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Using Exponential Modeling for DLC Demand Response Programs in Electricity Markets

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Abstract: Deregulation of power system has introduced new objectives and subjects in electric power systems. Along with expansion of deregulated systems in countries, new subjects such as Demand Response Programs (DRPs) have been provided to evaluate the effect of demand-side in electricity market. Participation of demand-side in network improves power system utilization, operation and also has a great effect on system social welfare. DRPs are divided into two categories which are priced-based and incentive-based demand response programs.With Regard to the problem, in this study an exponential modeling of Direct Load Control programs (DLC) in investigated as incentive-based DRPs. In order to more realistic modeling of demand response to DLC rates, the nonlinear behavioral characteristic of elastic loads is incorporated. Iranian power system with load profile of the peak day is considered to evaluate the effectiveness of the proposed technique. Simulation results demonstrate the great impact of running DLC programs using the proposed exponential model. Simulation results are carried out on MATLAB software by numerical simulations.

Key words: Demand response programs, direct load control programs, elasticity

INTRODUCTION

According to the U.S. Department of Energy (DOE) report, t edefinition 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 Fig. 1.

In Direct Load Control (DLC) programs, a utility or system operator as programs' sponsors, remotely shuts down or cycles a customer's electrical equipment very quickly. These programs triggered by system or local reliability contingencies or when programs' sponsor want to eschew high peak electricity purchases and in exchange for an incentive payment or bill credit. DLC has been in operation for at least two decades in the U.S. electricity markets (FERC report, 2006, 2008).

In considerable research works, a linear economic model for DRPs have been used (Goel *et al*., 2008; Faruqui *et al*., 2005; Aalami *et al*., 2009; Aalami *et al*., 2010; Schweppe *et al*., 1988 and Schweppe *et al*., 1985). 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 *et al*. (1988) and Schweppe *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 study, an exponential model to describe price dependent loads is developed such that the characteristics of DLC programs can be imitated.

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. This is represented mathematically by:

$$B(d) = \int_0^d \rho(d).\partial d \tag{1}$$

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

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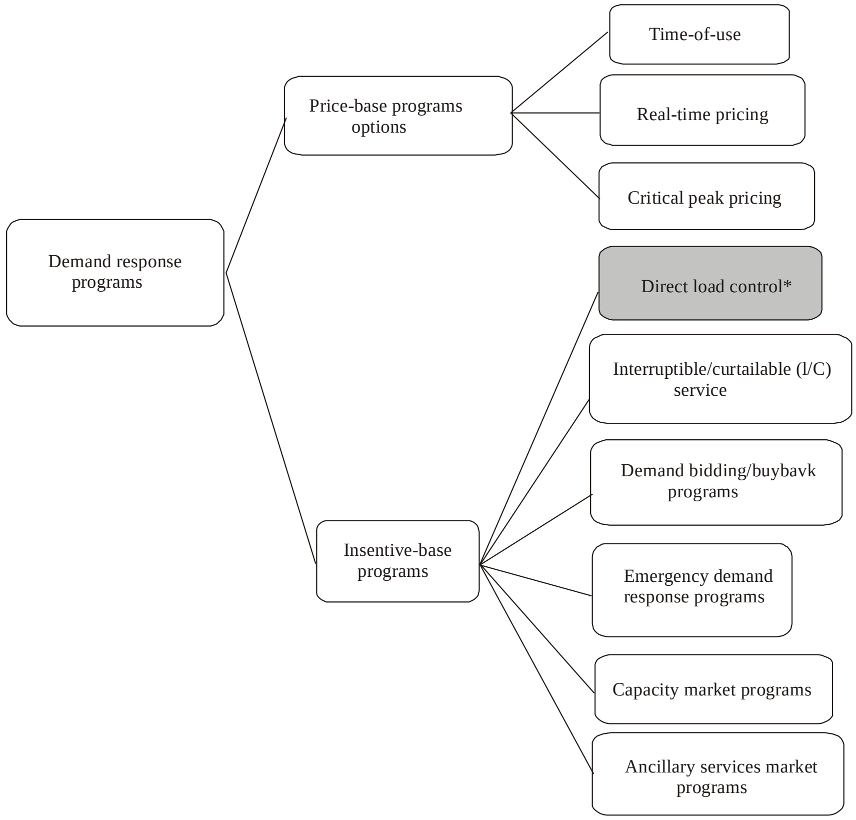

Fig. 1: Demand response programs, *: Highlighted program has been considered in this study

