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Smart operations of smart grids integrated with distributed generation: A review

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ABSTRACT

In last few years, many countries in the world have shown huge interest in smart grid technology. They are facing many challenges in the process of deployment of this technology at ground level. Hence a planned research is required to meet those challenges within time. This paper provides a detailed description of progress in the field of demand side management, demand response programs, distributed generation, technical issues in the way of their progress and key advantages, which will be received after the final deployment of these programs. Renewable energy resources are also becoming a main part of distributed generation, which provides a solution for environmental problems caused by conventional power plants. Few countries are working on the deployment of the advanced metering system. Along with this, the scope of research in various programs of smart grid technology has been explored.

1. Introduction

Keeping in view today's consumer expectations and environmental concerns, it is necessary for the utilities to reduce the electricity bills of the consumers and to interconnect the green energy generation with the conventional energy generation at a large scale. Along with this, it is well known that day to day increasing demand is overloading the current electrical grids and conventional solution techniques are increasing the complexity of existing networks. These critical issues made the researchers to think about smart grid as an overall and better solution. To meet the distribution side consumer's expectations such as reduction in electricity bill, increasing comfort level, data security and reliability etc.; detailed study of smart grid components like demand side management, demand response, distributed generation, smart devices is required. Some technologies of the smart grid give direct exposure to the consumers thereby enabling them to check the current electricity price and in the response of the real-time price they are able to control their load. Thus the smart grid technology facilitates load shedding during the peak load time, as the price increases during the peak loads [1]. It can also make aware the consumers to reduce the electricity consumption. Some of the interfaces of smart grid technology are beyond the consumer's reach. Such interfaces are handled by the utilities for the sake of proper operation of the grid. Here proper operation means to maintain the balance in supply and demand. In the conventional power grids, with the integration of renewable generation, it is difficult to apply load following strategy [2]. Intermittent renewable energy resources like solar and wind generation can't be forecast with certainty [3]. Both solar and wind generation profile largely depend on weather conditions. These uncertainties create a problem in the calculation of bids necessary to take part in the day ahead unit commitment process. In [4], this problem is solved by using fuzzy optimization technique to limit the risk of uncertainty. In [5], the necessity of demand response programs and storage devices at a microgrid scale to overcome the problem of intermittency of wind and solar power generation is examined. Hence, as a solution to incorporate renewable energy resources (RERs) in the current power system, strategy of direct load control with the help of information technology can be used.

The remaining paper is organized as follows: motivation and objectives of the review are included in section 2. Smart grid technology and its role in the present electricity networks are discussed in section 3. Demand side management of electricity and its benefits for the consumers are discussed in section 4. Demand response, distributed generation and smart devices are discussed in detail in section 5, sections 6 and 7 respectively. Key points of the paper and observations from the review are included in section 8. The paper conclude in section 9.

2. Motivation and objective of the review

The review presented is inspired by the issue of continually increasing demand and price of electricity at the consumer end,

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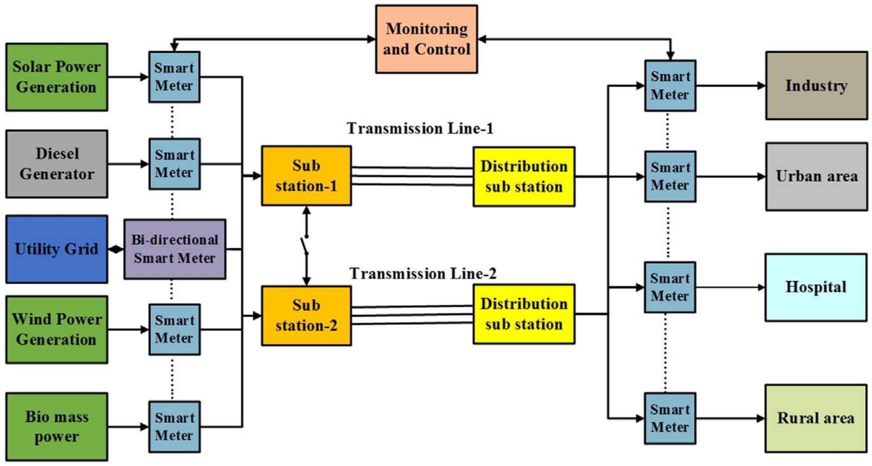

Fig. 1. Smart Grid model.

shortage of conventional energy sources, environmental problems caused by fossil fuel based energy generation plants and the issues related to the integration of renewable energy resources in the existing grid architecture. The objective of the review is to discuss in detail about the various smart grid components, their continuous development, technical challenges faced during their development, outcomes achieved and to find out the research scope in these areas.

3. Smart grid technology

A technology which is developed to maximize the benefits of utilities and its consumers and to provide the economic and reliable electricity services by efficiently using the available sources and smart tools is called smart grid technology. A smart grid is an intelligent network, which combines information technology with the current power system network [6]. Hence, it is possible for utilities to collect various electrical information from the electrical network using intelligent sensors and fast communication system which helps in balancing demand and supply [7]. A model of a smart grid is shown in Fig. 1.

