, the system peak load is 303.64MW.

Two scenarios will be observed in this paper:  
1-Test of system without considering DR programs,  
2- Test of system with considering DR programs.

By Simulation and test system, Fig.3 and 4 shows effected DR program in Nodal Marginal Pricing Spikes and Operation Cost Reduction of Restructured Power Systems. These Fig.s show that the higher prices decrease due to demand response program. Local marginal prices of other nodes change in the same pattern. Demand response program is therefore seen to reduce the LMP spikes, where the highest and lowest nodal marginal price without demand response program are 24.998\$/MWh and 16.233\$/MWh respectively; the highest and

lowest nodal marginal price with demand response program are 24.099\$/MWh and 16.889\$/MWh respectively.

Operation cost of the system for the 24-hour period without DR program is 99427.18\$ while with DR program is 98510.32\$. Therefore, implementing the DR program, nodal marginal price decreases in addition to decreasing operation cost of the system. It is desired to study the impact of EDRP program on nodal marginal price spikes reduction during emergency events.

During the system peak hours, in which emergency events such as lines and generators outages occur, the ISO uses EDRP resources in order to avoid system instability and increase of market price. In this section, the effect of the EDRP during emergency events where market prices go high is studied and simulated.

By implementation of this program, the system peak load and real time price in the New York market is reduced and price sudden spikes are avoided.

The following results (Table.2) have been attained by simulation of EDRP effect during emergency events on the 9-bus IEEE test system. The Table.2 shows that the outage of line 2-8 has had the most increment of spot price in the market while after implementing EDRP, the nodes spot prices have had a 10.8% decrease.

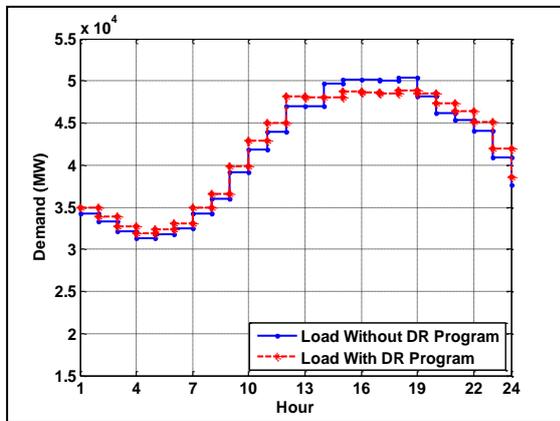


Fig.3. Load curve without and with DR program

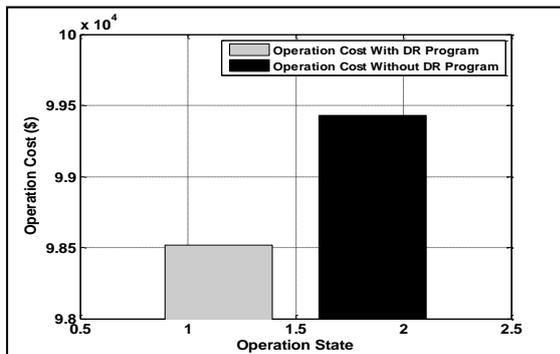


Fig.4. Operation cost without and with DR program

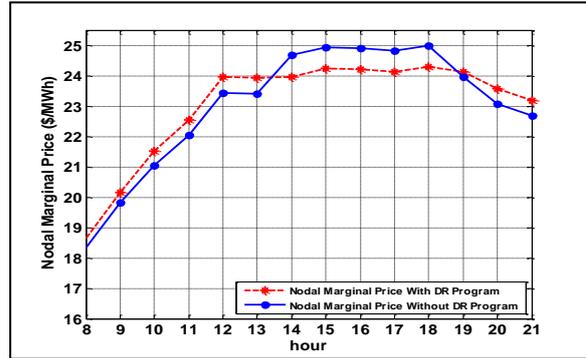


Fig.5. Nodal marginal price in bus 5

Table.2  
Nodal marginal prices for first-order line outages

Line from bus to bus	Nodal marginal price in bus 5 (\$/MWh)		Nodal marginal price in bus 7 (\$/MWh)		Nodal marginal price in bus 9 (\$/MWh)	
	Without EDRP	With EDRP	Without EDRP	With EDRP	Without EDRP	With EDRP
1-4	36.116	31.643	33.858	29.969	36.227	31.723
4-5	26.298	23.273	24.585	21.974	24.746	22.124
5-6	26.612	23.591	24.083	21.592	25.875	23.012
3-6	34.459	30.722	33.717	30.124	34.257	30.561
6-7	24.834	22.188	25.086	22.385	25.223	22.499
7-8	25.736	22.901	26.316	23.352	25.046	22.356
8-2	40.865	36.426	40.674	36.263	41.087	36.599
8-9	26.261	23.328	23.954	21.489	27.163	24.040
9-4	24.645	22.037	25.070	22.346	27.643	24.240

5. Conclusion

In this paper, the effects of demand response program on local marginal price spikes reduction and operation cost reduction of a deregulated power system are evaluated using emergency demand response program and economic load model, AC-OPF formulation and nodal marginal price evaluation techniques.

Furthermore, the impact of emergency events for sample lines outage is evaluated in real time price spikes with and without implementation of emergency demand response program

From the simulation results it can be seen that the emergency demand response program reduces local marginal price spikes of a deregulated power system when emergency events occur.

According to obtained results, EDRP using lead to volatility decrease in local marginal price (LMP). It can be said that solving problems such as congestion in transmission lines, power system reliability decrease and volatility decrease in local marginal price at load network peak hours, is impossible without customer interfering in power market. In other hand Consumer participation, makes the power markets more competition and enhance its performance.

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