EVALUATING THE IMPACT OF LOAD MANAGEMENT PROGRAMS ON THE GREENHOUSE GASES EMISSION

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ABSTRACT

It is clear that any burning process will create CO2 and other greenhouse gases. Coal generators, particularly those burning brown coal are dangers for emissions of substantial levels of CO2. On the other hand, one of the important challenges of power networks and electrical markets such as undesirable blackouts and price spikes mostly causes in the peak hours of demand. In recent years, load management programs are introduced as an impressive option in reducing of environmental emission. Under deregulation, the scope of load management programs has considerably been expanded to include demand response programs. The demand response programs (DR) are as a good way for facing to these problems which takes an important place for itself in the recent years. In this paper, the DR programs are introduced and some discussion are come about direct load control(DLC) and emergency demand response program(EDRP), which are incentive-based programs and time of use(TOU) as a time-based rate program. Also the effective factors on greenhouse gases will be discussed. Then, the economic model is presented and by introducing different scenarios, the effects of DR programs on greenhouse gases emission, load factor and loss factor is analyzed.

I. INTRODUCTION

Firstly, Demand Side Management (DSM) has been presented by Electric Power Research Institute (EPRI) in the 1980s. DSM programs consist of activities that governments or utilities use to change the amount or time of electric energy consumption, for achieving better social welfare or some times for maximizing the benefits of utilities or consumers. In fact, DSM is a global term that covers activities such as: Load Management, Energy Efficiency, Energy Saving and so on [1]. Electric power industry has been faced with restructuring and deregulation. New terms created in this new environment, such as Demand Response (DR). Demand Response is defined by Department of Energy (DOE) as" 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" [2]. Fuel combustion at power plants results in more than one third of total CO2 emissions and their fraction will increase in the forthcoming decades [3]. This paper focuses on environmental-driven measure of DR, while achieves environmental and/or social goals by reducing energy usage, deferring commitment of polluted units, leading to increased energy efficiency, and/or reduced greenhouse gas emissions. The remaining of the paper is organized as follows. In section II, a review of DR programs is briefly discussed. In section III, the greenhouse gases are discussed. In section IV, the load and loss factors are discussed. In section V, the mathematical model for DR programs is derived using price elasticity of demand and customer benefit function. Section VI conducts the numerical simulations. Finally, concluding remarks are drawn in Section VII.

II. DEMAND RESPONSE PROGRAMS

In strategic plan of International Energy Agency (IEA), for 2004-2009 years, DR programs have been dedicated to the United State of America [4]. Federal Energy Regulatory Commission (FERC) reported the results of DR investigations and implementations in US utilities and power markets [5]-[6]. In the mentioned report, DR is divided into two basic categories and several subgroups as shown in figure 1. In TBR programs, the electricity price changes for different periods according to the electricity supply cost. IBPs can be classified into three main subgroups namely; voluntary, mandatory and market clearing programs. In IBPs, there is incentive and/or penalty for customer response. In this paper, we have focused on DLC, EDRP and TOU programs. More detailed explanations of DR programs can be found in [7].

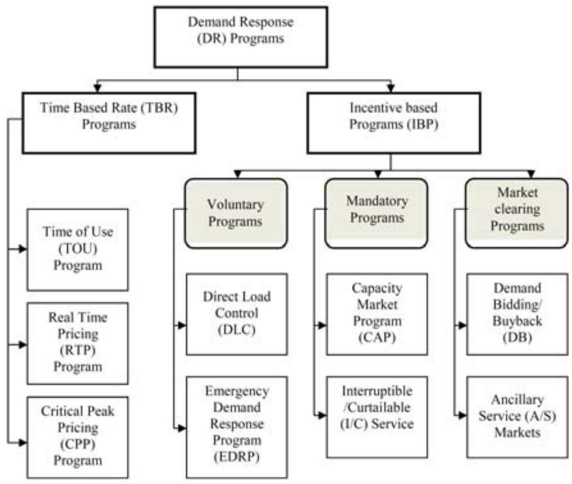

Fig. 1. Categories of demand response programs

III. GREENHOUSE GASES

The collection of gases that reserve the energy of sun in the earth atmosphere and cause increasing of the atmosphere temperature are presented as greenhouse gases. H2O, NO2, CO2 and CH4 have the most important proportion in greenhouse gases. Concentrations of these gases have increased exponentially in the last 150 years of human development [9].