The potential of smart grid network is very high as power grid is becoming complex and overloaded day by day. The infrastructure is getting old to support current energy requirement [8]. Demand during peak load hours is generally more than the supply from the grids. It causes power cuts, which is really a subject of worry. Power grids have different problems at different levels say generation, transmission and distribution [9]. Today, most of the power plants are using fossil fuel for the electricity generation. Therefore, environmental and economic challenges are also present in the power grids [10,11]. Authors in [12] have analyzed the economic and environmental impact of smart grid in detail. They presented their findings on the variation of cost estimation in this area. According to the author's findings, the definition of a smart grid is not still clear in the research papers in various journals. They found a common part in most of the definitions which help to get a clear definition of smart grid. The common part is application of digital processing and communication to the grid, making continuous data flow and information management control to the smart grid. They also found that if the analysis gap of the uncertainties related to estimates of environmental impacts and cost can be reduced, then more accurate results can be achieved. Coordination of latest technology with advance equipments converts a power grid to a smart grid. Smart grid technology is considered the best solution for the various problems of the power grids [13,14]. Smart grids enhance the use of renewable energy giving a solution to the environmental problems caused by electrical power plants [15,16]. The development process of smart grid technology has been discussed in [17]. This technology ensures high energy efficiency, continuity in energy flow, security and stability of the power system [17–21]. Various models are proposed for smart grids and the most suitable and reliable model is selected for the advancement of the power network [22]. Smart grid technology enhances the automation of distribution network, which is necessary to ensure the balance in supply and demand [23]. This contribution of smart grids helps in load shedding during peak load hours and results in an efficient electrical network. Thus, smart grid technology is the technology developed to meet the current energy expectations of the world efficiently and economically. Implementation of smart grid technology is also not an easy task. There are many challenges which occur during implementation. Authors in [24] presented some critical challenges in smart grid. Various issues related to measurement, sensing, information and communication technology, control and automation technologies, energy storage, power electronics have been discussed and a solution has been proposed. This paper has been also discussed about smart grid projects in Europe.

4. Demand side management

Every utility wants to avoid extra expenditure by installing more capacity to meet the daily increasing electricity demand. One way to achieve this goal is to use existing energy efficiently. Hence, utilities implement demand side management (DSM) programs to manage the energy consumption of the consumers [25]. So the main aims of DSM implementation can be listed as, to reduce the cost of electricity by managing energy consumption, social and environmental improvement, to increase reliability and to reduce the network issues. Energy management steps at different level of the power system are shown in Fig. 2.

DSM programs include different strategies such as demand response strategy, consumers (residential or commercial) load management strategy, energy efficiency strategy [26–28]. In the consumer load management strategy (mainly for the residential consumers) utility aims to reduce the consumption of electricity and to shift the peak hours demand to off peak hours [29]. Different load shape techniques can be seen in Fig. 3.

Consumption of electricity can be reduced by directly controlling the load by utility. When utility apply this approach to a residential consumer, there is always a concern of user's privacy. This acts as a barrier in implementation of this approach [31–35]. Other barriers in the way of implementing DSM programs are listed in [36]. These barriers can be omitted by using an alternative approach for consumer load control. In this approach, utility does not force a consumer to cut the load, rather it gives them options to reduce their electricity bill by managing their demand at different time of the day [37–39]. Utility uses changing price approach based on demand variation. It regularly conveys the electricity price information to the consumer through

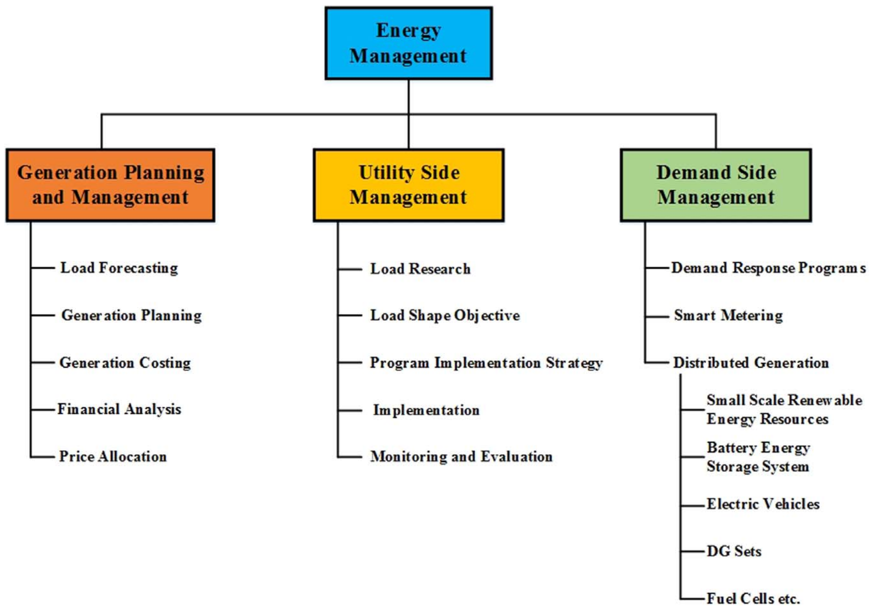

Fig. 2. Energy management steps at different levels.

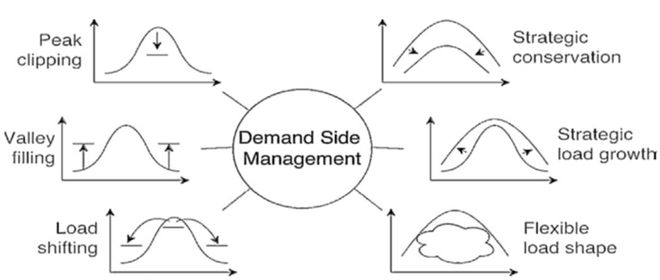

Fig. 3. Load shaping techniques [30].

smart devices and the consumer manages their load in response of the price. Thus the consumers are now connected with utility through two way communication networks [40–44]. This converts conventional demand side management to a smart demand side management. DSM helps in energy conservation by ensuring efficient use of electricity at the distribution end [45–49]. Authors in [50] have explained the application of artificial neural network (ANN) and DSM in industrial peak load management. In [51] authors examined the impact of grid component outage using simulation and the effect to DSM in such case. Home energy management (HEM) system combined with smart pricing schemes also forms a part of demand side management and contribute to the efficient use of electricity [52]. In [53] dynamic pricing is combined with small scale renewable energy resources and electric vehicle, to form a HEM system. Mixed integer linear programming is used to solve the framed problem and satisfactory results for HEM have been achieved. Energy management and related work is classified in Fig. 4.

