Implementation and Investigation of Demand-Side Management Polices in Iran's Industrial and Commercial Sectors

FARKHONDEH JABARI[1, *], **MORTEZA NAZARI HERIS**[2], AND **MEHDI ABAPOUR**[3]

[1] *Power Systems Operation and Planning Research Department, Niroo Research Institute (NRI), Shahrak Ghods, Tehran, Iran*
[2] *College of Engineering, Lawrence, Technological University, MI, USA*
[3] *Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran*
[*] *Corresponding author email: fjabbari@nri.ac.ir*

Manuscript received 7 April, 2022; revised 16 June, 2022; accepted 11 September, 2022. Paper no. JEMT-2204-1376.

Nowadays, large power systems are facing new challenges gifted from emerging and renewable energy resources. This is even worse in developing countries where load is growing rapidly and power systems are relatively weak. With more complex power systems occurrence of a contingency such as unexpected demand during extremely-hot summer days or transient heat waves may lead to voltage drops, cascaded trips and catastrophic wide area blackouts. A few solutions have been proposed, amongst which demand response is known as an effective tool. Demand response programs (DRPs) are implemented on residential, commercial and industrial loads to economically optimize energy systems, improve overall efficiency and reliability, and enhance their stability margins. This paper presents three demand-side management strategies implemented on Iran's commercial and industrial sectors. Operational reserve programs, incentive-based reduction or disruption of electricity demand during on-peak time intervals, and replacement of traditional lamps with energy efficient ones are applied as three strategic DRPs on industrial and commercial sectors. Three cost-effective solutions are provided for participation of industrial customers in summer peak clipping programs: (a) Transferring the weekend from Friday to one of midweek days, (b) Transferring a part of each co-operated consumer from on-peak demand hours with high electricity tariffs to off-peak time intervals with lower energy prices, (c) DSM by annual overhaul and work suspension. In case of 100 kW power consumption at medium-peak load hours, commercial customer must at least reduce 10% of this amount at on-peak demand time interval. Economic and environmental benefits obtained from numerical studies are comprehensively provided. It is found that the total asynchronous demand reduction after participation of 287 commercial centers in demand side management programs is equal to 10.187 MW. Total industrial load reduced after implementation of disruption strategy at annual on-peak day (July 20) is equal to 743 MW. © 2022 Journal of Energy Management and Technology

keywords: *Demand response programs, commercial consumers, industrial sectors, operational reserve, annual overhaul, work suspension.*

http://dx.doi.org/10.22109/JEMT.2022.336505.1376

SYMBOLS

P_r	Co-operated electrical demand (kW or MW)
λ	Real time electricity rate (kWh or MWh)
α	Participation coefficient
β	Scaling factor of co-operation hours
Energy allowance	Energy saving * Concession price
Power allowance	Reduced power * Co-efficiency of power price concession * Power price
Energy saving	Reduced power * 4 hours peak load during one day * participation days
Total allowance	Power allowance + Energy allowance

