# Challenges of Implementing Demand Side Management in Developing Countries

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**Abstract**

The energy crisis along with increasing per capita energy consumption of cities and nations poses a worldwide challenge. Smart grid technology facilitates the shift to more sustainable technologies such as microgrids, distributed generation, demand side management, and advanced metering infrastructure. This paper is mainly focused on demand side management (DSM); conventional and recent models of demand side management found in the literature are discussed. Implementation and practices of demand side management at various locations in India are also unveiled. With 16 pilot smart grid projects underway in India, there is a need to report on how smart grid technologies are living up to their potential. It is also essential to identify and discuss related challenges and the issues in the implementation of DSM. This paper focuses on analyzing global best practices in DSM and their implementation to fulfill the estimated potential, particularly in the residential, industrial and agriculture sectors.

**Keywords**: Demand Side Management, Demand Response, Energy Management, Smart Grid

## 1 Introduction

BP's statistical review on world energy, June 2018, reported that global energy demand has grown by 2.2% and is 1.7% higher than average demand of the last 10 years. 80% of increased global energy demand comes from developing nations. On the other hand, global $CO_2$ emissions in 2018 were 33508.4 million tons and India's $CO_2$ emission was almost 7% of the total, i.e., 2218 million tons [1]. The annual report on power supply position in 2018 by Central Electricity Authority, India [2] showed there was a requirement of 1213325 million units (MU) of energy but that only 1204697 MU was available. Whereas peak demand was 164066 MW, only 160752 MW was able to be met. The demand and supply position of the Indian power system and comparison of peak power demand and supply are shown in Fig. 1 and Fig. 2 respectively [1] and these figures reflect the fact that there is a huge gap between the two. India Smart Grid Forum (ISGF) claims that the existing power grid is not equipped to meet the requirements of the 21st century [3]. This is due to technical flaws in the power system viz. poorly planned distribution network, overloading of the system, lack of reactive power support and metering inefficiency. Consequently, the situation mandates the implementation of smart grid technologies [2]; [3].

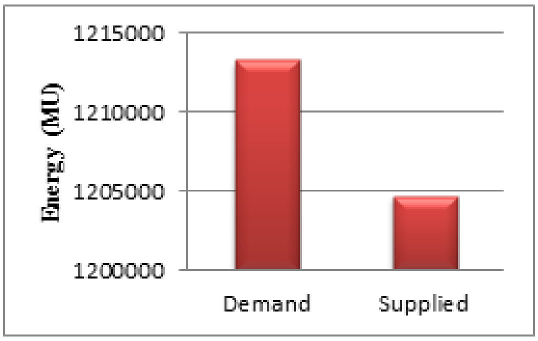


Figure 1: Power demand and supply in India (Year 2018)

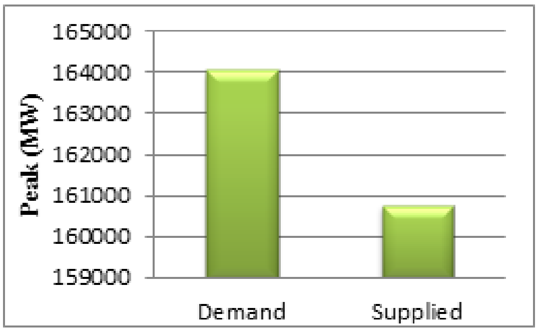


Figure 2: Peak demand and supply in India (Year 2018)

The smart grid is a term used for electric power network with attributes of demand side management (DSM), demand response, online monitoring, information communication and automation with a basic use of power supply. Smartness is the answer to the quetion of how to modernize the traditional power

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grid. Unlike the old power grid, the smart grid has the facility of real-time data collection, monitoring and flow of information [4]. The smart grid does not have one universally accepted definition; it may vary based on technologies used, functionalities and benefits. The term "Smart grid" was coined in 1997 by Khoi, M. Begvoic and Damir [5]. The National Institute of Standards and Technology (NIST) defines the smart grid as "A renovated power grid that enables bidirectional flows of energy and information; it also has control capabilities that will lead to a system of new functionalities and applications" [6]; [7]. The development of smart grid technologies initiated a revolution in the power sector by enabling the power system to transfer maximum power economically with the existing infrastructure [8] .

There are various functionalities incorporated in smart grid technology like advanced metering infrastructure (AMI), power quality management (PQM) [4] , home area network (HAN) [9], strong communication network [10]; [11], cyber security [12], distributed generation [13], demand response [2] and demand side management [14] as presented in Fig. 3.

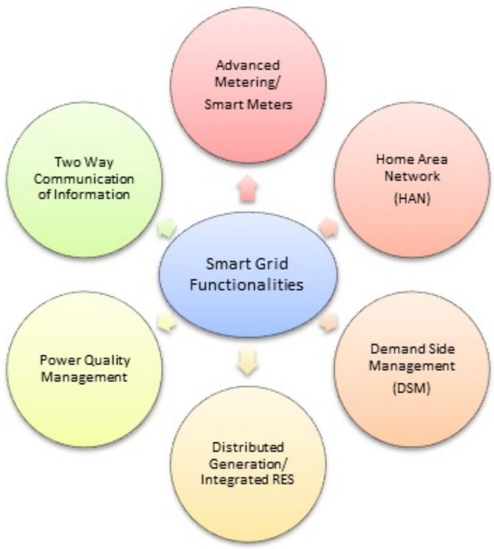


Figure 3: Smart grid functionalities

## 2 Methodology and bibliometric analysis

In this paper, a systematic review of DSM programs and policies is undertaken instead of specific trials, because the policies facet of DSM has received less attention. This paper also synthesizes all the work that has been done on a specific intervention. Works included are: published and unpublished material, educational and 'gray' literature (such as policy documents and industrial reports), and peer-reviewed papers. The approach of the paper is given in Fig. 4.