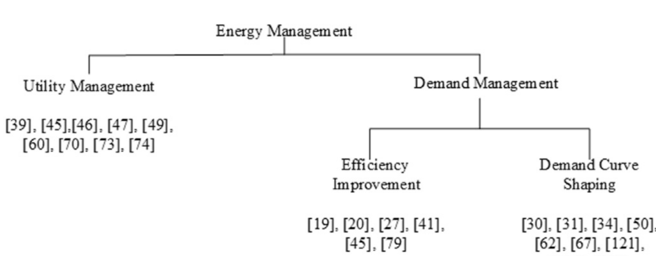

Fig. 4. Energy management and related work.

4.1. Benefits and Improving steps for DSM

By implementing DSM many benefits are expected at society level, consumers level and utilities level, such as, decrement in the requirement of new electricity generation plants, transmission and distribution networks, reduction in the amount of customers' electricity bills, decrement in peak electricity prices, increment in competitiveness of local distributers, decrement in environmental pollution, awareness to the new technologies and innovations, increment in the jobs in the market, increment in energy security, improvement in operating efficiency and flexibility etc.

To meet the expected aims of DSM and to receive the benefits of DSM, following improving steps for DSM are required:-

- *Political willingness:-* This is necessary for the political society to have a strong will to improve DSM programs to meet the increasing energy demand. These political steps increase the faith of industry and people, which of course helps in achieving the targets set during the implementation of DSM programs.
- *Regulations framework:-* Regulations are necessary for the execution of any task in a right way and within the time. Proper regulation formulation will always lead to better DSM programs.
- *Goal setup:-* In the implementation process of DSM programs, long term goals must be set up, which must have country wide impact. For the proper deployment of various DSM strategies, a perfect planning is also required. There must be proper arrangement for feedback and review of the implemented programs to achieve all the goals successfully.
- *Funding for DSM programs:-* To set up a large project or to improve the performance of any project, funds in enough quantity are very essential. To ensure the reliability and security of DSM programs in various sectors like residential, commercial, industrial etc., a big investment plays a very important role.
- *Private participation:-* In various countries, electricity is distributed by private companies. So for the implementation and success of DSM programs, private companies' participation can play a big role. For their participation, proper rules and regulations must be framed so that they may receive profit, while implementing energy efficient programs.
- *Training and skill development:-* Trained and skilled persons are back bone for the successful implementation and execution of DSM programs. Group of skilled persons always make it easy to achieve the set goals within time.

5. Demand response

Demand response is a very essential part of smart grid technology. For many years, demand response was just a peak clipping approach for specific hours of a year. Later on, definition was modified as change in electricity usage of end-use consumers from their normal consumption pattern in response to changes in the price of electricity over the time [54].

In traditional power system, consumers do not have idea of efficient consumption of their loads and they do not receive any incentive for change in their load pattern [55]. In such situations utility can only manage supply side resources to maintain a balance in demand and supply. In current demand response environment, generally three type of consumers exist. Few consumers change their electricity usage during peak load hours only. They do not change their energy consumption pattern for rest of the time. Some consumers shift their peak load to off peak hours in response of high price during peak load hours. Other consumers do not compromise with their energy consumption pattern during all conditions of the load variation. Such consumers fulfill their energy demand during high price peak load hours by consuming energy generated by local generation plants and maintain their energy requirement during peak load hours. In such way, utility total load is reduced by the consumer's participation. There are different DR programs such as incentive based programs (IBP) and price based programs (PBP). In IBPs, consumers allow the utility to control their loads during peak hours, congestion or any other emergency in the system and receive benefits in terms of incentives. In PBPs, consumers change their demand in response to price change of electricity. In these programs consumers have full control on their loads. By reducing their load during high price time, consumers reduce their electricity bills and get benefited [56,57]. Fig. 5 shows the classification of different DR programs.

Demand response programs have the capability to change the load profile of consumers. In [66] authors found a great impact of DR on load profile and voltage profile. They concluded that DR has potential to achieve a more reliable power system with balanced voltage and load profile. In [67], time varying electricity rate plans were used with automated energy management system to re-shape the electricity demand peaks. In [68] authors have formulated the shiftable load in a new way so that they can be locally controlled or can be controlled by direct method. It helps in reducing the number of optimization variables by which result is achieved in lesser time. Load forecasting methods in presence of demand response by considering active demand are presented in [69]. In [70] authors examined two type of models of consumers. First, price responsive uncontrolled load model is presented and worked upon by local distribution company. In second model a controlled load model is presented and it is found that second model gives more stable system load profile. Electric vehicle also affects the load profile when used in a distribution network under DR programs [71]. A controller is designed in [72] to schedule the operation of air conditioner with real time temperature and real time price and optimum schedule of air conditioner is successfully achieved.

Demand response programs have a big effect on cost of electricity. In [73], cost of electricity to the user is reduced using game theory by considering a game in the selection of different electrical sources such as fossil fuel sources, renewable energy sources. In [74] stackelberg game between electricity provider and users is established to maximize the profit of provider and welfare of the user. In [75] a modified PSO technique is used to minimize the operational cost of power player who manages all distributed generation resources scheduling in demand response environment. Variability of renewable energy resources can be managed by hourly demand response [76]. To support the demand response programs, storage capacity available in distribution network plays a very important role. This can be used as an additional helpful tool to achieve optimality between energy price and network congestion [77]. DR programs also help in maximization of capacity utilization of existing network. To check reliability of such system Sequential Monte Carlo Simulations (SMCS) are used in [78]. By implementing DR programs, benefits of individuals can be maximized. This has been shown in [79] by proposing interaction strategy between smart household and distribution service operator (DSO). Thus with number of benefits, DR programs are converting a grid into a smart grid and are encouraging the consumers to participate in electricity market. Different energy management tools used in the papers are shown in Fig. 6.

