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The study of CPP programs based on logarithmic model in electricity markets

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Abstract

Providing a suitable model for demand response programs (DRPs) in electricity market is a very important factor. In this regard considerable efforts have been carried out to model demand response in electricity market. By using DRPs some technical and economical characteristic of power system are improved. The DRPs are divided into two categories which are priced-based and incentive-based demand response programs. This paper presents a logarithmic 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. Numerical analysis on the load profile of the peak day of the Iranian power system in 2007 is conducted to examine the proposed model. Hence, different scenarios have also been considered. The results reveal the good performance of proposed models. The results are carried out by using MATLAB software.

Keywords: Demand Response programs, Elasticity, Critical peak pricing programs, Electricity market, Iran.

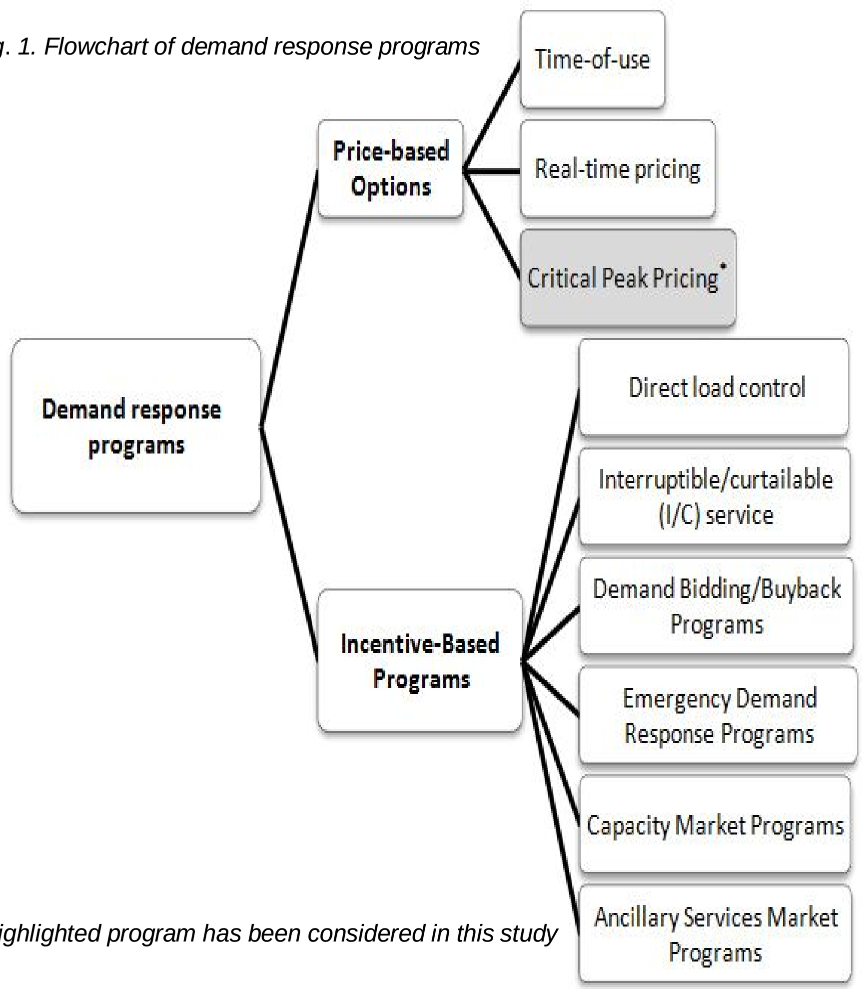
Nomenclature : 0-Initial state index (Superscript);$t, \acute{t}$ - Time period indices (subscript); NT- Number of hours within period of study; d- Load (MW);ρ - Price (Rials/MWh); Δd , $\Delta \rho$ - Demand change (MW) and Price change Price change (Rials/MWh);$B[d_t]$ - Benefit of consumer at time period *t by* consuming d_t ; e_{tt}, e_{tt}- Self elasticity and Cross elasticity;η - Demand response potential (%)

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" (DOE, 2002). According to DOE classification, demand response programs (DRPs) are divided into two categories as shown in Fig.1.

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, 2008).

