



# Application of Demand Response Programs to Heavy Industries: a Case Study on a Regional Electric Company

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## Abstract

In recent years, incremental rate of electrical demands made many challenges for policy makers of power systems. Besides, due to economic crisis and environmental concerns about the air pollution, the new investments in thermal power generation units have experienced a noticeable reduction. For this reason, the power system operators should propose novel approaches to make a balance between incremental rate of electrical demand and decreased rate of generation expansion planning. In this paper, in order to hedge against the aforementioned problem, Demand Response Programs (DRPs) are proposed to control the electrical demands of heavy industries which consume a considerable part of electrical demands in peak durations. In this regard, two types of incentive-based demand response programs, including spinning reserve and curtailable load program, are addressed to decrease the need of new investments in power generation during peak hours. In order to show applicability and proficiency of the proposed approach, a case study containing 23 numbers of heavy industries of Khorasan Regional Electric Company (KREC) is addressed to participate in the proposed demand response programs in summer 2016.

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## 1. Introduction

Recently, by increasing in the rate of electrical demands, policy makers of power systems should make capital investments in the generation units. On the other hand, economic crisis, all over the world, causes many challenges for investing in this regard. In such situation, making a balance between supply and demand needs to be further studied considering novel approaches of energy management.

Demand Response Programs (DRPs) are one of the most important approaches about the energy management of end-use consumers. Generally, demand response can be defined as the changes in electricity usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time [1]. DRPs may be categorized into two different programs as (1) incentive-based programs (2) price-based programs [2]. The incentive-based DRPs include Direct Load Control (DLC), Curtailable Load Program (CLP) and Demand side bidding, capacity and ancillary services [3]. The price-based DRPs can be categorized into

three programs as: Time-of-Use (TOU), Critical Peak Pricing (CPP) and Real Time Pricing (RTP) [4].

There is a great difference in the electricity consumption patterns of different types of users, such as domestic, commercial, industrial, agricultural, etc. Even for the same type of users, their patterns of electricity consumption may be different [5]. Therefore, the DRPs for different types of users should be studied considering their inherent characteristics.

Considering industrial consumers, different DRPs are described in the literatures. In paper [6], different DRPs are classified according to their control mechanisms, the motivations offered to reduce the power consumption and the DR decision variables. A survey of DRPs is presented in paper [7], including the existing applications and a possible implementation strategy in smart grid environments. Among the recent studies, regulation, contingency reserves (spinning and non-spinning reserve) and replacement reserve service can be addressed as the

most important DRPs for industrial consumers [8]. To sum up, Fig. 1 describes a classification of DRPs.

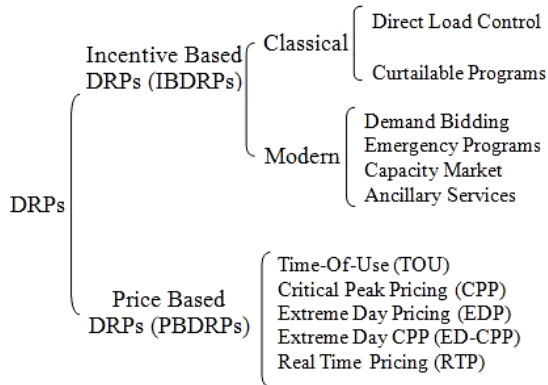


Fig. 1. A Classification of DRPs in Power Systems

Generally, the recent studies mostly refer to DR in residential or commercial sectors and only few articles focus on DR in the industrial sector. Nevertheless, implementing DR in industries is a more challenging task and careful knowledge and attention are needed. For this reason, application of DRPs to heavy industries of a power system is considered in this paper. In this way, four types of industries are addressed, including metals, cement, automotive and coal mining industries. In order to study the impacts of DRPs on power system operation, two kinds of DRPs are considered. The proposed DRPs are implemented into a real case study which consists of 23 heavy industries of Khorasan Regional Electric Company (KREC) located in the east of Iran.

The rest of paper is organized as follows. Section II provides the mathematical formulation for DR approach. Section III introduces the characteristics of two types of important industries. Section IV comprises the obtained results in a case study, which are discussed and analyzed in detail. Finally, section V provides the relevant conclusions.

