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A review on demand side management applications, techniques, and potential energy and cost saving

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Abstract: Electrical peak load demand all over the world is always anticipated to grow, which is challenging electrical utility to supply such increasing load demand in a cost effective, reliable and sustainable manner. Thus, there is a need to study some of load management (LM) techniques employed to minimize energy consumption, reduce consumers' electricity bills and decrease the greenhouse gas emissions responsible for global warming. This paper presents a review of several recent LM strategies and optimization algorithms in different domains. The review is complemented by tabulating several demand side management (DSM) techniques with a specific view on the used demand response (DR) programs, key finding and benefits gained. A special focus is directed to the communication protocols and wireless technology, incorporation of renewable energy resources (RERs), battery energy storage (BES), home appliances scheduling and power quality applications. The outcome of this review reveals that the real time pricing (RTP) is the most efficient price-based mechanism program (PBP), whilst time of use (TOU) is the basic PBP and easiest to implement. Energy efficiency (EE) programs have proved the highest influential impact on the annual energy saving over the other dynamic pricing mechanism programs. Through a forecasted proposal of future study, DSM proved tremendous potential annual energy savings, peak demand savings, and investment cost rates within different consumption sectors progressively up to year 2030.

Keywords: Automated demand response, Energy efficiency programs, Home appliances scheduling, Optimization techniques, Smart grid.

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1. INTRODUCTION

The electricity consumption is variable during the day and reaches its highest rate at peak hours. The generation resources must match the demand side load in real time in order to avoid potential blackouts or brownouts. Imbalance between both is potentially because the energy generations resources are not expanding at the same rate of the load demand. Therefore, the need to build additional power stations, transmissions and distribution networks to cope with the inevitable anticipated demand growth would be promptly essential. It is important to note that the balance between the supply side and demand levels is a difficult issue due to some reasons, such as unexpected forced outage of generation units, outage of transmission and distribution lines and load sudden changes. As a result of this imbalance, the solution could be addressed using demand side, which includes activities affecting consumer behavior. Clipping or shifting the consumer peak demand to off-peak time based on electricity dynamic pricing over time or incentive payments are to be projected by electricity providers to motivate lowering electricity use at high market price time. This strategy is called demand response [1, 2], which is less expensive compared with the other solutions for building new electrical energy generation substation or install electric storage devices in case of having distribution generation resources. Focusing on the issues of LM, DR and DSM, it is found that they could be used interchangeably [1, 3]. This needs a complete new infrastructure for data exchange through advanced metering infrastructure (AMI), which is an integral feature of the smart grid (SG). The most important objectives in the SG with advanced technologies from utilities and consumers' perspectives are the enhancement of the grid stability at peak demand period and to obtain maximum cost saving in electric bills, respectively. The intelligent technologies used in SG are extended across the entire generation, transmission, and distribution power systems up to end consumer's premises. The aim is at more efficient and reliable grid operation with an improved consumer services and a cleaner environment.

This paper is prepared as a review to different scientific researches providing more insights on the LM underlying principles, techniques and evolving practice. LM techniques are focused on communication protocols, wireless technology and incorporation of RERs, BES, power quality, and home appliances scheduling applications. A brief overview on the respective technology driven system engineering, such as SG communication technology, SG communication cyber security, and smart meters, is outlined. The complementary contribution to the existing surveys are highlighted by tabulating the forecasted annual energy savings, peak demand savings and investment cost rates within different consumption sectors progressively up to year 2030 with the significant impact of the EE in the DSM. Several DSM techniques in different countries with a specific view on the applied DR programs, key findings and benefits gained are summarized and tabulated in the following section.

2. OVERVIEW OF SMART GRIDS

2.1 Smart Grid Technologies

Information and communication technologies (ICTs) are being employed in typical grids to consolidate them as SGs. By using ICTs, internet protocol (IP) based digital network [4], and advanced control mechanism [3], two-way communication and data exchange between utility and consumers can be accomplished. SG not only collects data from consumers but also determines the number and capacity of active power plants needed to cope with the load demand using fewer power plants at off-peak hours and more power plants at on-peak hours. In SG, the exchange of information, monitoring and control of the facilities is performed in real time using communication networks. Thus, the grid can detect any failure and irregularities, almost instantly, and report any issues immediately without depriving consumers from electricity services for long time [5, 6].

In [7], a control algorithm, namely green charge (GC), is presented to manage RERs, BES, along with grid energy in smart buildings. Electricity bills are reduced by combining on-site RERs with BES, because electric energy is stored during the low-cost-prices periods and used to supply loads during high-cost-prices periods. In [8], state-of–the-art projects in different countries are outlined integrating dissimilar and intermittent RERs into SG. Figure 1 shows SG structure, where home area network (HAN) and neighborhood area network (NAN) are shown. HAN is composed of smart appliances equipped with sensors for automation control, information communication and exchanging data with the utility, and they are networked with main energy management system (EMS). NAN is composed of smart meters along with data collection point (DCP). The integration of HAN and NAN on a single system constructs AMI [3]. AMI collects and transmits short interval measured consumption rates between smart meter (SM) and utility and relaying utility price information back to the SM [7, 9].

The SG has economic and environmental benefits. In [9], it is reported that 34.5% average electrical consumption saving is achieved in California statewide pilot price in households when cycling appliances, communicated thermostats and display technologies are applied. On the other hand, 12.5 % saving only is achieved by pricing induced behavior. In [10], it is reported that each one billion US$ invested in SG is predicted to drive 100 billion US$ in domestic product growth. In addition, very important consumers could add 15-20 billion US$ to the domestic product growth by the year 2020. In terms of environmental plan, the US department of energy report (DOER) showed that 18% reduction in carbon dioxide emission could be achieved by the year 2030 in case of adopting 100% of SG technology in USA. Also, if the electricity grid became about 5% more efficient, it could cause elimination of fuel and greenhouse gases of 53 million cars, equivalent to displacing about 42 cool fired power plants [10].