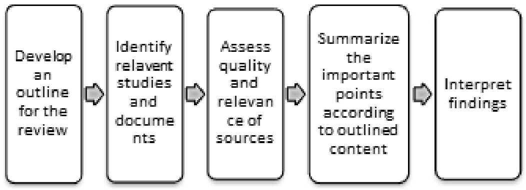


Figure 4: Summarized approach of the paper

As of March 15, 2019, there are 590 journal articles and 80 conference papers associated with techniques of demand side management in the smart grid in the time horizon of 2000-2019 at ScienceDirect, 112 journal articles at MDPI publications and 300 at IET Digital Library, using a general search. The search contents also contain repetitions and less relevant inclusions. An advanced search filtering for implementation of demand side management in power system in the abstract, title or keywords from 2000 to 2019 shows 250 journal articles and 90 conference papers at the IEEE Xplore Digital Library, IET Digital Library, Taylor & Francis and ScienceDirect. The increasing intensity of study interest in the DSM area with articles published in various journals is shown in Fig. 5 and Fig. 6.

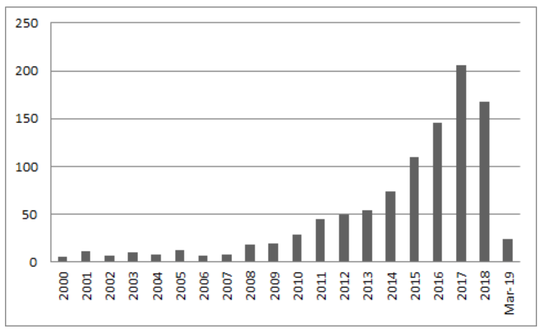


Figure 5: Annual publications for DSM implementation

The use of government reports, statistical data and other sources was required to obtained some necessary and recent information. Fig. 7 shows the ratio of publications related to various fields of smart grid technology concerning the Indian power system.

This paper seeks to provide a comprehensive review of most of the techniques and models associated with demand side management and chalk out the challenges faced by smart grid schemes introduced by the Indian

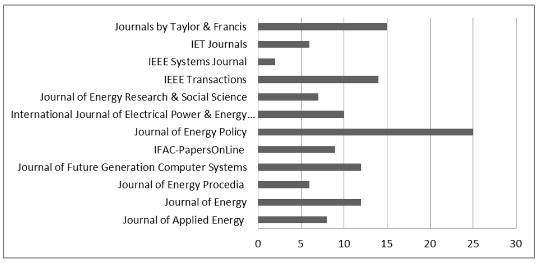


Figure 6: Summary of publications in different journal

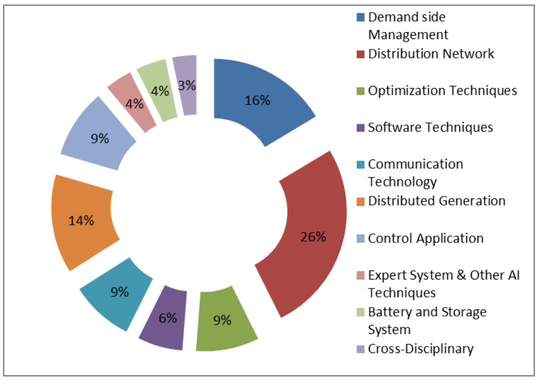


Figure 7: Articles published for smart grid technologies in the Indian power system (2000-18)

government. It intends to identify research activities, trends, issues and challenges in smart grid technology against the backdrop of a power system. This paper will facilitate attempts by researchers, policymakers, regulators and utility persons to identify bottlenecks in the domain of DSM and to adopt customized measures to mitigate issues especially prevalent in developing countries.

The paper starts with a brief introduction of smart grid technology and its functionalities. Section II reflects the methodology and bibliographical analysis adopted for the paper. Section III gives details about the development of techniques for demand side management. A history of DSM, classification & approaches of demand side management is contained in sections 3.3 and 3.4. Recent techniques and models developed in DSM technology are discussed in section 3.5. Details of pilot projects, policies, and plans initiated to implement DSM in different sectors are provided in section 4. Case studies for the implementation of DSM in SG pilot projects are given in section 4.2. Challenges in the implementation of DSM, possible solution and future research scope are also given in sections 4.4 and 4.5. Section V contains the conclusions.

# 3 Development of demand side management

## 3.1 Demand side management (DSM)

Demand side management (DSM) is a way for consumers to help the electricity grid manage electric power. It modifies the demand behavior of consumers by various methods such as financial incentives, rebates, and consciousness [6]. The goal of DSM is to encourage consumers to use less energy during peak hours and to shift their energy use to off-peak hours; it does not necessarily reduce energy consumption [14].

## 3.2 Historical development of DSM

Demand side management (DSM) was first introduced by Clark Gelling in **1980s**. It is now frequently used as one of the smart grid technologies. Motivations behind implementing DSM differ according to the parties involved (utilities, customers, regulators) . Gelling described three driving forces of DSM viz. environmental driven, network driven and market driven [15]. Earlier DSM programs were broadly classified as environmental driven. It was the strategy to achieve social goals by reducing energy use. In time, these types of DSM programs have been mainly redirected toward the reduction of greenhouse gas emissions.

