Demand Response Model Considering EDRP and TOU Programs

H. Aalami
aalami@modares.ac.ir

G. R. Yousefi, IEEE Member
yousefi@modares.ac.ir

M. Parsa Moghadam, IEEE Member
parsa@modares.ac.ir

Department of Electrical Engineering, Tarbiat Modares University
P.O.Box. 14115-364

***Abstract*- Demand Side Management (DSM) is one of the most important methods which has been used to maximize the benefits of the electric power market participants. In the deregulated power systems, DSM is called Demand Response (DR). In this paper, two DR programs have been focused: Time-Of-Use (TOU) and Emergency Demand Response Program (EDRP). In this paper DR is modeled considering both TOU and EDRP methods, simultaneously, using the single and multi period load models, based on the load elasticity concept. The proposed model is implemented on the peak load of the Iranian Power Grid and the optimum prices for TOU program and the optimum incentives for combined TOU and EDRP programs are determined.**

***Keywords*-- EDRP, TOU, Demand Response, Demand Side Management**

I. INTRODUCTION

Demand Side Management (DSM) introduced by Electric Power Research Institute (EPRI) in the 1980s. DSM 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 fact, DSM is a global term that covers activities such as: Load Management, Energy Efficiency, Energy Saving and so on [1].

Electric power industry bas been faced with restructuring and deregulation. Meanwhile a few new terms created in this new environment, such as "Demand Response" (DR).

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" [2].

DR is able to change the amount and time of electric energy usage so that the best efficiency of consumption takes place in the peak interval [3].

In this paper, we discuss about different DR methods, especially Emergency Demand Response Program (EDRP) and Time of Use (TOU) methods. Then the demand reaction to price is analyzed (self and cross elasticity). In this paper, we consider EDRP and TOU, simultaneously. In section 4, DR is modeled considering the electricity spot price (TOU) and EDRP. The numerical results are shown and the effect of running TOU and EDRP programs, individually and simultaneously, are discussed.

II. DEMAND RESPONSE PROGRAMS

In strategic plan of International Energy Agency (IEA), for 2004-2009 years, DR (analysis and implementation) is dedicated to United State of America [4]. Federal Energy Regulatory Commission (FERC) reported the results of DR investigations and implementations in US utilities and Power Markers [5,6]. In the mentioned report, DR is divided into two basic categories and several subgroups:

A- Incentive-based programs:
- A-1- Direct Load Control (DLC)
- A-2- Interruptible/curtail able service (I/C)
- A-3- Demand Bidding/Buy Back
- A-4- Emergency Demand Response Program (EDRP)
- A-5- Capacity Market Program (CAP)
- A-6- Ancillary Service Markets (A/S)

B- Time-based programs:
- B-1- Time-of-Use (TOU) program
- B-2- Real Time Pricing (RTP) program
- B-3- Critical Peak Pricing (CCP) Program

In this paper, we have focused on EDRP and TOU. So, in the following, these two programs are introduced, briefly.

II-1- Emergency Demand Response Program (EDRP)

Based on historical demand, price data, and short term load forecasting, ISO tries to reduce peak demand. The ISO tries to prevent occurring spike prices, by running the EDRP [7].

Large consumers that like to reduce or cut a portion of their consumption, based on ISO announcements, will participate in this program. The ISO will pay them a significant amount of money (almost 10 times of the electricity price in the off peak period) as an incentive. It is obvious that customers will

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participate in this program, voluntarily. This will produce an amount of uncertainty in the peak reduction, but because of predetermination the incentive amounts and also because no penalty is considered for the consumers which do not reduce or curtail their consumption, participation in this program had been very good results in USA (2005). Fig. 1 shows the implementation results of this program in New York Electricity Market in 2005 [5]. As it is shown, the ISO had been able to return the price to its normal value, by means of forecasting the load curve for 29th of July and running the EDRP and CAP programs. Peak load and price cutting are the program results.