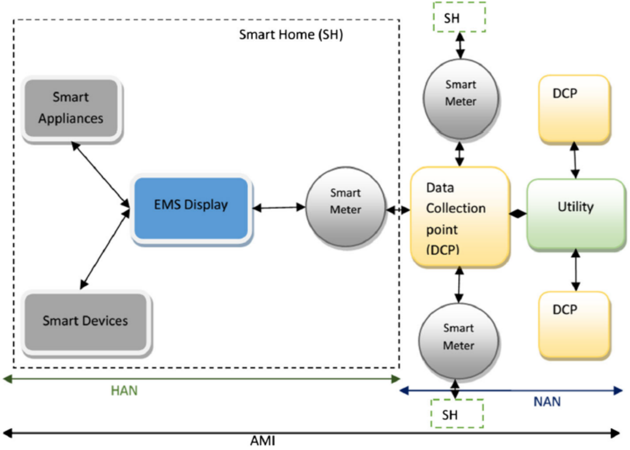

Figure 1. SG structure [3]

2.2 Smart Meters

SMs started with one-way communication from meter to the utility, which is called automatic meter reading (AMR) and continued to the advanced metering infrastructure (AMI) allowing two-way communication instead [1, 11]. Advanced SMs replaced traditional meters in very few countries, such as, Italy [1]. On the other hand, in some countries like Egypt, SMs projects have been commenced in 2018 for a total amount of 250000 SMs manufactured by different brands such as, El Sewedy Electrometer Group [12]. The steps of the project consist of proof of concept step (PoC), pilot step and roll out step. The project is still in the pilot step, which is around 10% of the total amount of the projected SMs. SMs projects are progressing worldwide, such as, Europe, USA, Asia and Middle East. By 2020, 80% of consumers at least in Europe will be supplied by SMs, while North America is considered the highest area worldwide furnished with SMs. Whereas, East Asia is in the earliest phase of the SMs roll-out. In Japan, the foremost distributor system operator (DSO) has declared SMs spreading out over the next 10 years. In South Korea, the construction of SG was planned to be completed by 2020. Middle East is in the early stage of SMs deployment, where Saudi Arabia, Qatar and Dubai are still in pilot phase. Only one utility in Abu Dhabi, i.e., Abu Dhabi Water and Electricity Authority (ADWEA), has completed electricity and water SMs phase one roll out [13,14]. There are numerous abilities and benefits for SMs [13-16]. They allow two way communications between users of SMs and electric utilities and enable monitoring and measuring real time electricity consumption at interval of about 15 min., 30 min., etc. Thus, they report the measured consumption to a meter data management system (MDMS) [17]. These patterns of energy consumption facilitate incorporating smarter intervention for energy reduction. They also produce precise forecasts of energy demand at LV side, which in turn enables DSO to improve load management planning of the LV network [18]. SMs incorporate new sophisticated pricing information and exchange data with smart home appliances within the users' premises allowing to optimize energy consumption and to subscribe in DR [17]. However, data collected by SMs are liable to serious privacy and security concerns and, therefore, security management for preserving SMs data delivery have to be adopted [17].

2.3 Smart Grid Communication Area Networks

They are segmented into HAN, NAN and Wide Area Network (WAN). The HAN is the smart and automated network formed by home appliance within the consumers' premises. A model of energy management based on priority levels assigned to each smart appliance and electric smart device at a certain time is developed in order to modulate the use of electricity and reduce energy consumption costs [19]. The NAN is the network that collects data from multiple HANs and delivers them to the data collection points (DCP) [3, 19]. HAN and NAN compose the AMI [3] which addresses peak demand during certain intervals of the day. Wide Area Network (WAN) is the data transportation network which transfers collected metering data from HAN participants to the control centers through gateways [19].

2.4 Smart Grid Communication Cyber Security

It is a great challenge to implement SG security, particularly when the level of the potential damages resulted from cyber-attack is considerable which in turn could jeopardize the crucial system functionality. Besides, the credibility of communicated data between the utility providers and the consumers would be at risk too. In the Electric Power Research Institute (EPRI) [20], the technical executive for industry cyber security stated that "the policy of the USA is to support the modernization of electricity transmission and distribution, which means an increase in the use of digital control, when it is digital, you have to worry about cyber security". Cyber security attacks could start at many spots throughout the whole path, from electrical substation power generation to the final branch point, whereby security breaches at any weak link might impact the whole network. Each SM is considered a point of potential attack as it contains communication chip to enable bidirectional flow of data and, thus, should be protected. In [21] the major challenges of cyber security in SG communication networks and proposed solutions are presented.

3. DEMAND SIDE MANAGEMENT

3.1 Definitions, Overview and Background

DSM is defined as any action to be performed on the demand side by which the utility or supply side load profile is affected. One of the main DSM activities is DR [11, 22] that is defined by the Federal Energy Regulatory Commission (FERC) as "changes in electric usage by end-use consumers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at time of high wholesale market prices or when system reliability is jeopardized" [2, 22, 23]. In a survey of 500 households in Sweden, the average reduction in electricity was 12.65% in two years after the introduction of time of use (TOU) tariffs [24]. Also in another research of 483 households in California, magnificent average response was accomplished for variable pricing programs, as residential consumers showed some potential of load shifting to DR programs [24]. In [25], the main advantages of using DSM are elucidated which are not limited to, improving EE, augmenting the integration of RERs, increasing grid reliability, and helping in eliminating expansion of generating plants through its induced reduction in energy consumption. DSM adds flexibility to the power systems by enabling management of energy demand supply balance in the network and using a sophisticated dynamic load management system. Also in [24], it is reported that there is uncertainty in evaluating the achievable benefits from DSM due to the shortage of the data pertaining the used DR programs.

