Trends in Energy Management System for Smart Microgrid—An Overview

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Abstract Smart Grid (SG) is an integrated grid to improve efficiency, consistency, and security with the incorporation of conventional and renewable energy sources, through automated control and modern communication technology. The development of Microgrid (MG) is a great solution for the incorporation of sustainable energy resources inside the smart grid environment. The emergence of Microgrid (MG) by decomposition of the grid is a combination of Distributed Energy Resources (DERs), Energy Storage System (ESS), loads and Control devices. This makes MG a single and controllable power supply system that can enhance versatility, dependability and furthermore incorporate the benefits of distributed generation. In MG, an EMS is fundamental for the ideal utilization of distributed energy sources in smart, secure, reliable and synchronized ways. The need for understanding the energy utilized is increasing since effective Energy Management is more challenging in Microgrid (MG). This paper reviews several Energy management systems developed based on different strategic approaches available for Microgrid on Demand-Side Management.

Keywords Microgrid · Energy management system · Demand-side management

1 Introduction

A Microgrid is a cutting edge distributed power system utilizing local sustainable energy sources designed through different smart grid initiatives. Renewable power resources like wind, solar, microturbines, latest generation technologies like combined heat and power (CHP) technology and fuel cell technologies become part of a Microgrid. Renewable energy resources normally have intermittency problems. To solve the intermittency problem electric vehicle technology, flywheel storage

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systems and Storage devices like battery energy storage systems can be used [1]. Due to their better coordination and control microgrid is preferred compared to the distributed generation sources. MG can be operated without the presence of the main grid (called as an islanded mode) so providing security for a local community. If it is connected to the grid it is grid-tied mode.

Three significant objectives of MG is

- Reliability—Cyber, physical
- Sustainability—environmental considerations
- Economics—efficiency, cost optimizing [2]. It is capable of operating with grid and/or without the grid (island mode). Figure 1 shows a MG architecture consisting of various DERs, critical and responsive loads. The main grid and the MG are linked through Point of Common Coupling (PCC). MG's advantage is, during grid-connected mode—power trading with the main grid is done and system stability shifts to the islanded mode when there are disturbances in the main grid. Microgrid Central Controller (MGCC) and Local Controllers (LCs) controls and coordinates the whole MG operation.

There are different classifications of MGs based on

1. Power type—AC and DC
2. Supervisory Control—Centralized and Decentralized
3. Operation Mode—Grid-connected and islanded
4. Phase—Single and Three Phases
5. Application—Residential/Commercial/Industrial and Utility/Municipality/ Military.

A few focal points of MGs are a decrease in Green House Gases (GHG) outflows, voltage level improvement, power supply decentralization, Demand Response (DR) and incorporation of cogeneration. It additionally lessens losses in line and blackouts in transmission and distribution (T&D) systems [3, 4]. On different operating modes, the MGs to protect the grid, managing the load connected to the system and the

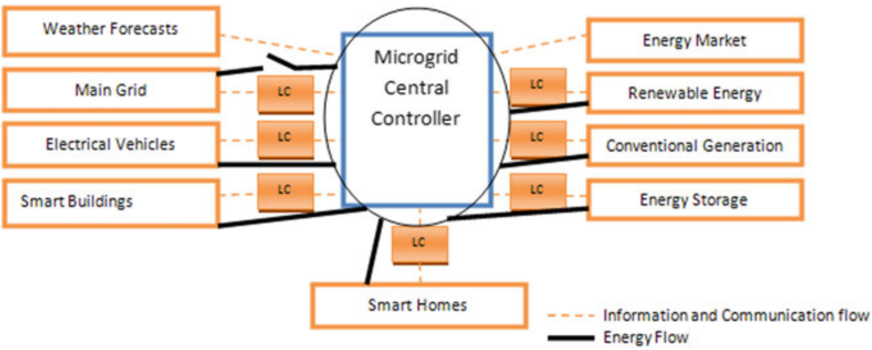

Fig. 1 Microgrid architecture

voltage and frequency adjustment is a requirement so resynchronization process and facilitation of the generation-side and load-side management is necessary.

Some restrictions of MGs are a high upfront cost of RERs, efficient use of power sources, problems due to control of MGs and non-availability of protected and administrative standards, and client security. Solving EMS problems is the key focus for researchers because of the non-availability of continuous RERs and increased integration of controllable loads [3].

In this paper, the Energy Management System (EMS) and the need for it is presented in Sect. 2. Demand-Side Management (DSM), necessity and different optimization techniques based on many mathematical optimization techniques which are used to solve the strategies are reviewed and discussed in Sect. 3. Finally, the paper is concluded in Sect. 4.