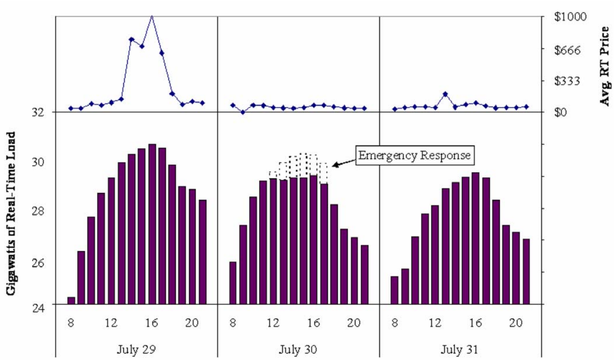

Fig. 1. EDRP and CAP implementation in New York electricity market (2005) [5]

II-2- Time-Of-Use (TOU) Program

In this program, the electricity prices are determined based on the production costs in the same period [5,8,9]. Thus, usually the price in the low load period will be cheap, in the off-peak period will be moderate, and will be high in the peak period. By running this program, the consumers, especially whom able to move their consumption, will adjust themselves with the prices. So, the peak demand will be reduced and loads will transfer from the peak period to off-peak or low periods.

III. LOAD ECONOMIC MODEL

In the first years of the deregulation, usually consumers had not effective participation in the power markets, and Independent Power Producers (IPPs), Regional Transmission Organizations (RTOs) and Regulatory Bodies have been the most effective players in the markets. The consumers were isolated from the benefits and the information of the markets. They had not enough knowledge and hardware to participate in the markets, effectively. On the other hand, so many of consumers prefer to be isolated from the price fluctuations and the risks in the volatile power markets.

This kind of consumers' behavior and their absence in the electricity markets, caused spike prices and congestion in the transmission lines [10].

Fig. 2 shows how the demand elasticity could effect on electric price, significantly [11].

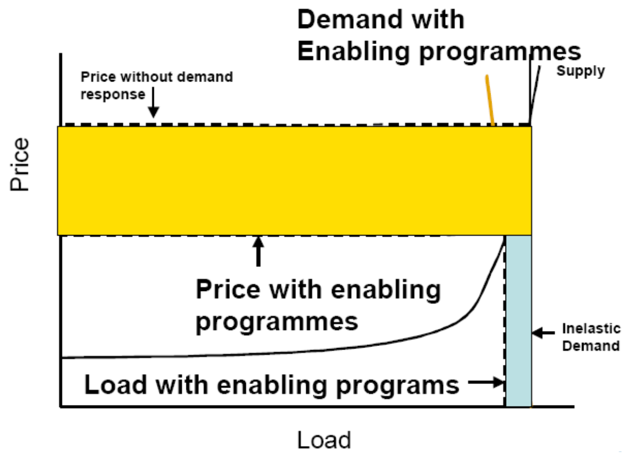

Fig. 2. Effect of demand variation on the electric energy price [11]

Elasticity is defined as the demand sensitivity respect to the price[12]:

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

where:

E=Elasticity of the demand

q = The demand value (MWh)

ρ = Electricity energy price ($/MWh)

ρ_0 = Initial electricity energy price ($/MWh)

q_0 = Initial demand value (MWh)

If the electric energy prices vary for different periods, then the demand reacts one of followings:

i) Some of loads are not able to move from one period to another (e.g. illuminating loads) and they could be only "on" or "off". So, such loads have a sensitivity just in a single period and it is called "self elasticity" [12], and it always has a negative value.

ii) Some consumptions could be transferred from the peak period to the off-peak or low periods. Such behavior is called multi period sensitivity and it is evaluated by "cross elasticity". This value is always positive.

According to equ. (1), self elasticity (E_{aa}) and cross elasticity (E_{ab}) could be written as:

$$E_{aa} = \frac{\Delta D_a}{\Delta \rho_a} \le 0 \qquad (2)$$

$$E_{ab} = \frac{\Delta D_a}{\Delta \rho_b} \ge 0 \qquad (3)$$

where:

ΔD_a = Demand changes in period "a"

$\Delta \rho_a$ = Price changes in period "a"

$\Delta\rho_b$ = Price changes in period "b".