Fig. 1. Flowchart of demand response programs



**Highlighted program has been considered in this study*

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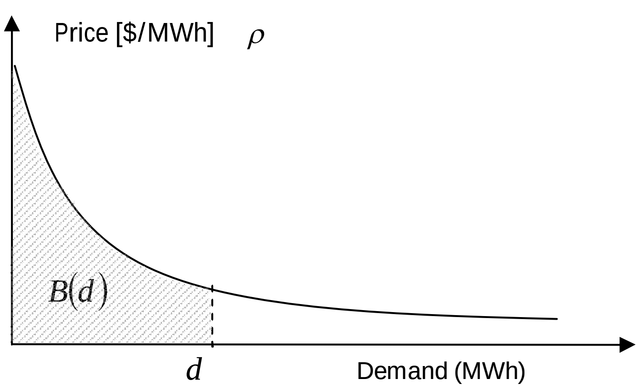
Earlier (Schweppe *et al.,* 1985; Schweppe *et al.,* 1998; Goel *et al.,* 2008; Faruqui & George, 2005; Aalami *et al.,* 2009; Aalami *et al.,* 2010), a linear economic model for DRPs have been developed. This simple and widely used model is based on an assumption in which demand will change linearly in respect to the elasticity. The outstanding researches considering the use of linear model of responsive demand have been presented and analyzed by Schweppe *et al.* (1985, 1998). 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, a logarithmic model to describe price dependent loads is developed such that the characteristics of CPP programs can be imitated.

Fig. 2. Demand curve versus price



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 Fig.2, as the demand curve**.**

Hachured area in fact shows the customer marginal benefit from the use of d MWh of electrical energy (MOE, 2007). This is represented mathematically by:

$$B(d) = \int_0^d \rho(d).\partial d \qquad (1)$$

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

$$\boldsymbol{e} = \frac{\Delta \boldsymbol{d} / \boldsymbol{d^0}}{\Delta \boldsymbol{\rho} / \boldsymbol{\rho}} \qquad (2)$$

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, $e_{t\acute{t}}$ (with positive value) which relates relative changes in consumption during time period *t* to the price relative changes during time period $\acute{t}$ are defined by following relations:

$$e_{tt} = \frac{\partial d_t / d_t^0}{\partial \rho_t / \rho_t} \qquad (3)$$

$$e_{t\acute{t}} = \frac{\partial d_t / d_t^0}{\partial \rho_{\acute{t}} / \rho_{\acute{t}}} \qquad (4)$$

Logarithmic 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.

$$\Delta d_t = d_t - d_t^0 \qquad (5)$$

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:

$$B[d_t] - d_t \cdot \rho_t \qquad (6)$$

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

$$\frac{\partial B[d_t]}{\partial d_t} - \rho_t = 0 \qquad (7)$$

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

$$\frac{\partial B[d_t]}{\partial d_t} = \rho_t \qquad (8)$$

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:

$$\frac{\partial d_t}{d_t^0} = e_{t\acute{t}} \frac{\partial \rho_{\acute{t}}}{\rho_{\acute{t}}} \qquad (9)$$

By assuming constant elasticity for NT-hours period, $e_{t\acute{t}}$ = Constant for t, ť □ NT integration of each term, we obtain the following relationship.

$$\int_{d_t^0}^{d_t} \frac{\partial d_t}{d_t^0} = \sum_{\acute{t}=1}^{NT} \left\{ e_{t\acute{t}} \left[\int_{\rho_{\acute{t}}^0}^{\rho_{\acute{t}}} \frac{\partial \rho_{\acute{t}}}{\rho_{\acute{t}}} \right] \right\} \qquad (10)$$

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

$$d_t = d_t^0 + d_t^0 \prod_{\acute{t}=1}^{NT} Ln\left(\frac{\rho_{\acute{t}}}{\rho_{\acute{t}}^0}\right)^{e_{t\acute{t}}} \qquad (11)$$

Parameter η is demand response potential which can be entered to model as follows:

$$d_t = d_t^0 + \eta d_t^0 \prod_{\acute{t}=1}^{NT} Ln\left(\frac{\rho_{\acute{t}}}{\rho_{\acute{t}}^0}\right)^{e_{t\acute{t}}} \qquad (12)$$

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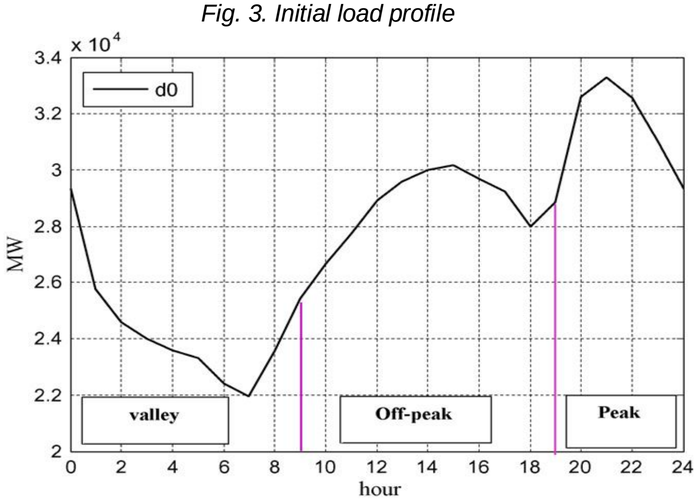
The larger value of η means the more customers' tendency to reduce or shift consumption from peak hours to the other hours.