2 Energy Management System (EMS)—Introduction, Architecture, and Strategies

An energy management system (EMS) monitors, controls, optimizes the performance of the transmission and generation system and also saves overall operating cost in electric utility grids [5]. EMS is defined as "a computer system comprising a software platform providing basic support services and a set of applications providing the functionality needed for the effective operation of electrical generation and transmission facilities to assure adequate security of energy supply at minimum cost" [3]. Energy management is a venture to control all kinds of energy.

A basic illustration of MG EMS is shown in Fig. 2. The microgrid EMS consists of some components. Modules for efficient execution of decision-making strategies are carried out by Human Machine Interfaces (HMI), DERs/load forecasting and Supervisory Control and Data Acquisition (SCADA) modules by transferring optimal decisions to the storage, generation and load units. Optimizer to determine the optimal power flow trajectories and for electricity demand use of forecasting modules and

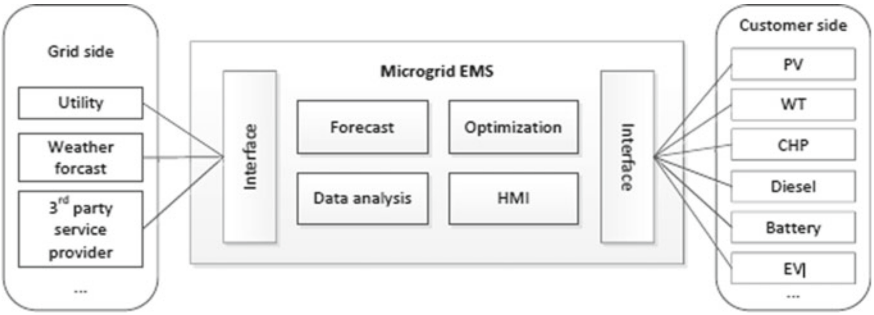

Fig. 2 An illustration of a microgrid energy management system

renewable energy sources power production are the main components of MG [6]. The local controller has the following functions—supervising the renewable energy sources (RES), energy storage (ES) and based on trajectories set by the optimizer collect the measurement data by activating the actuators.

In MG the main challenge is the reduction of energy balances caused due to the dynamic nature of electricity consumption and uncertainties in energy supply from renewable-based Distributed Generators (DGs). Small size imbalances can be handled by droop control or frequency control. In large supply-demand imbalances, these methods fail and which necessitates the need for the development of energy management strategies for microgrids [7]. These procedures give numerous advantages to live energy-saving, frequency regulation, low cost reduction, GHG emission reduction, and client privacy.

EMS of a MG incorporates both Demand-side and Supply-side Management, while fulfilling system constraints, to realize a reliable, cost-effective and sustainable working of MG. Scheduling DERs and loads, losses and system outages minimization, control of irregularity and unpredictability of RERs are the strategies of MG.

To achieve proficient and optimal operation of MG based on mathematical techniques various approaches [3, 8, 9] many researchers have been using to solve energy management strategies. An overview of these solution approaches and control strategies is described in the following sections. Table 1 gives some of the EMS based on strategic approaches used to solve the strategies.

3 Demand-Side Management

The expression "demand-side management" (DSM), also known as "energy demand management," stands for a various energy consumption related work. It incorporates the controls and alteration of energy use (e.g., energy preservation, efficiency, and storage) but also the practices that are engaged with the procedures [10].

Demand management refers to any strategy that reduces energy consumption or remodels the use of energy on the customer's side of the electricity grid as an alternative to increase supply capacity. Demand management strategies may include preservation programs, shift tasks, and an increase in the strategic task. Load control is a feature of demand-side management. The process of transforming conventional MG into the green system is facilitated by a powerful tool called Demand-side management (DSM). DSM is a cost-effective choice for balancing the energy imbalances caused by unreasonable utilization of power by adjusting the energy utilization to the supply. The main focal point of DSM strategies is moving the energy demand from peak hours to off-peak hours to lessen the peak demand [7].

A vital role is played by DSM for the development of industrial power, planning of energy and protection of the environment. In DSM there is a concept of Demand Response (DR), which refers to "changes in electric usage by end-use customers from

Table 1 EMS based on different strategic approaches

	Different methods	Approaches
Energy management system based on	Classical method	• Linear programming • Mixed integer linear programming • Nonlinear programming • Mixed nonlinear programming • Dynamic programming and rule-based methods
	Meta-heuristic approach	• Genetic algorithm • Particle swarm optimization • Differential evolution • Ant colony optimization • Gravitational search algorithm • Modified bacterial foraging • Artificial bee colony • Tabu search • Imperialist competition algorithm
	Artificial intelligence methods	• Fuzzy logic • Neural networks • Multi-agent system • Game theory • Markov decision process • Adaptive intelligence technique
	Stochastic and robust programming approaches	• Stochastic optimization • Robust optimization • Chance constrained programming • Scenario-based optimization
	Model predictive control	• Model predictive control
	Other methods	• Rolling horizon optimization • Hierarchical control • Homeostatic control • Predictor corrector proximal multiplier algorithm • Mesh adaptive direct search

their normal consumption patterns in response to changes in the price of electricity over time" [8].

