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Direct Load Control Programs by using of Logarithmic Modeling in Electricity Markets

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Abstract: In this study a logarithmic modeling for Direct Load Control programs (DLC) as incentive-based Demand Response Programs (DRPs) is presented. The proposed model considers nonlinear behavioral characteristic of elastic loads which causes to more realistic modeling of demand response to DLC rates. To demonstrate the validity of the proposed technique, a real world power system is considered as test system. Where, Iranian power system is investigated. Simulation results emphasis on the effectiveness impact of running DLC programs using proposed logarithmic model on load profile of the peak day of the proposed power system.

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

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" (US 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; FERC report, 2008).

In (Goel *et al*., 2008; Faruqui and George, 2005; Aalami *et al*., 2006; Aalami *et al*., 2010; Schweppe *et al*., 1988; Schweppe *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 *et al*., 1988; 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, a logarithmic 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 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:

$$e = \frac{\Delta d / d^0}{\Delta \rho / \rho} \tag{2}$$

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

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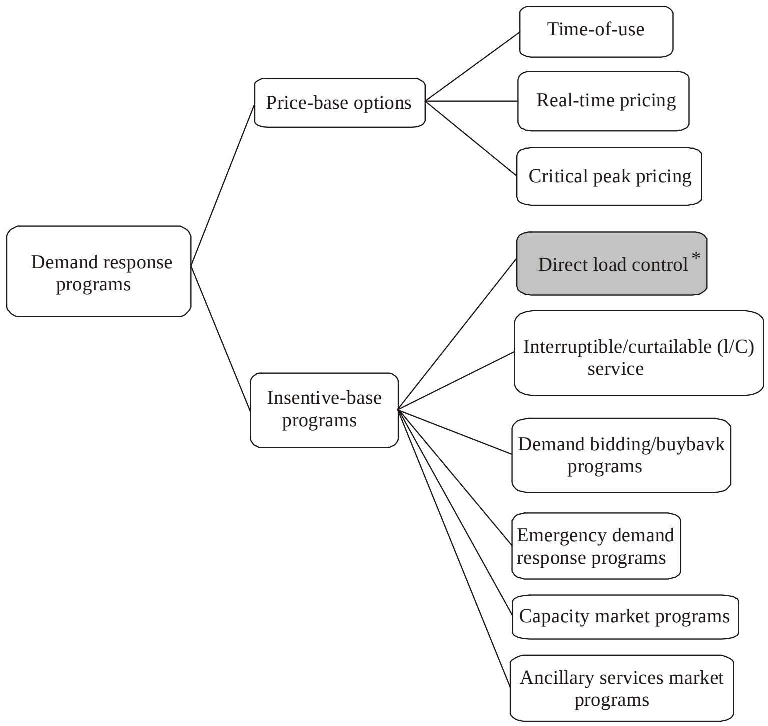

Fig. 1: Demand response programs (*: Highlighted program has been considered in this study)

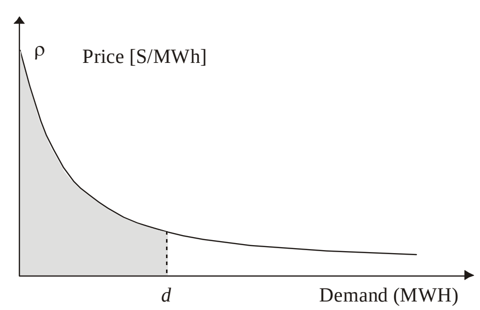

Fig. 2: Demand curveg

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:

$$e_{tt} = \frac{\partial d_t / d_t^0}{\partial \rho_t / \rho_t} \tag{3}$$

$$e_{tt'} = \frac{\partial d_t / d_t^0}{\partial \rho_{t'} / \rho_{t'}} \tag{4}$$

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.

$$\Delta d_t = d_t - d_t^0 \tag{5}$$

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:

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

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

$$\frac{\partial B[d_t]}{\partial d_t} = \rho_t + inc_t \qquad (9)$$

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:

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

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

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

Combining the costumer optimum behavior that leads to (9), (10) with (11) yields the power model of elastic loads, as follows:

$$d_t = d_t^0 + d_t^0 \prod_{t=1}^{NT} Ln\left[\frac{(\rho_{t'} + inc_{t'})^2}{\rho_{t'}(\rho_{t'}^0 + inc_{t'})} \right]^{e_{tt'}} \qquad (12)$$

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

$$d_t = d_t^0 + \eta d_t^0 \prod_{t=1}^{NT} Ln\left[\frac{(\rho + inc_{t'})^2}{\rho_{t'}(\rho + inc_{t'})} \right]^{e_{tt'}} \qquad (13)$$

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. Also the electricity price in Iran in 2007 was 150 Rials.(unit of lranian 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). 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 considered scenarios. Also the values of peak to valley are improved.