From the mid-1980s to the mid-1990s, regulators in North America and Canada imposed stringent requirements on electricity utilities to accept DSM [16]. It was realized that DSM was more economical than managing supply side resources. After the mid-1990s, regulators in the United States began to turn their attention away from environmental driven DSM. By the late **1990s**, only a few network driven DSM programs had been established due to the problem of aging network structures. But post **1995** the implementation of network driven DSM programs increased rapidly in countries that had major problems with peak load [17]. Post-1995 energy security issues became less prominent in the USA. The introduction of competitive electricity markets in some countries initiated research and implementation of market driven DSM, i.e., demand response programs. The implementation of market driven DSM is currently restricted to North America [16]; [17]; [18].

Interest in DSM revived in the period **2000 to 2010** as a result of environmental and energy security problems coming to the forefront of the political agenda [19]. Recently, the International Energy Agency (IEA), France started a research project on network-driven DSM with countries of Australia, France, Spain and the US. In **2007** three countries: India, New Zealand

and South Africa joined IEA for the DSM project [18]. Fig. 8 shows the timeline for the historical development of techniques used for DSM.

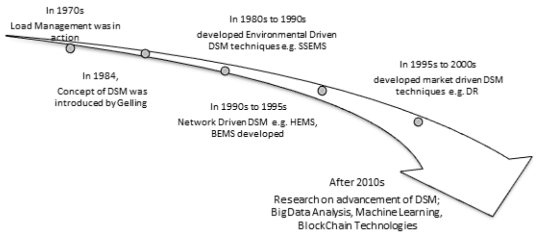


Figure 8: Timeline for the historical development of DSM

## 3.3 Classification of demand side management

Demand side management (DSM) attracts research due to the demand for strategic development in the power system. Mostly, DSM activities are put in place by utilities or end-side consumers. Demand side management activities can be classified by various programs, as shown in Fig. 9 [15]; [20].

### 3.3.1 Energy management program

In respect of the power system, the term energy management means "strategy of adjusting and optimizing resources, using efficient system and procedures to reduce per capita energy consumption which can result in the reduced total cost and enhanced competitive position" [21].

### 3.3.2 Load management program

With the help of load management, utilities or electricity suppliers can encourage consumers to redistribute their demand and time of consumption. Shifting demand to a different time reduces costs if and only if an appropriate tariff is available. Load management programs are of the following types:

- **Load leveling:** This technique is used to optimize the power generated and base load to meet the peak demand of a system without any reserve capacity. There are three forms of load leveling, as shown in Fig. 10 [22].
- **Load control:** Load control approach is pre-announced or informed rolling blackouts (systematic switching off of supply to any area) by the utility to reduce demand for a situation where demand exceeds capacity [23].
- **Tariff incentives and penalties:** A strategy to encourage customers to use energy in a certain pattern, with the help of tariff incentives or penalties. It includes:

  1. **Time of use (TOU) rates:** In this strategy utility charge differently for different periods of power use.
  2. **Power factor charges:** This imposes a penalty on users for having a low power factor.
  3. **Real time pricing:** A dynamic tariff, in which power rates vary continuously.

### 3.3.3 Load growth and conservation program

There are two terms associated with DSM, one is load management which came on the scene in the **1960s** and the second is strategic conservation, which gained support in the **1970s.** "Strategic" is anticipated to discriminate between naturally occurring and utility stimulated [16]. Hence, **strategic load growth** is implemented to increase the customer's productivity as well as to increase power sales for utilities. On the other hand, **strategic conservation** is the change in load shape which results in a reduction of power demand as well as a change in the pattern of energy consumption among end-users [15]; [19]. The third non-traditional load shape changing option is "**Flexible load shape**" which has the objective of making the load curve profile as consistent as possible. Load shapes objectives of DSM are shown in Fig. 11. The concept of flexible load shape is related to reliability [24].

## 3.4 Approaches to demand side management

Types of approaches for DSM are categorized on the bases of three driving forces viz. environmental driven; network driven; and market driven [16].

- **Environmental driven DSM:** Aimed at achieving environmental goals and social benefits, such as reducing emission of GHG and improving energy efficiency.
- **Network driven DSM:** Concerned with problems of the electricity network by reducing energy demands immediately or for a longer time.
- **Market driven DSM:** Provides a short term response to electricity market e.g. reducing energy demand during high price periods.

### 3.4.1 Supply side energy management system (SSEMS)

Supply side energy management (SSEMS) aims to optimize operational resources on the supply side [14].