## 2. Problem Formulation

In this section, mathematical formulations of DRPs for industrial consumers are presented. Moreover, the proposed approach about the incentives, cost and the benefits of the DRPs are illustrated.

### A) Spinning Reserve

We consider a Demand Response Aggregator (DRA) who contracts with individual facilities to procure DR. These facilities receive compensation for agreeing to reduce load when called upon. In turn, the aggregator sells the cumulative DR capability to a utility or grid operator. In this way, a minimum/maximum size for load participation in DRPs is defined by the DR aggregator as follow:

$$DR_{\min} \leq DR_i(t) \leq DR_{\max} \quad (1)$$

Where DR is the potential of DRP implementation (the percentage of participation),  $DR_{\max}$  and  $DR_{\min}$  are the maximum and minimum size of load participation in DRPs, respectively. In addition,  $i$  is the index of facilities and  $t$  is the index of time period (hour).

DRAs are most likely to target large commercial participants and earn revenue based on the market clearing price and magnitude of load response, and incur costs to enable spinning reserve in participant facilities. Revenue is calculated by matching hourly DR resource availability with market clearing price. The revenue of DRPs are allocated to participant facilities through two incentive bonus programs: (1) Incentive Bonus of Readiness (IBR) (2) Incentive Bonus of Participation (IBP). Mathematical formulations of the incentive bonus involvement in the demand response program are described as follows:

$$C_i^R = DR_i(t) \times (\Lambda_1 + \Lambda_2 + \Lambda_3) \quad (2)$$

$$C_i^P = (\alpha + \beta) \times (P_d) \times (\Lambda_1 + \Lambda_2 + \Lambda_3) \quad (3)$$

$$\alpha = \frac{P_d}{P_{ave}} = \frac{P_{ave} - P_h}{P_{ave}} \quad (4)$$

$$\beta = 1.6 \times \exp\left(-\frac{h}{100}\right), 1 \leq h \leq 200 \quad (5)$$

Where  $C_i^R$  and  $C_i^P$  are IBR and IBP, respectively,  $\Lambda_k$  is the demand price (\$/MW) for contractual electrical demands,  $\alpha$  is the participation factor,  $\beta$  is adjustment factor,  $P_d$  is the amount of power reduction (MW),  $P_{ave}$  is the average of power consumption during a specified time period before participation in DRP and  $h$  is the time duration of participation in DRP. Note that the maximum value of 200 hours is allocated for time duration of DR participation for each consumer.

The DRA make contracts with the large facilities to participate in DRPs. If a facility signs the DR contract, the DRA allocates the IBR to the participant facility. Signing DR contracts with large-scale facilities, the DRA provides a fraction of the unloaded capacity of generation units connected or synchronized to the grid to be ready for delivery in a few minutes.

The IBP allocates to the facilities not only for signing the DR contract, but also for agreeing to reduce load when called upon. It is worth mentioning that if a facility signs the DR contract, but refuses to reduce load when called upon, faces heavy financial penalties. In addition, such industries are located in the first priorities of load shedding program when a power shortage occurs in power system.

### B) Curtailable Load

Curtailable load programs are addressed to medium and large consumers. Participants in these programs receive incentives in order to (1) turn off specific loads (2) interrupt their energy usage (3) shift their energy usage from critical time durations to other durations, responding to calls emitted by the DRA. In this program, contracts should specify the maximum number and the duration of calls. These programs are mandatory, i.e. customers may face penalties in case they fail to respond to DR requests. DRA/power system operator may call the consumer to respond to reliability events; however, load curtailments may also be traded in the market [3, 9].

In this paper, the curtailable load program is divided into three categories as follows:

- Shifting some parts of energy usage from weekdays to weekend days.
- Decreasing the energy usage in critical time durations, i.e. peak demand durations.
- Interrupting energy usage through performing minor/major maintenance works in critical days of the year.

In this program, the utilities make contracts with DRA to participate in the aforementioned DRPs. The facilities receive compensation for participating in the DRPs according to the contracts signed. The incentive bonus of facilities is calculated as follows:

$$\Delta P = \frac{d}{30} \times [P(t-1) - P(t)] \quad (6)$$

$$\Delta E = \left[ \frac{d}{30} \times E(t-1) \right] - E(t) \quad (7)$$

$$C_i^{Energy} = \lambda^{Shoulder} \times \Delta E \quad (8)$$

$$C_i = C_i^{Energy} + C_i^{Power} \quad (9)$$

Where  $\Delta P$  and  $\Delta E$  are the power and energy reduction values during participation in DR.  $P(t)$  and  $E(t)$  are power and energy consumption values during DRP performance, respectively.  $P(t-1)$  and  $E(t-1)$  are power and energy consumption values before DRP performance, during one month (30 days) duration.  $d$  is the time duration (number of days) of participation in DRP.