3.2 Applications Areas of Demand Response Programs

In [22] four electricity consumers are identified which are: Transportation, residential, commercial and industrial. The share of each of them in the electricity consumption in USA is illustrated in [26], while the DR programs are mainly applied on three of them as follows:

3.2.1 Residential consumers

Effective design of DR program of residential consumers is very complex with respect to industrial consumers, as the residential consumers have various power consumption behaviors [27]. Residential consumers are classified into different classes:

- short-range consumers, who are concerned about the energy price at the current instant,
- real-world-advancing consumers, who are concerned only about the energy prices at the current and past periods,
- real-world-postponing consumers, who are concerned about only the energy prices at the current and future periods,
- real-world-mixed consumers, who are a mixture of the postponing and advancing consumers, and
- long-range consumers, who are able to shift their consumption over a long time period [27]

DR program can be achieved by designing residential load management programs by either reducing or shifting energy consumption [28]. The reduction of energy consumption is obtained via construction of high energy efficient buildings and encouraging consumers for energy conscious consumption patterns [29]. Shifting the energy consumption from on-peak to off-peak hours may result in a considerable reduction of peak to average ratio (PAR) [29]. Some factors should be accounted for while performing the design of residential DR programs such as: the charging schedules of the plug-in electric vehicles (PEVs) in order not to overburden the power grid [30]. Besides, the local power generation at the residential level has to be evolved enabling the consumers to supply the grid with their excess power [30]. In [31], it is outlined that PEVs aggregation could increase its profit by trading vehicle to grid (V2G) and setting a TOU contract with DR aggregators.

3.2.2 Commercial consumers

Energy consumption in commercial buildings is identified by weather conditions, energy management control framework, building operation scenarios and international design standards. These types of consumers are assumed to respond to electricity prices independently [32]. The typical heavy loads installed in the commercial premises are heating, ventilation and air conditioning (HVAC), lighting systems and electronically-driven equipment. The reduction of power consumption can be accomplished by the usage of building energy efficient technology and / or by controlling the energy consumption behavior correlated to the power demand pricing scheme. HVAC system could respond to DR programs by automated operational systems or by controlling the space ambient temperature and/or air quantity modulation. Lighting management system is based on the season and the time of the day, where reducing light in summer season results in another saving in cooling as light produces heat, which needs more cooling [32]. A Lawrence Berkeley National Laboratory (LBNL) study reveals that each 1 kWh lighting savings results in 0.48 kWH cooling savings [32]. In [32–38], various case studies are presented for the application of DR programs in the commercial buildings.

3.2.3 Industrial consumers

Industrial sectors are high energy consumers, where peak loads reach hundreds of MWs at high voltage levels. In many industrial domains millisecond scale monitoring and control is necessary [39]. In [40–44], various case studies are presented for the application of the DR programs in different industrial activities.

In addition, in [45], the effect of DR application on security constrained unit commitment (SCUC) problem considering economic and security objectives is studied.

3.3 Demand Response Programs Taxonomy

3.3.1 Demand Response programs

In [46], DR programs are classified as given in Figure 2, which can provide many benefits such as, cut down the electricity prices, improve system reliability and reduce price volatility. DR participants are entitled to receive incentive payments and saving in their electricity bills. The environmental benefits result from avoiding or deferring constructing new generation units, transmission systems and distribution networks that contributes in improving air and water quality, due to efficient use of resources, and reducing depletion of natural resources.

It is reported in [46] that RTP programs are the most efficient DR programs due to their suitability for the competitive electricity markets. On the other hand, TOU is the basic PBP and easiest to be implemented. It has been reported in [46] that 5 % reduction in demand yielded 50% price reduction during California crisis in 2000-2001. This is because the generation cost increases exponentially near maximum generation capacity. A small reduction in demand will lead to considerable reduction in generation cost and in electricity price, as DR programs induce a negative slope on the original demand curve, as depicted in Figure 3.

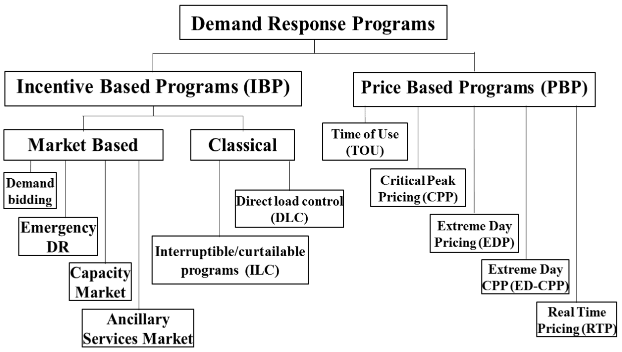

Figure 2. Classification of DR programs [46]

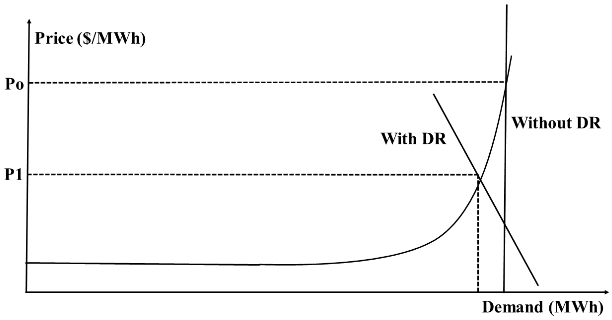

Figure 3. Effect of DR on electricity market prices [46]

3.3.2 Demand Response Costs

DR programs costs are classified as illustrated in Figure 4, where DR programs owners and participants incur initial and running costs [46].