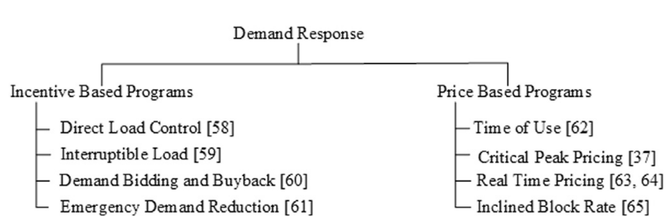

Fig. 5. Demand response programs in Smart Grid [58–65].

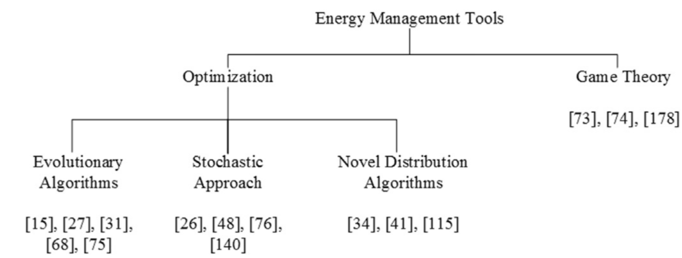

Fig. 6. Energy management tools.

5.1. Benefits and challenges

There are large numbers of other benefits provided by demand response such as reducing network congestion, reducing the risk of black-outs, reducing risk of system security, reducing greenhouse gas emission, improving market economic efficiency, saving the cost of addition of new generation by providing maximum use of existing generation etc. [80].

Implementation of DR program is also not an easy task. In [81] various barriers in the implantation of DR have been discussed in details which include distribution system operator remuneration, tariff regulation, market role, market entry, consumer protection and standardization. Other challenges are inclusion of latest technology, integration of distributed energy resources (DERs), planning and implementation of energy storage, interfacing with transmission system, natural disaster etc. [82]. An idea to absorb fluctuations in demand response is proposed in [83] by the integration of nanogrids at household level. Thus integration of small scale generation at distribution end can lead to the reduction of few barriers coming in the way of demand response programs.

6. Distributed generation

Major part of the total electricity demand in every country of the world is fulfilled by electricity generated by conventional power plants. These plants use coal, gas, diesel, water etc. as fuel or input to run the turbines. All fossil fuel based plants emit very dangerous gases in the environment which causes many deceases in the human beings, animals and in plants. Global warming issue is also a matter of concern which is also raised by these power plants. Another big problem is the limited quantity of fossil fuels on the earth. The formation rate of fossil fuel is very less than the consumption rate. So at present we are left with a less amount of fossil fuel which can fulfill our requirement for few decades. In [84], authors explained the difficulties in the expansion of traditional power generation and distribution system in various developing countries to meet the future electricity demand at reasonable cost.

The development of technology in the field of DERs and deployment of power electronics based devices has given rise the power generation economy towards smaller scale. Hence, it has become necessary to think about DERs as alternate energy sources. Some other motivating factors towards the DERs are increase in distributed generation, reduction of cost and minimization of outage problems etc.

The concept of integrating DERs started in the year of 1999. In [85], authors represented the review of the facilities for integrated DERs. During the initial surveys, resources and facilities for the testing of distributed generation and storage system were identified. In distributed generation, integrated small nonconventional energy resources can be used to generate the electricity at load end. This technology increases system security, reliability, efficiency and power quality, however operating cost and impact on environment decreases [86]. Geographical location and environmental conditions of different countries are favorable for the use of renewable energy resources. This encourages the integration of low capacity RERs to give the desirable outcomes of distributed generation technology with a solution method to decrease the load congestion on the traditional power system [87]. DERs can be used to aid utilities by fulfilling its fundamental requirement to operate in parallel with the utility and to supply sensitive loads during disturbance in power system like momentary voltage sag caused by line faults. DERs are active devices installed in distribution network instead of transmission network [88]. Dynamic active and reactive power control, load side control are also provided in power system networks integrated with DERs [89].

Report of failure of a modern grid of North America in 2003 due to inability of existing electrical capacity to provide for growing electrical loads with enough reliability was discussed in [90]. This failure gave a boost in the advancement of distributed energy generation. Expansion of role of distributed generation in centralized grid is explained in [91]. Authors in [92,93] has presented a hierarchical framework with both AC and DC links to implement distributed generation.

Proper integration of DERs in the neighborhood of distribution network is important [94]. The correct integration of DERs depends on the versatile characteristics of distributed generation like wind power, PV system, tidal, small hydro turbines, biogas, geothermal etc. which have the ability to support conventional power system [95]. Research on integration of DERs in Europe is reviewed in [96]. Thermal generators operation with distribution generators like wind generators, PV generators, battery storage units is examined in distribution network having smart houses on demand side [97]. In the presence of electric vehicle in above distribution network, generation cost of smart grid also reduces. Distributed energy resources have very high impact on the way of consumer's electricity utilization which tends to become flexible according to the provisions provided by the utilities. For detail talk about distributed generation, microgrid, role of RERs and energy storage devices in electrical network are discussed in the subsections below.

6.1. Concept of microgrid

The integration of renewable energy resources with the small sources having storage facility leads to the concept of microgrid [98–101]. In the technical literature, the concept of microgrid was first presented in [102–104]. They gave a solution for the reliable integration of DERs, including Energy Storage Systems (ESSs) and controllable, sensitive loads. During the advancement of microgrid concept, it was necessary to verify the feasibility of distributed energy resources within the industrial environment where large numbers of induction machines are connected as load [105]. To obtain power flow, voltage profile and system losses in different cases were analyzed by performing steady state analysis.