The three energy management programs for decreasing the greenhouse gases are considered as following:

1- Conservation programs
2- Shifting load from peak hours to off peak hours
3- Distributed generation

In the first case, because of decreasing the consumers' consumption level, the generation of power plants is decreased which leads to greenhouse gases amount reduction. In the second state, because of shifting consumption from high price hours in to the periods with the lower price, more efficient power plants are used. It should be noted that in the peak hours, the gas turbine plants are used in the network. By shifting the load into off peak hours, the fossil fuel plants (i.e. oil, gasoline) are used more in the circuit with more emission in comparison with gas turbine units. Hence, by using these programs, the greenhouse gases emission will be increased, unless, the renewable resources or the other less emission technologies such as nuclear plants have been considered in the parallel [10]. The amount of CO2 emission according to multifarious type of fuels is listed in Table I [11]. The consisting emissions cause more costs in to the society. Supplying these costs is very hard, but according to the report of European energy committee, the external costs from several plants are mentioned as Table II [12].

TABLE I
CO2 GENERATION LEVEL

Generation by	Per Mwh	Per 10^8 Btu
Coal	2249	659.1
Natural gas	1135	332.6
Oil	1672	490
Biomass	1500	439.6
Geothermal energy	0	0
Wind	0	0
Photovoltaic	0	0
Hydropower	0	0
Nuclear	0	0

TABLE II
COST ACCORDING TO EMISSION OF PLANTS

Type of power station	Coil	Natural gas	Wind
Price (Euro)	0.018-0.15	0.005-0.33	0.001-0.003

IV. LOAD FACTOR AND LOSS FACTOR

The load factor of a network is defined as the average of energy consumption in ratio with peak of energy consumption in each time period which can show the special pattern for optimum usage of electrical device. Improving the load factor causes the benefits in the both of generating side and consumption side such as improving the pattern of load, increasing the electrical efficiency and increasing the electrical equipment efficiency. The load and loss factors can be defined as [13]:

$$LF = \frac{AE}{P} \tag{1}$$

$$LSF = 0.7 * (LF^2) + 0.3 * LF \tag{2}$$

Where, "AE" and "P" represent average energy usage and peak of demand, respectively.

V. RESPONSIVE LOAD ECONOMIC MODEL

In order to evaluate the impact of customers' participation in DR programs on load profile characteristics, development of responsive load economic models seems to be necessary.

1. Price Elasticity of Demand

Elasticity is defined as the demand sensitivity with respect to the price [14]-[15]:

$$E = \frac{\rho_0}{d_0} \cdot \frac{\partial d}{\partial \rho} \tag{3}$$

According to equation (3), the price elasticity of the i-th period versus j-th period can be defined as:

$$E(i,j) = \frac{\rho_0(j)}{d_0(i)} \cdot \frac{\partial d(i)}{\partial \rho(j)} \tag{4}$$

The self elasticity $E(i,i)$ and the cross elasticity $E(i,j)$ can be classified as [15]:

$$\begin{cases} E(i,j) \le 0 & if \quad i = j \\ E(i,j) \ge 0 & if \quad i \ne j \end{cases} \tag{5}$$

2. Modeling of Single Period Elastic Loads

Suppose that the customer changes his demand from $d_0(i)$ (initial value) to $d(i)$ as:

$$\Delta d(i) = d(i) - d_0(i) \tag{6}$$

The total incentive for participating in DR programs will be as:

$$P(\Delta d(i)) = A(i).[d_0(i) - d(i)] \tag{7}$$

Therefore, the customer's benefit, S, can be written as:

$$S = B(d(i)) - \rho(i)\, d(i) + P(\Delta d(i)) \tag{8}$$

According to the classical optimization rules, to maximize the customer's benefit, $\partial S/\partial d(i)$ should be equal to zero:

$$\frac{\partial B(d(i))}{\partial d(i)} = \rho(i) + A(i) \tag{9}$$

The benefit function, most often used, is [14]:

$$B(d(i)) = B_0(i) + \rho_0(i)\left[d(i) - d_0(i)\right]\left\{1 + \frac{d(i) - d_0(i)}{2E(i).d_0(i)}\right\} \tag{10}$$