Electricity Market can have the following advantages by the introduction of DSM [10]:

- Supply and demand information trading can be done instantly, transparent transactions can be facilitated and rapidly improve the development of an electricity price mechanism.
- The efficient market operation and good control of power of market is possible.

- Improve power system reliability by addressing peak hours demand congestion problems.
- Lessen the cost of power generation, transmission, and distribution.
- A new diagnosis for Energy management and emission reduction can be facilitated.

For improving energy efficiency by balancing supply and demand the combined work of advanced DSM and distributed energy resources (DERs) in a MG along with a good communication plan can play a vital role. The DSM by using developed optimal methods and information technologies can achieve a reduction in energy consumption, energy handling efficiency enhancement and cost reduction.

Due to the heterogeneous nature of the MG network which comprises of ESS, diesel generators, solar power, wind turbines, and electric vehicles, the specific objective function need to be defined, unlike the classical power grid where optimization is based on the centralized objective function. To control and enhance SG systems that include a MG distribution network it is natural to implement distributed analytical methods. In this regard, a few open issues in microgrids can be dealt with utilizing various strategies [11].

3.1 Classical Methods

An optimization method was proposed in [12] for the DSM EMS based on Linear Programming (LP) approach. EMS is for a given customer's hourly electricity prices. The proposed EMS which is developed using optimization algorithm based in LP, the customer can use their own plan to

- Control load and prices in the energy distribution system
- Forecast future energy use
- Efficiency improvement
- Losses reduction.

During the demand for energy excess energy which is stored in the battery can be utilized. In [13] focus is on both DSM and SSM load scheduling problem for users in SG using LP models to

- Minimize energy cost in DSM
- Maximize the load factor in SSM.

For the operation of intended appliances, the LP model offers various flexibilities to preset if the appliance has to operate without interruption and to define multiple time intervals. Uncertainty aspect of the MG system with RERs is addressed by designing and experimentally testing an adaptive online MG EMS in [14]. Interfacing with controller and incorporation with other modules and communication between them is tested using the designed EMS architecture. Optimization module is based on Mixed Integer Linear Programming (MILP).

3.2 Meta-Heuristic Approach

To solve the objective function the interior point method and for demand response, particle swarm optimization and artificial immune systems are applied in [15]. For both customer and utility in the MG environment the DR management proposed, a service provider who carries out the optimization decides a common solution. It has the following features

- For energy balance problems application of DR techniques
- Decrease the revelation of the supplier to the market instability by improving the cost of both supplier and consumer
- Utilized newest and extensively used realistic tools
- Easy adaptation in the energy industry to develop real-world applications.

The main focus of [16] is to develop a microgrid generation scheduling model using the intelligent meta-heuristic algorithm. Here a modified cuckoo search algorithm is developed and utilized for EMS in microgrids. The results of the studies conducted for

- Reducing operating costs with and without DR participation.
- Wind and PV resources uncertainties.

The results show that the operating costs are reduced by adaptive demand response programs.

Various heuristic techniques like Particle Swarm Optimization (PSO), Firefly Algorithm (FA), and Artificial Bee Colony (ABC) are applied in [17] for optimal consumption of renewable energy resources (RES). To incorporate increased energy demand at reduced cost batteries are used. Comparing these techniques ABC turns out to be very effective.

In paper [18], a combined solution using a genetic algorithm for residential loads for both economic dispatch and DSM in a MG is presented. The evaluations show that the given approach can

- Reduce the cost of operation for both suppliers and consumers in a single and multiple-facility microgrid.
- Cost generation reduction.
- Reduction in shifting of loads inconvenience.

The objective function of [19] containing discontinuous functions uses a Genetic Algorithm (GA) based solution for savings for the customer with DSM. For Real-time Microgrid Power Management problem two computational intelligence methods, particle swarm optimization (PSO) and Ant Colony Optimization (ACO) were introduced in [20]. A mathematical framework or multi-objective and multi-constraint optimization was presented and the advantages of intelligent methods over traditional computational techniques for optimization were discussed.

3.3 Artificial Intelligence Methods

A home automation economic model that has integration with the residential DERs, dynamic tariffs and enables actions to DR based on the Internet of Things was proposed in [21]. Decision making is based on the application of Artificial Intelligence (Fuzzy Logic) for automatic load management.

In paper [22] two Genetic Algorithm (GA) executed alternately, one for determining the microgrid scheduling and the fuzzy rules and others to tune the membership functions for optimizing microgrid operation. By using a hybridized Fuzzy and GA algorithm a MG generation schedule, day ahead wind generation electricity prices and based on load demand allocation of storage power is developed.