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 (Unit of Iranian currency). This load curve, shown in Fig.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



The selected values for the self and cross elasticity have been shown in Table 1. Different scenarios are considered as Table 2. The impact of adopting scenarios 1-5 on load profiles have been shown all together in Fig. 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.

Table 1. Self and cross elasticity

	Low	Off-peak	Peak
Low	-0.10	0.010	0.012
Off-peak	0.010	-0. 10	0.016
Peak	0.012	0.016	-0. 10

Technical characteristics of the load profile in scenario 1-5 have been given in Table 3. 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. The considered scenarios

Scenario number	CPP rates (Rials/MWh)	Demand response potential (%)
1	300 at 20, 21, 22 h	5%
2	450 at 20, 21, 22 h	5%
3	600 at 20, 21, 22 h	5%
4	750 at 20, 21, 22 h	5%
5	750 at 20, 21, 22 h	15%

Fig.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. 4. The impact of adopting scenarios 1-5on load profile

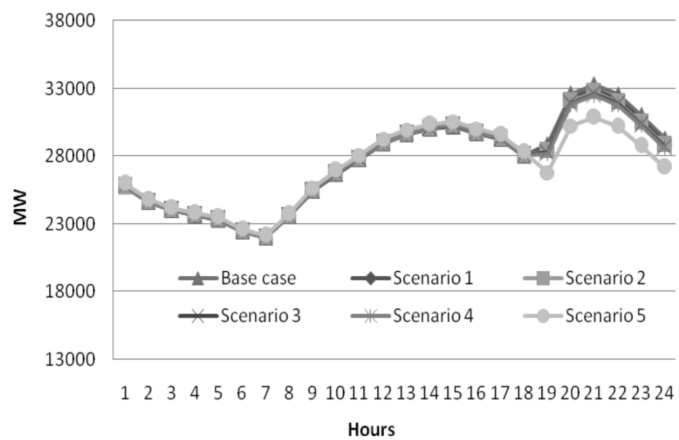
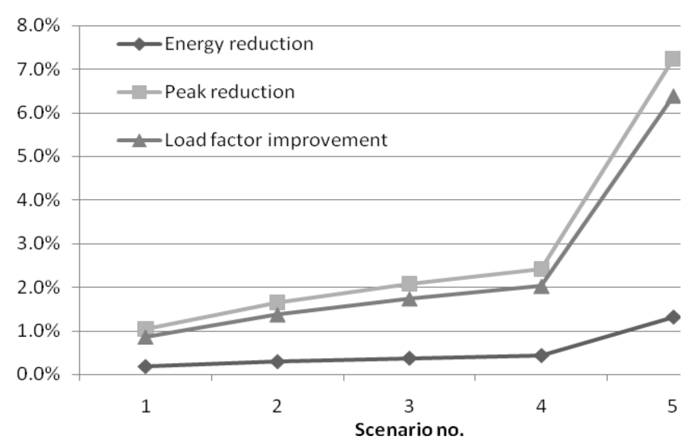


Fig. 5. The impact of adopting scenarios 1-5 on energy and peak reduction as well as load factor improvement in percent.



Conclusion

This paper presents a logarithmic model of demand response. The proposed model contains appropriated characteristics to model response of customers participated in CPP programs as prevalent DRPs. By using this model, CPP programs can easily be modeled and the behavior of participated customers for the purpose of improvement of load profile characteristics can be simulated. Simulation results which have been carried out on Iranian power system showed viability of the proposed model.

Table 3. Technical characteristics of the load profile in scenarios 1-2 in comparison with the base case.

	Energy (MWh)	Energy reduction (%)	Peak (MW)	Peak reduction (%)	Load factor	Load factor improvement (%)	Peak to valley (MW)
Base case	662268	0	33286	0	0.829012	0	11318
Scenario 1	661017.4322	0.2%	32939.919	1.0%	0.83614	0.9%	10944.51
Scenario 2	660285.8969	0.3%	32737.474	1.6%	0.84038	1.4%	10726.03
Scenario 3	659766.8644	0.4%	32593.837	2.1%	0.84342	1.7%	10571.02
Scenario 4	659364.2714	0.4%	32482.424	2.4%	0.845796	2.0%	10450.78
Scenario 5	653556.8143	1.3%	30875.271	7.2%	0.881985	6.4%	8716.348

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