By differentiating the above equation and substituting the result in (9) we will have:

$$\rho(i) + A(i) = \rho_0(i)\left\{1 + \frac{d(i) - d_0(i)}{E(i)\, d_0(i)}\right\} \tag{11}$$

Therefore, customer's consumption will be as following:

$$d(i) = d_0(i)\left\{1 + E(i,i).\frac{\left[\rho(i) - \rho_0(i) + A(i)\right]}{\rho_0(i)}\right\} \tag{12}$$

3. Modeling of Multi Period Elastic Loads

According to the definition of the cross elasticity in equation (4) and with the linearity assumption we have:

$$d(i) = d_0(i).\left\{1 + \sum_{\substack{j=1 \\ j \neq i}}^{24} E(i,j).\frac{[\rho(j) - \rho_0(j) + A(j)]}{\rho_0(j)}\right\} \quad (13)$$

4. Load Economic Model

By combining equations (12) and (13), we will have the responsive load economic model as:

$$d(i) = d_0(i).\left\{\begin{array}{l} 1 + E(i,i).\dfrac{[\rho(i) - \rho_0(i) + A(i)]}{\rho_0(i)} \\ + \sum\limits_{\substack{j=1 \\ j \neq i}}^{24} E(i,j).\dfrac{[\rho(j) - \rho_0(j) + A(j)]}{\rho_0(j)} \end{array}\right\} \quad (14)$$

VI. NUMERICAL STUDIES

In order to evaluate the impact of economic DR model on: greenhouse gases emission level, load and loss factors as well as peak of demand, the actual peak load curve of the Iranian power grid on 28/08/2007 has been used for our simulation studies as shown in figure 2 [16].

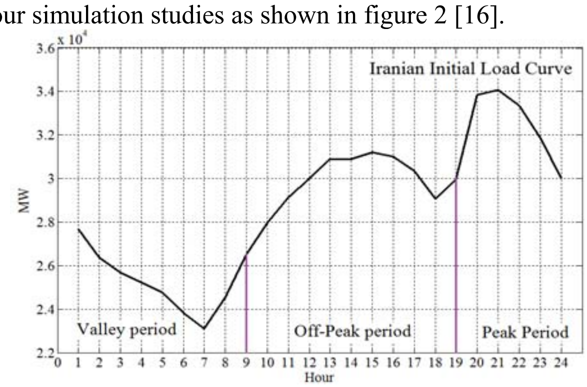

Fig. 2. Iranian peak load curve on 28/08/2007

The electricity price in 2007 was 150 Rails/kWh for 24 hours [17]. We assume that based upon the DLC and EDRP program contracts, customers commit to reduce their loads as much as 20% of their initial loads. The price elasticity of demand is considered as listed in Table III. Several scenarios have been suggested as shown in Table IV. The results of implementing DR programs are presented in the subsequent sections.

Scenario 1: This scenario is the base case with actual load curve, where no DR program is implemented.

Scenario 2: In this case, we assume 150 ℜ/kWh as the incentive for the peak period (7:00pm- 12:00pm). In the other words, it is considered that ISO prize the customers for load reduction, but doesn't penalize them. By applying DR model (equation (14)) on the initial load curve, the peak is reduced by 8425 MW (4.36%), which is shown in figure 3. The amount of CO2 pollution by coal generation units is 415 (pound/Twh) and 1568 (pound/Twh) for peak and total periods, respectively.

Scenario 3: Now, we assume ISO pays 300 ℜ/kWh as incentive for load reduction. By implementing DR programs on the initial load curve, the peak of demand curve is reduced 6.36%. Here, CO2 emission by coal generation units is equal to 406 (pound/Twh) and 1578 (pound/Twh) in peak and total periods, respectively.

TABLE III
SELF AND CROSS ELASTICITIES

	Peak	Off-Peak	Valley
Peak	-0.10	0.016	0.012
Off-Peak	0.016	-0.10	0.01
Valley	0.012	0.01	-0.10

Table IV
STATEMENT OF SCENARIOS

Scenario.	Incentive value (ℜ/kWh)	Peak period	Price elasticity
1	0	7:00pm-12:00pm	As Table III
2	150	7:00pm-12:00pm	As Table III
3	300	7:00pm-12:00pm	As Table III
4	150	7:00pm-12:00pm	As 1/2 value of Table III
5	300	7:00pm-12:00pm	As 1/2 value of Table III