1. INTRODUCTION

In modern power systems, several factors such as fluctuations of renewable energy resources, uncertain nature of electricity demand, insufficient ramping down or up capabilities of thermal units, lower spinning reserve, and etc. may cause some cascaded outages and wide-area blackouts. Hence, implementation of demand-side management (DSM) strategies plays a major role in optimal operation of power distribution grids [1, 2]. According to definition provided by U.S. department of energy, DSM schemes aim to change the power consumption pattern of the residential, commercial, and industrial loads considering the variations of electricity tariffs and incentive payments [3]. Generally, demand response programs are classified into two categories; time-value based approaches and incentive-oriented ones. In this context, authors of [4] developed a time-of-use demand response program for manufacturing services. Time of use energy tariffs enable for manufacturing industries to shift their electricity consumption process from on-peak hours to off-peak periods with lower energy prices, reduce their monthly electricity bill, build an energy-efficient and load-responsive approach. In [5], an intelligent integration of time-of-use demand response program with price-based day-ahead dynamic economic dispatch of thermal units are presented. In this research, not only total fuel cost of conventional fossil fuels driven power plants is minimized, but optimum values of electricity selling prices are also determined in on-peak, mid-peak and off-peak time horizons. In other words, demand response coupled optimal short-term scheduling of thermal units is a win-win game for both generation and demand sides. Game-theory based half-hourly real-time, time-of-use, and day-night pricing strategies are implemented on Singapore's residential and commercial sectors [6]. In [7], economic benefit of real time prices depends on customers' participation and willingness to limit their electricity consumption patterns. Hence, generation companies offer lower electricity selling prices when consumers participate in real time pricing based demand side management strategy and vice versa for non-flexible loads. In [8], real time pricing based demand response policies are applied on flexible consumers to encourage them for saving electricity in load aggregator's transactions. If customers change their daily energy usage patterns according to aggregator's suggested curve, both of them will get benefit. Kato et al. [9] investigated a summer critical peak pricing experience occurred in 2013, which was used for saving electricity in a benchmark residential complex. It is proved that if the households face with electricity prices lower than 50 Yen per kWh, maximum value of energy saving or minimum value of electricity usage will be obtained. For critical peak prices between 50-100 Yen/kWh, it did not change significantly. Daily energy saving was considerably improved up to 50-60% for peak prices equal to or more than 150 Yen per kWh. Authors of [10] analyzed a critical peak pricing strategy implemented on Korean residential, industrial and commercial end-users in winter 2013. It is obvious that customers belong to high-variability category lead to a significant reduction in annual peak demand and consumers with lower flexibility show a limited peak-shaving capability. On the other hand, incentive-based DRPs have successfully been applied on electrical energy markets. In [11], day-ahead market-clearing based bidding mechanism is proposed for maximization of social welfare. Ruiz et al. [12] developed an optimization tool for managing a virtual power plant (VPP), which contains a series of industrial consumers with thermostatically controlled appliances. In this model, DLC is employed for optimal scheduling of VPP's different equipment in order to minimize total load-generation mismatch and transmission congestion over the specified control period. An optimal and automatic residential energy consumption scheduling framework is presented in [13] to obtain a trade-off between minimum electricity payment and minimum waiting time of household appliances in a real-time pricing tariff combined inclining block rates. In [14], an incentive-based demand response program is applied on a micro-grid, which composed of wind turbine, photovoltaic cell, micro-turbine, full cell, battery hybrid power source and responsive loads, to minimize total electricity procurement cost and greenhouse emissions of pollutant gases. A multi-objective particle swarm optimization algorithm is also employed to obtain a set of Pareto solutions. It is found that incentive based DRPs deals with uncertainties arising from intermittent nature of wind and solar irradiance. Kamyab et al. [15] addressed two non-cooperative games for maximizing the expected profit of the generation companies and the daily payoff of the participated customers by achieving optimal flexible load curves. In [16], a stochastic multi-objective Nash–Cournot competition approach is presented for studying DRPs in the uncertain energy market, where impact of DRPs and energy demand uncertainty is investigated. In [17], a multi-objective model is proposed for optimal operation of hub energy systems, where two conflicting objectives are studied including minimization of operation cost and emission of pollutant gases. In this study, time-of-use rates of DRPs are employed for improving the economic performance of the studied system. The application of incentive-based DRPs as a tool for preparing the reserve capacity and covering the uncertainties associated with wind power plants in energy systems with high penetration of wind turbines has been studied in [18]. Authors of [19] presented an agent-based appliance-level stochastic method for studying the electricity demand of the household, and shifting the load demand by using the dispatch strategies. Accordingly, the proposed agent-based model will be effective for increasing the profit of the building owner and decreasing the electricity cost of the revised load demand with realistic tariffs. In [20], residential DRPs has been studied to find the optimal operating points of the home appliances and accordingly, lower building electricity cost. It is found that 25% cost saving is attained after application of time-of-use and incentive based DRPs. In [21], a two-stage risk-aware stochastic model is proposed for electricity procurement of large consumers with energy storage unit, PVs, wind turbines, geothermal power generator, slow and fast DSM, bilateral contracts and pool market. Conditional-value-at-risk (CVaR) is used as a risk index to consider the variability of energy procurement cost. A home energy management system that incorporates DSM programs is presented in [22]. In this research, PVs, battery energy storage and plug-in electric vehicles, controllable appliances, a thermostatically controllable air conditioning unit, and time-of-use DR strategy is optimally scheduled. In [23], potentials, benefits and implementation mechanism designs of China's DSM programs are presented. The peak demand duration is very short in China (only 1.6% of total hours in a year). The peak demand usually occurred at hour 19 p.m. in most provinces of China. In [24], multi-energy DR is developed for application in data centers, electric vehicles and air conditioning loads. A day-ahead energy pricing and management model for regional integrated energy systems is also presented. A bi-level Stackelberg game optimization model is run to maximize profit of energy service provider in the upper level and minimize cost of energy consumption for customers in the lower level. Jabari et al. [25] optimized a tidal-battery-diesel driven energy-efficient standalone microgrid performance considering the load-curve flattening program. The total fuel consumption of the marine-scale diesel generation units is minimized by shifting a part of electrical load of offshore drilling rigs from peak hours to other periods. Moreover, a battery pack participates in load curve flattening program. There are several research studies on the evaluation of DRPs on industrial and commercial sectors all around the world. The authors in [26] provided an energy hub management model that takes DRPs into account for residential, commercial, and industrial hubs. To prohibit any unreal power transactions in the system, the network design and AC optimal power flow restrictions have been implemented to the model. DR from families, business, and the tertiary sector might provide significant flexibility in renewable-based energy systems, but its utilization is currently limited. So, the authors in [27] looked at the future economic possibilities of DR in the renewable-rich northern European region, as well as the power market implications of large-scale DR implementation. In [28], the authors have investigated how companies might modify their power consumption flexibly due to economic, legal, technological, organizational, behavioral, informational, and competency restrictions. The characteristics of industrial loads' DRP is studied in [29], where the industrial process modeling methodologies, as well as the demand response potential assessment is summarized. The authors in [30] reviewed the two main short-term load forecasting approaches using a real-world dataset, where the results of a controlled experiment are analyzed for application of DRPs in commercial buildings. As shown in Fig. 1, this paper aims to present all optimal executive policies defined for implementation and investigation of three strategic DRPs on industrial and commercial districts of Iran: (a) operational reserve program, (b) incentive-based reduction or disruption of electricity demand during on-peak time intervals, (c) replacing traditional lamps with energy efficient ones. Sections 2 and 3 of this paper introduce all policies used for designing two strategic demand side management methodologies such as operational reserve program and incentive-based load curtailment approach. Afterwards, numerical results and discussions are drawn in Section 4. Conclusion is then presented in Section 5.