In this paper, we are going to model and formulate how TOU and EDRP programs affect on the electricity demands and prices and how the maximum benefit of customers could be achieved due to these programs.

III-1- Single Period modeling

Suppose that:

d(i) = Customer demand in i-th hour (MWh).

ρ(i) = Spot electricity price in i-th hour ($/MWh).

A(i) = Incentive in i-th hour ($/MWh).

B(d(i)) = Customer's income in i-th hour ($).

And also suppose that the customer changes its demand from $d_o(i)$ (initial value) to d(i), based on the value that is considered for the incentive (A(i)):

$$\Delta d(i) = d_o(i) - d(i) \qquad (MWh) \tag{4}$$

So, incentive prize, P ($), due to running EDRP will be as:

$$P(\Delta d(i)) = A(i).\Delta d(i) \qquad \$ \tag{5}$$

Therefore, the customer's benefit, S ($), for i-th hour will be as follow:

$$S(d(i)) = B(d(i)) - d(i).\rho(i) + P(\Delta d(i)) \qquad \$ \tag{6}$$

To maximize the customer's benefit, $\frac{\partial S}{\partial d(i)}$ should be equal to zero, so:

$$\frac{\partial S}{\partial d(i)} = \frac{\partial B(d(i))}{\partial d(i)} - \rho(i) + \frac{\partial P(\Delta d(i))}{\partial d(i)} = 0 \tag{7}$$

$$\frac{\partial B(d(i))}{\partial d(i)} = \rho(i) + A(i) \tag{8}$$

The benefit function, most often used, is the quadratic benefit function [13,14]:

$$B(d(i)) = B_0(i) + \rho_0(i)[d(i) - d_0(i)]\left\{1 + \frac{d(i) - d_0(i)}{2E(i).d_0(i)}\right\} \tag{9}$$

where:

$B_0(i)$= Benefit when the demand is at nominal value ($d_0(i)$)

$\rho_0(i)$= Nominal electricity price when the demand is nominal.

Considering (8) and (9):

$$\rho(i) + A(i) = \rho_0(i)\left\{1 + \frac{d(i) - d_0(i)}{E(i).d_0(i)}\right\} \tag{10}$$

$$\rho(i) - \rho_0(i) + A(i) = \rho_0(i).\frac{d(i) - d_0(i)}{E(i).d_0(i)} \tag{11}$$

Therefore, customer's consumption will be as follow:

$$d(i) = d_0(i).\left\{1 + \frac{E(i).[\rho(i) - \rho_0(i) + A(i)]}{\rho_0(i)}\right\} \tag{12}$$

In the above equation, if A(i) be equal to zero (i.e. no incentive prize), d(i) will be equal to $d_0(i)$. Thus, the electricity price will not change and price elasticity will be equal to zero.

III-2- Multi Period Modeling

The cross elasticity between i-th and j-th hour is defined as [15]:

$$E_0(i,j) = \frac{\rho_0(j)}{d_0(i)}.\frac{\partial d(i)}{\partial \rho(j)} \tag{13}$$

$$\begin{cases} E_0(i,j) \le 0 & if \quad i = j \\ E_0(i,j) \ge 0 & if \quad i \ne j \end{cases}$$

In (13), we suppose that $\frac{\partial d(i)}{\partial \rho(j)}$ is constant. So, the demand response to price variation could be defined as a linear function [16]:

$$d(i) = d_0(i) + \sum_{i=1}^{24} E_0(i,j).\frac{d_0(i)}{\rho_0(j)}.[\rho(j) - \rho_0(j)] \qquad i = 1,2,...,24 \tag{14}$$

In (14), we have considered a 24 hours interval. If the incentive in j-th hour, A(j), for EDRP program is considered in the energy price, we could write:

$$\Delta\rho(j) = \rho(j) - \rho_0(j) + A(j) \tag{15}$$

A(j) in $/MWh is the incentive which is paid in j-th hour, and it could be defined as a positive value in peak periods and zero in other periods.