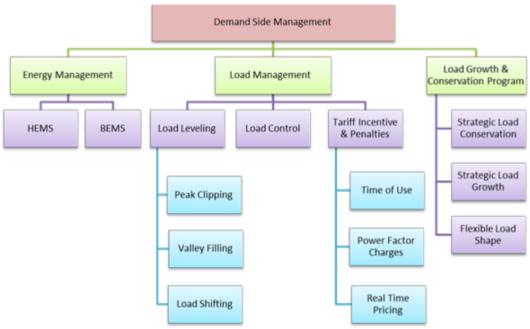


Figure 9: Classification of demand side management

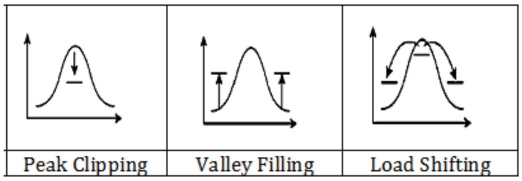


Figure 10: Forms of load leveling

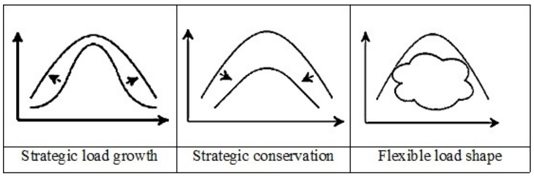


Figure 11: Load shapes objectives of DSM

Table 1: Comparisons of deterministic and stochastic optimization techniques

| S. No. | Objective | Deterministic | Stochastic |
|---|---|---|---|
| 1 | Quality of Optimum | Local Optimum | Global Solution |
| 2 | Objective Unimodel | Smooth and Non-linear | Linear or Function |
| 3 | Constraints Accurate | Less Accurate | More Handling |
| 4 | Convergence | Premature | Good |
| 5 | Parameter Required | Less Required | More Tuning |

Its objective is to reduce production cost and emission of greenhouse gases (GHG). SSEMS is an "**environmental driven approach"** of DSM. Its objectives can also be formulated and solved as an optimization problem [25]. Manyh researchers have explored demand side management in terms of various single objective and multi objective functions e.g. peak load minimization [14], production cost minimization [25], dynamic economic dispatch [26] with optimal emission [27]; [28], compensation and incentive costs considering consumer behavior of various types of loads [29]. There are various optimization algorithms available in the literature which can be classified as deterministic or stochastic . Stochastic algorithms include nature-inspired algorithms, such as: genetic algorithm (GA), particle swarm optimization (PSO), ant colony method, simulated annealing (SA), etc. Solutions of different objective functions of DSM using various optimization techniques have been given in the literature viz. multi objective PSO (MOPSO) [30], non-dominated sorting genetic algorithm-II (NSGA-II), teaching and learning based optimization (TLBO), shuffled frog leaping (SFL) [31] for multi objective functions, and bi-level programming [32] to optimize the benefits of utilities as well as consumers. Comparative analysis of deterministic and stochastic algorithms of optimization is given in Table 1 [25]; [26]; [27]; [28]; [29]; [32]; [33].

### 3.4.2 Home energy management system (HEMS)

Home energy management system (HEMS) and building energy management system (BEMS) are "**network driven approaches"** of DSM that are applied on residential loads [5]; [15]. HEMS can be very effective in reducing peak demands and maximizing the customer's monetary benefits [34] if it is implemented with smart electronic devices. With advancements in the Internet of Things (IoT), HEMS allows consumers to optimize their energy consumption by real time monitoring of home appliances [11]. A new development in this era is the smart home. Smart homes consist of smart meters with energy management algorithms, home gateway, sensors, controllers and a communication system. These mecha-

Table 2: Relationship between DSM load shapes and different objectives

| S. No. | DSM Load Shapes | Fuel Cost | Electricity Bill Cost | Peak Demand |
|---|---|---|---|---|
| 1 | Peak Clipping | Low | Low | Low |
| 2 | Valley Filling | High | No change | No change |
| 3 | Load Shifting | Low | Initially high | Low and later low |
| 4 | Strategic | Low | Low | Low Conservation |
| 5 | Strategic | High | High | High Load Growth |

nisms gave rise to the term advanced metering infrastructure (AMI) [35]; [36]. AMI technology enabled two-way end to end communication in the smart grid. Smart meters can connect all the home appliances through a wireless communication system (Home Plug Power line Alliance, Z-Wave and ZigBee Alliance). Smart meters can help regulate a real time pricing scheme [37].

#### 3.4.3 Demand response (DR)

The change in the regular consumption pattern of end users of electricity in response to the change in electricity prices by time is known as "Demand Response" [20]. Demand response is a type of "**market driven strategy"** of DSM, which provides a short term response to energy market conditions [22]. There are two building blocks of DR: one is direct load control and the other is dynamic pricing, which come under the category of explicit DR and implicit DR respectively. In explicit DR, electricity companies order or suggest to customers to change their consumption of dispatchable loads. On the other hand, implicit DR provides demand and supply based pricing strategy viz. time of use (TOU) for non-dispatchable loads. Another action that could be taken in response to peak pricing is to delay the use of electricity from peak hours to off-peak hours [5].

An analytical study for applicability (low or high) of various DSM programs and load shapes in achieving different objectives, with reference to a case in which no DSM applied, is given in Table 2 [13]; [14]; [15]; [16]; [17]. Table 3 compares frequently used DSM techniques [20]; [21]; [30]; [22]; [24].

### 3.5 Recent techniques and models in DSM

#### 3.5.1 Synergy based model of DSM

A new model of optimal scheduling of DSM is proposed in [14], which is synergy between home energy management system (HEMS) and supply side energy management system (SSEMS). It integrates the problems of consumers (time of dispatch, reduction of electricity costs, etc.) as well as constraints of suppliers (reduced operational cost, reduced emissions). Standard deviation based genetic algorithm has been implemented to minimize the objective function of home electricity bill.

#### 3.5.2 Prosumers based model of DSM

Traditional grids interact exclusively with the generation, transmission and distribution system. Interaction with consumers remains one sided. With the development of a distributed energy system, renewable energy produced at the consumer end can also be used as a new source. In this direction, another model of DSM has been discussed by [38]: prosumers based energy management system (PEMS). Prosumers are consumers as well as producers. This model is based on a two-way flow of energy as well as information. Prosumers can share surplus energy with the grid or other consumers. Sharing of energy among prosumers may result in improved reliability and sustainability of the system [39].