Moreover,  $C_i^{Power}$  and  $C_i^{Energy}$  are incentive bonus values for power and energy reduction values, respectively,  $k$  is adjustment factor and  $\lambda^{Shoulder}$  is the electricity price for off-peak duration. Finally,  $C_i$  is the total incentives allocated to the facility  $i$ .

### 3. Type of Industries

The objective of this section is to introduce two types of the most important heavy industries which are the target of DRPs in the industrial sector. Based on the studies, cement and metals are the main

industries participating in DRPs among the heavy industries.

#### A) Cement

The cement industry is one of the major consumers of energy; since it annually consumes over 350 trillion Btu of fuel and 10 billion kWh of electricity in the U.S. [10]. The electricity cost in a typical cement plant approximately consists 30% of its total cost [11]. Fig. 2 shows a schematic diagram about the production process in a typical cement industry. Considering the figure, the most electricity incentive processes are figured with blue lines.

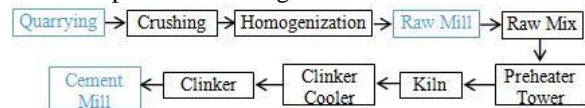


Fig. 2. Production processes for a typical cement industry [3]

The energy intensity of cement milling in reference [12] is stated 0.1 MWh for every ton of cement produced. Normally, a typical mill would be sized for 20 h/day of operation, while some of them are sized to work 16–18 h/day in order to be more flexible to turn off during higher prices. Regarding suitable DRPs for this industry, since the characteristics of every cement plant is particular, useful DR strategies vary from one site to another.

In general, in a cement plant during the production process, only the kiln must keep running continuously; while if financially advantageous the operating time of raw mill, coal mill and cement mill can be adjusted as required [3]. It is worth mentioning that although mills are suitable for DR purposes, but the mills performance are the most efficient for steady operation, so for efficient load shedding the financial incentives from the utility must outweigh the cost of stop and start of mills, both in wasted product and operator time if applicable [10]. Further information about the characteristics of cement industries for participation in DRPs are described in reference [10].

#### B) Metals: steel

Steel manufacturing processes are known as one of the most complicated industries to schedule. It is considered as a large-scale, multilevel, and multiproduct industry which consists of parallel tools, complicated processes and energy limitations [13]. The production processes for a typical steel industry is depicted in Fig. 3. In this process, melt shop is the most energy intensive process which is specified with blue lines. The energy intensity for this process is around 0.525 MWh for every ton of steel produced [12]. Therefore, the melting process is the main target for implementing DRPs in a steel industry. Although the melting process is able to halt instantly for DRPs, this process has to resume again if the disruption exceeds half an hour, since the scrap metal begins to cool down after that.

In papers [13, 14], energy scheduling and optimization for steel industries are presented. In these papers, different optimum energy usage levels are attained based on changes in pricing scenarios. Increases in scheduling horizon will also lead to increase in total profit as it becomes more time flexible. On the basis of the results in this case, the improvement in Time-Of-Use (TOU) pricing is over 50%, under Critical Peak Pricing (CPP) is around 40%, under day-ahead pricing is over 20%, and under peak pricing is over 10%. Further information about the price-based DRPs in a typical steel industry can be found in [15].

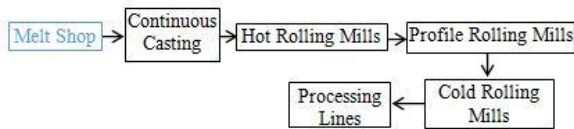


Fig. 3. Production processes for a typical steel industry [3]

#### 4. Case Studies and Simulation Results

##### A) Input Data

In order to show applicability of the proposed DR approach, a case study containing 23 heavy industries of Khorasan Regional Electric Company (KREC), located in the east of Iran Power Network (IPG), are considered. Fig. 4 shows location of the heavy industries inside the KREC territory. Moreover, the electrical demands of the industries are described in Table 1.