It is concluded that many utilities in North America and others around the globe have experienced Incentive Based Programs (IBP). In general, it was reported that the return of investment of these programs exceeded the cost by a factor of 7:1 [46].

In [47] a DSM baseline forecast proposal of future energy use is outlined. The forecast time duration is 30 years. Different types of dynamic LM programs and EE programs are applied. The DSM has proved tremendous potential annual energy savings along with investment cost rates in different consumption sectors as illustrated in Table 1 in addition to the corresponding peak demand savings as depicted Table 2.

It is noticed from Table 1 that annual energy saving from EE programs are much higher compared with that yielding from the dynamic load management programs such as TOU and RTP. Additionally, it was stated that the amount of carbon reduced is directly proportional with the amount of DSM achieved. By the year 2030, the amount of carbon reduction will be potentially ranging from 115 to 287 million tons. The cost of achieving these savings ranges from $17.8 billion to $44.3 billion. The research concluded that more involvement from nonutility and nongovernmental identities is required to afford sophisticated and environmentally friendly DSM programs.

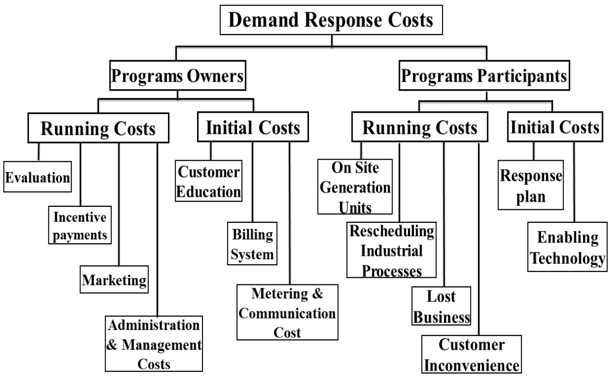

Figure 4. Classification of DR costs [46]

Table 1. Annual Energy savings / Investment cost rates by applying DSM [47]

	Billion kWh (TWh)		
	2010	2020	2030
Residential Programs:			
Time-Of-Use Rates	0.26	0.36	0.46
Direct Load Control	1.13	1.58	2.02
Real-Time Pricing	0.00	0.00	0.00
Energy Efficiency	45.56	180.40	314.29
Commercial Programs:			
Time-Of-Use Rates	0.52	0.68	0.82
Demand Curtailment	0.00	0.00	0.00
Real-Time Pricing	0.14	0.19	0.23
Energy Efficiency	117.45	269.17	397.64
Industrial Programs:			
Time-Of-Use Rates	1.09	1.50	1.91
Demand Curtailment	0.00	0.00	0.00
Real-Time Pricing	0.90	1.25	1.59
Energy Efficiency	65.44	149.65	172.70
TOTAL DSM IMPACT	232.48	604.80	891.67
DSM investment rates billion $	4.7	12.1	17.8

3.4 Demand Side Management Techniques and Applications in Different Countries

In [48], DSM using Simulink/Matlab→ was implemented in order to verify the effect of DR on residential consumers and on the supply network as the cost of electricity and peak demand is high during on-peak periods. The third priority loads were shifted to Off-peak periods when the peak demand exceed the demand limit, which resulted in about 30% peak demand daily saving and about 11.28% daily saving in the electricity bill. Thus, DSM in residential sector can considerably reduce peak demand and electricity bills, which in turn has operational and financial benefits to electricity networks.

Table 2. Peak demand savings by applying DSM [47]

	Gigawatts (GW)		
	2010	2020	2030
Residential Programs:			
Time-Of-Use Rates	0.37	0.65	0.70
Direct Load Control	9.28	16.35	17.60
Real-Time Pricing	0.01	0.01	0.01
Energy Efficiency	9.58	46.54	68.29
Commercial Programs:			
Time-Of-Use Rates	0.89	1.50	1.57
Demand Curtailment	1.75	3.08	3.31
Real-Time Pricing	0.23	0.41	0.44
Energy Efficiency	28.85	84.05	109.64
Industrial Programs:			
Time-Of-Use Rates	1.64	2.90	3.12
Demand Curtailment	16.43	28.96	31.17
Real-Time Pricing	0.20	0.34	0.37
Energy Efficiency	14.15	41.21	40.32
TOTAL DSM IMPACT	83.38	226.00	276.56

In [49], prior work of autonomous DR by using energy consumption scheduling device to each user was focusing on minimizing the cost of power generation or minimizing the peak load demand to average load demand ratio. This was based on updated electricity pricing information. In this research, a novel fairness index is developed, proving that some of the billing mechanisms in the autonomous DR are unfair in rewarding the participants compared with their contribution in achieving the system design goals. An alternative billing model aimed improving fairness is projected keeping the optimality of the overall system performance. The above proposals also are substantiated by analytical case studies and simulations.

In [50], a scheme consisting of a router, programmable internet relay and solid state switches to control load demand at consumer premises is presented. An economic model corresponding to the aforesaid scheme representing an incentive based DR program is simulated. The application of this simulated program resulted in reducing energy cost, peak demand magnitudes energy consumption, and also in lowering the likelihood and consequences of forced outages. The scheme contributes in delaying investments in new infrastructure and constructing costly new power plants as well as improving grid usability and reliability.

In [51], a new efficient DR program is proposed to protect the participants' returns. The tendency of the new DR program is to control load demand by awarding incentives to participants when a DR event occurs in the incentive-based program. Also, it is intended to control load demand by responding to market tariff on the price-based DR program. A bid-based DR program is proposed in this research to evaluate the load forecast and to improve the DR program. It is concluded that the bid-based DR program can reflect various opinions of participants allowing planning of the power system operation with the variance in electricity demand.

