Smart Environment Effect on Running Logarithmic-Based Model of Emergency Demand Response Programs in Electricity Markets

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Abstract: The deregulation of power system has introduced new challenges in the field of power system utilization. The main goal of deregulation can be summarized as defining a competitive market for maximizing the overall social welfare while maintaining power system reliability. The consumers have a vital role in new electricity market because their offer in pool markets has a great effect on power system operation. Therefore, it is necessary to modeling demand-side responses in electricity market. A new model for demand-side should be capable of considering the objectives and interests of each stakeholder and also should be based on technical and economical analysis. Demand response programs (DRPs) are new tools to analysis effect 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 goal of this paper is logarithmic modeling of emergency demand response programs (EDRP) as incentive-based DRPs**.** In Regard to this purpose, nonlinear behavioral characteristic of elastic loads is considered which causes to more realistic modeling of demand response to EDRP 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 EDRP programs using proposed logarithmic model on load profile of the peak day of the proposed power system.

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1. Introduction

A power system which is modern and intelligent is referred to Smart Grid. This system would have a wide range of advantages for electrical power industry. Smart Grid's characteristics will help customers to respond to changes in electricity price and vary their energy consumption during the day more effectively. In this new environment, even smallest customers would have the ability to participate in power market and to adjust their consumption with electricity price to reach the highest welfare. Enabled by Smart Grid infrastructures, each customer would be able to install his own electric plant and appear as a producer who sells power to the grid at times of extra production [1-3].

U.S. Department of energy defines Smart grid as today's grid joined by advanced metering and control devices such as Information Technology (IT), sensors, high speed, real-time two way communications, energy Storages, Distributed Generation (DG), In-home energy controllers, automated home energy use.

Enabled by smart infrastructures, each customer will pay the instantaneous market price (depending on market, price will be determined every hour, half an hour or every quarter). Smart grid enables the use of distributed generation in all voltage levels and with real time pricing and smart meters, even domestic customers would be able to install their own distributed generator. Domestic generators such as wind turbines or photovoltaic cells would help customers to reduce their energy bills and even sell extra to demand electricity to the grid.

Hybrid cars would be able to act as distributed storages, storing the energy at times of low electricity price and discharging the stored energy at times of high price. An in-home controller would be needed to control all of these actions. The controller receives energy spot price trough high speed connections and controls home appliances. In other words, it makes it possible for customers to use electricity as flexible as possible. For example the controller can be set to increase room temperature at times of high spot price, or to turn on washing machines at times of low spot price (2 or 3 am).
Some of Smart Grid's characteristics can be summarized as figure 1.

According to the U.S. Department of Energy (DOE) report, he 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"[4].

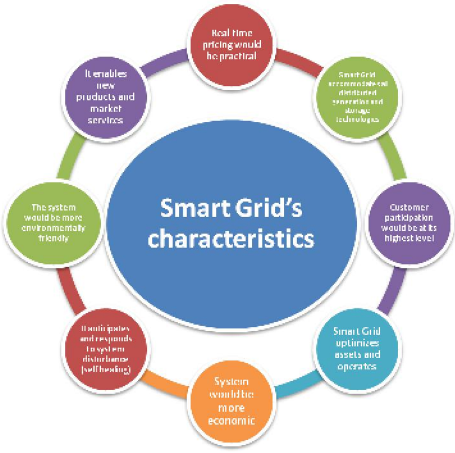

Figure 1: Smart Grid's characteristics

According to DOE classification, demand response programs (DRPs) are divided into two categories as follows:

Price-based Options

- Time-of-use
- Real-time pricing
- Critical Peak Pricing

Incentive-Based Programs

- Direct load control
- Interruptible/curtailable (I/C) service
- Demand Bidding/Buyback Programs
- Emergency Demand Response Programs *
- Capacity Market Programs
- Ancillary Services Market Programs

In this paper, we focus on Emergency Demand Response Programs (EDRPs) as incentive-based programs. In EDRPs a significant amount of money (almost 10 times of the off peak electricity price) as an incentive payments provide to customers who reduce their load during reliability-triggered events; EDRPs may or may not contain penalties for non respondent customers. However, participation in such programs is voluntary. Running these programs had been very good results in USA. Figure 2 shows the implementation results of this program in New York Electricity Market in 2002 [4]. As it is shown, the ISO had been able to mitigate the price spark and turn prices back to its normal value. Also Peak load reduction is another result of EDRP implementation [5, 6].