To meet different electrical loads at customer level, cost minimization approach for distributed energy resources has been discussed in [106]. Customers' range of microgrid may extend from household customers to restaurants, office buildings, shopping malls etc. [107]. A microgrid model based on mini gas turbine generation system was first time explained in [108]. They proved the supply from this gas based microgrid model was efficient for residential and commercial customers with high load factors.

Need of power electronics in the development of microgrid and distributed generation is explained in [109,110]. They discussed the issue of voltage control, power flow balancing etc. Authors revealed the way of realization of power electronics based control. To provide the required flexibility in microgrid control, plug-and-play functionality can be implemented using inverters [111]. Results of ongoing research on development of high power electronic systems for distributed generation system based on the consortium for electric reliability technology solutions (CERTS) executive summary report were presented in [112]. They presented Bricks & Buses framework for the realization of convertors. 'Brick' or 'modular component' helps in the formation of ant practical convertor topology and connecting architecture is provided by the Buses to interconnect the Bricks.

Microgrid controlling methods have been explained in many papers. Desirable features of control system of microgrid are, output voltage and current control of various DER units, ability to balance the power, ability to implement DSM strategies, economic dispatch of DER units and ability to work in both stand-alone and grid connected modes of operation [113]. In [114] a distributed voltage control scheme is proposed to solve the reactive power sharing problem in autonomous inverter based microgrids. This control method gives guarantee of desired reactive power distribution and at the same time it does not require central computing and communication units. In [115,116] authors presented droop control method for microgrid control. In [117] authors proposed a new power control scheme which is based on hybrid distributed network to get improvement in microgrid dynamic performance, high reliability and robustness on the event of network failure. In [118] a model predictive control approach is presented for the efficient optimization of microgrid and for the solution of problem formulated, mixed integer linear programming (MILP) is used.

6.2. Role of renewable energy resources and energy storage devices

To deploy environment friendly and cost effective technologies, integration of RERs in distribution networks can play a major role to supply power. The need of RERs is explained on the basis of lack of adequate reserves of fossil fuel. From 2006, integration of RERs has increased to a great extent. Technology to integrate RERs should be robust, economic and environment friendly [119]. In [120,121], integration of RERs and electric vehicle is discussed and a control strategy to control the operation of electric vehicle and electricity consumption of household appliance is proposed. MILP is used to achieve the optimality of problem taken [120]. In [122], approach for integration of RERs with the power grid has been explained. In [123], various available renewable energy resources have been investigated and an optimal combination has been found aiming to reduce the annual energy losses. Distributed generation, based on renewable energy resources is non-dispatchable because of the variable nature of RERs generation availability across different time scales, which make it difficult to get the accurate idea of future RERs generation [124]. But large numbers of advantages of RERs make them important to use in distributed networks.

High penetration of distributed energy resources not only brings many benefits but also creates number of operational issues like power quality, reliability, generation dispatch, protection etc. [125–127]. Authors in [128] have included various protection strategies for grid connected only and mircogrid operations. They explained the requirement of new protection schemes for the new microgrid based system.

In [129], protection techniques for centralized and distributed system have been proposed. Techniques and problems of islanding in the grid connected with renewable energy based distributed generators have been discussed in detail in [130]. Speed and accuracy of various techniques have been compared. Various software tools helpful in islanding study have also been discussed with their operational limitations. Power balancing issues can appear in a grid integrated with RERs, storage and flexible loads. In [131], a distribution implementation algorithm is provided for power balancing problem of integrated system. This algorithm provides fast convergence rate and hence computation, communication burdens are reduced. In [132], dynamics of system is analyzed with and without penetration of PV. Different penetration levels are imposed to check the changes in dynamics of the system. It is found that major overvoltage problem occurs at 20% penetration level in such system. Proper control method for the operation of network having RERs reduces the challenges at some extent. A cooperative control strategy is proposed in [133] to make a distributed control network. A multi-function control scheme is proposed in [134] for stable and reliable operation of DG units. This control model is developed using Lyapunov control theory to provide a stable region of operation. Importance of real time information exchange for the proper operation of networks having RERs is discussed in [135]. In this paper a demand side management scheme is proposed for smooth operation of smart grid. Operational cost is also affected by the control scheme. In [136], operational cost is reduced by using an intelligent control scheme, in which battery scheduling process is improved by using fuzzy logic system. For the real time management, unit size must be selected precisely. Some researchers have done work for optimal unit sizing using intelligent control in a hybrid energy system [137–141]. In [142,143], authors have presented some work on real time management of power system using multi-objective optimization. The classification of various energy sources and related work is shown in Fig. 7.

Authors in [144,145] have determined that with the high penetration of renewable energy generation and for the proper operation of the grid energy storage is required. Different energy storage techniques such as compressed air energy storage, fly wheel energy storage, pumped hydro energy storage, different kind of battery energy storage, flow battery energy storage, superconducting magnetic energy storage, super capacitor energy storage, chemical energy storage, thermal energy storage have been discussed in [146]. In [147], various energy policies related to mechanical, thermal and electrochemical energy storage technologies have been discussed in detail. Authors also included the regulatory discussions which took place during United Nations conference on Sustainable Development Goals (SDG). This paper also provides the factors helpful in deciding a suitable storage technology for a particular application. Historical progress of energy storage technology, its application and challenges have been explored in [148,149]. Authors in [150,151] discussed the old research and ongoing development in the area of energy storage technology. The problems and importance associated with the integration of energy storage devices in the system have been also discussed. Other issues related to RERs integration and need of storage devices for reliable operation of power system have been discussed in [152]. In recent research, various applications and methods of charging and discharging of battery energy storage system have been proposed. Excess energy is stored in battery when renewable energy source output exceeds a threshold and battery discharges to the grid when the load demand is increased [153–157]. In [158], a fuzzy logic based strategy is used to make stored energy balance in the system. Some authors have investigated the idea of power dispatch with renewable energy resources [159–161]. In rural areas, the scope of renewable energy resources and energy storage system is explicated by Smith et al. [162].

