A review on demand response based ancillary services offered by industries

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Abstract

Industrial power consumers have a considerable share of the global power demand; as a result, effective solutions have to be adopted to optimize the industrial power consumption. Demand response Programs (DRPs) provide such solutions. These programs are growingly studied as the industrial power consumption has increased and the implementation costs of the new technologies have decreased in recent years. DRP implementation reduces the dependency on the expensive energy storage technologies and flexible backup power sources. It seems that, DRP is not widely used in industry, yet its benefits are not practically exploited. The present work reviews the implementation of DRPs in industry and introduces the opportunities of industries for offering ancillary services to the market. Then, the industries which highly suit the specific kind of industrial DRPs are introduced and their processes are analyzed from the DRP point of view. Next, the DRP projects are continentally categorized and the advancements of different countries in specific kind of industrial DRPs are noted. Finally, the discussions and conclusion are presented.

Keywords: Energy Pricing, Demand Side Management, Demand Response, Smart Grid.

1. Introduction

The present decade is an era of economic and industrial evolution and the competition for development seems to be intense. Industrial countries are in close competition to supply their growing power demand so that they could be praised in the international competitive markets. Electricity, as a clean energy, is highly demanded with a growing trend in recent years especially by the industries. This occurs although power generation, transmission, and distribution are expensive with specific technical limitations. As a result, providing optimal approaches and procedures of efficient energy use seems essential for all industries and organizations. These procedures should also be considered in power generation and operation units.

Despite all endeavors for enhancement of power generation, transmission, and distribution units, the present power grid systems are not adequate for our requirements. Hence, new infrastructures for modern power grids are highly needed.

Having access to the consumption information is feasible by progressions in Information and Communication Technology (ICT). Therefore, the electric grids have to be updated and gradually changed into the Smart Grids (SGs) so that a reliable and stable infrastructure is established, the costs and the possibility of power failure are reduced, and the deviations of voltage and frequency are controlled.

Economically and from the energy efficiency point of view, SGs result in efficient operation of the grid by providing real-time monitoring of the consumed power and accurate modeling of the power generation units. The final value of electricity can change for each quarter or hour. This is due to the special properties of the electricity and the fact that it cannot be saved in large scales. Most consumers, however, pay a fixed price for electricity which corresponds to the average cost of power generation. Therefore, the consumers hardly have incentives for efficient energy use and optimal utilization of the grid capacity. If the consumers are actively involved in operation of power systems, both the power system efficiency and flexibility can be improved. DRPs implementation in an SG makes it possible for the consumers, power generation companies, and grid operators to benefit from various economical and technical advantages.

The change in electricity consumption by the end consumers in the response to penalties and incentives is called demand response (DR).

DR can also be considered as a change of electricity price for different levels of power consumption [1-3]. Generally, technologies, and business agreements which make it possible for the consumers to adjust their operation of the power systems which are included in DR [4].

Power consumers are roughly categorized into the residential, commercial, and industrial consumers. Sometimes in the literature, the data centers and electric vehicles are included in separate categories [5]. The maximum number of consumers with a low level of power consumption is included in the residential category where the DR technology highly relies on the smart houses as the main component of the domestic Energy Management System (EMS) [4]. The second category consists of the commercial consumers and non-residential consumers such as the hotels and training centers that are involved in DR ancillary services and load curtailment. The third category, the industrial units, consume a considerable share of the total generated electricity. As stated in reports published by various organizations, 2-10% of the industrial consumers consume 80% of the generated electricity [6]. As a result, the involvement of industrial units in DR is more expected compared to the residential or commercial consumers [7]. According to the recent works, however, the industries are less involved in such programs [7]. This is due to the complexity of industrial processes especially the management of the production process. Power failure results in production halt, defects of daily operations, and constraints of production in industry. Production processes are sometimes interconnected and isolation of any component or any halt can disturb the final product. In some cases, the materials have to be saved for each process halt. This can impose considerable costs and big challenges.

The rest of this paper is organized as follows. Section 2 introduces and classifies the DRP types. The DRP based ancillary services are investigated in Section 3. Various industries which suit the implementation of DRP are reviewed in Section 4. Section 5 explains and classifies different DRPs applied in different industries around the world and the discussions are presented in Section 6. Finally, Section 7 concludes the paper.

2. Demand response programs

According to the International Energy Agency (IEA) strategic plan from 2008 to 2012, the Demand Side Management (DSM) was widely accepted due to the economic benefits and various levels of operation [8]. DSM optimizes the network load distribution, improves the voltage profile, affects the reactive power and transformer tap changing in substations, reduces the energy loss, configures the network, and operates the storage units and consumer loads.

Many years, DR was an important part of DSM to only eliminate the on-peak hours at specific times of the year. But according to the order no.719 announced by the FERC, DR is defined as the reduction of the customers' power consumption based on the consumption patterns so that the low-consumption customers are encouraged [9]. Indeed, DR consists of actions to reduce and eliminate the on-peak hours. The Nordic electricity market presents a similar definition of the DR, but it expects the consumer to voluntarily be involved in the DRP [8].

Inconsistencies between short-term costs of power generation and the electricity bills result in inappropriate use of power sources. The consumers, actually, do not pay for the short-term and spontaneous costs of power generation. Hence, they have no incentive to tune their power consumption with respect to the power generation condition. When the power system cannot supply the on-peak loads in long-term, new investments should be considered to establish new power generation units. In other words, direct advantage of power supply responsiveness is to avoid excess investments in new power generation units which only are established to compensate for the power shortage at limited time slots. As a result, the DR has various economical, technical, and environmental benefits [10].

2.1. Classification of DRPs

Since the first assessment of DR and advanced measurements published by FERC in 2006, the classification of DRP has undergone considerable changes. DRPs are classified in two major categories [11, 12]:

1. Price-Based Programs (PBPs).
2. Incentive-Based Programs (IBPs).

Fig. 1 depicts this classification. Various subsets of this classification which suit the industries are then explained in detail.

2.1.1. Price-Based Programs

In the PBP, time-dependent prices are suggested for electricity consumption. The consumer, in this program, pays a lot for power consumption during the on-peak hours compared to the off-peak time slots. These sets of programs aim at convincing the consumers not to consume power at high-price time slots.