Finally, the customer's demand function, considering prices and incentives, could be written as:

$$d(i) = d_0(i) + \sum_{i=1}^{24} E_0(i,j).\frac{d_0(i)}{\rho_0(j)}.[\rho(i) - \rho_0(j) + A(j)] \qquad i = 1,2,...,24 \tag{16}$$

III-3- Final Model

With combining (12) and (16), we will have "final model" as:

$$d(i) = \left\{d_0(i) + \sum_{j=1}^{24} E_0(i,j).\frac{d_0(i)}{\rho_0(j)}.[\rho(j) - \rho_0(j) + A(j)]\right\}. \left\{1 + \frac{E(i)[\rho(i) - \rho_0(i) + A(i)]}{\rho_0(i)}\right\} \quad i = 1,2,...,24. \tag{17}$$

Above equation shows how much should be the customer's consumption to achieve maximum benefit in a 24 hours interval. In the next part, in the numerical results section, we will show how incentives could change the demand curve while running EDRP and TOU Programs.

IV. Numerical Results

Iranian Power Grid is selected to test and analyze the effect of EDRP and TOU programs. The peak load of the Grid in 2006 has occurred on 28th of August [17]. Fig. 3 shows the load curve for the mentioned date. The load curve is divided into three intervals:

Low load period (12.00 p.m. to 9:00 a.m.), off-peak period (9:00 a.m. to 7:00 p.m.) and peak period (7:00 p.m. to 12:00 p.m.).

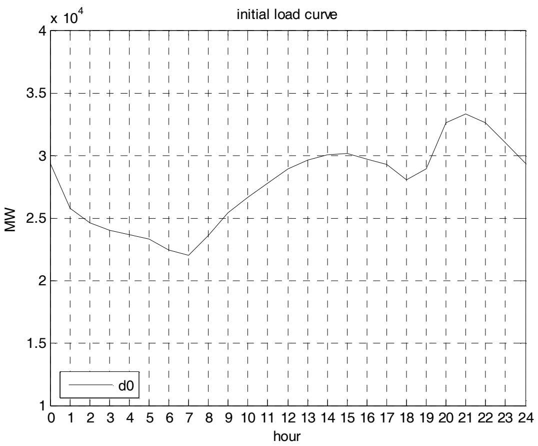

Fig. 3. The peak load curve of the Grid (8/28/2006) [17]

The average electricity energy price in 2006 had been 150 Rials/kWh [18]. We consider 260, 160 and 80 Rials Per kWh for the electricity energy price for peak, off-Peak and low load periods, respectively.

In this step, we considered 150 Rials/kWh as an incentive in EDRP program (equal to the average price of electricity). And also we considered self and cross elasticity as table (1) and the potential for DR programs as 100% .

TABLE 1
SELF AND CROSS ELASTICITIES

	Peak	Off-Peak	Low
Peak	-0.10	0.016	0.012
Off-Peak	0.016	-0.10	0.01
Low	0.012	0.01	-0.10

IV-1- Running of TOU

In Fig. 4, the initial load curve, changed load curve due to running of TOU program in single period case and multi period case, have been shown.

As it could be seen in Fig. 4, based on the difference between the prices and elasticities in different periods, loads are transferred from expensive periods to cheap periods, so that it is possible to create a new peak in previous valley periods.

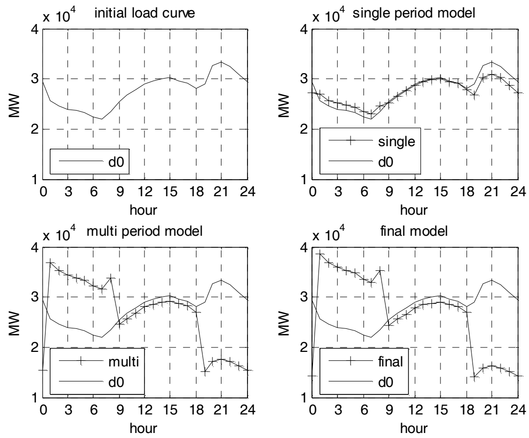

Fig. 4. Effect of TOU program on load curve

In other to show how elasticity values could change the results, previous test is repeated while elasticities (Table 1) are divided by 2. Fig. 5 shows the results. With reducing the elasticity values, TOU program has lower effect on the load shape.