#### 3.5.3 DSM with game theoretic approach

Two different approaches are proposed in the literature viz. optimization and game theory. In the former, all consumers are supposed to cooperate in managing their resources. Optimization based models are used to minimize a shared utility function. But the involvement of consumers actively makes the system diverse and solving this problem in the centralized fashion makes the system more challenging due to the wide constraints of consumers.

A game theoretic approach with modelling and optimization in "GAMS" (general algebraic modelling software) has been proposed to minimize the peak to average ratio of energy demand [40]. Game theory approach turns the problem from centralized to distributed fashion [41]. In this approach, all the consumers (decision makers) are assumed as players; and they can have their specific strategy to optimize their electricity bill with the tariff differentiated according to time and level of consumption [42]. This approach can also be used to minimize peak demand and production cost as well.

Table 3: Comparison of Different DSM Techniques

| S. No. | Direct Load Control (DLC) Method Program | Energy Efficiency (EE) | Implicit Demand Response (DR) Method |
|---|---|---|---|
| 1 | Explicit DR program, based on incentive provided to customers | Use of less energy at any time | Price based program |
| 2 | Incentive provided for reducing the load | No incentive provided for reducing the load | No incentive provided for reducing the load |
| 3 | Controlled by load shedding | Controlled by reduced consumption with discomfort | Controlled by load shifting |
| 4 | Controlled by utility but in some cases, users have an authority to override the utility decision | Totally under users control | Users defined control |
| 5 | Mostly in system emergencies | Permanent reduction in electricity usage | Every day phenomenon |
| 6 | Event driven | Environmental driven | Market driven |
| 7 | The utility might be in loss; it has to pay for DLC | Users and utility both are benefited | Benefits the utility |

#### 3.5.4 Distributed DSM model

The residential load consumes the largest portion of electricity (about 50%) and also a cause of peak load [43]. Energy management in residential loads is considered difficult, as it depends on consumer behavior [44] and requires control of each electric device [45]. Two major objectives of residential load management are reducing consumption and load shifting at peak time[42]. Time of use (TOU) tariff is the most suitable way to shift energy consumption out of peak hours [22]. A game theory based model of distributed demand side management has been proposed and an energy scheduling game formulated to reduce peak demand of residential load [44]. In this approach, the minimized energy cost is achieved at Nash Equilibrium (a solution concept of a non-cooperative game involving two or more players).

Another approach for residential load management is direct load control (DLC); here the utility remotely controls the operation of household appliances like lighting, heating, air conditioning and pumps [46]; [47]. In the DLC approach; consumer privacy poses a major barrier to implementation [48]. Besides DLC, in the distributed demand side management program, users can apply their response strategy without sharing the details of their energy consumption schedule with other users [42].

#### 3.5.5 Security based model of DSM

With the developed distributed energy trading market, a direct path is set up among producers, consumers, and prosumers. Direct peer to peer transactional behavior resulted in lower power losses, generated revenue and solved power demand issues [46]. The power trading required a robust and seamless communication system and strong database management system. Implementation of "blockchain technology" can fulfil this requirement. Blockchain can be used for peer to peer transactions with any central third party monitoring [45]; [47]. This enables users to record and share a standard view of the system's states across a distributed network [49].

#### 3.5.6 Integrated DSM model

Another approach to increase the adoption of DSM, with which the industry has limited experience to date, is the integration of DSM programs. Integrated demand side management (IDSM) at a conceptual level is a strategic approach to designing and delivering a portfolio of DSM programs to customers. Most utility and 3$^{rd}$ party administrator programs currently identified with the concept of IDSM only integrate two DSM measures, namely energy efficiency (EE) and demand response (DR) [50].

The Northeast Energy Efficiency Partnership (NEEP) has defined the term IDSM as "*The integration of the delivery for three or more of: (1) Energy Efficiency (EE); (2) Demand Response (DR); (3) Distributed Generation (DG); (4) Storage; (5) Electric Vehicles; and (6) Time-Based Rate (TBR) programs for residential and commercial electric utility customers.*" Three of the five DSM components must be offered as an integrated solution to qualify as IDSM based on our definition [51].

In recent years, the concept of DSM has expanded beyond EE and DR to include customer-sited distributed energy resource (DER) technologies. The **model of aggregation** proposed in [50] is for residential customers who have renewable power generation at their location. In this method, the author proposed a distribution grid composed of several microgrids. This centralized distribution of the aggregated energy resulted in increased customer satisfaction.

An integrated DSM scheme using energy storage devices is also proposed by [52] for load management, load leveling, and peak demand reduction using average pricing. A time of use (ToU) tariff plan can also be used in home energy management system (HEMS), which decides when to draw power from an energy storage device and when to draw from the grid [53]; [54]; [55]. HEMS can also be programmed to control the switching of home appliances [56]. Integrated DSM can result in reducing peak demand and energy consumption beyond what EE and DR can deliver alone.

# 4 Demand side management implementation

## 4.1 Worldwide policies and activities for DSM

Various European countries, Australia, and South Korea are working towards the development and deployment of smart grid functionalities like demand side management (DSM), automating metering and billing, dynamic pricing, integration of renewable energy sources, etc. [57]. The United States and Canada have highly developed DSM programs (environmental driven) like no other country [58]. Some other countries like Denmark, Norway, Thailand and Vietnam have developed smaller DSM programs. Smart grid technologies have different policies for different countries as per their requirements [18].