According to the FERC, the PBP is divided into the *static* and *dynamic pricing* schemes [13]. In static pricing, there are *Time-of-Use* (TOU) and *flat* tariffs. In dynamic pricing, the tariffs are based on the *Critical-Peak-Pricing* (CPP), *Real-Time Pricing* (RTP) and *Extreme-Day Pricing* (EDP).

2.1.2. Incentive-Based Programs

The IBP is affected by ongoing events. Despite the condition and remarks of the contracts and advanced information flow, the consumers change their power consumption pattern temporarily. This pricing scheme suggests a punitive response for unfavorable consumption patterns [14]. The IBPs are divided into the *classical programs* and *market-based programs*. In classical programs of IBP, the consumers who contribute to the program benefit from some discounts or credit. Classical IBP involves the *direct load control* and *curtailable load programs*. The latter program suits units with medium- to high-power consumption. There should be some incentives for the consumers to control the loads when required by the generation unit. In curtailable load programs, the maximum times and duration of load curtailment should be determined by the provider. This program cannot be applied to all consumers. Some industrial consumers like the silicon chip producers which require power for the whole day cannot be involved in curtailment load programs. Market-based IPBs include the Emergency DRP (EDRP), demand-bidding, capacity market, and ancillary service schemes [14]. In market-based programs, the participants receive money based on their positive contributions to the load reduction in critical conditions. The demand-bidding programs, also known as *buyback*, encourage high-power demand consumers (especially the commercial and industrial units) to reduce their load according to the bids for load reduction.

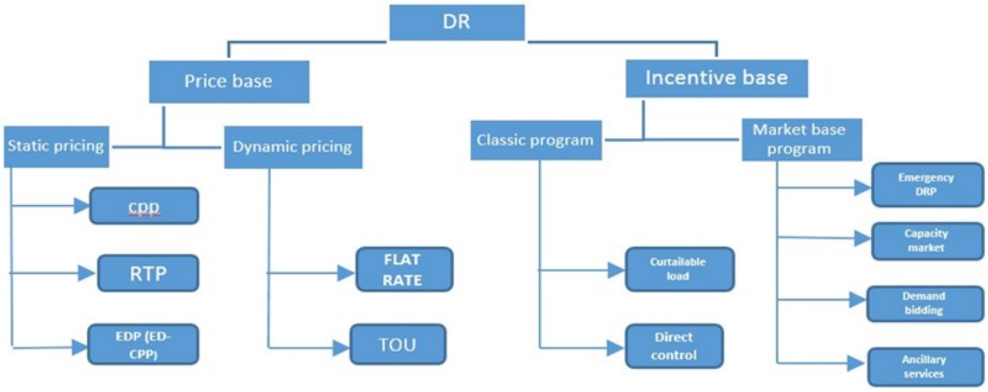

Figure 1: Classification of DRP

3. Ancillary Service Programs

The Ancillary services are defined as essential services to support a safe, reliable, and quality power system. As renewable power sources are more involved in power systems, the network flexibility and ancillary services become more vital. Aging of old generators and increased operation costs require more contributions for ancillary services. Advancements in communication technology and automatic control result in more contribution and involvement of small loads in sequential and continuous DRPs [15]. Although the potential for implementation of ancillary service programs is still high, the DR schemes are rarely involved in ancillary service markets [16]. The main differences between the conventional DRP and those with ancillary services are the reduction of the notification time and more complex technical requirements for accurate and apt measurements.

Unlike the conventional DRP requirements which matter only at the on-peak times, the requirements of ancillary services elongate for more than a whole year and change depending on the location and various technologies. The main value of the ancillary services lies in the high capacity operated when required in a reserved manner to enhance the system reliability [16]. DRP with ancillary services is the most frequent program in industry [17].

3.1. Well-Known Ancillary Services in Industry

According to the FERC, ancillary services are the set of actions to support fundamental services of power generation, and power supply and distribution by the equipment and people responsible for power generation, control, and transmission. These services should satisfy two main characteristics of a bulk power system [18]:

1- The Real-time balance between the load and generated power
2- Power management of transmission equipment by reprogramming the generated power and the available loads.

As stated in [19], the FERC considers six key ancillary services:

1. System management and control and transmission services condition.
2. Reactive power source for voltage control.
3. Frequency regulation and reaction.
4. Energy imbalance services.
5. Spinning reserve services.
6. Replacement reserve services.

Table Table 1 lists the key ancillary services usually used by ISOs in competitive markets. The table also qualitatively compares various aspects of ancillary services. Ancillary services have different values based on their specifications. Regulation and spinning reserves are the most valuable services [8]. Regulation, spinning, non-spinning, and responsive reserves are widely used in industry [8].

3.1.1. Replacement or Supplemental Reserve

Replacement reserve starts with a reaction time of about 30 to 60 minutes [18]. This reserve is distinguished from non-spinning reserve using its period (duration). Responsive loads, in a proper condition, can usually provide the supplemental or replacement services.

3.1.2. Emergency Reserve (Spinning and Non-Spinning Reserve)

Spinning reserve is a part of load-free capacity in reference generator units which are either connected to or synchronized with the network. This capacity can be prepared in 10 minutes. Non-spinning reserve is the capacity which possibly can be prepared in 10 minutes to supply a specific load [8]. The calculated capacity of sources to provide the spinning reserve is usually larger and requires fewer times compared to the sources providing regulation services. The reaction in emergency reserve must be quick. The complete reaction is attained in 10 minutes even if the immediate reaction is preferred.

The loads and processes which do not require notification time are the best sources for emergency reserves.

Table 1: Qualitative comparison of different ancillary services

Ancillary services	**Requirement**					
Type of program	*Dispatch frequency*	*Time to complete the reaction*	*Duration of reaction*	*Reaction speed*	*Duration*	*Time*
Replacement	****	-	****	***	****	****
Regulation (up and down)	--	*	***	***	***	***
Spinning reserve	*****	***	***	*	***	*
Non spinning reserve	****	**	***	**	**	***

Suitable examples of these services are the thermal loads, air compression, water pump, and other loads with inherent conserving capability and those which do not need advanced notification for reaction. In [20], some industrial processes like chlor-alkali electrolysis, aluminum electrolysis, cement factory, wood pulp products and electric arc furnace are investigated in power markets for their economic efficiency and capability in providing non-spinning reserve. The results reveal that those processes can supply 50% of the non-spinning reserve for the market balance until 2020 [20]. In another work [21], the spinning reserve of a foundry is studied in extreme power consumption.