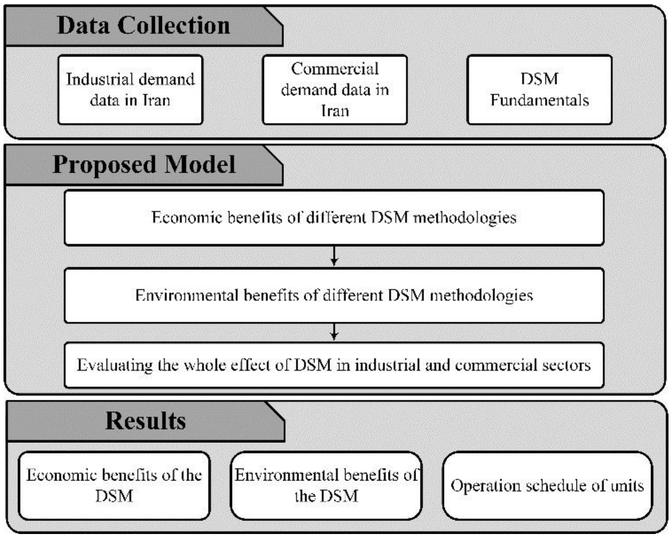

Fig. 1. Flowchart of economic/environmental analysis of DSM deployment in Iran

2. OPERATIONAL RESERVE METHODOLOGY FOR APPLICATION IN INDUSTRIAL SECTORS

In this section, all criteria used for implementation of operational reserve program in industrial sectors are discussed. Firstly, several key parameters such as working days, co-operation duration, contracted demand, agreement, involved customer, co-operated or participated customer, maximum and average values of power and energy consumptions can be respectively defined as follows:

Working days: All days during a week except the weekend (Thursday and Friday are the weekend in Iran) and official holidays **Co-operation duration**: June 4th to September 5th (3 months)

Contracted demand: Values of electrical power and energy consumed by each industrial consumer, which is agreed in bilateral contract and signed by customer and regional distribution company

Agreement: An ordered script which is agreed and signed by customer and regional distribution company and demonstrates the customer participation in load curve smoothing strategy

Involved customer: Industrial customer with contracted demand equal to or more than 250 kW

Co-operated customer: An involved customer that participates in demand side management approach and signs an agreement with regional distribution company.

A. Fundamentals

Minimum value of contracted demand, which should be reduced or interrupted during the operational reserve program, is equal to 15% of its average electricity consumption. Moreover, co-operation time limit will be maximum 200 hours within participation duration from June 4th to September 5th and daily time interval from $12^{a.m.}$ to $22^{p.m.}$. Meanwhile, regional distribution companies sign agreements with involved customers at least before May 30 and submit them to Tavanir. They have to install the measurement instruments and read the hourly electricity consumption of the involved customers. If a customer has more than two non-participation experiences (two failures in its demand reduction), 10% of its participation allowance and 10% of its reliability declaration must be reduced and it should be placed in load reduction or disruption priority.

B. Incentives

Industrial customers with electrical power consumption equal to or more than 250 kW receive declaration allowance incentives (DAIs) and participation allowance according to equations 1 and 2, respectively.

$$Decleration\ allowance\ incentive = \lambda P_r \tag{1}$$

$$Participation\ allowance = \lambda P_r(\alpha + \beta) \tag{2}$$

where, P_r and λ indicate the co-operated electrical demand and real time electricity rate, respectively. Moreover, the parameters α and β refer to the participation coefficient and the scaling factor of the co-operation hours, which can be given by equations 3 and 4, respectively. It should be mentioned that total allowance of each customer is calculated through the electricity bill and applied before November.

$$\alpha = Participated\ load / Average\ demand \tag{3}$$

$$\alpha = 1.6 * \exp(0.01 * h); 1 \leq h \leq 200 \tag{4}$$

C. Reduction of industrial loads using work suspension and annual overhaul

Three cost-effective solutions are provided for participation of industrial customers in summer peak clipping programs as follows:

Table 1. Power and energy discounts for industries [31]

Participation time interval	Power reduction (%)	Price concession (Rials)	
		Power (kW)	Energy (kWh)
		k*Power price * Reduced power	
June 4th to July 5th and August 22nd	10 to 40	k=1.3	On-peak tariff (Rials/kWh) * Energy saving (kWh)
	41 to 70	k=1.4	
	71 to 100	k=1.5	
to July 6th September to August 21st 5th	10 to 40	k=1.5	
	41 to 70	k=1.8	
	71 to 100	k=2	

- Transferring the weekend from Friday (note that Thursday and Friday are the weekend days in Iran) to one of midweek days: Decision on participation day and transfer the weekend of the industrial consumers from Friday to one of midweek days (Saturday to Wednesday) should be carried out after coordination with regional distribution companies.
- Transferring a part of each co-operated consumer from on-peak demand hours with high electricity tariffs to off-peak time intervals with lower energy prices for five consecutive days: In this case, depending on co-operation time criterion (June 4th to July 5th, August 22nd to September 5th, and July 6th to August 21st), power and energy discounts are calculated according to Table 1.

- DSM by annual overhaul and work suspension: At least five consecutive days during peak load periods should be selected with coordination and information of regional distribution companies. This time interval is from June 4th to September 5th. Besides, the values of energy saving and power consumption reduction provided by the co-operated industries can be estimated using 5 and 6, respectively:

$$\begin{aligned}\mathit{Saved\ energy} &= \mathit{Energy\ consumed\ in\ 3\ months\ before\ DRPs}\\ &*\mathit{Number\ of\ participation\ days}/(31 - \mathit{Energy\ consumed\ within}\\ &\mathit{participation\ days})\end{aligned} \tag{5}$$

$$\begin{aligned}\mathit{Reduced\ power} &= \mathit{Power\ consumed\ in\ 3\ months\ before\ DRPs}\\ &*\mathit{Number\ of\ participation\ days}/(31 - \mathit{Power\ consumed\ within}\\ &\mathit{participation\ days})\end{aligned} \tag{6}$$

3. INCENTIVE BASED LOAD MANAGEMENT STRATEGY FOR COMMERCIAL CENTERS

A special peak clipping strategy is proposed for public and commercial centers. Accordingly, Tavanir considered similar indices for participation of commercial consumers in DRPs as following items: Scheduling time horizon for co-operation of commercial sectors in DRPs is June 4th to September 5th. Peak load hours will be considered according to time adjustment of customer's meter. Percentage of power reduction will be acceptable only at peak load hours, which registered by meter. Co-operation of commercial customers in DRPs will be considered according to Table 2. In case of 100 kW power consumption at medium-peak load hours, customer must at least reduce 10% of this amount at on-peak demand time interval. Power and energy allowances for commercial customers participated in DRPs can be obtained from relations 7 and 8, respectively. where, the expected value of the energy saving is calculated as 9. Hence, total allowance for commercial consumers participated in peak-shaving demand side management strategy is calculated as 10.

