Exponential Model Effect of Critical Peak Pricing Programs on Customers' Load Profile

1Shoorangiz Shams Shamsabad Farahani, 2Hossain Tourang, 3Behrang Yousefpour, 4Mehdi Ghasemi Naraghi and 5Seyed Ali Mohammad Javadian

1-5Department of Electrical Engineering, Islamshahr Branch, Islamic Azad University, Tehran, Iran.

Abstract: Recently by appearance of demand response programs (DRPs), many opportunities have been created for voluntary participation of demand-side in electricity markets. The results of such programs are improvement of some technical and economical characteristic of power system. DRPs are divided into two categories which are priced-based and incentive-based demand response programs. The focus of this paper is exponential modeling of critical peak pricing programs (CPP) as most prevalent priced-based DRPs. In this way, nonlinear behavioral characteristic of elastic loads is considered which causes to more realistic modeling of demand response to CPP rates. In order to evaluation of proposed model, the impact of running CPP programs using proposed exponential model on load profile of the peak day of the Iranian power system in 2007 is investigated.

Key words: Demand Response programs, Elasticity, Critical peak pricing programs.

INTRODUCTION

According to the U.S. Department of Energy (DOE) report, the definition of demand response (DR) is: "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" (Department of Energy, 2006).

According to DOE classification, demand response programs (DRPs) are divided into two categories as shown in figure 1.

Fig. 1: Demand response programs.
*Highlighted program has been considered in this study.

对应作者: Shoorangiz Shams Shamsabad Farahani, Department of Electrical Engineering, Islamic Azad University, Islamshahr branch, Tehran, Iran, P. O. Box 3135-369.
E-mail: shoorangiz.farahani@yahoo.com; Cell: +989122261946; Fax: +982188043167
Critical Peak Pricing (CPP) is a relatively new form of priced-based DRPs that relies on very high, critical peak prices. A specified high per-unit rate for usage is in operation during times that the utility defines as critical peak periods. CPP events may be triggered by system contingencies or high prices faced by the utility in procuring power in the wholesale market. The days in which critical peaks occur are not designated in the tariff, but dispatched on relatively short notice as needed, for a limited number of days during the year. CPP rates can be superimposed on either a time of use or fix rate (FERC report, 2006; FERC report, 2008).

In (L. Goel et al., 2008; Faruqui A. and George S., 2005; Aalami H.A. et al., 2009; Aalami H.A. et al., 2010; Schweppe F. et al., 1988; Schweppe F. et al., 1985), a linear economic model for DRPs have been developed. This simple and widely used model is based on an assumption in which demand will change linearly in respect to the elasticity. The outstanding researches considering the use of linear model of responsive demand have been presented and analyzed in (Schweppe F. et al., 1988; Schweppe F. et al., 1985). However, those models do not consider nonlinear behavior of the demand which is of great importance in analyzing and yielding the results.

In this paper, an exponential model to describe price dependent loads is developed such that the characteristics of CPP programs can be imitated. The remaining parts of the paper are organized as following: the definition of elasticity is reviewed in section 2. Exponential modeling of DR based on the concept of price elasticity of demand is developed in section 3. Section 5 is devoted to simulation results where the impact of CPP programs via proposed exponential model on load profile of the peak day of the Iranian power system in 2007 is investigated. Finally, the paper is concluded in section 5.

**Elasticity Definition:**

Generally, electricity consumption like most other commodities, to some extent, is price sensitive. This means when the total rate of electricity decreases, the consumers will have more incentives to increase the demand. This concept is shown in figure 2, as the demand curve.

![Demand Curve](image)

**Fig. 2:** Demand Curve.

Hachured area in fact shows the customer marginal benefit from the use of $d \text{ MWh}$ of electrical energy. This is represented mathematically by:

$$B(d) = \int_{0}^{d} \rho(d).\,d\,d$$

(1)

Based on economics theory, the demand-price elasticity can be defined as follows:

$$e = \frac{\Delta d}{d} / \frac{\Delta \rho}{\rho}$$

(2)

For time varying loads, for which the electricity consumptions vary during different periods, cross-time elasticity should also be considered. Cross-time elasticity, which is represented by cross-time coefficients, relates the effect of price change at one point in time to consumptions at other time periods. The self-elasticity coefficient, $e_{tt}$, (with negative value), which shows the effect of price change in time period $t$ on load of the same time period and the cross-elasticity coefficient, $e_{tt}$, (with positive value) which relates relative changes in
consumption during time period $t$ to the price relative changes during time period $\hat{t}$ are defined by following relations:

$$e_{tt} = \frac{\partial d_t}{\partial \rho_t} \frac{d_t^0}{\rho_t^0}$$

(3)

$$e_{\hat{t}t} = \frac{\partial d_{\hat{t}}}{\partial \rho_{\hat{t}}} \frac{d_{\hat{t}}^0}{\rho_{\hat{t}}^0}$$

(4)

**Exponential Modeling of Elastic Loads:**

The proper offered rates can motivate the participated customers to revise their consumption pattern from the initial value $d_t^0$ to a modified level $d_t$ in period $t$.

$$\Delta d_t = d_t - d_t^0$$

(5)

It is reasonable to assume that customers will always choose a level of demand $d_t$ to maximize their total benefits which are difference between incomes from consuming electricity and incurred costs; i.e. to maximize the cost function given below:

$$B[d_t] - d_t \cdot \rho_t$$

(6)

The necessary condition to realize the mentioned objective is to have:

$$\frac{\partial B[d_t]}{\partial d_t} - \rho_t = 0$$

(7)