Some loads, like the thermal loads, can provide a quick complete reaction, but other loads require some time to switch to the off-period due to the delay in control equipment such as the relays and gates. The latter loads have to face ISO constraints for a complete reaction in 10 minutes. ISOs have a time constraint for returning to the network. The responsive load is also encountered with the time constraint.

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3.2. Regulation

Regulation is defined as the control services or an accurate and immediate capacity which is applied in normal network conditions in a real-time manner. These services are followed when a continuous balance exists between the power generation and the loads [18]. DR sources which provide regulation services are authorized by the ISOs to change their output as a function of Automatic Generation Control (AGC) of the EMS operator. In some ISOs and Regional Transmission Organizations (RTOs), the regulations are classified into regulation up and regulation down categories. In this case, the DR source is only required to compensate for the deviations from the normal operating point in a specific direction. In some markets, the sources can suggest unbalanced regulations.

Table 2: Industries with a high potential for DRP implementation and the corresponding references

Industry	Process	References		
		Case study of particular industry	DR Markets and ISOs	Other works in industrial DR
1- Food and similar industries (milk and cheese, sugar, ...)	Electric defrost, refrigerated warehouses, cooling production and distribution	[25-31]	[8,29,44, 45,46,47]	[30,34,38, 42,48,49, 50]
2-Iron and steel manufacturing (basic and tubes)	Steel mill, electric arc furnace, oxygen generation facilities, crushing	[32-35]		

3-Chemical product manufacturing	Catalytic cracking, crude oil process Catalytic cracking	[22,32,36,37,38]
4-Motor vehicles manufacturing, transportation equipment, automobile manufacturing	Assembly chambers, Workshop and press workshop	[39]
5-Electrical equipment manufacturing for engines and vehicles	Assembly chambers	-
6-textile mill product and apparel	Wrapping, weaving	-
7-lumber and wood products, -pulp, paper and paper board mill, convert paper product manufacturing	Mechanical refining	[32]
8-Wastewater collection and treatment	Operations, water and wastewater plant construction, equipment supply and specialist water treatment chemicals	-
9- Rubber and plastics and leather products	Packaging, building and construction, electronics, aerospace, and transportation.	-
10-Stone, clay, cement, glass, and concrete products	Grinding mills, quarrying operations, raw mix grinding, fuel grinding, and clinker grinding, crushing	[32,40,41,42,52]
11-primery metal industries: iron and steel mills, alumina and aluminum products	Aluminum electrolysis, smelting	[18,32,41,42,43]

Due to the fact that the regulation service is the most expensive service which exploits the financial sources, if the load provides this service, fewer interruptions (failures) are preferred. Therefore, some loads with specific specifications (like those with frequent on/off periods) tend to provide regulation services [22]. A load with adjustable drivers (solid-state control) is a proper source for regulation implementation. Aluminum arc furnaces are controlled electrically and can automatically follow the generation control signals. Therefore, they are a suitable source for regulation and spinning reserve services [22, 23].

4. Industries with high level of DR Implementation

This section aims at introducing and categorizing the industries with special potentials for DR implementation. In a power plant, the high-consumption units are the machine drives, electric heaters, and electro-chemical processes [24]. These processes and components are roughly classified into two categories for involvement in DRP and ancillary services. The first category is the set of equipment as a component of the industrial process. This class includes the furnaces, pumps, motors, and so forth. The power plant production can be halted if these components lack electricity. The second category includes the loads that require no direct involvement but they are needed at the site. Lamps, coolers, heaters, ventilation systems, office tools, and so forth are examples of the second class. The latter category has a small share of the total power consumption. In chemical industries, for example, the share of the second class amounts to 8-12% of the total load [24]. Table 2 lists the industries which are promising for DR implementation. This table also presents a classification of the corresponding references. The capability of implementing DRP is presented in a descending order, i.e. the first rows and elements of the table are more capable for DRP. The references are divided into three classes. The first column of the references in Table 2 introduces the references which study that particular industry for DRP implementation. The second column presents the electricity markets and their system operators (ISO/RTO). The third column of references investigates novel methods of DR implementation in industry.

Some industrial processes have an important sequential nature. Scheduling these processes requires special attention to their interdependencies and constraints. Next, the DRP implementation method of these industries is presented.

4.1. Cement Industry

There are four essential stages in cement industry:

1. Preparation of raw material
2. Clinkering
3. Crushing the cement rock
4. Production packaging [40].

The electricity cost of a usual cement factory is almost 30% of the total costs [51]. Different processes of a typical cement factory are illustrated in Fig. Figure 2a. In this figure, the processes which highly suit the DRP are colored in light blue. Fig. Figure 3a depicts the share of typical cement processes in total power consumption. Non-continuous processes like quarrying operations, raw mills, clinker mills, and fuel mills suit the DR plans in a cement factory. The most energy is consumed in the furnace. The electrical loads of the furnace include the drivers, coolers, material transfer, fans, and filtering systems. These loads, if shifted, harm the furnace or waste the final product. Therefore, the furnace has to operate continuously.

Usually, a typical factory is constructed to operate 20 hours a day. Some factories suit working hours of 16-18 h/day to flexibly be turned off at high-price hours. The specification of each cement factory is unique. As a result, their DR implementation method differs in various factories [32]. The capability of a cement factory for DR implementation depends on the storage levels which can be applied to different processes. Cement factories with a small and limited storage capacity are not flexible enough for load shift programs. If the cement factory or the raw material producer has a small capacity than the furnace, the continuous operation of the whole process will be mandatory not to delay the cement production process. These cases are inappropriate for DR plans [52]. Generally, only the furnace has to constantly operate in a cement factory, but the quarrying operations, raw mills, and other cement processes can be tuned for more economical efficiency provided that the furnace operation is not disturbed. According to Figure Figure 3a, these adjustable processes consume 60-70% of the total power consumption. It should be noted that although the factories suit the DRP, they have their most benefits in sustainable and continuous operation; therefore, the incentives offered by the electric companies should cover the shut-down and start-up costs of these factories [52].