Table 2. Energy tariff concessions for participated commercial sectors [31]

Participation time	Power reduction (%)	Co-efficiency of power price	Concession price (Rials/kWh)
June 4th to August 21st	>=10%	concession 5	Peak load rate + Medium load rate
July 22nd to August 21st	10%	12	
	11% to 20%	13	
	>= 21%	14	

$$\mathit{Energy\ allowance} = (\mathit{Energy\ saving}) * (\mathit{Concession\ price}) \tag{7}$$

$$\begin{aligned}&\mathit{Power\ allowance} = (\mathit{Reduced\ power})\\ &*(\mathit{Coefficiency\ of\ power\ price\ concession}) * (\mathit{Power\ price})\end{aligned} \tag{8}$$

$$\begin{aligned}&\mathit{Energy\ saving} = (\mathit{Reduced\ power})\\ &*(4\ \mathit{hours\ peak\ load\ during\ one\ day}) * (\mathit{participation\ days})\end{aligned} \tag{9}$$

$$\begin{aligned}&\mathit{Total\ allowance\ for\ participated\ commercial\ customers} =\\ &(\mathit{Power\ allowance}) + (\mathit{Energy\ allowance})\end{aligned} \tag{10}$$

4. NUMERICAL ANALYSIS AND DISCUSSIONS

A. Economic and environmental benefits of operational reserve program

Total electrical power consumed by different residential, industrial, commercial and agricultural sectors before and after implementation of operational reserve programs in industrial district level is demonstrated in Fig. 2, where the reduced or disrupted industrial load is reported from June 4th to September 5th 2016. The following points can be obtained by analyzing the reported statistics:

- Total reduced or disrupted electrical power after application of operational reserve program at annual on-peak day (July 20) is equal to 594 MW.
- Number of industrial customers, which participated in this program, is equal to 1,433 with 4,021 MW contracted demand.
- Industries participated in operational reserve program are allocated 1365 and 68 customers from distribution companies and regional transmission network service providers, respectively.

- Number of industrial customers with electrical power demand equal to or more than 1 MW, which are capable to participate in operational reserve program, is equal to 684, whereas 749 customers are with electricity consumption less than 1 MW.

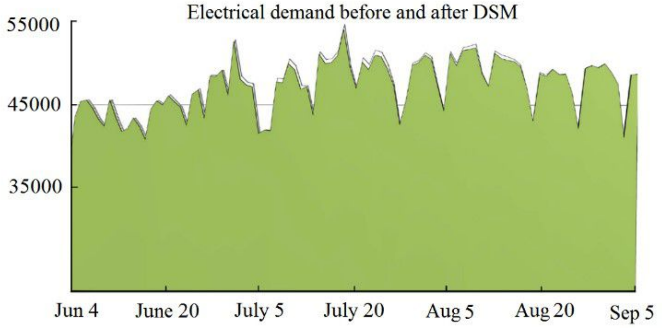

Fig. 2. Total electrical demand of Iran's interconnected power system before and after application of operational reserve program [32]

For supplying 1 kW electrical demand, 1.2 kW power should be generated due to internal energy consumptions of power production units, and transmission and distribution active power losses. Total capital investment and operation cost of a combined cycle power plant associated with generation of 1 kW electrical power considering 30-year lifetime is equal to 690 USD. For supplying 1 kW electrical power to each consumer, 1.2×690 USD is required. Assuming that 1 USD is equivalent to 32,367 Rials, total capital investment and operation cost for 1 kW power generation is obtained as $(32367 * 1.2 * 690 * 1.1^{30} * 0.1)/(1.1^{30} - 1) = 2842911$ Rials per kW=87.8 USD per kW. If we consider that operational reserve program is selected for reduction of on-peak electricity demand on July 20, discount payment will be equal to (17364052 Rials)/(594000 kW)=292700 Rials per kW=9.04 USD per kW. Hence, this value is 9.71 times smaller than total investment and operation cost as follows:

$$\frac{Totalcapitalinvestmentandoperationcost}{Discountpayment} = \frac{2,842,911}{292,700} = 9.71$$

B. Results of work suspension and annual overhaul programs

Total electrical power reduction after implementation of industrial load curtailment strategy from June 4th to September 5th, is illustrated in Fig.3. Moreover, its effectiveness in Iran's electricity grid is shown in Fig.4. This analysis points out the following results:

- Total industrial load reduced after implementation of disruption strategy at annual on-peak day (July 20) is equal to 743 MW.
- Maximum value of electrical load disrupted by regional distribution companies is related to August 14th, which 1,024 MW power saving is achieved.
- Number of industrial customers participated in this program is 3,596 having a contracted demand of 7,884 MW. The asynchronous demand reduced by the co-operated customers is equal to 2,046 MW.
- Number of industrial customers with electrical demand more than 1 MW, which are capable to cooperate in reduction or disruption program, is equal to 4,026 with 20,512 MW contracted demand. However, 1044 customers are participated in this program.