Thus moving the last term to the right side of the equality,

$$\frac{\partial B[d_t]}{\partial d_t} = \rho_t$$

(8)

Substituting (8) to (3) and (4), a general relation based on self and cross elasticity coefficients is obtained for each time period $t$ as follows:

$$\frac{\partial d_t}{d_t} = e_{tt} \frac{\partial \rho_t}{\rho_t^0}$$

(9)

By assuming constant elasticity for NT-hours period, $e_{tt} = \text{Constant for } t$, $\hat{t}$ (NT) integration of each term, we obtain the following relationship.

$$\int_{d_{\hat{t}}^0}^{d_{\hat{t}}} \frac{\partial d_{\hat{t}}}{d_{\hat{t}}} = \sum_{t=1}^{NT} \left\{ e_{\hat{t}t} \int_{\rho_t^0}^{\rho_{\hat{t}}^0} \frac{\partial \rho_t}{\rho_t^0} \right\}$$

(10)

Combining the costumer optimum behavior that leads to (8), (9) with (10) yields the exponential model of elastic loads, as follows:

$$d_t = d_t^0 \prod_{t=1}^{NT} \exp \left[ e_{tt} \frac{\left( \rho_t - \rho_t^0 \right)}{\rho_t^0} \right]$$

(11)

Parameter $\eta$ is demand response potential which can be entered to model as follows:

$$d_t = d_t^0 + \eta d_t^0 \prod_{t=1}^{NT} \exp \left[ e_{tt} \frac{\left( \rho_t - \rho_t^0 \right)}{\rho_t^0} \right] - 1$$

(12)
The larger value of $\eta$ means the more customers' tendency to reduce or shift consumption from peak hours to the other hours.

**Simulation Results:**

In this section numerical study for evaluation of proposed model of CPP programs are presented. For this purpose the peak load curve of the Iranian power grid on 28/08/2007 (annual peak load), has been used for our simulation studies. Also the electricity price in Iran in 2007 was 150 Rials. This load curve, shown in figure 3, divided into three different periods, namely valley period (00:00 am-9:00 am), off-peak period (9:00 am-7:00 pm) and peak period (7:00 pm-12:00 pm).

![Fig. 3: Initial load profile.](image)

The selected values for the self and cross elasticities have been shown in Table 1.

<table>
<thead>
<tr>
<th>Self and cross elasticities.</th>
<th>Low</th>
<th>Off-peak</th>
<th>Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>-0.10</td>
<td>0.010</td>
<td>0.012</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.010</td>
<td>-0.10</td>
<td>0.016</td>
</tr>
<tr>
<td>Peak</td>
<td>0.012</td>
<td>0.016</td>
<td>-0.10</td>
</tr>
</tbody>
</table>

Different scenarios are considered as Table 3.

<table>
<thead>
<tr>
<th>Scenario number</th>
<th>CPP rates (Rials/MWh)</th>
<th>Demand response potential (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300 at 20, 21, 22 h</td>
<td>5%</td>
</tr>
<tr>
<td>2</td>
<td>450 at 20, 21, 22 h</td>
<td>5%</td>
</tr>
<tr>
<td>3</td>
<td>600 at 20, 21, 22 h</td>
<td>5%</td>
</tr>
<tr>
<td>4</td>
<td>750 at 20, 21, 22 h</td>
<td>5%</td>
</tr>
<tr>
<td>5</td>
<td>750 at 20, 21, 22 h</td>
<td>10%</td>
</tr>
</tbody>
</table>

The impact of adopting scenarios 1-5 on load profiles have been shown all together in figure 4. As seen, the load of peak periods is reduced. However, Load shift is not sensible. By increasing the value of demand response potential according to scenario 5, the peak reduction is more increased.

Technical characteristics of the load profile in scenario 1-5 have been given in table 2. It is seen that the technical characteristics such as energy and peak reduction, load factor have been improved by adopting considered scenarios. Also the values of peak to valley are improved.

![Table 2: Technical characteristics of the load profile in scenarios 1-2 in comparison with the base case.](image)
Fig. 4: The impact of adopting scenarios 1-5 on load profile.

Figure 5 shows the impact of adopting scenarios 1-5 on energy and peak reduction as well as load factor improvement in percent. As seen, by increase of CPP rate according to scenarios 1-4 the percent of peak reduction and load factor improvement is increased. Moreover by increase of demand response potential according to scenario 5, the percent of peak reduction and load factor improvement are increased. Also the energy reduction has an increasing trend in all scenarios.

Fig. 5: The impact of adopting scenarios 1-5 on energy and peak reduction as well as load factor improvement in percent.

**Conclusion:**

In this paper, an exponential model of demand response program has been introduced. It has been shown that this model could imitate customers' response to CPP program as prevalent DRPs. This model can help sponsor's CPP programs to simulate the behavior of customers for the purpose of improvement of load profile characteristics.

**ACKNOWLEDGEMENT**

The authors gratefully acknowledge the financial and other support of this research, provided by Islamic Azad University, Islamshahr Branch, Tehran, Iran.

**Nomenclature:**

0 Initial state index (Superscript)

$t, \dot{t}$ Time period indices (subscript)

NT Number of hours within period of study

d Load (MW)

$\rho$ Price (Rials/MWh)
\[ \Delta d \]  Demand change (MW)
\[ \Delta \rho \]  Price change (Rials/MWh)
\[ B[d_t] \]  Benefit of consumer at time period \( t \) by consuming \( d_t \)
\( e_{tt} \)  Self elasticity
\( e_{tt} \)  Cross elasticity
\( \eta \)  Demand response potential (%)

REFERENCES