In [52], a method to quantify the level of responsiveness among residential consumers is proposed. The load profiles of different domestic appliances within a group of consumers' premises are obtained based on the electricity price, which affect the operation timing of different appliances. The total load profile is simulated and it is concluded that DR could be achieved through certain types of domestic appliances. However, it is still essential to study to which extent of demand those domestic appliances could be responsive. Generally, residential consumers have not benefited from this technology.

In [53], smart home energy management DR application is investigated, regarding appliances of one household in one day, by proposing an optimal scheduling model. In this study, the TOU electricity price, incentives and inconvenience of consumers are taken into account. The model resulted in 34.7% reduction in total costs when inconvenience weighting factor is equal to 0.2, whereby the consumer will shift load from peak period to valley periods in response to incentives and electricity prices. The smaller weighting factor means that consumers are willing to shift more load to reduce total cost, which leads to lower penalty on inconvenience. Higher weighting factor means a high penalty on inconvenience, where shifting loads will cause great inconvenience to the consumers, whereby the consumers will be unwilling to participate in DR programs and will incur high penalty and extra cost. The weighting factor is a tradeoff between the total cost and the participants' inconvenience. The results show that incentives are conducive to shifting loads and reducing costs. Further studies are required assuming more numbers of households and longer study periods considering household consumption modulating appliances such as heaters and HVAC system.

In [54], an application of a dynamic energy resources priority (DERP) method is presented to manage the consumption and generation in an office building. It is concluded that DERP method facilitates an efficient performance of DR program between different types of resources in the smart grids and microgrids via an optimization algorithm and ease means of interaction between users and grid. DERP application contributes in reducing the loads consumption in certain divisions of buildings, sending energy to the grid and diminishing power supplied by the grid.

In [55], three main developed methods are applied on supply side for LM technique, which are: direct load control (DLC), interruptible load control (ILC) and time of use (TOU). The implementation of these methods on demand side resulted in reduction of electrical energy consumption. More LM techniques are cited such as: power wheeling, energy efficient electrical equipment, energy storage devices, co-generation and renewable energy resources. Improvement of power factor is considered as one of LM techniques contributing in improving the reliability of power supply and saving consumption of the demand side. It has been found out that the capacity of power factor capacitor banks in many industrial consumers needs to be reevaluated to achieve more energy saving. The necessity of harmonic filters in modern industries needs to be investigated too. This research proposes and recommends automatic demand control methods to be used in demand side in order to improve the reliability of the supply side, minimize energy cost and lessen environmental degradation. The controller should be able to detect maximum demand and prioritize loads. It is recommended to consider this paper as an incentive for the electrical power supply industry particularly in developing countries where DSM programs are not yet implemented.

In [56], a virtual power plant (VPP) comprising a residential building is used to apply a monitoring and control system for the building energy resources aiming to achieve grid flexibility by aggregating DR of households. This was implemented by using computational intelligent techniques of thermal load predictive control model. The VPP receives input data from the building sensors, electricity market, consumers, the aggregator and predictive control model. The VPP computational intelligence unit processes all these inputs and takes control over the HVAC systems, lighting, plug loads, local storage, and local production installed within the building to achieve grid flexibility and to control electricity systems within the building using a predictive control model.

In [57], a novel on-line smart load management algorithm is presented using artificial neural network (ANN) aiming to measure, analyze, monitor, control and optimize residential consumer energy consumption. It is reported that the proposed strategy can reduce peak demand, electricity consumption, energy prices, harmful gas emission and dependency on fuel in addition to mitigating electrical system emergencies. The subject algorithm governs the power consumption by allocating the residential load in coordination with the utilities power supply events and during the demand response periods. The input data to the algorithm are a set containing the load categories, utility power limitation, load priority and energy bill limitation. The input data are processed and supplied to the algorithm, by which residential loads are, precisely, managed using external controlled disconnector. The simulation of the subject algorithm shows a 32% to 40% saving of daily energy consumption in residential sector, which represents the largest portion of electricity consumption in Gulf Cooperation Council region. This, in turn, yields to improve the overall grid efficiency particularly in case of demand response events. Some of the DSM techniques and applications in different countries are summarized in Table 3.

Table 3. DSM techniques and applications in different countries

Reference	Enabled technique	Benefits gained	Country
Reference 48 (2018)	Simulink / Matlab	- A 30% peak demand daily saving - About 11.28% daily saving in electricity bill.	Turkey
Reference 50 (2013)	Wireless sensor network at consumer premises	- Using modern communication, allowing consumer to observe electricity prices and network congestion	Mashhad city

	representing IBP program.	- Reducing energy consumption, cost and peak demand	
Reference 51 (2010)	Bidding based DR program.	- Reflecting various opinions of participants allowing the planning of the power system operation within the variance in electricity demand	South Korean
Reference 52 (2009)	Modeling of aggregated load profile.	- Achieving DR by specific types of domestic appliances, while still need to study to which extent of demand those appliances can become responsive	United Kingdom
Reference 53 (2017)	Optimal scheduling model of smart home appliance energy management – TOU	- A 34.7% reduction in total cost with 0.2 inconvenience weighing factor.	China
Reference 54 (2016)	DERP application between different types of resources in SG and microgrids via an optimization algorithm.	- Reducing loads consumption - Sending energy to the grid - Diminish power supplied by the grid - Assuring comfort level for essential loads.	Porto – Portugal
Reference 55 (2009)	DSM on consumer side by using automatic demand control method. - DLC, ILC and TOU at supply side.	- Encouraging power supply industry particularly in developing countries - Highlighting the use of automatic demand control in demand side - Detecting maximum demand and prioritizing loads - Investigating the necessity of harmonic filter.	South Africa
Reference 56 (2015)	Computational intelligence technique of VPP using predictive control model.	- Regulating energy resources - Optimizing energy usage - Adapting consumption to the momentary available production	Denmark
Reference 57 (2015)	On line smart load management algorithm using ANN	- A 32% to 40% saving in the daily energy consumption - Improving grid efficiency and reliability.	Gulf Area