Table 3. Emissions of pollutant gases in Tons

Gas	Coal-fired power plants	Gas-fired units	Combined cycle power plants
NO_X	2,181	2,430	2,545
SO_2	7,467	649	249
CO	1,459	88	65
SPM	164	119	74
CO_2	765,394	743,575	422,727
CH_4	21	16	11

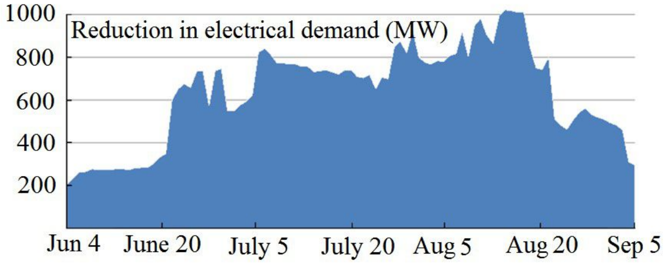

Fig. 3. Contribution of industrial customers in reduction or disruption of their electrical demand

The maximum value of demand reduction occurred in July 20, which is called "maximum simultaneous load reduction", after implementation of load curtailment method in industrial sections is shown in Fig. 5. Assuming that the work suspension and the annual overhaul programs are applied on July 20, the total discount payment will be equal to: $919,113,009 Rials/743000 kW = 1,237,029 Rials per kW$ Hence, it is 2.3 times smaller than total capital investment and operation cost. Moreover, 877,104 GWh energy saving is achieved as a result of work suspension and annual overhaul programs. The total greenhouse gas emissions produced by the fossil fuel-based power plants are reported in Table 3.

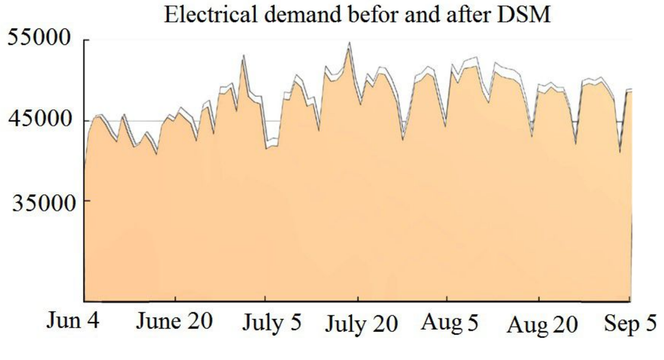

Fig. 4. Effectiveness of reduction or disruption of industrial consumers

C. Collecting traditional lamps from commercial sectors

Since 2009, traditional lamps with high energy consumptions have been replaced with energy-efficient types. For this purpose, they have been collected from Iran's commercial districts in order to reduce total electricity demand. Number of collected lamps with high electricity consumption, economic and environmental benefits of this project during 2011-2016 are depicted in Figs. **??**, respectively. Studies show that replacing a traditional lamp with an energy-efficient type causes 300W electricity saving. In Fig. 7(b), it is assumed that all participated commercial customers have approximately 300 working days in a year with average five-hour electricity consumption during each working day. Figures 5-7 demonstrate that more commercial sectors of Iran have been equipped with energy-efficient lamps from 2011 to 2016. In other words, 729 MW electrical power saving, 1,093,050 MWh energy saving, and 78493435 Thousands Rials economic benefit, and 506462 Tons emission reduction have been achieved by removing 2429204 traditional lamps from Iran's commercial centers. According to Fig. 7(a), 31.1 MW demand reduction is achieved after collecting 103752 high-energy lamps from different commercial centers. Considering internal electricity consumptions of power generation units, transmission and distribution real power losses, 1.2 kW should be generated for satisfying 1 kW electrical demand of each end-user. As mentioned before, total investment and operation cost of a combined cycle power plant associated with generation of 1 kW power considering 30-year lifetime is equal to 690 USD. Assuming that 1 USD is equivalent to 32367 Rials, and 20% of 31.1 MW load reduction coincided with annual on-peak electricity demand, the total economic benefit resulted from this project can be calculated as follows:
$Benefit = 32,3671.26900.231,100 = 166,695,228,720Rials = 5,150,160USD$