### 4.1.1 Japan

The Ministry of Economy, Trade & Industry (METI), Government of Japan (GoJ) has promoted "Eco-Model Cities" which adopted smart metering as an aid to DSM after the tsunami earthquake in 2011, Japan's energy policies emphasize energy security, environmental protection and having an economic and efficient system. It aims to reduce $CO_2$ emission from power generation by up to 30% and raise the energy independence ratio to 70% by 2030 [59].

### 4.1.2 United States

The Department of Energy (DOE), Government of US formed energy policies for electric grid modernization, produced a model of "Grid 2030" targeted to increase use of smart meters and to achieve zero emission by power resources through increasing integration of renewable sources by 2030 [60].

### 4.1.3 China

The China Electricity Council (CEC), Government of China has initiated energy policies and the *Ministry of Science and Technology* (MOST) has taken charge of research and development, with smart grid technologies as one of the priorities in its $12^{th}$ five-year plan. China has targeted conservation, reliance on domestic energy sources and use of energy efficient appliances [61].

### 4.1.4 Europe

The European Council adopted the objective 20:20:20 under electricity policy no. 2009/752/EC, which aims to reduce greenhouse gases, increase renewable integration and increase efficiency each up to 20%. The EU targeted implementation of smart meters in 80% of households [62].

### 4.1.5 New England, USA

New England Independent System Operator (ISO) implemented a DR program in which commercial and industrial users receive payment incentives if they reduce their energy consumption or operate their electricity generation facilities in response to high real time price signals [63]. This program involved about 200 small consumers and achieved a peak load reduction of about 100MW.

### 4.1.6 India

The Government of India launched the National Smart Grid Mission (NSGM) which focuses on the activities of SG development and provides the policies, funds, and guidelines for the SG project. The National Project Management Unit (NPMU) has been formed to operationalize implementation [64].

The target set for distribution utilities is to reduce the aggregate technical and commercial (AT&C) losses to below 12% by 2022 and below 10% by 2027. The target for transmission utilities (above 66 kV) is to reduce transmission losses to below 3.5% by 2022 in the country. On the other hand, Indian utilities have targeted mandatory demand response for all loads above 20kW by 2027 and peak load management in all utilities – target: 5% of peak load [58]. A comparative

Table 4: DSM Programs by India, UK, and USA

| S. No. | Implemented DSM Program | India | UK | USA |
|---|---|---|---|---|
| 1 | Peak Load Management | M | S | S |
| 2 | Smart Metering | M | M | S |
| 3 | Dynamic Tariff | N | S | M |
| 4 | Energy Audits | M | S | M |
| 5 | Power Factor Improvement | M | S | S |

S: Strongly; M: Moderately; N: Negligible or Not

overview of DSM programs in India, the UK and USA is given in Table 4 [65]. This paper presents case studies of implementing DSM and other SG functionalities in diverse sectors of India.

## 4.2 Experience with implementation of DSM: a case study

More than 30 countries around the world have started projects to implement smart grid technologies. For example, Thailand, Australia and Japan initiated DSM programs with an automatic tariff mechanism in 1993 [66]. Other examples are those of South Africa, Vietnam and China, which started programs to promote combined DSM and energy efficiency as part of long term power sector strategy [67]. The Ministry of Power (MoP), India has also started pilot projects under the National Smart Grid Mission (NSGM) [68] with the total estimated investment of Rs 3.73 billion. Table 5 gives a summary of the strategies adopted to implement smart grid functionalities in South Korea, Japan and India. Table 6 gives the brief description of SG pilot projects in India and the functionalities adopted in these such as outage management system (OMS), peak load management (PLM), power quality management (PQM), advanced metering infrastructure in the residential sector (AMI-R), advanced metering infrastructure in the industrial sector (AMI-I) and distributed generation (DG).

### 4.2.1 Case study of DSM implemented in the industrial sector

The smart grid pilot project at Ajmer Vidyut Vitran Nigam Ltd (AVVNL), India went operational on 1$^{st}$ October 2016. It demonstrated the benefits of smart grid functionalities in terms of improved operational efficiency and financial performance. AMI functionalities including automatic energy audit, loss reduction analytics and energy theft monitoring are selected for demonstration. This enabled AVVNL to regularly track system losses and initiate control measures, resulting in a reduction of aggregated transmission & commercial (AT&C) losses from 20% to 13.5%. It reduced the bill generation cycle from 14 days to 5 days. It also reduced the meter failure rate by 50%, transformer failure rate by 30% and outage time by 20%. The total cumulative benefits of 10 years considering tariff and demand growth is around INR 19.3 lakh per annum while the total cost of the pilot project was INR 67 lakh. A payback period of about 4 to 5 years is estimated for the investment made [69].

Another smart grid pilot project started in Darjeeling (India) by West Bengal State Electricity Distribution Company (WBSEDC) commenced in June 2015. It adopted smart grid functionalities such as advanced metering infrastructure (AMI) in industrial areas and peak load management through demand response. Average AT&C losses in WBSEDC for the period August 2014 - May 2015 (before SGPP) were 38.5%, falling to 16.5% for June 2015 - March 2016 (after SGPP). Monthly average AT&C losses for the period August 2014 - March 2016 are given in Table 7 [65].