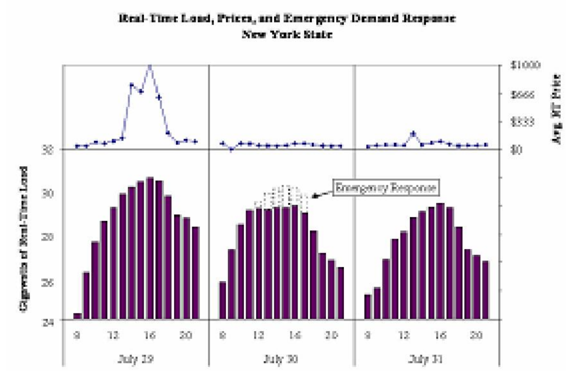

Figure 2. Impact of New York ISO emergency demand response during July 2002[5]

Considerable researches have been done to introduce and extend linear economic modeling of DRPs [7-12]. This simple and widely used model is based on an assumption in which demand will change linearly in respect to the elasticity. Based on nonlinear behavior of real demand, those models don't be able to simulate demand responses accurately.

In this paper, a logarithmic model to describe price dependent loads is developed such that the characteristics of EDRP programs can be imitated. Also Smart Grid as a new tool for better execution of EDRP programs is introduced, modeled and analyzed. The remaining parts of the paper are organized as following: the definition of elasticity is reviewed in section 2. Logarithmic 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 EDRP programs via proposed exponential model on load profile of the peak day of the Iranian power system in 2007 is investigated. The impact of Smart grid on EDRP programs is discussed and it is shown that EDRP programs would be executed more effectively in a smart grid. Finally, the paper is concluded in section 5.

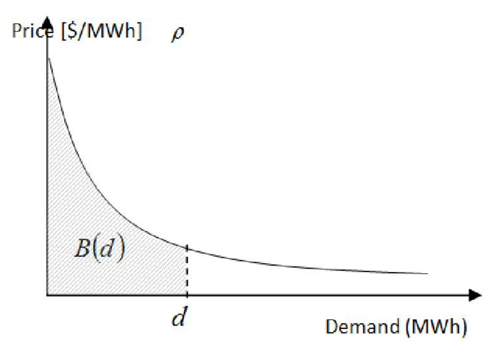

Figure 3: demand curve

2. 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 3, 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:

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

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 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_{tf},(with positive value) which relates relative changes in consumption during time period t to the price relative changes during time period f are defined by following relations:

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

$$e_{tf} = \frac{\partial d_t / d_t^0}{\partial \rho_f / \rho_f} \tag{4}$$

3. 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:

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

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:

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

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:

$$\frac{\partial d_t}{d_t^0} = e_{tf} \frac{\partial(\rho_f + inc_f)}{\rho_f + inc_f} \tag{10}$$

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

$$\int_{d_t^0}^{d_t} \frac{\partial d_t}{d_t^0} = \sum_{f=1}^{NT} \left\{ e_{tf} \left[\int_{\rho_f^0}^{\rho_f} \frac{\partial \rho_f}{\rho_f + inc_f} + \int_0^{inc_f} \frac{\partial inc_f}{\rho_f + inc_f} \right] \right\} \tag{11}$$

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

$$d_t = d_t^0 + d_t^0 \prod_{f=1}^{NT} Ln \left[\frac{(\rho_f + inc_f)^2}{\rho_f(\rho_f^0 + inc_f)} \right]^{e_{tf}} \tag{12}$$

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

$$d_t = d_t^0 + \eta d_t^0 \prod_{f=1}^{NT} Ln \left[\frac{(\rho_f + inc_f)^2}{\rho_f(\rho_f^0 + inc_f)} \right]^{e_{tf}} \tag{13}$$

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

4. Simulation results

In this section numerical study for evaluation of proposed model of EDRP programs in smart and non-smart grids 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 [13]. Also the electricity price in Iran in 2007 was 150 Rials[1]. This load curve, shown in figure 4, 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).

[1] Unit of Iranian currency.