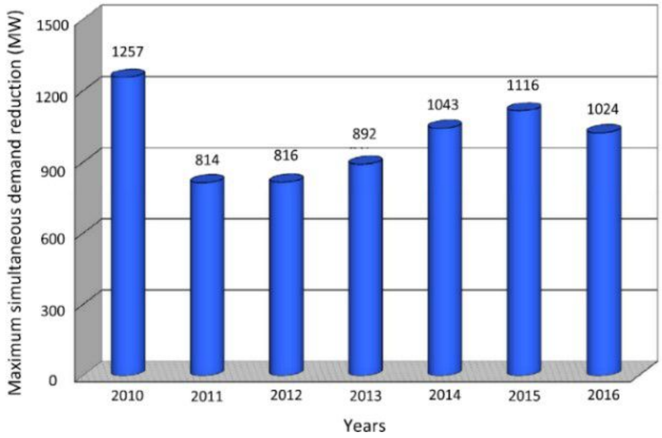

Fig. 5. Simultaneous demand reduction in six years

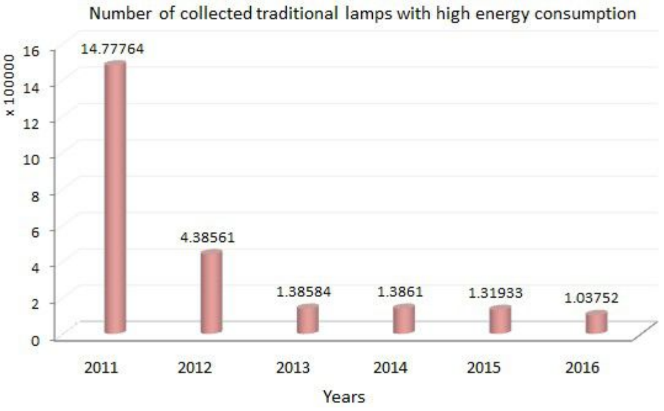

Fig. 6. Number of collected traditional lamps from candidate commercial sectors

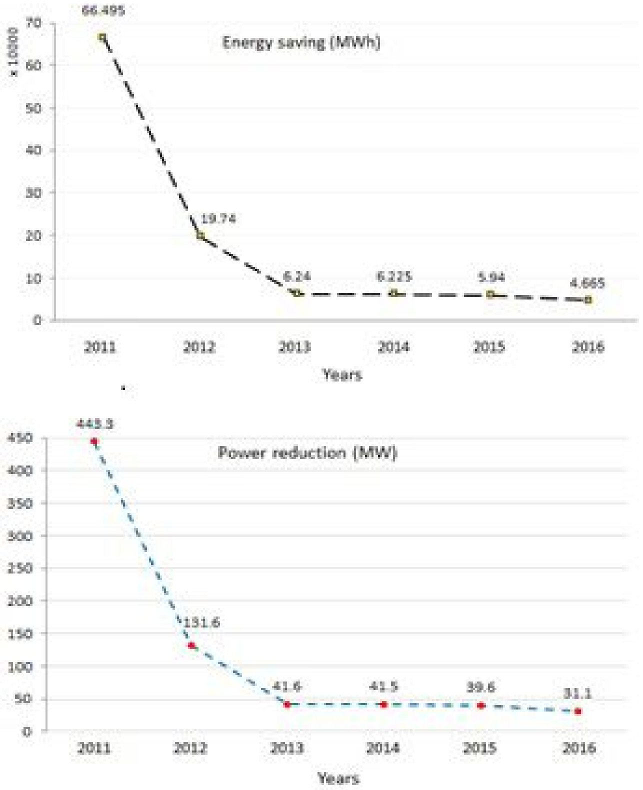

Fig. 7. Power and energy savings after lamp replacement

If this project is applied on commercial consumers in order to reduce total electricity consumption and all participated customers have approximately 300 working days in year with average 5-hour electricity consumption for lighting during each day, total energy saving and economic benefit can be estimated as follows:
$Energysaving = 31.1(MW) * 5(hours/day) * 300(days) = 46,650MWh$ $Expectedprofit = 46,650(MWh) * 1,204(Rials/kWh) = 56,166,600,000Rials = 1,735,304.5USD$
Total pollutant emissions produced in supplying 46650 MWh electricity demand by conventional fossil fuel-based power plants is shown in Fig. 9. It is shown that by removing 2429204 traditional lamps from Iran's commercial sectors, 824.899, 849.37 and 469.945 grams CO2 reduction are attained for generating 1kWh energy by thermal units, natural gas fueled generation stations and combined cycle power plants. Iran's department of environment reports that 1kg production of each pollutant gas has a social cost due to environmental degradation, as presented in Table 4. Hence, social cost reduces significantly by 46650 MWh energy saving after implementation of this project, as obvious from Fig. 10. Number of co-operated customers, discounts, electrical power reduction and energy saving after implementation of incentive-based DRPs on commercial sectors

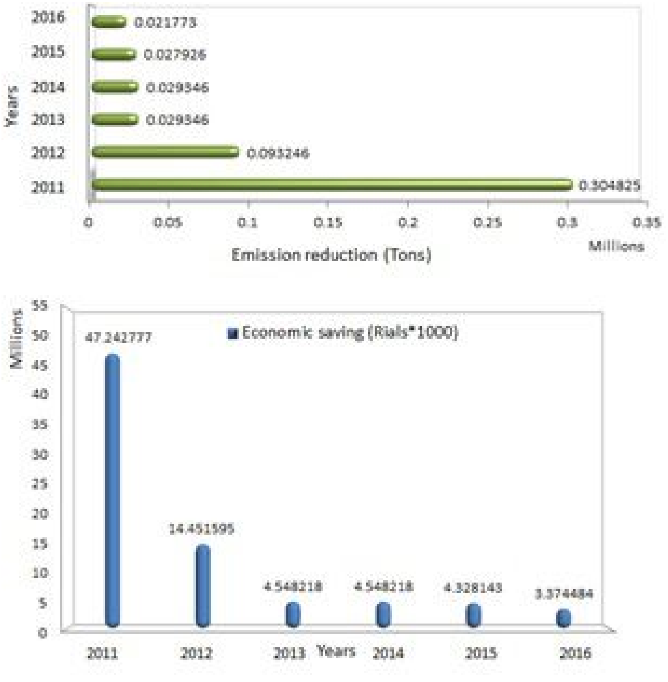

Fig. 8. Environmental benefits after replacement of traditional lamps with energy-efficient ones

Table 4. Social costs of greenhouse gases in Rials/kg

Gas	CH_4	CO_2	SPM	CO	SO_2	NO_X
Cost	2100	100	43000	1,875	18,250	6000

is summarized in Table 5. Accordingly, the total asynchronous demand reduction after participation of 287 commercial centers in demand side management programs is equal to 10.187 MW. Moreover, 13,285,830,611 Rials discount paid to commercial customers, has led to 217,713 MWh energy saving. As mentioned before, total cost for 1 kW power generation is equal to 2,842,911 Rials. Supposing that 50% of 10,187 MW load reduction occurred simultaneous with annual on-peak electricity demand, $(13,285,830,611 Rials)/((0.510,187 kW)) = 2,608,389$ Rials per kW has been paid as discount to each participated commercial consumer. It is found that this value is 9% lower than total investment and operation cost of conventional thermal units. According to Table 5, this is an interesting result indicating that each electricity regional distribution company paid $(13,285,830,611 Rials)/(217,713,147 kWh) = 61$Rials per kWh as energy tariff to commercial consumers for purchasing electricity. If 217 MWh is generated by a thermal unit, gas-fueled generation station, and a combined cycle power plant, different pollutant gases will be released as shown in Fig. 8. Based on Tables 4 and 5 and Fig. 8, total environmental benefit for 217,713 MWh electricity saving after implementation of DRPs in commercial consumers is demonstrated in Fig. 11.