3.5 Evolving Practice of Demand Side Management

The research in [58] focused on the energy EE programs, where a study introduced by EPRI reported that this type of programs would potentially reduce USA consumption in energy in the year 2035 between 11% and 14%. EPRI experts admitted that the more advancement of building energy codes, regulations and appliances efficiency standards, the more is the level of electricity consumption saving. Building energy codes and standard are not limited to, efficient air conditioning, electronically commutated motors, efficient lighting, programmable thermostats, building insulation, high efficiency windows and energy management systems.

The research also reveals that by 2050, the usage of plug-in electric vehicles (PEVs) in USA could become 53% of the driven vehicles (today it is only 1%). It would result in a 48% to 70% reduction in greenhouse gas emission. DSM will continue to be a significant solution as long as power system continues to develop. In the next ten years the changes in power system would be more than that have been in the last century, due to the advantages and dramatic changes in cost and performance of RERs, other distributed generation (DG), BES and smart energy appliances. This will result in a positive change in electricity generation, delivery and utilization and all pertaining electric energy services.

In [59], the opportunities and importance of business EE programs and how to break the barriers in promoting EE projects are elaborated. In [60], the favorable return upon investment in industrial EE rebate programs by utility company in U.S state of Ohio is presented. The economic and environmental impacts of the programs that provide monetary rewards for firms who employ EE equipment in their premises are estimated too.

In [61], the automated demand response (ADR) system with a two-way architecture scheme for household appliance is studied, and the ADR main technologies are analyzed as well. Main technologies of ADR include DR strategy, where the consumer changes consumption profile with predefined plan to cut down electricity peak load. Also, the centralized controller device can perform a remote control to room air conditioners and other equipment. It can customize an intelligent control scenario to achieve the targeted energy saving. Among the ADR main technologies are the measurement, verification techniques and data acquisition for several energy power meters, gas meter, water meter. This entails data gateway to support multiple metering devices with multiple communication protocols. Further, the interaction between the grid side and consumer side via the interface communication protocol is ensured, whereby the power company shall take care of all DR events, such as, editing, omitting, initializing and governing the DR participants list, events and programs. In this research, the key technologies of ADR program are outlined. It is highlighted that, ADR program would be widely performed in China with favorable chances of success, once the electricity price policy is improved therein.

3.6 Impacts of Specific Load Types on Demand Side Management

In [62], a DLC concept is developed via g-DLC controller that considers the least on-time for the air conditioning units and produces best possible DLC schedule for all associated units. Air conditioning units are equipped with a least enthalpy estimation (LEE) based thermal comfort control, whereby thermal comfort level (TCL) to satisfy consumers is achieved. The off-shift time of DLC program is extended by which the load shedding is increased and, in addition, the impact of the outdoor weather temperature is lessen and transient load payback effect is avoided. In conclusion, the load management program can diminish the DLC constraints on air conditioning loads by presenting g-DLC controller, which is deemed the threshold for conflicts between air conditioning units and the load management program. On the other hand, the effectiveness of air conditioning system, equipped with energy storage capacity, is proven when DLC scheme is performed for air conditioning loads as a demand side load management wherein the system peak load profile is reshaped favorably.

In [63], an efficient DLC algorithm LEE based fuzzy thermal controller of central air conditioning system is employed. The objective was to provide suitable setting for multi-zone fan coil units, which can improve the energy saving efficiency of the conditioning system. Additionally, maintaining TCL of the consumers within an acceptable limit will avoid the higher fuel generation cost spent to compensate the peak load demand.

The proposed DLC algorithm operates with the concept of pre-storing chilled water heat transfer capacity and makes use of the merits of the LEE based Fuzzy thermal controller. In addition to what stated above, it can avoid the air conditioning load payback effect and elongate the load shedding time. Besides it will avoid constructing less efficient power plants and also relieve the overload capacity on the transmission lines.

In [64], Pacific Gas and Electric (PG&E) smartAC was successfully deployed as a new DLC program by the utility throughout California. Consumers are given a choice of two control strategies, the adaptive switches or programmable communicating thermostats with ramping capability, by increasing the temperature set point in various increments within the control period. Adaptive switches proved an efficient impact under peak load conditions compared with the traditional one-way single mode switch technologies. On the other hand, thermostats programmed with increased daytime temperature set points proved difficulty to achieve load reduction therein.

In [65], the implementation of a relaxed dynamic programming (RDP) algorithm to produce a daily air conditioning load (ACL) and load control scheduling (LCS) schemes is presented.

An online scheduling policy has been applied on a case study involving control of 16 large air conditioners. It is concluded that RDP algorithm is applicable for solving problems with other types of load control operation. The online LCS helps consumers in restraining peak load demand, in saving electricity cost more effectively, in executing different load management projects and in solving electricity supply shortage during peak consumption seasons. The subject approach gives the same results within the optimal solution searching in comparison with the preliminary dynamic programming (DP) approach in the case studies involving the same ACL group.

4. DIFFERENT LOAD MANAGEMENT STRATEGIES IN VARIOUS DOMAINS

4.1 Load Management in Distribution Energy Generation/Microgrids

In [66], it is outlined that, it is mandatory in microgrid LM system to maintain the balance between the load and the generation capacity during island operation and also to set up a set of actions and solutions for contingencies that may occur during grid parallel operation. Constantly updated load calculations allow the microgrid to accurately apply load reduction, if needed, with minimum or no visible impact on the consumer convenience.