6.3. Challenges

With inclusion of new technology many new challenges arise. Large number of challenges in distributed networks, such as small potential size of DERs models, low load factors, desired contract structure, integration of DERs, demand response, energy storage etc., rise the necessity of smart operations in the distribution networks. Technical issues for DERs integration are briefly reviewed in [163]. They explained the issues related to steady state and short circuit current constraints, active and reactive power, voltage profile, power quality, stability, protection aspects and system safety. In [164], integration impact of renewable energy resources on the smart grid is examined. In [165], analysis of issues related to integration of RERs for 10 year span starting from 2011 has been explained. Authors in [166] explained the challenges with large penetration of RERs. The key issues under there challenges are transmission system issues, distribution system issues, operational issues, interconnection standards, forecasting, scheduling privacy and security. Due to increased penetration of RERs, mainly at the distribution level, challenges related to voltage regulation and frequency stability arise. This problem can be solved by proper energy management in the power system. Researchers have done survey on the integrated renewable energy resources and presented programs for the solution of frequency regulation problems [167–169]. Various other challenges appear while controlling methods are employed for microgrid control, as discussed in [113]. These challenges include bidirectional power flow, stability issues, modeling related issues, issues with low inertia of microgrid units, issues of uncertainty of load profile and weather forecast. Some important references with their objective and work are shown in Table 1.

7. Smart devices

Most important tools for the demand side load optimization are smart devices. These smart devices covers smart meters, smart control of the loads etc. In [170], need of smart metering and communication is discussed in detail. Their advantages and need of improvement have

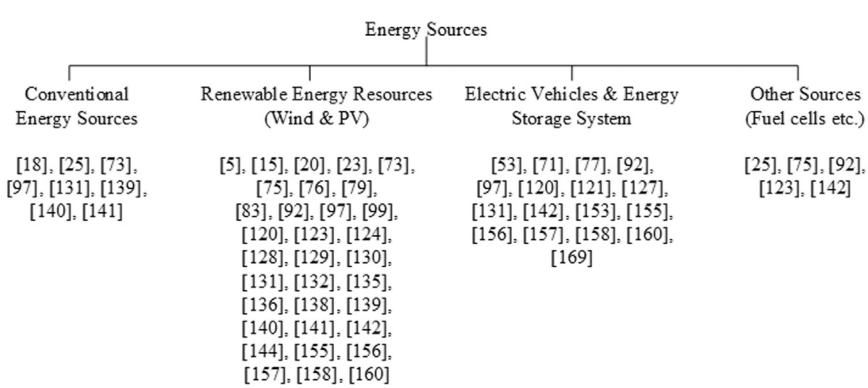

Fig. 7. Classification of energy sources and related work.

Table 1
A summary of few papers with their main objective and work.

Key Ref.	Main objective	Approach	Work explanation
[26,31,32,34]	Demand side management (DSM) by direct load control	Monte-Carlo based programming, Evolutionary algorithm, Least enthalpy estimator (LEE), Linear programming based algorithm	Optimization of consumer discomfort along with general load management issues like cost minimization, energy efficiency improvement, load reduction have been solved.
[27]	Scheduling of demand side resources	Binary particle swarm optimization (BPSO)	Minimization of numbers of interruptions under the limit of various constraints is achieved in this paper.
[38]	Dynamic pricing of electricity	Stochastic programming	A new retail tariff structure is proposed keeping in view the present open market situations.
[41]	Demand side management by real time pricing	A novel real time distributed algorithm,	Utility maximization and cost minimization is achieved by the use of distributed algorithm.
[50]	Peak load management	Artificial neural network (ANN) and DSM	By applying ANN controller and DSM techniques in an industry, energy management is achieved by peak load management.
[52]	Energy management	Home appliance co-ordination scheme energy management (HACSEM) algorithm	Optimum energy consumption is achieved by the appliances co-ordination in home energy management (HEM) system.
[66]	Cost and active losses reduction	A novel distribution system operator (DSO) dynamic tariff based co-ordination strategy	Individual's benefits have been maximized by providing interactive strategy between smart households and DSO.
[68]	Load management	Extensive glowworm swarm particle optimization	A local and direct control strategy is proposed for shift-able load management.
[72]	Energy cost minimization	Air conditioner controller design and implementation	Air conditioner operation is scheduled with help of designed controller to reduce the electricity bills of consumers
[86]	Location and size of distribution generation	Primal dual interior point (PDIP) algorithm	Solution for optimum location and size of distributed generation is achieved and it has been observed that system efficiency is increased, voltage profile is improved and line losses are reduced.
[93]	Integration of DERs	Micro source local controller (MSLC) Combo-source inverter controller (CSIC) Microgrid coordinating controller (MGCC)	Separate controlling of DC and AC zones has been done to integrate the DERs in microgrid paradigm.
[120]	Microgrid reliability, stability and cost effectiveness	MILP	Optimal scheduling of microgrid has been done and other objectives have been successfully achieved.
[123]	Energy loss minimization	Mixed integer non-linear programming (MINLP)	Different type of distribution generation units has been optimally analyzed to minimize the energy losses.
[135]	Household energy management	Bottom up approach	Optimum cost solution is achieved by applying bottom up approach to hourly load profiles.
[136]	Intelligent energy management	Fuzzy logic along with linear programming based optimization	Operation cost of microgrid has been reduced by improving the battery scheduling process.
[159]	Production cost minimization	Model predictive control (MPC)	With 5-type generations a 12-bus system has been analyzed to reduce the production cost of energy by using MPC.
[168]	Operating cost minimization	Multi-objective optimization (MO) method	With the application of MO on microgrid having different generation units, the operating cost has been successfully reduced.
[179]	Consumer energy management	Supervisory control and data acquisition (SCADA) and programmable logic controller (PLC) implementation	A consumer energy management system with smart meter has been achieved by providing control scheme using SCADA and PLC controllers.