5. CONCLUDING REMARKS

In summer, large-scale power systems face with annual on-peak electrical demand due to huge amount of energy consumed by air conditioning equipment of residential, industrial and

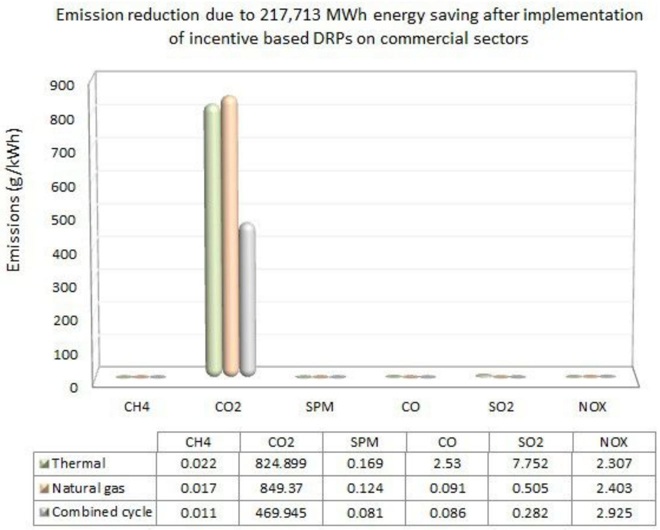

Fig. 9. Emission reduction after collecting traditional lamps from Iran's commercial sectors

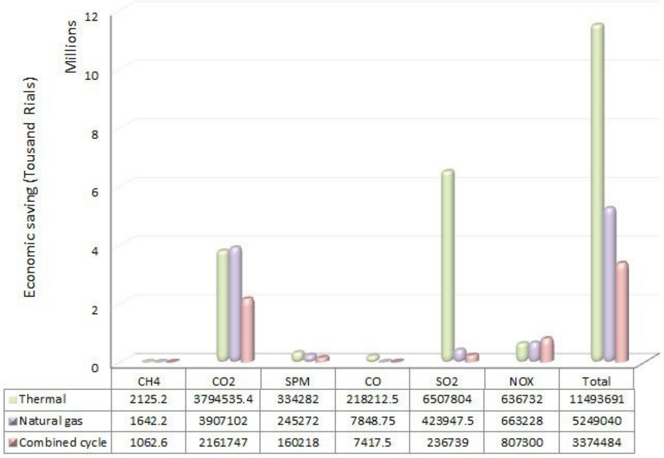

Fig. 10. Social cost reduction after replacement of traditional lamps with energy-efficient ones in commercial sectors

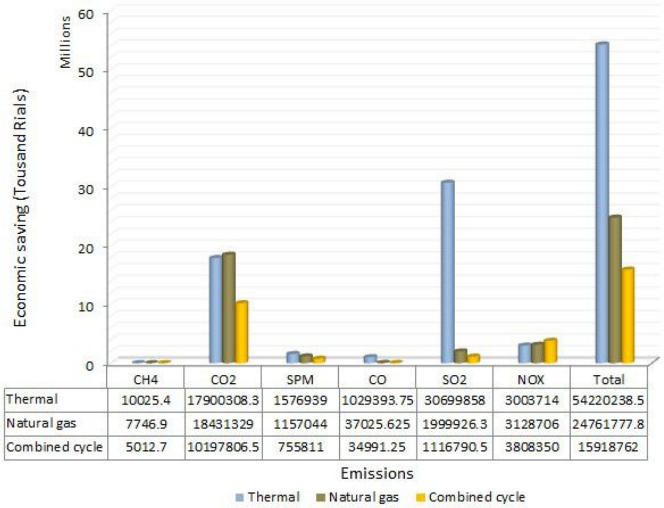

Fig. 11. Economic saving due to emission reduction after application of incentive based DRPs in commercial centers

Table 5. Social costs of greenhouse gases in Rials/kg

Number of co-operated customers	287
Discount (Rials)	13,285,830,611
Reduced power (kW)	10,187
Energy saving (kWh)	217,713,147

commercial buildings. Therefore, optimal operation of power systems for minimization of this unexpected power demand is crucial. In Iran, Tavanir as specialized holding company is responsible for management of generation, transmission and distribution of electrical power. Three demand side management strategies consist of operational reserve program, incentive-based reduction or disruption of electricity loads during on-peak time intervals, and replaced traditional lamps with energy efficient ones have been implemented on industrial and commercial sectors. All policies and criteria used for reducing peak demand were presented. In addition, economic and environmental benefits of DRPs were comprehensively discussed. The future work can be focused on evaluating the current successful DRPs all around the world on industrial and commercial sectors of Iran based on a deep calculation and investigation. On the other side, the recent challenges and methodologies in smart grid demand for industrial, residential, and commercial areas in Iran can be an attractive topic for future studies.