It is also concluded that binary signals are to be applied for load status rather than analogue data methods, which is more expensive and needs greater commercial bandwidth. In addition, using developed technologies that permit wireless monitoring and control of loads has the largest chance for general agreement by the consumers.

In [67], a method of the optimum management with real-time pricing is proposed. This is accomplished by considering inelastic energy demands (lighting, TV, PC) and elastic demands (HVAC, PEVs, water heater, dish washer), RERs and BES to reduce the electricity cost for a residential consumer in smart grid. By using the Lyapunov optimization technique, a good tradeoff between the cost saving and the increased BES capacity was identified. The reason behind this approach was to use energy storage to reap the excessive renewable generation for later use when the electricity price is high and recharge when the electricity price is low. The case for elastic energy demand and use of the virtual queue technique is also investigated to assure that the worst case delay for any storage energy demand is finite.

In [68], a grid accommodating distributed energy production and storage is proposed. A day-ahead optimization process regulated by an independent central control unit and consumers to reduce their monetary expenses is introduced by producing or storing energy rather than purchasing energy. In this research, a distributed and iterative algorithm is described based on the proximal decomposition allowing computing the optimal strategies of the consumers with minimal exchange data between the central unit and the network demand side and realistic simulation is performed. The simulation resulted in favorably flattened demand curve, which in turn reduced the need for carbon control and the need for expensive peaking power plants. The subject day-ahead optimization algorithm proved its applicability to larger consumers such as small cities and communities.

In [69], a game theoretic model predictive control (MPC) based algorithm is implemented for distributed PV generation and storage resources. Real time data is used to reduce uncertainty and ensure the DSM benefits more effectively compared with a day-ahead scheme, where greater than 10% average error forecasting was found out which often has detrimental consequences. The subject MPC approach reduces effective forecasting error, which in turn leads to greater electricity cost saving for all consumers within a NAN and reduces PAR for the utility. Greater generation and storage capabilities increase electricity cost saving and motivate consumers to invest in appropriate distribution technology. On the other hand, reduction in PAR relieves stress on the utility and expands the utilization of generation infrastructure. Many subgroup electricity costs increased slightly in the MPC based algorithm, but the improvement in the forecasting accuracy offset these losses.

In [70], a new home energy management (HEM) model is presented using binary particle swarm optimization (BPSO), genetic algorithm (GA), cuckoo search for scheduling the appliances of residential users. The model is simulated based on TOU pricing scheme for traditional homes, smart homes and smart homes with RERs. It is resulted in significant reduction in electricity bills and high peaks. It is found out that cuckoo search algorithm provides highest cost saving compared with GA and BPSO in case of smart homes with and without RERs.

4.2 Load Management using Smart Home Appliances

In [71], an energy saving method is put forth for household electric appliances. Appliances are technologically networked as many means of communication are available such as, Ethernet, electric power line and radio communication, enabling exchange of information with home appliances. An outcome of simulator showed a 15.6% reduction in electricity consumption, whereby the electric power could be favorably distributed at the real time constrained by setting priority levels on the appliances operations.

In [72], a wireless sensor network is designed and executed for home appliance energy management based on ZigBee technology along with system software development and hardware, analysis and real time testing. The system testing ensured low power consumption, which could be applied to a group of buildings, such that electric system scheduling will be manageable. In particular, the system is characterized by its reliability, low cost and simple structure.

In [73], a metaheuristic algorithm based on cooperative particle swarm optimization (PSO) is used and simulated to obtain operation and coordination scheduling of a set of time-shiftable controllable appliances in smart homes. The aim of this study is to avoid peak rebounds at periods with lower electricity prices, which may cause unexpected disasters in the utility power grid. The simulation of the above mentioned algorithm succeeded to prove a coordination management among a set of smart homes appliances that averted the possibility of peak loads and peak rebounds. In addition, it guaranteed the consumers comfort and reduction of electricity bill of individual homes.

In [74], multi criteria decision making (MCDM) techniques are merged with evolutionary multi objective optimization (EMOO) to select the most appropriate electrical appliances scheduling. A multi objective Antlion optimizer (MOALO) is produced and tested for a case study to conclude the lowest expenses solutions for appliances scheduling. The evidential reasoning (ER) method is used to assess the efficiency of the resulted solutions. The proposed strategy proved its effectiveness in improving the means of smart appliances scheduling in terms of electricity bill, peak to average ratio and CO2 emission.

4.3 Load Management Based on Power Quality Techniques.

In [75], a sensitivity congestion management technique based on cost efficient generation rescheduling and/or load shedding is presented. Participating generators and loads are selected by a sensitivity indicator, which correlates changes in real and reactive power injections at buses to the changes in line current. The projected technique is simulated on IEEE 30-bus and 118-bus systems and proved its ability to accomplish the purpose. This method of management furnishes a set of best possible solutions and alternatives means to enable congestion management most efficiently.

In [76], incorporation of power quality improvement in load side management strategies of SG is addressed based on using decoupled harmonic load flow algorithm. It was aiming to assess the harmonic stresses at the distribution transformer supplying nonlinear loads. The derating K-Factor is an important issue in order to determine loads that must be shed to diminish harmonic losses at the transformer and distribution feeders. Thus, the electric system reliability shall be increased and efficiency shall be improved. Since the main concern is the proliferation of PEVs in smart grid, a load management for PEVs is studied in this research for an IEEE 30-bus and 23 kV distribution systems. It is concluded that at peak load period with high insertion of PEVs or any smart appliance, transformer load and harmonic losses are reduced, while K-Factor is reduced at off peak but significant current harmonics are generated that needs further loads to be shed. Also, DG resources could be used to reduce transformer loading. Further, in case of implementing this strategy in the consumer side load management, peak demand reduction and low harmonic distortion could be achieved.