been explained. Various issues like information security and sustainability have been also discussed. Many countries have already started smart meter deployment to develop a link of communication between utilities and consumers [171]. This communication helps the consumers in making decision to control their loads and helps the utilities to send the information of current price of the electricity on pre-determined time schedule to consumers, to watch the load variations of the consumers, to apply fast safety measures in case of any problem at any point [172,173]. During the peak load hours utility aims to cut down unnecessary load of consumer, not by force but by choice of the consumer. To achieve this aim, utility provide hourly price of electricity to its consumers. Price of electricity during peak load hours is generally higher. So if it is possible to shift the load to some other time then consumers do not use that load during peak load hours and it is shifted to off peak load hours. To apply this, it is necessary to get data from individual load at house. To get this data an explicit-duration hidden Markov model with differential observations is proposed in [174]. For proper microgrid scheduling, smart meter data is used in [175]. Similarly smart devices play an important role in demand side management. It is necessary to use advance measurement and control system to be a smart utility to get efficient smart system [176]. A home load management system can perform a big role to achieve coordinated demand response. It can be embedded in consumers' smart meter [177]. A distribution algorithm is proposed in [178] which can applied on smart meter operation to optimize the production and storage schemes for demand side management. In [179], a combined control scheme using Supervisory Control and Data Acquisition (SCADA) System, Programmable Logic controllers (PLC) and smart meter is proposed for consumer energy management. A simple advance metering system is shown in Fig. 8.

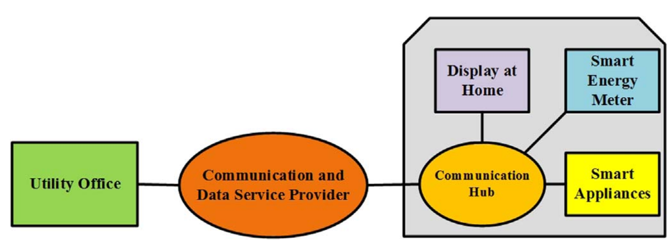

Fig. 8. Advance metering system.

Air conditioners share nearly 20% of the total residential load [180]. Refrigerator is also a high electricity consuming load. Smart controllers and smart methodologies can be used to control these loads. In [181] authors have investigated min-max fairness and proportional fairness control mechanism for air conditioner control. In [182] authors have produced a device for load management for refrigerator which is based on consumer habits. They analyzed the data related to load offset during the peak load periods and completed their aim of energy saving during peak load hours. Thus with the use of smart devices a network approaches towards a smart

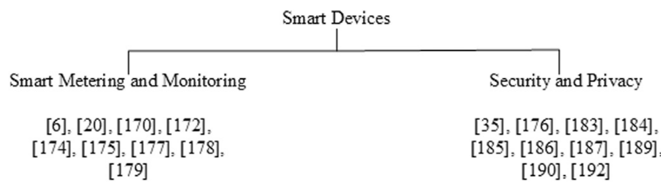

Fig. 9. Classification of the work related to smart devices.

network at demand side. The classification of the work related to smart devices is shown in Fig. 9.

Main concerns in the deployment process of smart meters are cost and outcomes. In a report of European Commission, following data has been presented in Figs. 10 and 11, regarding key benefits and main cost for the deployment of smart meter system in Europe.

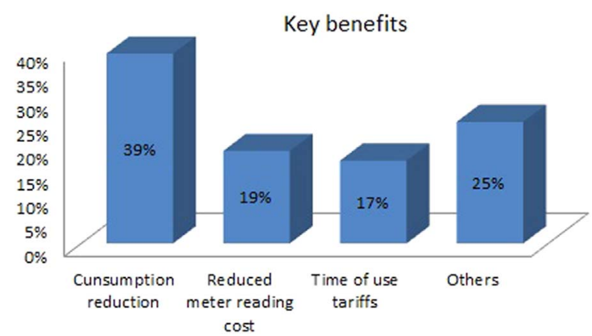

Fig. 10. Key benefits of advance metering system.

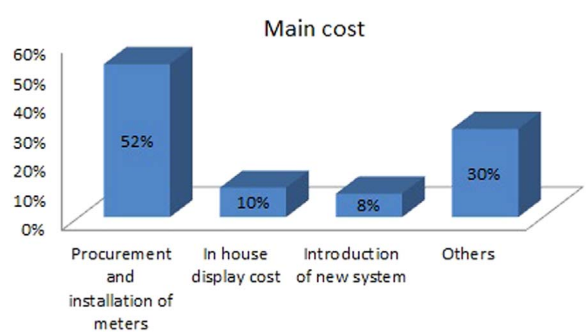

Fig. 11. Main cost in deployment of advance metering system.

7.1. Challenges with the implementation of smart devices

Various challenges have been observed by researchers in the operation of smart devices. Generally challenges regarding smart meters have been observed. One of the most important aspect of smart meters is accuracy in data reading and data transmission when it is being requested. Smart meter has to communicate at a higher frequency. It raises question of accuracy and privacy regarding availability and processing of such a huge data [183].

Radio frequency exposure is another challenge associated with smart meters. When smart meters communicate wirelessly, the communication give rise the radio frequency waves, which must have some limitations. Now various regulators in different countries are keeping eye on such RF exposure to keep it within limits [172].