REFERENCES

1. S. A. Mansouri, M. S. Javadi, A. Ahmarinejad, E. Nematbakhsh, A. Zare, and J. P. Catalão, "A coordinated energy management framework for industrial, residential and commercial energy hubs considering demand response programs," Sustainable Energy Technologies and Assessments, vol. 47, p. 101376, 2021.
2. J. Valinejad, Z. Oladi, T. Barforoushi, and M. Parvania, "Stochastic unit commitment in the presence of demand response program under uncertainties," International Journal of Engineering, vol. 30, no. 8, pp. 1134-1143, 2017.
3. Q. Qdr, "Benefits of demand response in electricity markets and recommendations for achieving them," US department of energy, 2006.
4. Y. Wang and L. Li, "Time-of-use based electricity demand response for sustainable manufacturing systems," Energy, vol. 63, pp. 233-244, 2013.
5. E. Dehnavi and H. Abdi, "Optimal pricing in time of use demand response by integrating with dynamic economic dispatch problem," Energy, vol. 109, pp. 1086-1094, 2016.
6. D. Srinivasan, S. Rajgarhia, B. M. Radhakrishnan, A. Sharma, and H. Khincha, "Game-Theory based dynamic pricing strategies for demand side management in smart grids," Energy, vol. 126, pp. 132-143, 2017.
7. E. Salies, "Real-time pricing when some consumers resist in saving electricity," Energy Policy, vol. 59, pp. 843-849, 2013.
8. S. Favuzza et al., "Real-time pricing for aggregates energy resources in the Italian energy market," Energy, vol. 87, pp. 251-258, 2015.
9. T. Kato, A. Tokuhara, Y. Ushifusa, A. Sakurai, K. Aramaki, and F. Maruyama, "Consumer responses to critical peak pricing: Impacts of maximum electricity-saving behavior," The Electricity Journal, vol. 29, no. 2, pp. 12-19, 2016.
10. D. Jang, J. Eom, M. Jae Park, and J. Jeung Rho, "Variability of electricity load patterns and its effect on demand response: A critical peak pricing experiment on Korean commercial and industrial customers," Energy Policy, vol. 88, pp. 11-26, 2016.
11. C.-L. Su and D. Kirschen, "Quantifying the effect of demand response on electricity markets," IEEE Transactions on Power Systems, vol. 24, no. 3, pp. 1199-1207, 2009.
12. N. Ruiz, I. Cobelo, and J. Oyarzabal, "A direct load control model for virtual power plant management," IEEE Transactions on Power Systems, vol. 24, no. 2, pp. 959-966, 2009.
13. A.-H. Mohsenian-Rad and A. Leon-Garcia, "Optimal residential load control with price prediction in real-time electricity pricing environments," IEEE transactions on Smart Grid, vol. 1, no. 2, pp. 120-133, 2010.
14. G. Aghajani, H. Shayanfar, and H. Shayeghi, "Presenting a multi-objective generation scheduling model for pricing demand response rate in micro-grid energy management," Energy Conversion and Management, vol. 106, pp. 308-321, 2015.
15. F. Kamyab, M. Amini, S. Sheykhha, M. Hasanpour, and M. M. Jalali, "Demand response program in smart grid using supply function bidding mechanism," IEEE Transactions on Smart Grid, vol. 7, no. 3, pp. 1277-1284, 2016.
16. M.-C. Hu, S.-Y. Lu, and Y.-H. Chen, "Stochastic–multiobjective market equilibrium analysis of a demand response program in energy market under uncertainty," Applied Energy, vol. 182, pp. 500-506, 2016.
17. M. Majidi, S. Nojavan, and K. Zare, "A cost-emission framework for hub energy system under demand response program," Energy, vol. 134, pp. 157-166, 2017.
18. H. Falsafi, A. Zakariazadeh, and S. Jadid, "The role of demand response in single and multi-objective wind-thermal generation scheduling: A stochastic programming," Energy, vol. 64, pp. 853-867, 2014.
19. M. Zheng, C. J. Meinrenken, and K. S. Lackner, "Agent-based model for electricity consumption and storage to evaluate economic viability of tariff arbitrage for residential sector demand response," Applied Energy, vol. 126, pp. 297-306, 2014
20. D. Setlhaolo, X. Xia, and J. Zhang, "Optimal scheduling of household appliances for demand response," Electric Power Systems Research, vol. 116, pp. 24-28, 2014.
21. A. R. Jordehi, "Risk-aware two-stage stochastic programming for electricity procurement of a large consumer with storage system and demand response," Journal of Energy Storage, vol. 51, p. 104478, 2022.
22. M. Tostado-Véliz, P. Arévalo, S. Kamel, H. M. Zawbaa, and F. Jurado, "Home energy management system considering effective demand response strategies and uncertainties," Energy Reports, vol. 8, pp. 5256-5271, 2022.
23. H. Chen, B. Zhang, H. Geng, M.-M. Wang, and H. Gao, "Demand response during the peak load period in China: Potentials, benefits and implementation mechanism designs," Computers and Industrial Engineering, vol. 168, p. 108117, 2022.
24. X. Zhu et al., "Day-ahead energy pricing and management method for regional integrated energy systems considering multi-energy demand responses," Energy, vol. 251, p. 123914, 2022.
25. F. Jabari, H. Arasteh, A. Sheikhi-Fini, and B. Mohammadi-Ivatloo, "Optimization of a tidal-battery-diesel driven energy-efficient standalone microgrid considering the load-curve flattening program," International Transactions on Electrical Energy Systems, vol. 31, no. 9, p. e12993, 2021.
26. S.A. Mansouri, M.S. Javadi, A. Ahmarinejad, E. Nematbakhsh, A. Zare, J.P. Catalão, “A coordinated energy management framework for industrial, residential and commercial energy hubs considering demand response programs,” Sustainable Energy Technologies and Assessments. vol. 47, 101376, 2021.
27. J. G. Kirkerud, O. N. Niels, T. F. Bolkesjø. "The role of demand response in the future renewable northern European energy system," Energy, vol. 235, 121336, 2021.
28. C. Leinauer, P.Schott, G. Fridgen, R. Keller, P. Ollig, and M. Weibelzahl, “Obstacles to demand response: Why industrial companies do not adapt their power consumption to volatile power generation,” Energy Policy, vol. 165, p.112876, 2022.
29. X. Dai, H. Chen, D. Xiao, Q. He, and Y. Huang, “Distributed Energy Resource-Assisted Industrial Demand Response: A Survey on Technologies, Business Models, and Applications in China,” In 2022 International Conference on Power Energy Systems and Applications (ICoPESA), pp. 503-510. IEEE, 2022.
30. F. Pallonetto, C. Jin, and E. Mangina, “Forecast electricity demand in

commercial building with machine learning models to enable demand response programs," Energy and AI, 7, p.100121, 2022.
31. https://eeo.trec.co.ir
32. https://www.igmc.ir