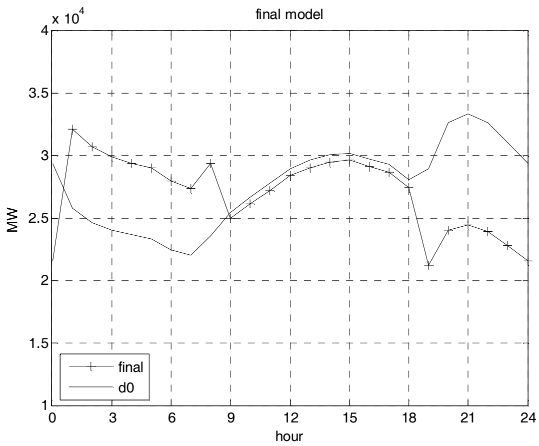

Fig. 5. TOU program with smaller elasticity values

If the ISO sets these prices: 200, 150 and 110 Rials/kWh for the peak, off peak and low periods, respectively, the valley load will be filled up with peak load (Fig. 6).

In this case, the distance between maximum and minimum in load curve will reduce to 5000 MW which was 11500 MW and load factor increases from 80% to 93%.

The load shape will change like Fig. 7 under running TOU and EDRP programs, simultaneously. A 150 Rials/kWh is considered as the incentive. It could be seen in Fig. 7 that incentive cuts the peak load and transfers the demand to the valley period.

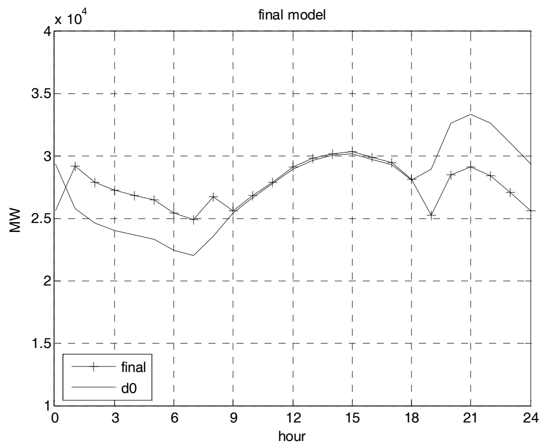

Fig. 6. TOU program, with 200, 150 and 110 Rials/kWh as tariffs for peak, off-peak and low periods

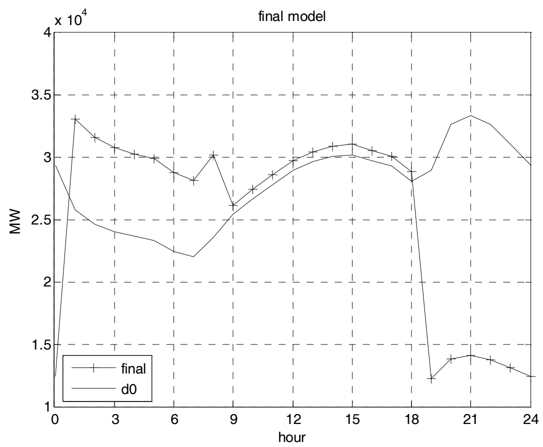

Fig. 7. TOU and EDRP programs (incentive: 150 Rials/kWh)

If TOU and EDRP programs run for just half of the load, the better results will happen in load curve, in smoothness view point (Fig. 8).

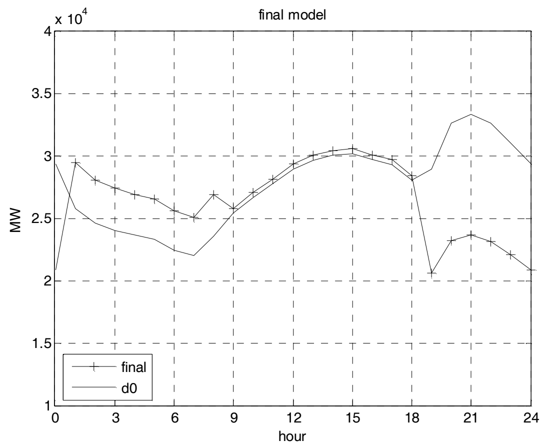

Fig. 8. TOU and EDRP results on half of the load

It is obvious that if a lower value is considered as the incentive, the peak reduction will be smaller. Fig. 9 is the result in the case that incentive be equal to 50 Rials/kWh.