### 4.2.2 Case study of DSM implemented in the agricultural sector

The agricultural sector in India accounts for 20-22% of total electricity consumption. There are an estimated 19 million pump-sets in the country and most are inefficient [70]. Energy savings in the agricultural sector of about 30 .. 40% are achievable by implementing energy efficient star labeled pump-sets. Agriculture DSM (AgDSM) was initiated in India for the first time during XI plan by Bureau of Energy Efficiency (BEE) [71] and is still being rolled out. The objectives of the AgDSM program are to reduce peak demand and total energy consumption in the agricultural sector [72].

Under this project, a total of 2209 pump-sets were replaced in Solapur, Maharashtra by energy efficient star rated units which reflected annual energy savings of approximately 6.1 million units. 590 pump-set units were replaced in Hubli Electricity Supply Company Limited (HESCOM) circle of Karnataka state at energy savings of 37% [73].

### 4.2.3 Case study of DSM implemented in the residential and commercial sector

Tata Power, Mumbai started an automatic meter reading (AMR) system in **2009**. Tata Power is the first company to start an AMR system in India for accurate measurement of energy consumption. In an au-

Table 5: Objectives and Strategies of Smart Grid Functionalities

| S. No. | Functionalities | Objectives | Strategies |
|---|---|---|---|
| 1 | Advanced Metering Infrastructure Residential (AMI-R) & Industrial (AMI-I) with Demand Response | Reduced AT&C losses | ToU/CPP tariff policy; Rate recovery for AMI investment |
| 2 | Peak Load Management (PLM) by Direct Load Control Technology | Optimal resource utilization, Distribution capacity enhancement, and Load curtailment | Remote connect/ disconnect |
| 3 | Power Quality Management (PQM) | Improved voltage control and reduced harmonics | Performance index dashboard via Intelligent Electronic Device; Penalty tariff for injecting harmonics |
| 4 | Outage Management System (OMS) | Improved reliability and Uninterrupted power supply | Employee incentives based on outage-based Key Performance Indicators (KPIs) |
| 5 | Distributed Generation (DG) | Improved power supply in rural areas, Integration of renewable sources, and reduced carbon emission | Feed-in tariff and remote disconnection for grid security |

tomated meter reading system, meter data is captured in a central server using GPRS. Power utilities can use this data to manage power distribution to avoid overloading and blackouts [24]. In **2013** one of the largest smart metering projects based on radio transmission was started in Mumbai. In this project about 5,000 meters were installed with built-in RF communication modules, data concentrator units (DCUs) and meter data acquisition (MDAS) for lower-end residential consumers. Meter data is collected every hour through RF mesh network communication, which is used for automated generation of bills without human involvement. This data also gives consumers insight into their usage of electricity in their homes and/or offices, thus empowering them to make informed decisions to reduce their power bills [52].

In **2017**, TATA Power announced the implementation of automatic demand response (ADR) with advanced metering infrastructure (AMI) for their smart meters project in Delhi. In this technology, meter data is integrated via a Meter Data Management System (MDMS), where consumer meter data is integrated with each site. The meter ID is used to associate the gateway with the meter data to determine the telemetry, baseline and calculated demand. Smart grid functionalities installed in distribution utilities in different countries resulted in the following benefits [66]; [67]; [70]; [72]:

- Reduction in AT&C losses
- Savings in peak power purchase cost
- Reduction in transformer failure rate
- Reduction in the number of outages
- Reduction in meter reading and payment collection cost
- Revenue increased through power quality measurements and power factor penalty.

## 4.3 Discussion

As can be seen in Table 6, the smart grid project at Telangana State Southern Power Distribution Company Ltd (TSSPDCL) and Maharashtra State Electricity Distribution Corporation Ltd (MSEDCL), Baramati was cancelled/ stopped due to the unavailability of bidders who can meet project expectations and funding requirements. It is also observed from Table 6 and Table 7 that implementation of advanced metering, time of use (TOU) tariff and DSM policies is limited to exclusively commercial and large industrial consumers, disregarding residential consumers [74]. This is because they collect a large portion of revenue from large-scale users. Revenue is one of the reasons for the limited implementation of DSM policies. Under the Electricity Act 2003 and Energy Conservation Act 2001 implementation of DSM is not mandatory for residential consumers in India.

The dynamic tariff mechanism is also absent in India. The traditional tariff plan does not reflect the difference between the costs of supplying electricity in peak hours and off-peak hours [75]. However, dynamic pric-