Privacy of consumers' data is very important issue while implementing advance metering infrastructure (AMI) [184]. In [185–187], authors proposed privacy preserving and cost effective energy management methods. Sometimes in a smart system equipped with smart meters, there may be some malicious meters, which can be a security threat to the whole system. So inspection of such meters is required. To inspect such meters, inspection algorithms are given in [188]. In [189], energy harvesting and energy storage devices are used for the maintenance of privacy of consumer data to achieve efficient smart grid network.

Security of smart meters is also an important issue. Data and billing information is communicated through various WLAN/NAN/HAN networks. Cyber-attacks may steal the original data and information may be affected by external controllers. In [190], authors proposed information centric network (ICN) to deal with such type of problems in advance metering infrastructure. Hence smart meters security becomes necessary for the utilities [172,191]. Another risk is about electricity theft. To deal with this type of problems, authors in [192] proposed a energy theft detector which detects the difference in the consumption pattern of consumers. This CPBETD (consumer pattern based energy theft detector) detects energy theft in AMI and provide a reliable security feature in smart metering system.

8. Key points of the review and observations

8.1. Key points and discussion

- This review work has explored various smart grid components in detail to fulfill today's world energy requirements in green manner, where conventional energy generation sources fails to deliver. These components include demand side management, demand response programs, distributed generation, renewable energy resources and smart devices.
- Authors, in many papers (Fig. 4), have explained the need of energy management at both utility side and demand side to ensure high energy efficiency, continuity in energy flow, security and stability of electrical network. Many researchers have rightly focused on main requirements of demand side management i.e. energy efficiency improvement and demand curve shaping.
- Various demand response strategies, explained in the literature (Fig. 5), have been used by the researchers to flatten the demand curve and smoothening of voltage profile. Many authors explained the demand response strategies as electricity cost reduction and consumer welfare maximization technique. For such multiobjective type problems, game theory, different evolutionary algorithms like genetic algorithm, BPSO, modified PSO etc., some novel distribution algorithm have been used to get the optimum solution (Fig. 6).
- Many authors raised the issue of requirement of distributed generation for the solution of conventional grids problems, like system security, reliability, efficiency improvement, operational cost issues, environment related issues etc. Researchers have focused on the issue of correct integration of wind, PV generations, energy storage system, fuel cells, electric vehicle etc., with the existing grids, to get the expected results of distributed generation (Fig. 7).
- For the formation of mathematical model of the problems various programming tools like Sequential Monte Carlo Simulation, model predictive control, LP, MILP, MINLP etc. have been used in many papers, which helped in getting the satisfactory results in time. Various controlling techniques have been used in research papers for microgrid control. Droop control, power control, distributed voltage control, model predictive control etc. are few controlling objective and methods, which have been used.
- There are many latest papers in which energy storage system is used with RERs for proper and smooth operation of the grid. Different storage techniques such as mechanical storage, electrical storage, chemical storage etc. have been explored in research. Protection issues, charging-discharging issues of battery storage system have been also included by few authors (Fig. 7).
- Advance metering infrastructure is back bone of smart grids, this is explained by many authors, who used AMI for real time data exchange to get the satisfactory results by implementing different demand response programs in distribution networks. The authors

have also raised the issue of improvement in bidirectional communication network for fast information exchange between utility and consumers (Fig. 9).

8.2. Observations

- When we think about smart grids or microgrids or nano grids with the small scale distributed generation and advance metering infrastructure, a new set of rules and regulations is required for successful and efficient implementation of demand side management programs. It is found in research that many countries are not able to implement advance energy management programs due to lack of advance energy policies suitable for their region. Hence the work towards making appropriate energy policies is very urgently required.
- It has been found in research that DSM programs have not been accepted by the industrial consumers at large level. The main reason of this is lack of planning and scheduling programs for industrial demand side management.
- It is found that in large number of research papers, optimal scheduling is done for single user. Very few researchers expanded their work for multiusers energy scheduling. This can be explored in future research.
- In many papers, price prediction techniques have been developed and used to find optimal demand schedule. It is found that more work is required to increase the accuracy of price prediction methods.
- In most of the research papers, published for energy management, work is done using single energy provider. This work can be expanded using multiple energy providers.
- It is found that with the use of smart devices in smart grids, data storage and data security problems arise as a very big issue. More work to solve these types of issues is required.

9. Conclusion

In this paper, we have observed that a smart grid is an emerging technology with growing research in various fields of smart grid. Many developed countries have already started using this technology in their electricity network. But there are many other countries which are lagging in the area of smart grid technology. Large numbers of research papers have been reviewed to include best basic knowledge of smart grid technology, various smart grid components like demand side management, demand response, distributed generation, smart devices. Each component of the smart grid has been explored in detail and details of their continue progress, controlling methods for the improvement of their process, benefits with their implementation and technical challenges in their advancement have been explained in detail. It is also found that various problem solution tools like evolutionary algorithms, novel distributed algorithms, model predictive control, game theory, etc. have been frequently used by the researchers to get the solution of demand side energy management problems. To deal with the environmental issues occurring due to conventional power plants, distributed energy resources have been found as a solution. Detail of integration of various RERs like wind generation, PV generation, etc., electric vehicles, energy storage systems, their role in smoothening the demand curve and challenges in their implementation has been included in our review. The role of smart metering system for real time measurement and monitoring purpose, with the challenge of data privacy and security, has also been explored. By reviewing a number of research papers in our text, it is found that in future more research work is required to make outcome oriented energy management programs for industrial demand management and to find improved real time price prediction techniques for the improvement of energy scheduling programs. Researchers can also work to find out simple and fast techniques which can be used for the control and proper integration of the various DERs in lesser time and effective work is required to get the solution for the problems of digital data storage and data privacy. Along with the full text, the discussion and observation points presented in the paper are helpful for the researchers wishing to work in the area of smart grid for demand side management with the inclusion of DR programs, DERs and smart devices.

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