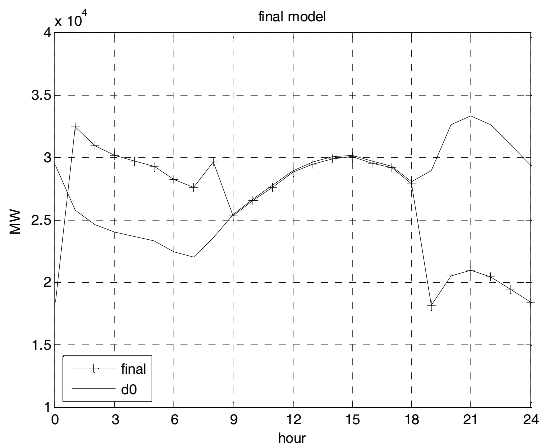

Fig. 9. TOU and EDRP results (incentive 50 Rials/kWh)

If the ISO defines a base load line, customers will adjust themselves with that line and there is no any reason for the customers to reduce their loads lower than defined base load. Fig. 10 shows the results of TOU and EDRP program when 150 Rials/kWh and 23000 MW are defined as the incentive and base load line, respectively.

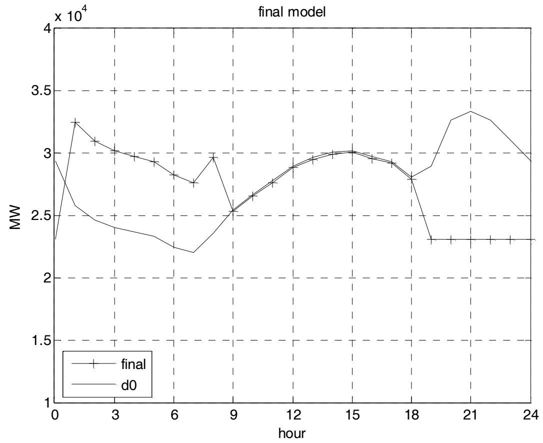

Fig. 10. TOU and EDRP programs with 23000 MW base load line and 150 Rials/kWh incentive

If 23000 MW is considered by the ISO as a base load line, 19 Rials/kWh will be sufficient to reduce the peak load to the mentioned base load line. This value is obtained by a trial–and–error algorithm (see Fig. 11).

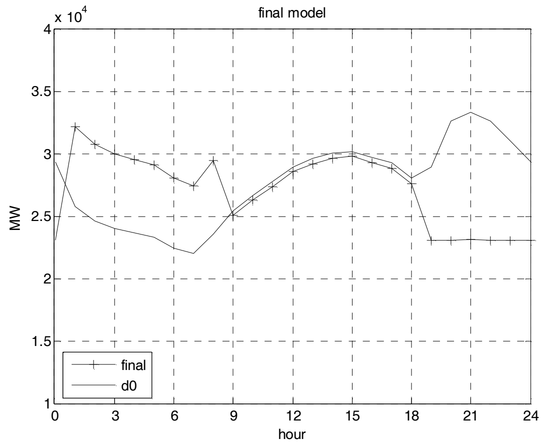

Fig. 11. The optimum value for incentive to cut the peak load to the defined base load line (23000 MW)

V. Conclusion

In this paper, the strategic plan of International Energy Agency (IEA), in 2004-2009 reviewed. A model for running combined TOU and EDRP programs formulated and the test results for peak load of Iranian Power Grid (in 2006) simulated.

It is shown in this paper that demand and load shape could be changed due to the ISO policy in running the Demand Response programs. And the impact of demand elasticities, load curve, TOU prices, incentives in the EDRP and definition of peak, off-peak and low load periods tested and analyzed.

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