Another way for the cement factories to be involved in DR plans is to manufacture multiple cement products. In this manufacturing process, less energy is consumed for grinding at on-peak periods while the final production rate remains unchanged [53].

4.2. Steel Industry

Steel manufacturing factories are counted as advanced factories with special complexities. High energy consumption, multiple and multi-layered production by parallel production lines, complicated processes, and numerous energy constraints are responsible for this complexity [16]. Figure Figure 3b estimates the energy consumption of steel industry by 2050. As it is seen, in 2050, raw steel manufacturing will be 1.7- 1.9 times of the current production [54]. Hence, the total energy consumption is equivalent to 5000 million tons of crude oil [55]. Twenty percent of total industrial energy consumption is allocated to the steel industry, which indicates how significant the steel industry is.

The energy required for steel manufacturing involves:

1. *Energy for iron ore recovery:* This unit consumes 10 GJ/ton on iron.
2. *Energy for iron scrap melting and cast steel production:*1.5 *GJ/t* of iron is allocated to this unit
3. *Steel warming for final product formation:* The energy used by this unit is 0.88 GJ/tone of iron.

Fig. 2b illustrates a simple diagram for the steel production. In this figure, the processes colored in light blue have the most power consumption. Steel scraps require a lot of energy for melting. The power rate in this process is about 0.524 MWh of the produced steel [32]. Heat, in the melting process, is generated using an electric arc furnace by induction. This process, although can be halted, has to be re-started if the heating process is stopped for half an hour unless the scraps start cooling. According to the reports, the melting time lasts for at last 45 minutes. Furnace re-loading for the next cycles takes 15 minutes. The factory can fully stop this process; instead, it can sell the electricity in energy regulation markets. The reserve cost should be low compared to the saved energy costs since a considerable economical benefit is lost if the heating process is halted [32].

4.3. Aluminum Industry

Aluminum electrolysis closely suits the DR plans.

Figure Figure 3c illustrates the energy use of a typical aluminum factory from the mining operations to the aluminum electrolysis process [15]. As it is seen, the electrolysis process is the dominant power consumer in the aluminum manufacturing process. Aluminum melting is based on the electrolysis process to convert alumina to aluminum. Aluminum is employed as the preliminary material in various industries including the automotive industry and canning industry. Forty six percent of the total energy consumption in American aluminum factories belongs to the melting process. In a typical aluminum melting unit, 30 to 40% of the total cost of aluminum production is for the electricity costs [43, 56]. Compared to the cement or steel industries, aluminum factory possesses a simple process. The melting furnace of aluminum is controlled electrically; hence, it can accept regulation signals for aluminum production [56]. Melting occurs in special containers where a DC current passes through the aluminum to separate the oxygen from the metallic aluminum. Aluminum oxides and the electric current are both constantly injected. These furnaces operate under hundreds of kA currents and a low voltage of 10V. Each furnace has hundreds of melting containers which act as loads in series. The total power consumption can amount to hundreds of MW. A furnace may also include some other multiple furnaces. One way for flexible production and power consumption is to exchange heat in a short time as the melting containers are being halted by a breaker. In this way, the container becomes flexible such that aluminum melting process would be an ideal source for DR plans [43]. Therefore, the power break period, namely the power interruption, is more critical and can continue only for short durations depending on the factory constraints. The power interruption, in a melting line, may last for a few minutes to two hours. Multiple furnaces can spin the off periods and cause layer break durations.

4.4. Food Industry

Freezers and refrigerators have a special role in our lives. In the food chain, the freezers are responsible for elongated lifetime of the materials. The air conditioners can provide a mild atmosphere in the buildings regardless of the outside weather. Cold storage warehouses are constructed for efficient energy use; hence, they are technically the best candidates for open Automated DR (ADR) plans. The authors of [30] explain the rationale for considering the freezers and cold storage warehouses as a potent candidate for the DR plans. The history of food industry is presented in [57, 58]. Various industrial food processes from those of raw materials to the final products are fully reviewed in [57, 58]. These processes are categorized into two classes:

1. Production processes which convert raw materials to various products or semi-products as a part of production cycle.
2. Auxiliary processes which provide some sources for the production cycle, preparation of compresses air, vapor, and illumination.

Each category includes the following steps:

1. Preparation (reception, separation, cleaning, and disinfection of raw materials).
2. Modification (size reduction, mixing, and output production).
3. Maintenance (drying, sterilizing, freezing).
4. Packaging.

All food industries share the features mentioned above. The heaters, ventilation systems, and coolers consume the largest amount of energy in food industries [59]. The major share of electricity is consumed by the ventilation systems and coolers. Fossil fuels are mainly utilized for heating. Ventilation, in food industries, has a share of 35% of the total energy consumption. The distribution and cooling equipment uses 45-55% of the electricity in a working day [60]. This share of electricity consumption motivates the food industry to participate in efficient energy use programs. Different shares of power consumption in food industry are illustrated in Fig. Figure 3d.

DRP is also widely applicable to the cooling and freezing processes where the buffers are employed for food transmission and consumption adjustment purposes [32, 61]. Due to the fact that the cooling units of the warehouses possess a central control unit, they can readily accept the DRP. The ADR protocol is used, in this case, to continuously communicate the necessary signals through the Internet [62].

4.5. Chemical Industries

4.5.1. Chloride Manufacturing

The chlor-alkali process is a well-known process for chloride manufacturing. Chloride is produced as the electrolysis process is applied for chlor-alkali dilution. This manufacturing technique started in 2005. The process guarantees maximum production for basic chemical processes in full operation mode.

The operation level usually amounts to 80-90%. The power load of chlor-alkali can be reduced to 40% for a maximum of 2 hours [32]. Shifting the load in different time slots reduces the operation level. Now, 40% of the load shift capacity (which amounts to about 660 MW) is sold at the market as “tertiary reserve capacity.”