In [77], the effect of voltage variation is analyzed for different types of loads such as LED lighting and fluorescent lamps with electronic ballasts and thermal loads on active, reactive and apparent power. It is concluded that for the LED and fluorescent lamps with developed electronic driver, the active power consumption is either constant or increasing by decreasing the supply voltage. Similar to thermal loads, such as heater, the reduction of the supply voltage causes reduction in the instantaneous consumed power. However, considering long working hours, no energy saving would be anticipated. However, in these types of loads, reducing the voltage may increase the number of turning on and off actions, which in turn would decrease the device lifetime. In summary, decreasing the voltage in the recent developed loads could yield some reduction in power consumption with insignificant energy saving.

Some of the outlined load management techniques, key finding and types of DR program in different domains are summarized in table 4.

Table 4. Different load management techniques

Reference	Enabled technique	Key finding	*DR program
Reference 61 (2015)	ADR system technology.	- Interaction between grid and consumer - Allowing remote control of air conditioners via centralized controller	DLC

		- Customizing intelligent scheduling scenario aimed at energy saving - Performing measurement and data acquisition for energy, water and gas meter.	
Reference 62 (2008)	Novel group DLC algorithm using g-DLC controller.	- Achieving consumer TCL - Avoiding transient load payback effect - Avoiding impact of outdoor weather temperature.	DLC
Reference 63 (2005)	DLC algorithm LEE based fuzzy thermal controller of central air condition system.	- Achieving consumer TCL - Avoiding transient load payback effect, higher fuel generation cost, construction of less efficient power plants - Relieving overload capacity on transmission lines	DLC
Reference 64 (2008)	PG&E smartAC DLC program with two control strategies: adaptive switches or programmable communicating thermostats.	- Proving an efficient impact in load reduction under peak load conditions by adaptive switches unlike programmable communicating thermostats that proved difficulty to achieve load reduction.	DLC
Reference 66 (2016)	Microgrid load management.	- Maintaining balance between load and generation capacity during island operation - Providing pre-planned solutions during grid parallel operation - Implementing binary signals rather than analogue ones.	DLC
Reference 67 (2012)	Lyapunov optimization technique and virtual queue technique with RTP	- Achieving good tradeoff between the cost saving and the increased battery storage capacity. - Guarantee of finite delay time for any storage energy.	IDLC
Reference 69 (2014)	Game theoretic model predictive control (MPC) based algorithm for distributed PV generation and storage resources.	- Reducing PAR for the utility - Increasing electricity cost saving, and perfect forecasting accuracy information, while many subgroup electricity costs slightly increased.	IDLC
Reference 70 (2017)	BPSO, GA and cuckoo search based on TOU pricing scheme	- Significant reduction in electricity bills and high peaks	DLC
Reference 72 (2010)	ZigBee technology wireless sensor network.	- Achieving low power consumption and reliable and simple structure for a group of buildings.	DLC
Reference 73 (2015)	Metaheuristic algorithm based on cooperative PSO and coordination scheduling among set of smart home appliances.	- Averting peak rebounds and power grid damage - Reduction in electricity bill - Guarantee of consumer comfort.	DLC
Reference 74 (2020)	MCDM merged with EMOO, MOALO optimizer and ER method	- Creating tradeoff between optimization criteria. - Improving the means of smart appliances scheduling	DLC
Reference 76 (2010)	Decoupled harmonic load flow algorithm on IEEE 30-bus based on derating k-Factor.	- Increasing electrical system reliability and efficiency - Diminishing harmonic stress at the transformer and distribution feeders - Achieving peak demand reduction and low harmonic distortion in case of implementation in consumer side load management.	DLC
Reference 77 (2019)	Voltage variation for new generation lighting and thermal loads.	- Load- power behavior is changed due to recent technologies evolution on loads.	DLC.

- * DLC: Direct control load management
- * IDLC: Indirect control load management

5. CONCLUSIONS

DSM is categorized into two main parts which are EE and DR programs. In this paper it is found out that EE programs have the most influential impact on the annual energy and peak demand savings compared with other dynamic LM programs, such as RTP and TOU. It is emphasized by EPRI that EE programs would potentially reduce USA consumption in energy in the year 2035 between 11% and 14%. It is revealed that RTP is the most efficient DR program, whilst TOU is the basic PBP and easiest to implement. Applications of different DR programs, algorithms, pricing signals and appliances automatic scheduling with multiple techniques in various domains resulted in saving in daily energy consumption ranging between 30-40% in some countries, managing dynamic energy resources in SG and microgrids allow sending energy to the grid and diminishing power supplied by the grid. In addition to the consequent daily saving in electricity bills, improvement in grid efficiency and reliability, maintaining balance between consumption and generation capacity, augmenting the integration of RERs and deferring constructing new generation substations and networks. It is inferred that decreasing the voltage for the recent developed loads yields insignificant energy saving. The effectiveness of reshaping the peak load profile by DLC algorithm of air conditioning systems equipped with LEE based TCL and energy storage capacity is verified. It is also revealed that each 1 kWh lighting savings induces 0.48 kWh cooling savings. Environmentally, postponing constructing new generation substations will definitely contribute in improving air and water quality and decrease the greenhouse gas emissions. In conclusion, the more advancement of building energy codes, standards and appliances efficiency, the more is the level of energy consumption saving. Also more involvement from nonutility and nongovernmental identities is required to afford sophisticated DSM programs.

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