Table 6: Functionalities Adopted in Smart Grid Pilot Projects in India

| S. No. | Project Name / Distribution Company | Consumers under project | Status as on 30.03.19 | Technologies Adopted | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | AMI - R | AMI - I | OMS | PLM | PQM | DG |
| 1 | Uttar Haryana Bijli Vitran Nigam Ltd (UHBVN), Haryana | 11000 | Completed | * | * | * | | | |
| 2 | Himachal Pradesh State Electricity Board (HPSEB), Himachal Pradesh | 1550 | Completed | | * | * | * | * | |
| 3 | Chamundeshwari Electricity Supply Corporation (CESC), Karnataka | 24532 | Completed in June 2015 | * | * | | * | * | * |
| 4 | Assam Power Distribution Company Ltd (APDCL), Assam | 15000 | Under progress | | * | * | * | * | * |
| 5 | Punjab State Power Corporation Ltd (PSPCL), Punjab | 2737 | Under progress | | * | | * | | |
| 6 | Tripura State Electricity Corporation Ltd (TSECL), Tripura | 45290 | Delayed, started on 14.01.19 | * | * | | * | | |
| 7 | Telangana State Southern Power Distribution Company Ltd (TSSPDCL), Telangana | 11904 | Stopped | | * | * | * | * | * |
| 8 | Puducherry Electricity Department (PED), Pududcherry | 34000 | Resumed on 28.12.18 | * | * | | | | |
| 9 | Uttar Gujarat Vij Company Ltd (UGVCL), Gujarat | 22,230 | Sanctioned on 27.02.19 | * | * | * | * | | |
| 10 | West Bengal State Electricity Distribution Company (WBSEDCL), West Bengal | 5265 | Resumed on 31.12.18 | | * | | * | | |
| 11 | Ajmer Vidyut Vitran Nigam Ltd (AVVNL), Ajmer | 1000 | Completed | * | * | | * | | * |
| 12 | Chandigarh Electricity Department (CED), Chandigarh | 29433 | Under progress | | * | | * | | * |
| 13 | Maharashtra State Electricity Distribution Corporation Ltd (MSEDCL), Baramati | 1,48,000 | Cancelled | * | | | * | | |
| 14 | Maharashtra State Electricity Distribution Corporation Ltd (MSEDCL), Nagpur | 1,25,000 | Under progress | * | * | * | * | | |
| 15 | Kerala State Electricity Board (KSEB), Kochi City, Kerala | 2200 | Sanctioned on 28.09.18 | | * | | | | |
| 16 | AMI Project, TATA Power Mumbai | 5000 | Under progress | * | * | | | | |

Table 7: Aggregated Transmission & Commercial Losses Accounted by WBSEDC

| Before implementing DSM | After implementing DSM | | |
|---|---|---|---|
| Aug, 2014 | 47.40% | June, 2015 | 15.30% |
| Sep, 2014 | 43.50% | July, 2015 | 18.60% |
| Oct, 2014 | 21.50% | Aug, 2015 | 19.20% |
| Nov, 2014 | 45.90% | Sep, 2015 | 13.00% |
| Dec, 2014 | 38.60% | Oct, 2015 | 12.40% |
| Jan, 2015 | 41.90% | Nov, 2015 | 12.90% |
| Feb, 2015 | 31.60% | Dec, 2015 | 15.70% |
| Mar, 2015 | 35.70% | Jan, 2016 | 19.20% |
| Apr, 2015 | 39.20% | Feb, 2016 | 19.70% |
| May, 2015 | 38.10% | Mar, 2016 | 14.40% |

ing options such as time of use (TOU), critical peak pricing (CPP), critical peak rebate (CPR), real time pricing (RTP), and variable peak pricing (VPP) can reflect the time-varying cost of electricity supply [76]. A transparent dynamic pricing scheme can also be implemented in support of AMI with a cost benefit analysis.

### 4.4 Challenges in implementation of DSM

This paper presents a broad-based study of policies developed and action taken by various countries for the implementation of DSM programs. Challenges in the implementation of DSM in developing countries can be divided into two categories: technical challenges and socio-economic challenges [77]. Major technical challenges in the implementation of the Integrated Power Development Program (IPDP) are: infrastructure inadequacy, cyber security, battery technology (raw material inadequacy and short life span) and delays in collection of data and data management [78]. In addition to technical and socio-economic challenges, the policies adopted are insufficient to address economic incentives and shortages of skilled manpower and moreover lack funding [79].

The following immediate actions are required for rapid development of DSM:

- Development of policies and regulations for advanced metering and cyber security.
- Development of technical standards for interoperability and integration of various functionalities of smart grid technology.
- Selecting from the multiple options of communication available e.g. GPRS, CDMA, Zigbee, SubGig, RFand etc. A specific policy is required to decide which option is appropriate for which category of consumers or geographical area.
- Appropriate tariff revision is required for prosumers, like feed-in-tariff.
- Required specification of low cost smart meters, because the cost of smart meters is to be paid by consumers in India.

### 4.5 Possible solutions and future research

The current practice to manage the energy discrepancy is load shedding for different feeders on a rotational basis i.e. rolling blackout. Some possible solutions can be suggested to improve reliability, such as the implementation of '**brownout**' in place of '**blackout**' as part of demand response. 'Brownout' is referred to as selective load control at the premises of consumers, connected to a particular feeder during peak load conditions. With the brownout strategy, residential consumers can be facilitated by providing minimum lifeline supply through smart meters for their basic requirements of lighting, fans, television, etc.

DSM can be applied in a wider range by envisaging real time pricing schemes [80]; [81]. Participation in new tariff schemes may be offered to consumers with an undertaking that, everything else being equal, future bills will not exceed the amount payable as per the current tariff plan.

Countries like United States, China, Russia, Japan, India, and Canada have started international collaborative research projects on market transformation [82]. Some potential research areas in the development of smart grid technology include:

- Network platform that can support multiple applications like AMI, distribution automation (DA), automated demand response (ADR), and distributed energy resources (DER).
- Advancement of battery storage systems.
- Development and implementation of integrated DSM schemes.
- Management and processing of large volumes of data.
- Energy savings by micro demand response (MDR).

## 5 Conclusion

This paper traces the emergence of demand side management and identified related challenges, issues and research activities. Possible solutions and actions required for the development of DSM are given. It also discusses policies and pilot projects to implement demand side management. It highlights that any plan must be adaptable to the unique needs and resource constraints of consumers from different regions, cultures and states. A key error to avoid at this early stage of implementing smart grid technology is to adopt a rigid 'one size fits all' approach. In respect of India, the development and appropriate implementation of smart grid technologies could provide a green and optimal solution to national energy needs. Adequate thought must be given to the practicalities of overcoming foreseeable hurdles and challenges associated with the implementation of smart grid technology.

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