When the curtailable loads are missed or reduced, the share of the tertiary reserve capacity decreases. In [32], the chlor-alkali process, as a base for chloride productions, is used in DRP. This process provides an incentive of 2.85 MWh per one tone of chloride. It is estimated that this process has a capacity of 660 MW for the tertiary reserve capacity in Germany. This value constitutes more than 40% of the total capacity.

4.5.2. Air Separation Plants

Air separation plants consume tens of MW power. Parallel compressors, in these plants, provide the compressed air to be separated in respective units. These plants are responsible for separating the air according to the demands and saving the production (separated air in this case) in buffers. Storage in buffers makes these plants flexible for curtailable load DR services. The compressors are energetically fed by the electric motors. The automatic process center provides the set points for the compressors. The power management center is responsible for the communications between the automatic process center and the power system using the Transmission System Operator (TSO) [37].

Oxygen plants are important in chemical industries especially the steel, glass, and water treatment industries. Studies like those conducted on the chloride industry show that electro-chemical processes suit the DRP. The authors of [23] study the compatibility of chemical industries with DRP. They find an optimal sequence of operations in oil treatment based on the load control framework. Industrial load control in this work is investigated for various pricing schemes like the day-ahead, emergency DRP, and the on-peak emergency pricing scheme to effectively compare the results and adopt the most proper procedure. The cost of optimal pricing scheme in each scenario is less than the basic scheme. The optimal load control can reduce the costs for more than 14% in average.

4.6. Wood Product Industry

Paper industry manufactures different types of paper and cardboards. The inputs of these factories include the recycling paper sheets and wood pulp which are produced either chemical or mechanical. The primary DSM is suitable for the high-consumption mechanical processes (refinery units) which produce wood pulp. The refinery units can operate continuously or stop working for several minutes. Aging and wearing are the only limiting factors. On-off periods should not be intermittent and immediate. Although the operation level of this industry is variable, it is set on a rate of 80%. According to the investigations, the paper industry is highly capable of saving the wood pulp. This potential can be used both in the spot market and the positive and negative tertiary reserve markets. The positive DSM potential is defined as the average operation capacity of refinery units which amounts to 250 MW. Likewise, negative DSM potential is defined by an average operation capacity of 62MW. The current saving rate of wood pulp in most paper workshops is large enough to include 1.5 hours of the maximum capacity. This means a saving capacity of 468 MWh [32].

4.7. Data Centers

Data centers consume a lot of power and suit the DRP implementation. These high-consumption units benefit from electrical storage units which make them flexible [21]. In 2011, the data centers consumed 1.5% of the power consumed globally. In some cases, the capacity of individual data centers amounts to 50MW or more [63- 65]. The average annual consumption of these centers is 10-12% with an ascending trend [63, 64, 66]. Data centers are mostly automatic and monitored; hence, their control and regulation are simple with no extra costs. The case studies of [64 – 67] involve four data centers under various management schemes. The results show that controlling the temperature can yield a load curtailment of 50% and 10% for 5 and 10 minutes, respectively, without disturbing the capacity of the IT unit. If the capacity was changed, the load curtailment capacity could have been much more flexible.

Figure Figure 2 illustrates the sequential manufacturing processes of each industry. As it is seen, aluminum and food industries have a simpler mechanism than the cement and steel industries; as a consequence, they are more appropriate for DRP. As it can be inferred, high consumption is not the only factor for the suitability of DRP implementation. The manufacturing chain, mechanisms, and constraints of factories are also important. In cement industry, for example, although the furnace requires the largest amount of energy, the ore mining unit in raw material factories is more proper for DRP. This is due to the fact that the furnace has to operate continuously to avoid production defects. The largest energy in the steel industry is consumed in the arc furnaces, but unlike the cement furnace, these arc furnaces highly suit the DRP. In aluminum and food industries, the electrolyzing and food maintenance units (freezers and coolers) respectively suit the DR implementation.

5. DRP in Practice

5.1. The United States of America

A System Operator (SO) is an organization which controls, localizes, and monitors the power network in a pre-specified zone. An SO which only works in a specific State is known as an Independent SO (ISO). SOs that cover more States are known as Regional Transmission Operators (RTOs).

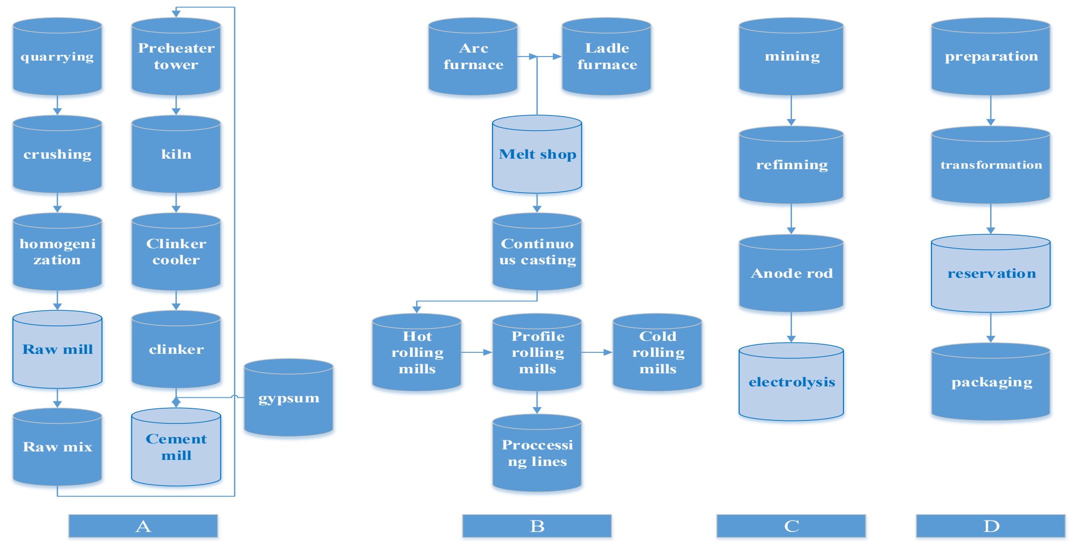

Figure 2: The manufacturing chain of a) cement b) steel c) aluminum and d) food industries