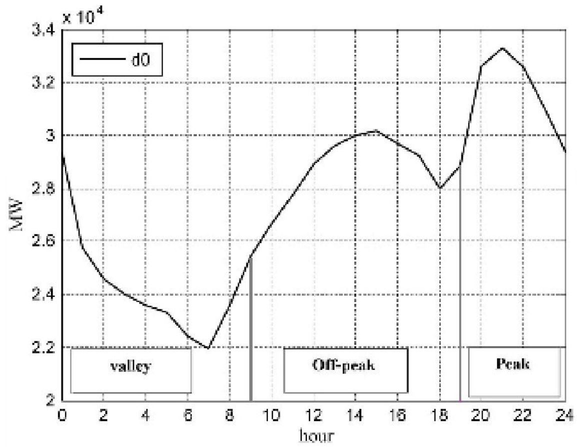

Figure 4: Initial load profile

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

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

As it has been discussed in the introduction section, smart grid helps customers to be able to buy less energy from grid at times of high price, by shifting loads, using their own DG plant or even through discharging batteries of their hybrid vehicle charged during the last night. So Smart Grid's characteristics can be added to the proposed model as an increase in self and cross elasticities of demand between different time periods. It is assumed that in smart environment, demand response potential increases for 10% and reaches a portion of 40%. Elasticities between different time intervals are increased comparing to the case of non-smart grid. The increase is 10% for self elasticities and 100% for cross. In order to investigate about the effect of smart grid on the considered DRP, different scenarios are considered according to Table 2.

Table 2: The Considered Scenarios

Scenario number	Grid type	EDRP rates (Rials/MWh)	Incentive in peak periods (Rials/MWh)	Demand response potential (%)
1	Non-smart	Flat 150	30	10%
2	Non-smart	Flat 150	60	10%
3	smart	Flat 150	30	40%
4	smart	Flat 150	60	40%

The impact of adopting scenarios 1-4 on load profile have been shown all together in figure 5.

As it is seen in all scenarios, the load of peak periods is reduced. In scenario 1 and 2, load shift effect is not sensible. By considering smart grid (according to scenarios 3 and 4), the peak reduction and load shift are more increased. It shows that smart grid leads to an effective peak reduction and load shift.

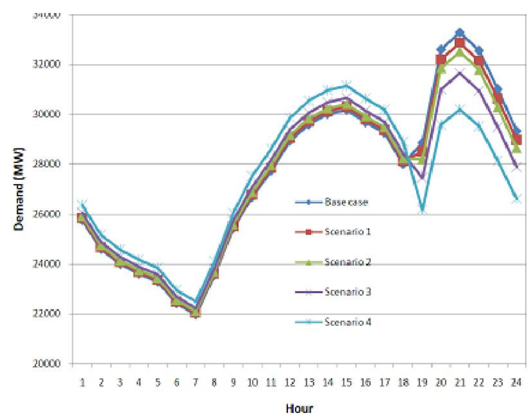

Figure 5: The impact of adopting different scenarios on load profile

Technical characteristics of the load profile in scenario 1-4 have been given in table 3. It is seen that the technical characteristics such as energy and peak reduction, values of load factor and peak to valley in different scenarios have been improved respect to the base case.

Table 3: Technical characteristics of the load profile in scenarios 1-4 in comparison with the base case.

	Base case	Scenario 1	Scenario 2
Energy (MWh)	662268	661592.7	661262.5
Energy reduction	0	0.1%	0.2%
Peak (MW)	33286	32874.4	32513.7
Peak reduction	0	1.2%	2.3%
load factor	0.829	0.839	0.847
Load factor improvement	0	1.1%	2.2%
Peak to valley (MW)	11318	10842.2	10415.4

	Base case	Scenario 3	Scenario 4
Energy (MWh)	662268	659566.7	658245.8
Energy reduction	0	0.4%	0.6%
Peak (MW)	33286	31639.6	31137.5
Peak reduction	0	4.9%	6.5%
load factor	0.829	0.869	0.881
Load factor improvement	0	4.8%	6.3%
Peak to valley (MW)	11318	9414.8	8648.5

Figure 6 shows the impact of adopting scenarios 1-4 on energy and peak reduction as well as load factor improvement in percent. By looking to these figures can be concluded that for a specific incentive rate, smart environment causes to better results. Also by increasing the amount of incentive rate, these technical factors (i.e. energy and peak reduction and load factor improvement) are increased in both smart and non smart grids. According to figure 6, in scenarios 1 and 3 which incentive rate is 30 Rial/MWh, results in smart grid are about 4 times greater than the results in non smart grid. While in scenarios 1 and 2 in which incentive rate has increased (60 Rial/MWh), these amounts in smart grid are about 3 times greater than the results in non smart grid. It shows that the smart grid preferences, from technical view point, are more obvious in lower incentive rates.