Regarding the heavy industries, 5 cement industries, 7 steel industries and 2 other industries, including IKCO automotive factory and Tabas coal mining, participate in the DRPs. Therefore, total demands of participant facilities are 543 MW. Time interval of DRPs is three-month duration, from 4 June to 5 September 2016.

##### B) Simulation Results

Fig. 5 describes the spinning reserve for demand response program. As the graph reveals, the first request for providing the spinning reserve is submitted in 1<sup>st</sup> July. Afterwards, 14 requests for spinning reserve are submitted between 2<sup>nd</sup> July and 24<sup>th</sup> July. It is evident that July 2016 is the time duration which the most power shortage is observed in the IPG. For this reason, the most participation of heavy industries is requested in this month. Based on the graph, the highest value of load reduction in July is just over 103 MW which is occurred in 10<sup>th</sup> July. The last request is submitted in 8<sup>th</sup> August with just under 122 MW which is the highest value for spinning reserve in the study horizon. Considering the graph, it is observed that the value of 875 MW is provided for spinning reserve from 4 June to 5 September.

Table 2 describes the role of spinning reserve of KREC industries in the peak shaving for both KREC

and IPG. Based on the Table, regarding the peak demand of IPG, the spinning reserve program could reduce 45 MW of peak demand. In addition, the spinning reserve reduces 30 MW of KREC peak demand. The information shows that the participation duration of facilities equals 20 days with 4 hours a day. Moreover 60 % of industries participate in the DRPs. Daily load profile of two facilities, including cement and steel industries, during DRP performance are depicted in Appendix.

Note that the needs of load reduction are evaluated not only considering the KREC requirements, but also to meet the IPG requirements. In this way, the Iran Grid Management Company (IGMC) plays the role of DRA in Iran power system.

Fig. 6 describes the load reduction due to implementation of curtailable load program. As the graph reveals, the most requests are submitted between 2<sup>nd</sup> July and 31<sup>st</sup> August. In this way, the most load reduction is approximately 112 MW which is occurred in 8<sup>th</sup> August. In addition, two time intervals, including 13<sup>th</sup>-19<sup>th</sup> July and 4<sup>th</sup>-8<sup>th</sup> August have the most requests for load reduction. In the study horizon, total demand of 1457 MW is reduced through curtailable load program.

Table 3 illustrates the role of curtailable load program in peak reduction for both KREC and IPG. Based on the table, application of curtailable DRP decreases 8.3 and 13.4 MW of peak demand for IPG and KREC, respectively. In addition, implementation of curtailable DRP decreased 30000 MWh of energy usage for heavy industries. It means that the pressure on the power generation units and power lines during the annual peak hours of IPG and KREC has been decreased considerably.

As a result, the probability of load shedding or *unscheduled outage for industrial sector minimized*. It is worth mentioning that the unscheduled load shedding can impose heavy or even irrecoverable losses to heavy industries. Therefore, application of DRPs with scheduled load curtailment can increase the security in the production process of heavy industries. On the other hand, by diminishing the probability of unscheduled outage, the cost of energy not supplied and power system failures are minimized.

Table 4 shows the incentive costs involvement in the DRPs, including spinning reserve and load curtailment programs.

As the table reveals, for spinning reserve program two kinds of incentive bonus costs, including IBR and IBP, are considered. Moreover, a penalty cost is imposed to the facilities which refuse to respond to the requests for load reduction. In this program, 834033 \$ is allocated to the participant facilities. Moreover, a penalty cost of 216446 \$ is imposed to the facilities which do not respond to the requests emitted by the DRA for load reduction.



Regarding the curtailable load program, 1207186 \$ is allocated to the facilities for energy reduction consumed by the facilities. In addition, total cost of 92257 \$ is devoted for participation of facilities in power reduction during the peak hours.

To sum up, the results show that the DRPs implemented in KREC industries provides 53.3 (45+8.3) MW power reduction during the peak hours of Iran power grid. In order to encourage the industries to participate in the DRPs, total cost of 1917030 \$ (834033-216446+1207186+92257) is allocated to the facilities. It is assumed that the capital investment cost for conventional gas/oil combined cycle is around 106 \$/MW [16]. Therefore, allocating 1917030 \$ for 53.3 MW power reduction in peak hours can be an economic way to make a balance between supply and demand.