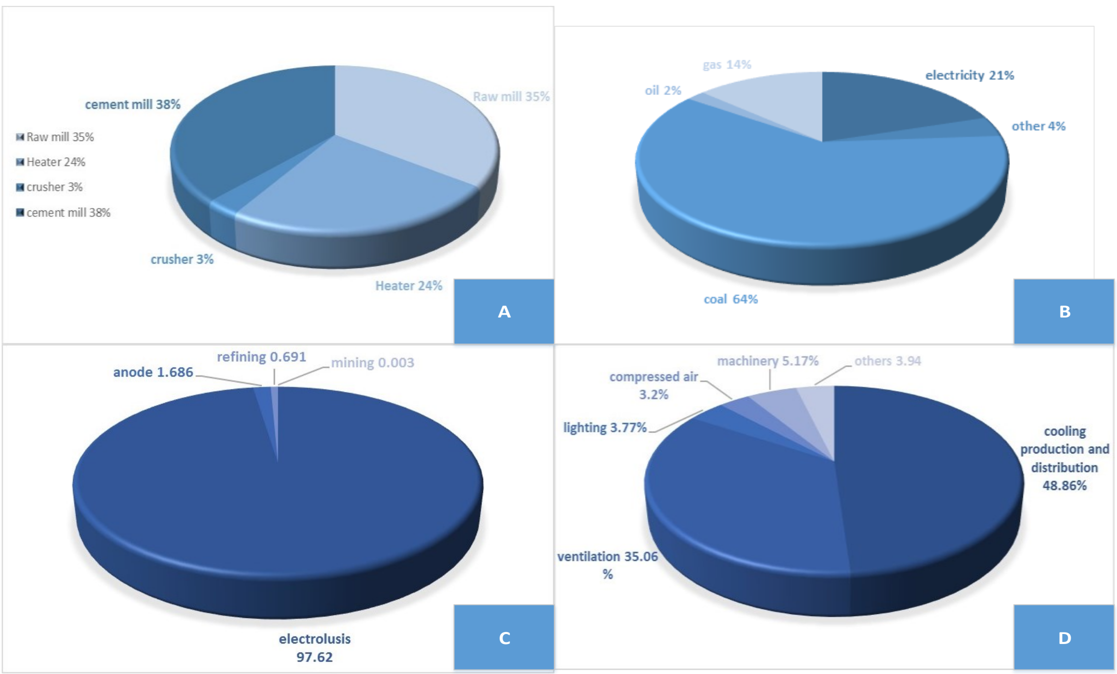

Figure 3: The consumption chart of a) cement b) steel c) aluminum and d) food industries

ISOs and RTOs play an important role in development of the DR markets. Nowadays, the operators enable their consumers to act as the demand sources in markets using the day-ahead, real-time, and ancillary service schemes [68]. The largest development of the DR sources, based on the incentive tariffs, has occurred in the American wholesale markets of the ISOs and RTOs [69]. Table Table 3 lists the properties and plans conducted in each market.

Table 3: American markets and their DRP

type	Market	System operator	Programs	States where it operates
ISO	NYISO	New York independent system operator	EDRP, SCR1, DADRP2	New York
RTO	ISO-NE	Independent system operator new England	Reliability programs price response programs	Connecticut, Main, Vermont, Massachusetts, New Hampshire, Rhode Island
ISO	CAISO	California independent system operator	Participating load program, proxy DR	California
ISO	ERCOT	Electric reliability council of Texas	EILS3, BUL4, LAAR5	Texas
RTO	PJM	PJM interconnection ICC	EDRP, FELM6, ELRP7,	Delaware, Illinois, Indiana, Kentucky, Mary Land, Michigan, New Jersey, North California, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia
RTO	SPP	Southwest power pool	VDDR8	Arkansas, Kansas, Louisiana, Missouri, Nebraska, New Mexico, Oklahoma and Texas

Southern California Edison Company (SCE) presents an organized program called "Agricultural and Pumping Interruptible Program" in which the power of the agricultural pumps is removed during the on-peak periods. A controller is installed on the pumps which

[1] Special Case Resources
[2] Day ahead DRP
[3] The Emergency Interruptible Load Service
[4] the Balancing Up Load Program
[5] the Loads Acting as a Resource programs
[6] Full Emergency Load Management
[7] Economic Load Response Programs
[8] Variable Dispatch Demand Response Program

enables the SCE to remove the power supply temporarily until the on-peak period is over. The farmers should demand 37 kW or a minimum load of 50 hp to be eligible for this program [70]. The interruption (curtailment) time is limited to 6 hours which annually constitutes 250 interruptions or 150 hours of power curtailment [70]. In this program, the consumers receive a constant value of 0.01102 $/kWh in their bills even if no interruption occurs monthly [70]. In addition, the customers may receive an extra value of 16.27 $/kWh for each power break in the on-peak periods of the summer. SCE also presents the ADR programs, permanent load shift, TOU, capacity programs, Demand Bidding Program (DBP), CPP, OBMP, RTP, Scheduled Load Program (SLRP), and RTP, and also summer discount programs [70]. Transmission and Distribution Service Providers (TDSP) also present different load management programs in specific regions. CPS Energy, as a TDSP in Texas State, offers incentive plans for the commercial and industrial consumers to voluntarily cut their loads in special conditions of some summer days. This program focuses on the mid-days of the week at 3 p.m. and 6 p.m. with a notification time of 2 hours. The consumers have to share at least 50 kW on curtailable electrical load to be eligible for the program [71]. The American Electric Power (AEP) in Texas presents the irrigation load management program in corporation with the EnerNOC Company for the agricultural sections. In this program, the irrigation electric pumps are automatically turned off during the on-peak periods in change for financial benefits. This program is held for 1 p.m. to 7 p.m. in mid-days of the week for 1-4 hours in each interruption with the notification time of 60 minutes. This program allows for four monthly interruptions [72]. Texas AEP Company presents Load Management Standards Offer Programs (LMSOPs) for customers with an installed power of 500 kW or more. This company encourages the customers to disconnect the loads in short periods of the on-peak times. The company offers 5 different plans for various interruption numbers and durations [73]. El Paso Company provides the load control for non-residential consumers with a minimum curtailable load of 100 kW from June 1st to September 30th. The interruption, however, can last for 5 hours at each curtailment. To be eligible for the program, it is necessary that the participants admit 90 mandatory interruptions or a maximum scheduled load curtailment of 50 hours annually. The customers, however, can obtain 60 $/kW for each interruption [74, 75].