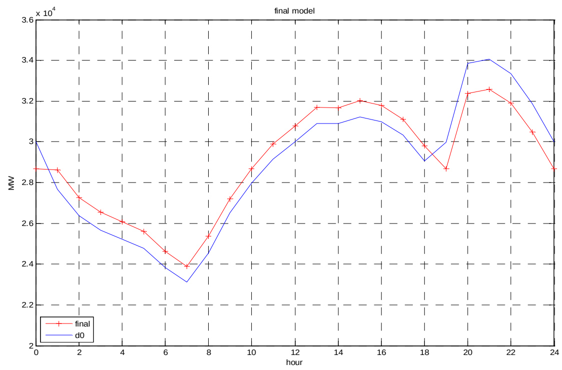

Fig. 3. Load curve after implementing scenario # 2

Scenario 4: In this case, the sensitivity of the results versus demand elasticity is evaluated. In this case, we assume that the elasticity values are one half of the values denoted in Table III. By applying DR model on the initial load curve, the peak is reduced by 4212 MW, where the CO2 emission is 424 (pound/Twh) and 1560 (pound/Twh) in peak and total periods, respectively.

Scenario 5: In this case, sensitivity of the results versus elasticity values is studied considering 300 ℜ/kWh as incentive. By implementing demand response model, the peak is reduced 3.18% while the amount of CO2 emission is equal to 420 (pound/Twh) and 1566 (pound/Twh) for peak period and total period, respectively.

VI-1 Analysis of the Results

In this section, we will discuss on the results of scenarios from "economic", "load profile characteristics" as well as "CO2 emission" view points. Therefore, different indices such as peak reduction, load factor, loss factor, and CO2 emission are investigated as a consequence of implementing different scenarios. As shown in Table V, in scenario 2, 8425 MW load reduction is achieved in comparison with the base case. For this case, load factor is 81.04%, and the loss factor is 70.28%. By implementing scenario 2, the amount of CO2 emission is 209 (pound/Twh), 308 (pound/Twh), and 415 (pound/Twh) for natural gas generation, oil, and coal respectively.

TABLE V
COMPARISON OF LOAD PROFILE CHARACTERISTIC

Scenario	Peak Reduction (MW)	Peak Reduction (%)	Load factor (%)	Loss factor (%)
1	0	0	81.04	70.28
2	8425	4.36	85.54	76.89
3	12288	6.36	86.04	77.63
4	4212	2.18	83.24	73.48
5	6143	3.18	84.4	75.19

By implementing scenario 3, the results of Tables V show that load reduction index is increased to 12288 MW. For this case, load factor is 85.54%, and the loss factor is 76.89%. It can be concluded that when the incentive increases, the amount of peak reduction and load factor are both increased. It can be also mentioned that in scenario 3, the amount of CO2 emission in peak period is equal to 205 (pound/Twh), 302 (pound/Twh), and 406 (pound/Twh) for natural gas generation, oil, and coal, respectively. It should be emphasized that when the incentive increases, the amount of CO2 emission in peak period has been decreased, while the amount of CO2 emission in the total period is increased. Implementation of scenario 4 represents that reduction of the demand elasticity will result in decreasing of the peak reduction and load factor indices, but the CO2 emission is increased. The result of implementing scenario 5 emphasizes that reducing of demand elasticity as well as increasing the incentive value will increase the peak reduction and load factor indices in comparison with scenario 4. It can be concluded that using DR programs can increase the amount of CO2 pollution. The main reason of this issue is shifting the demand from peak-period to off-peak period. If increasing of the demand has been responded by using clean energies such as nuclear and renewable, the final result is decreasing of greenhouse gases emission. It means that implementing DR programs caused to decrease the greenhouse gases emission. On the other hand, if the request of increasing demand is responded with the generation units using the other kind of fuels such as natural gases and oil, the running of DR programs will be increased the emission of greenhouse gases.

VII. Conclusion

In this paper, DR programs have been introduced as demand side virtual power plants which have potential to offer substantial benefits in the electricity markets. Based upon the price elasticity of demand and customers' benefit function, an economic model of responsive loads has been established for DR programs. Also, the environmental-driven measure of DR programs has been investigated. The main result of this study emphasizes on more attention in usage of clean fuels such as nuclear and renewable energies in parallel with demand response to achieve its various benefits such as decreasing the environmental emission.

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