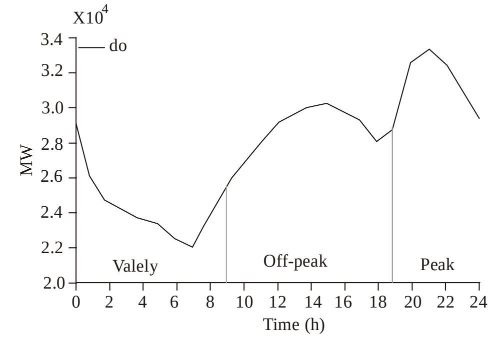

Fig. 3: Initial load profile

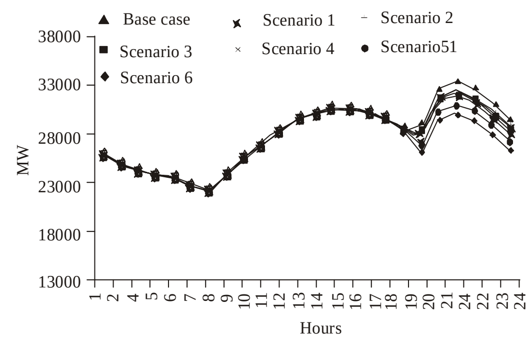

Fig. 4: The impact of adopting different scenarios on load profile

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	Flat 150	100	10
3	Flat 150	150	10
4	Flat 150	200	10
5	Flat 150	200	15
6	Flat 150	200	20

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	662268.000	0	33286.00	0	0.829012	0	11318.000
Scenario 1	658115.7397	0.6	32136.91	3.5	0.853271	2.9	10077.900
Scenario 2	658581.4982	0.6	32265.80	3.1	0.850464	2.6	10217.000
Scenario 3	657265.7287	0.8	31901.67	4.2	0.858453	3.6	9824.039
Scenario 4	656153.2615	0.9	31593.81	5.1	0.865350	4.4	9491.794
Scenario 5	653095.8922	1.4	30747.72	7.6	0.885020	6.8	8578.691
Scenario 6	650038.5230	1.8	30664.87	7.9	0.883256	6.5	8428.841

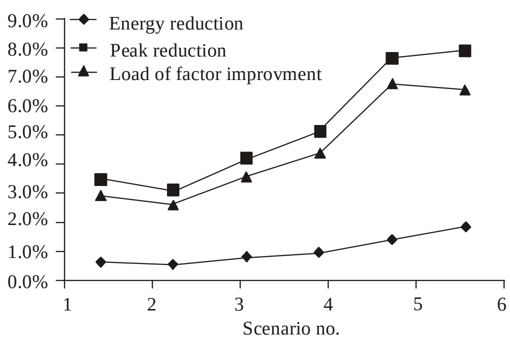

Fig. 5: The impact of adopting scenarios 1-6 on energy and peak reduction as well as load factor improvement in percent

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. Moreover by increase of demand response potential according to scenarios 5 and 6, the percent of peak reduction is increased, but load factor improvement is 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.

CONCLUSION

The study proposes a logarithmic model of demand response program. It has been investigated that the presented model could resemble customers' response to DLC program as predominate DRPs. This model can help sponsor's DLC programs to simulate the behavior of customers for the purpose of improvement of load profile characteristics as well as satisfaction of customers. An actual power system has been considered to evaluate the proposed method. Simulation results showed the impressiveness of the proposed technique.

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 ase	99340200	-	-
Scenario 1	98393000	323880	1.0
Scenario 2	98212000	575100	1.1
Scenario 3	97419000	1170500	1.9
Scenario 4	96515000	1907800	2.8
Scenario 5	95103000	2861700	4.3
Scenario 6	93690000	3815600	5.7

NOMENCLATURE

0	Initial state index (superscript)
t, t'	Time period indices (subscript)
NT	Number of hours within period of study
d	Load (MW)
$\Delta\rho$	Price (Rials/MWh)
Δd	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 (%)

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