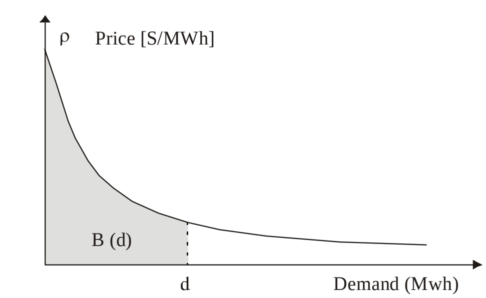

Fig. 2: Demand curve

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

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, $e_{tt'}$, (with positive value) which relates relative changes in consumption during time period *t* to the price relative changes during time period t′ are defined by following relations:

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

$$e_{tt'} \frac{\partial d_t / d_t}{\partial \rho_{t'} / \rho_i^0} \qquad (4)$$

Exponential modeling of elastic loads: The proper offered rates can motivate the participated customers to revise their consumption pattern from the initial value d^0_t to a modified level d_t in period t.

$$\Delta d_t = d_t - 1d_t^0 \qquad (5)$$

Total incentive paid to customer in programs which contain incentive inc_t for load reduction in period t, will be as follows:

$$INC(\Delta d_t) = inc_t.(d_t^0 - d_t) \tag{6}$$

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:

$$B[d_t] - d_t.\rho_t + INC(\Delta d_t) \tag{7}$$

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

$$\frac{\partial B[d_t]}{\partial d_t} - \rho_t + \frac{\partial INC(\Delta d_t)}{\partial d_t} = 0 \tag{8}$$

Thus moving the two last term to the right side of the equality:

$$\frac{\partial B[d_t]}{\partial d_t} = \rho_t + inc_t \tag{9}$$

Substituting (9) to (3) and (4), a general relation based on self and cross elasticity coefficients is obtained for each time period t as follows:

$$\frac{\partial d_t}{d_t} = e_{tt'}\frac{\partial(\rho_{t'} + inc_{t'})}{\rho_{t'}^0} \tag{10}$$

By assuming constant elasticity for NT-hours period, $e_{tt'} = 1$ Constant for t, t′ϵ NT integration of each term, we obtain the following relationship.

$$\int_{d_t^0}^{dt}\frac{\partial d_t}{d_t} = \sum_{t=1}^{NT}\left\{e_{tt'}\left[\int_{\rho_t^0}^{\rho_t}\frac{\partial \rho_{t'}}{\rho_{t'}^0} + \int_0^{inc_t}\frac{\partial inc_{t'}}{\rho_{t'}^0}\right]\right\} \tag{11}$$

Combining the costumer optimum behavior that leads to (8), (9) with (11) yields the exponential model of elastic loads, as follows:

$$d_t = d_t^0 \prod_{t=1}^{NT} \exp\left[e_{tt'}.\frac{\rho_{t'} + inc_{t'} - \rho_{t'}^0}{\rho_{t'}^0}\right] \tag{12}$$

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

$$d_t = d_t^0 + \eta d_t^0\left\{\prod_{t=1}^{NT} \exp\left[e_{tt'}.\frac{\left(\rho_{t'} + inc_{t'} - \rho_{t'}^0\right)}{\rho_{t'}^0}\right] - 1\right\} \tag{13}$$

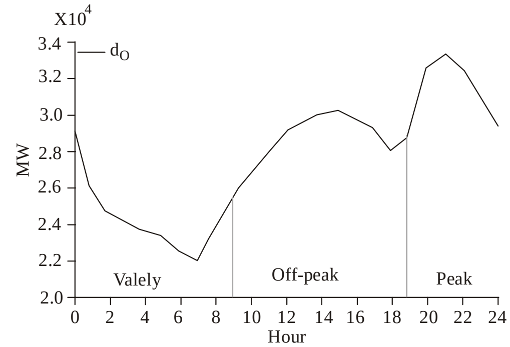

Fig. 3: Initial load profile

Table 1: self and cross elasticities

	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

Table 2: The considered scenarios

Scenario No.	DLC rates (Rials/MWh)	Incentive in peak periods (Rials/MWh)	Demand response potential (%)
1	Flat 150	50	10
2	Flat150	100	10
3	Flat 150	150	10
4	Flat 150	200	10
5	Flat 150	200	15
6	Flat 150	200	20

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 DLC 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 (Ministry of Energy of IRAN, 2007). Also the electricity price in Iran in 2007 was 150 Rials. 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).