TECO and Progress Energy Companies (PEC) present a program based on the on-site production called "the standby generator program" and "backup generator program." Both programs provide the control of the on-site generators so as to compensate for a part of the power demand and reduce the grid load during the on-peak times [76].

In New York, ISO (NYISO) offers the Emergency DRP (EDR) programs and SCR incentive plans to the commercial and industrial consumers for power reduction at critical times. Day-Ahead DRP (DADR) programs enable the consumers to suggest their power reduction in day-ahead markets. Then, NYISO can specify which recommendation is more economical for the market.

Finally, Demand Side Ancillary Services Program (DSASP) enables the retail customers to specify their power interruption in the day-ahead and real-time markets in change for the replacement and/or regulation services [77].

5.2. Europe

In the past 20 years, European energy organizations have employed various power interruption mechanisms to reduce the industrial demands in the on-peak periods. In the UK, the industrial and commercial consumers with remarkable power consumption are eligible for TOU and curtailable load programs. The SO can directly make contracts with these consumers as a network balance activity. KIWI Power Company has offered the Demand Reduction Strategy (DRS) which resembles its American counterparts. This program aims at temporal curtailment of the specific loads like the HVAC, illumination, and similar systems.

An example of this is the implemented programs of the steel factories [78]. UK Power Networks Company has developed some programs to involve the demand side in the DRP. This company flexibly works on the “low carbon London” project. EDF Energy and EnerNOC aggregate the commercial and industrial partners in London to reduce the load in MW level when the power demand is high. German industries comparatively consume less energy. The major energy consumption is for the chemical, iron, and steel industries. Since 1995, the federal government and German industries have agreed to hold CO2 reduction programs (IEA 2013). In 2012, the programs were updated to reduce the annual power demand rate until 2022 (IIP 2016a). Efficient energy use and participation in such programs make the German companies eligible for lower taxes. The German government supports the EMS program in big companies. This helps the high-consumption companies follow their efficient energy schemes. In Italy, load curtailment programs are categorized into the spontaneous programs (without notification) and programs with notification time of 15 minutes. The capacity of this program is 1200 MW for the spontaneous scheme and 1750 MW for the other category. In presence of the notification time, the curtailable load can amount to 3MW and for the spontaneous this load will not exceed 10MW. Italy has utilized the TOU tariffs for years and it has modified the TOU tariffs considerably. These modifications aim at shifting the loads to the low-cost hours such that a desirable load profile is resulted. Spain develops the DRP to exploit the wind energy [79]. The classical system-based programs have changed to the market-based programs. Direct control programs which were used for about 20 years have been replaced by the ancillary services. Since 1988, some high-consumption industries (about 200 industries with a power demand of more than 5 MW) have been able to voluntarily benefit from special tariffs. Spanish TSO (Red Electrica de Espan) can request power limitation for periods of 15 minutes to 12 hours. TSO defines a maximum annual power reduction for each customer. Each year, the industrial consumers use the discounts based on their power reduction requests for constant and variable tariffs.

The authors of [44] study 87 high-consumption industries which used the TOU tariffs in 1994 according to the Spanish royal instruction (2004/ 2392). This study shows that the customers which reduced their production for electricity saving enjoyed no financial benefit [44]. In other words, the financial loss of reduced production has been more than the electricity bill in the on-peak periods. It should be noted that TOU tariff is not economical in Spain because the electricity costs at many times are higher than the market cost.

In Sweden, some regulations were set for the peak consumption capacity in 2003- 2008. These regulations state that industries are able to reduce 30 minutes or 3 hours of their power consumption. The regulation evaluated the capacity of the power system and guaranteed the availability of the power sources [80]. Then, auctions were put up for a reserve capacity of 2000MW in Sweden [81].

Similarly, power curtailment programs have been done in Finland for distributed sources. Companies made annual contracts with the Finland’s transmission SO (Fingrid) [44]. In 2005, it was estimated that a Finnish large-scale industry has a potential of 1280 MW in DR plans, which constitutes 9% of the Finland peak demand [82]. Finland invested on measurement systems in 2008 to manage 60,000 customers locally and automatically.

The Ministry of Economic Affairs and the Environment (Netherland) states that there is a capacity of 1000-1500 MW power for load management which is proportional to the market prices. This capacity is expected to increase until 2020 as predicted by the Dutch TSO company [83].

ELIA is a Belgian TSO which employs the DR capacity to compensate for the imbalance between the power generation and peak demand [84]. ELIA focuses on the industrial consumers and is supported by the Federation of Belgian Industrial Energy Consumers (FEBELIEC) [85]. The DR aggregator companies like the Restore [86] and Energy Pool [87] companies support ELIA at critical times. These companies, for example, make contracts of hundreds of MWs for flexible operation of ELIA in Belgian power systems.

5.3. Oceania

Australia has made tremendous efforts for DR development. There are remarkable and large-scaled projects done in Australia many of which are in the experimental phase. AusNet Company constantly proposes new DRP and experiments [88]. One DRP, called the "dynamic peak rebate trial" suits non-residential consumers with medium to high power consumption. This program resembles other plans in that it encourages demand reduction in on-peak periods [89]. A similar experimental DR is performed by the AusNet Company for the commercial and industrial customers in summer (December to February in Australia). This plan evaluates the effectiveness of various DR strategies and provides an opportunity for different strategies like the remote generation, energy saver, incentive, and tariff-based plans [90, 91]. Endeavour Energy Company has adopted the "energy saver program" for its high-consumption consumers around the Arndell Park and Rooty Hill areas.