As a result, implementing DRPs for large-scale power systems can be interpreted as an economic approach for peak shaving in critical hours a year in comparison with the generation expansion planning which imposes higher costs to the power system owners.

Table.1.  
Electrical characteristics of heavy industries

No.	Type	Industry	Demand (MW)	DRP
1	Cement	Shargh Cement	36	Yes
2		Lar Cement	19.5	Yes
3		Zaveh Cement	23	No
4		Bojnourd Cement	20	Yes
5		Majd Cement	15	Yes
6		Jovein Cement	20	Yes
7		Bagheran Cement	18	No
8		Asia Cement	14.5	No
9	Metal	Barsava Steel	19	Yes
10		Kabkan Steel	18	Yes
11		Behkaran Steel	14	No
12		Sabzevar Ferrochrome	15	Yes
13		Esfarayen Steel	55	Yes
14		Esfarayen Rolling	8	Yes
15		Sangan Steel	49	Yes
16		Safatoos Rolling	20	No
17	Other Industries	Khorasan Steel	240	Yes
18		Shirin Darre Reservoir Dam	8.8	No
19		Doosti Reservoir Dam	37	No
20		IKCO Automative	8.5	Yes
21		Khangiran Gas Refinery	7	No
22		Tabas Coal Mining	12	Yes
23	Light Rain Train	-	No	

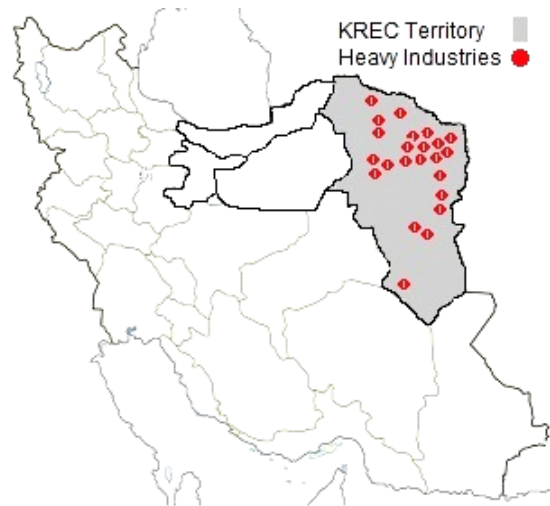


Fig. 4. Location of heavy industries and KREC territory in IPG

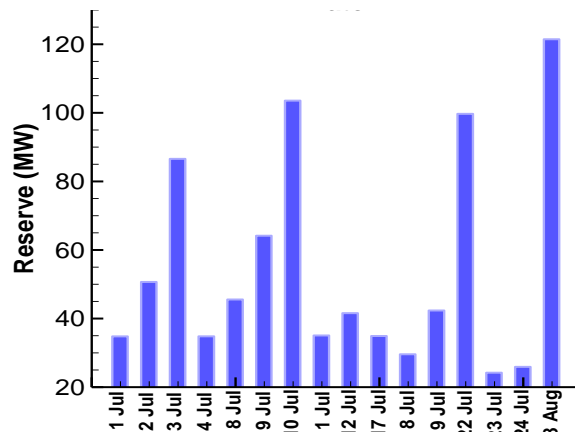


Fig. 5. Load reduction due to spinning reserve for DRP

Table.1.  
The rule of spinning reserve for load reduction in IPG and KRED

Grid	Demand Reduction	Participation		
		Duration		Percentage
		Days	Hours	
IPG	45	20	80	60
KREC	30			

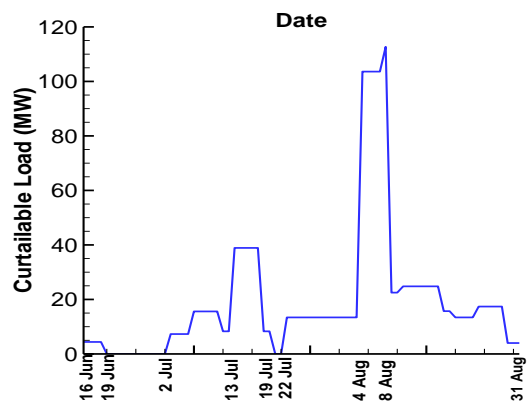


Fig. 6. Load reduction due to curtailable load program for DR

Table.2.  
The role of curtailable load program for load reduction

Grid	Curtailable Load			
	Demand Reduction (MW)	Energy Reduction (MWh)	Participation	
			Duration (Day)	Percentage (%)
IPG	8.3	30000	104	55
KREC	13.4			