The selected values for the self and cross elasticities have been shown in Table 1. Different scenarios are considered as Table 2.

The impact of adopting scenarios 1-6 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 scenarios 5 and 6, the peak reduction is more increased.

Technical characteristics of the load profile in scenario 1-6 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

Table 3: Technical characteristics of the load profile in scenarios 1 and 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	0.0	33286.000	0	0.829012	0.0	11318.00
Scenario	1660233.5592	0.3	32682.627	1.8	0.841723	1.5	10661.27
Scenario	2658855.8198	0.5	32188.627	3.3	0.852858	2.9	10112.61
Scenario	3658024.2229	0.6	31784.174	4.5	0.862620	4.1	9652.172
Scenario	4657648.5049	0.7	31453.036	5.5	0.871204	5.1	9263.689
Scenario	5655338.7573	1.0	30792.053	7.5	0.886780	7.0	8492.031
Scenario	6653029.0098	1.4	30998.070	6.9	0.877782	5.9	8587.375

Table 4: Economical characteristics of the load profile in scenarios 1 and 2 in comparison with the base case

	Bill in scenario 1 (Rials/Day)	Incentive (Rials/Day)	Bill reduction (Profit) (%)
Base case	99340200.00	-	-
Scenario 1	99035033.88	0	0.3
Scenario 2	98828372.97	170063.18	0.5
Scenario 3	98703633.44	618598.28	0.6
Scenario 4	98647275.73	1269887.7	0.7
Scenario 5	98300813.59	2066514.2	1.0
Scenario 6	97954351.46	3099771.3	1.4

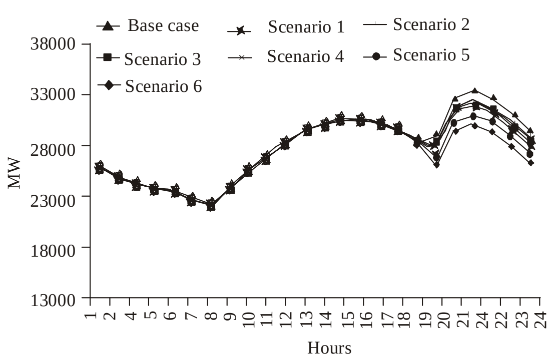

Fig. 4: The impact of adopting different scenarios on load profile

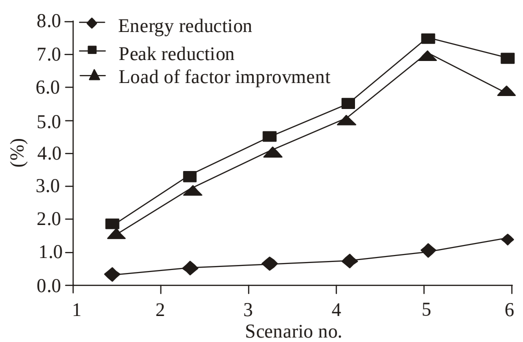

Fig. 5: The impact of adopting scenarios 1-6 on energy and peak reduction as well as load factor improvement in percent

considered scenarios. Also the values of peak to valley are improved.

Figure 5 shows the impact of adopting scenarios 1-6 on energy and peak reduction as well as load factor improvement in percent. As seen, by increase of incentive rate according to scenarios 1-5 the percent of peak reduction and load factor improvement is increased. But by increase of demand response potential according to scenarios 5 and 6, the percent of peak reduction and load factor improvement are slightly reduced due to the load shifting. The energy reduction has an increasing trend in all scenarios.

According to data reported in Table 4 which are economical characteristics of the load profile in different scenarios, running DLC program is profitable for participated customers. By increase of incentive rate and demand response potential according to scenario 1-6 customers' profit is increased and it leads to more satisfaction of customers to participate in DLC program.

NOMENCLATURE

0	Initial state index (superscript)
T, t	Time period indices (subscript)
NT	Number of hours within period of study
d	Load (MW)
ρ	Price (Rials/MWh)
d	Demand change (MW) Demand change (MW)
ρ	Price change 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
inc_t	incentive payment for load reduction in period t
η	Demand response potential (%)

CONCLUSION

In this study a suitable model for demand response investigated. Where, an exponential model of demand response program successfully presented. The proposed technique showed an appropriate performance in modeling customers' response to DLC program as common DRPs. Simulation results which have been obtained on Iranian power system showed the flexibility and suitability of the proposed method. Application to a real world power system such as Iranian power system guarantees the viability of the proposed method.

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