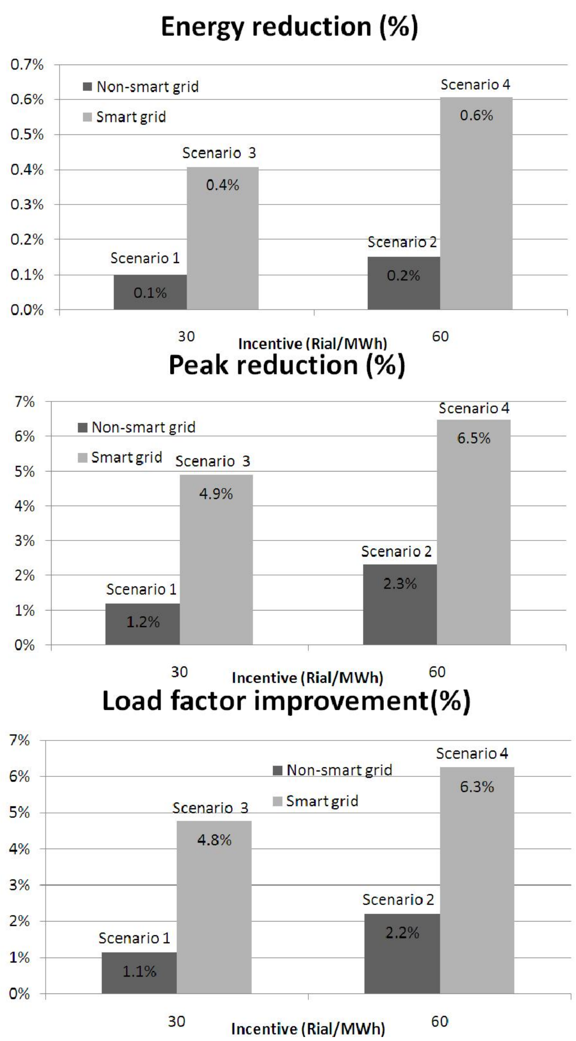

Figure 6: The impact of adopting scenarios 1-4 on energy and peak reduction as well as load factor improvement in percent.

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

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

	Bill in scenario 1 (Rials/day)	Incentive (Rials/day)	Bill reduction (profit)(%)
Base case	99340200	0	0
Scenario 1	99169293	69608.64	0.17%
Scenario 2	98928149	261219.1	0.41%
Scenario 3	98656574	278434.6	0.69%
Scenario 4	97691996	1044876	1.66%

Figure 7 shows the impact of adopting scenarios 1-4 on customers' bill reduction in percent. For a specific incentive rate, customers more satisfy in smart environment than non smart one. Also by increasing the amount of incentive rate, customers' profit is increased. In scenarios 1 and 3 which incentive rate is 30 Rial/MWh, customers' profit in smart grid is 3.5 times greater than its value in non smart grid. Also in scenarios 1 and 2 in which incentive rate has been greater (60 Rial/MWh), this value in smart grid is 4.25 times greater than customers' profit in non smart grid. It shows that the smart grid preferences, from economical view point, are more obvious in higher incentive rates.

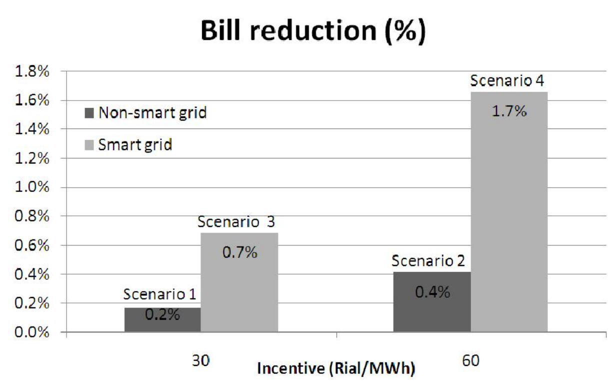

Figure 7: The impact of adopting scenarios 1-4 on bill reduction (profit) in percent.

5. Conclusion

In this paper, effect of smart grid on running EDRP through a logarithmic demand response model has been investigated. Simulation results have been done over Iranian power system. It has been shown that smart environment causes to better result for EDRP execution from economical and technical view points. Also preference of smart grids respect to non smart grids is seen in low incentive rates for technical view point, and in high incentive rate for economical view point. Application to a real world power system such as Iranian power system guarantees the viability of the proposed EDRP model.

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