EnerNOC, based on the Demand SMART program, transmits the curtailable loads of the industrial and commercial consumers to the Instantaneous Reserves (IR) market. The program constraints involve respectively 6 and 2 interruptions for the northern and southern islands each lasting for 30 minutes. The target loads include the refrigerator compressors, fans, cooling equipment of the stored foods, storage pumps and aerators in water treatment centers, purifiers, paper pulp fans, paper industry, wood process equipment, melt and arc furnaces, and ventilation systems of data centers and large buildings [92]. Various solutions have also been proposed by the load serving entity (LSE), DRP, and technological companies in New Zealand.

5.4. Asia

Asian countries are mostly not equipped with the DRP. Some experimental plans are being performed in southern and east southern countries. Japan, South Korea, and China are expected to develop the DRP in future. Kyocera, IBM Japan and Tokyo Community have recommended experimental management systems for ADRP. The DRP, in this project, automatically transmits the energy saving requests (DR signals) to the consumers at critical conditions. These signals may also be employed for EMS control [94]. Open ADR and Fujitsu companies have also proposed some DRP [95, 96].

Since 2014, an experimental project has been started by the natural resource defense council, Shanghai electric power, NARI group, the State Grid Corporation of China and, and Honeywell Company in China as the first official DRP. In this project, 33 public and commercial buildings, 31 steel, chemical, and automotive industries are involved to provide a curtailable capacity of 100 MW for each interruption. This project proves that the economical and technical aspects of DRP differ for various consumers [97].

Other DR activities in Asia are in the experimental phase. The CLP Company in Hong Kong has introduced a project to integrate the Building Management System (BMS) tools in commercial and industrial units under the scope of automatic integrated DRP. This project enables the CLP to cut the loads in necessary and critical conditions directly [98].

5.5. Africa

People with various lifestyles have settled in Africa. While a minor group enjoys high salaries, the other has even no access to the electricity. As a consequence, the DRP is highly limited; however, this limited DRP is remarkable. Eskom Company offers different DRPs for its high-demand consumers in South Africa. The "Standby Generator Programs" ask the customers to curtail their power demand (at least 1000 kW) for 2 hours per day and 100 interruptions per year. This company is not responsible for the generator control. It only informs the DRP in the notification time (at 3 p.m. of the previous day and 30 minutes before the power interruption). At the informed time, the consumers have no access to the power. Proportional to the curtailed load, the customers are paid. Another program conducted by Eskom is called the "Supplement DR Compensation." This program suits the commercial and industrial customers which can reduce their power demand 500 kW or 10% of their average power demand (the larger value is chosen) at the pre-specified critical times determined by the Eskom. The constraints include 1-2 hours of load curtailment in scheduled days, and 150 interruptions in year with the notification time of 3 p.m. at the previous day and 30 minutes before the interruption. The payment is calculated per 1 kW of power curtailment [99].

6. Discussion

In Various DRPs implemented around the world were discussed. The American and European countries made considerable progression in DRP. The industrial section of the developing countries is also potent for DRP. Table Table 4 presents and compares five different efficiency criteria and power operation schemes in industrial sections of different countries [100]. These criteria include the industrial power demand (energy intensity), voluntary agreements for industrial efficiency, international mandates for energy management, mandatory energy audits of the factories, the investments on Research and Development (R&D) in industrial units, and the strategies to manage the power capabilities using the Energy Management Systems.

A successful country, in DRP, should have a lower power demand and governmental voluntary plans for power efficiency improvement and enrichment of the commercial incentives. Power operation policies of different countries highly differ in the industrial section and no country has been able to succeed in all criteria. However, the European countries seem more successful especially in the voluntary agreements and mandatory energy audits. All countries are able to make progression in these criteria too. As it is seen, Germany and then Japan have the most capabilities in DRP. The UK and Italy win the third and fourth places, respectively.

Table 4: Evaluation and comparison of different efficiency and power operation criteria in industrial sections of different countries

Country	Energy intensity of industry	Voluntary agreements	Mandate for energy managers	Mandatory energy audits	EMS policy	R&D investment
Germany	*****	***	-	**	**	***
Japan	*****	**	**	**	**	****
The UK	******	***	-	**	**	***
Italy	*****	***	**	**	*	*
South Korea	****	**	-	**	**	****
Netherlands	*****	**	-	**	*	**
Spain	****	***	-	**	**	*
China	-	***	**	**	**	**

The US	***	**	-	-	**	****
Mexico	*****	-	-	-	**	-
Australia	**	-	-	-	-	**
South Africa	-	***	-	-	-	-
Saudi Arabia	*	-	-	-	-	-

7. Conclusion

Industrial power consumption is more than half of the total global power demand. Industries are a prominent factor of national development. Attempts of countries to provide the necessary equipment and pre-requisites of modern infrastructures with the increased payments prove the effectiveness of the industrial section. The industrial consumers around the world are highly potent for DRP, but no satisfactory attention has been paid to this potential. Although the industrial customers are able to reduce their power demand aptly and reliably for limited hours, they are not willing to implement the DRP so as not to lose their production capacity. The DRP, therefore, should focus on the flexible industries to exploit their new curtailment capability and simultaneously offer financial and technical incentives for these sections. Various sections have different energy management systems with unique production procedure. Hence, the DRP should consider the main constraints and inter-dependencies of the production mechanisms. The costs for investment on each industry have to be separately studied.

As discussed in the present work, the food industry has the most capability for DRP. Then, there are iron and steel industries with high energy consumption, complicated procedure, and more complex constraints. Automotive, chemical, wood pulp, aluminum, and cement factories also possess mechanisms which suit the DRP. These industries should be involved in DRP so as to exploit the flexibility of industrial consumers. Moreover, the energy markets have to provide comparable flexibility. However, the current market regulations are mostly based on "the generator electricity production" style. As a result, prior to the DR implementation, the load management techniques, regulations, communication, and control systems have to be enhanced. Automatic DRP seems a proper solution for big industries like the data centers. Beside the technical improvements, widespread involvement and enhanced knowledge of industries about the DR should also be considered. The studies on the economic and load responsiveness aspects of DR show that there are different capabilities for DR implementation around the world. This potential depends on different factors like the intensity of industrial power consumption, voluntary agreements, mandatory energy audits for big factories, and investments on R&D and EMS strategies.

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