Table.3.  
Incentive bonus costs involvement in DRPS

Industry	Spinning			Curtailable	
	IBR (\$)	IBP (\$)	Penalty (\$)	$C^{Energy}$ (\$)	$C^{Power}$ (\$)
Shargh Cement	0	0	0	63833.03	10694.6
Lar Cement	8105.0	15483.2	0	53863.8	2599.3
Bojnourd Cement	0	0	0	511508.4	0
Majd Cement	232.01	388.7	62.08	0	0
Jovein Cement	7786.13	13024.9	2081.1	57424.7	11462.3
Barsava Steel	16514.5	30878.7	14217.9	0	0
Kabkan Steel	7624.9	11541.6	1916.6	14258.1	796.33
Sabzevar Ferrochrome	3168.8	5200.41	2510.7	0	0
Esfarayen Steel	48699.3	149893.2	0	70094.5	0
Esfarayen Rolling	1496.4	1803.50	989.9	0	0
Sangan Steel	13007.1	20856.93	6772.8	0	0
Khorasan Steel	41504.0	425369.2	186749.3	383509.4	63929.1
IKCO Automotive	0	0	0	31503.2	2775.50
Tabas Coal M.	4824.6	6630.04	1145.4	21191.1	0

## 5. Conclusion

In this paper, two types of Demand Response Programs (DRPs), including spinning reserve and curtailable load program, are proposed. The proposed DRP approaches are devised to implement in heavy industries during peak hours of a power system. For this reason, two types of important heavy industries, including cement and metals are studied to find the appropriate production process for implementing DRPs.

Among metal industries, the melting process is the main target for implementing DRPs in a steel industry. Regarding cement industry, during the production process, only the kiln must keep running continuously; while if financially advantageous the operating time of raw mill, coal mill and cement mill can be adjusted for implementing DRPs.

The results show that the application of DRPs in Khorasan Regional Electric Company (KREC) has been resulted in 53.3 MW power reductions in critical hours of the annual peak day of Iran Power Network (IPG). In order to encourage the heavy industries to participate in the DRPs, incentive bonus costs are allocated to the facilities. Comparing the costs of DRPs with the capital investment costs of gas/oil combined generation units, it is found that implementing DRPs can be interpreted an economic

way to make a balance between supply and demand in the annual critical hours of power systems.

## Appendix

The figures A.1 and A.2 describe the impacts of DRPs on the power reduction of two test industries, including Barsava Steel and Lar Cement, during peak hours of Iran power grid (1 pm to 16 pm), in the 10<sup>st</sup> July 2016.

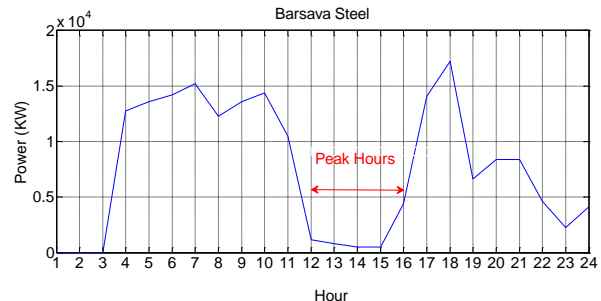


Fig. A.1. Daily load profile of Barsava Steel during DRP implementation

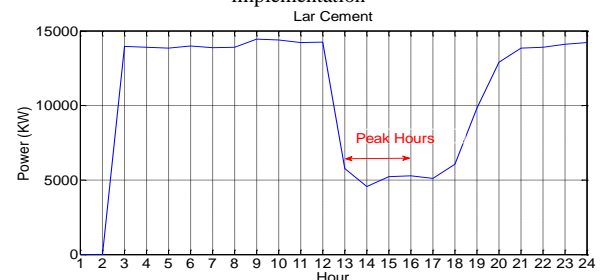


Fig. A.2. Daily load profile of Lar Cement during DRP implementation

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