In [23, 24] a novel DSM method using dynamic game theory is proposed which can aid in

- Effective use of DERs by analyzing and coordinating the interactions among users [23].
- Reduce the total energy cost [23].
- Be modeled for variations in wind power using the Markov chain [23].
- Saves the cost of generation using DSM [24].
- Reduces the Peak-to-Average ratio [24].

A DSM framework integrating smart fuzzy load controller and DR in MG is proposed in [25]. The Fuzzy load controller for load shifting and load usage uses the data procured by the smart load monitoring system to make decisions. This method can

- lessen peak demand
- to minimize energy loss
- increase the efficiency
- effective cost saving.

In [26] a load management system for highly stochastic loads (treated as Markov models) is proposed. Markov decision process is used to

- reduce the overall cost linked with DR control action.
- increase the certainty of fulfilling the DR.
- reduce the load by modeling the load using each household as Markov chains.
- cost saving compared with the industry used model.

The key focus of an agent-based EMS proposed in [27] is to

- aid trading of power among microgrids with distributed storage and DR.
- make use of energy accessibility from the DERs and diversity in load usage patterns of the customers.
- DR in reducing the peak demand.
- to reduce electricity costs.

In paper [28] based on the Lagrangian multiplier method, Lagrange programming neural network is introduced for

- economic dispatch optimization
- reduction in the objective function
- functional cost reduction and
- increase in RERs power generation.

The optimal solutions for power production resources and ESS can be determined using this approach. Neural network helps in achieving prediction of renewable resources and load demand a day ahead.

3.4 *Stochastic and Robust Programming Approaches*

Stochastic model predictive control scheme energy scheduling for optimal EM, the supply and demand-side uncertainties are taken into consideration in [29]. In this solution is found efficiently because

- Uncertainties can be handled.
- The energy trading between MG and main grid is found to be in a assigned trajectory.
- References tracking including uncertainties have considerable improvement than the traditional scheduling scheme.

In [30] microgrid EMS framework based on agent-based modeling by introducing Robust Optimization (RO) is proposed. Uncertainties can be handled using the extension of the framework. Evaluation of each uncertainty impact on the cost accuracy and revenue function is made possible in this proposed optimization framework. An increase in the reliability indicators and reduction in energy shortage is evident from the reliability analysis.

3.5 *Model Predictive Control*

For MG optimization neural network load forecasting and model predictive control (MPC) are implemented in the paper [31]. The algorithm updates the optimal course at each stage for

- energy balance
- operational cost reduction
- reducing load forecasting errors.

A 2 stage Real-time demand-side management (RDSM) method using MPC based optimization model for Response Executers (RE) under an environment with uncertainties consist of the ESS and the Plug-in electric vehicles (PEV) is proposed in [32]. With the proposed framework MG can achieve

- economic benefits
- better dealing with uncertainty
- improve net load characters
- enhancing energy balance.

The analysis of MG DSMs based on different approaches, their contributions and limitation are given in Table 2. Further, this review will pave the way for developing a Demand-Side Management System considering the issues caused due to conventional generators, the privacy of consumers, incorporation of demand response, reliability, battery status and losses in the system.

4 Conclusions and Scope

Due to various challenges and opportunities, Microgrid penetration is presently rising across the globe. This paper attempted to provide a review of the various microgrid demand-side energy management approaches. The review consists of an introduction to microgrids, their components and associated benefits, limitations, which further followed by a discussion on Energy Management systems, its architecture, advantages, and constraints. The process of transforming conventional MG into the green system is facilitated by a powerful tool called Demand-side management (DSM). These MG DSMs mainly focuses to reduce the energy cost, utilization of renewable energy resources, reduction of MG system losses and energy trading with the main grid. Even though many efforts are taken for developing DSM algorithms for Intelligent Energy Management, the following challenges have to be met in the microgrid system: integration of demand response, the robustness of power management, losses cost of MGs and system reliability. The choice of approaches which is discussed in this paper to be implemented for optimization depends on various factors like uncertainties caused due to renewable energy resources, integration of demand response, computational time complexity, operational cost of battery and depth of discharge of battery of in energy storage systems and many more. Artificial Intelligence promises to be more effective and standalone approach to address the issues related to demand-side management while considering the different factors mentioned above. The benefits of Artificial intelligence on Microgrid are worth for future efforts.

Table 2 Contributions and limitation of MG DSM based on different approaches

References	Approach	Contributions	Limitations
[12]	Artificial neural network based linear programming	Losses reduction, optimal use of resources on demands, energy balance flexibility	Demand response was not considered which required external control techniques
[13]	Linear programming (LP)	Reduction in demand-side scheduling cost and improve the load factor while supply-side scheduling	Integration of 2 LP problems into one model not considered
[14]	Mixed integer linear programming	Operational cost reduction, able to operate on different modes	Advanced forecast, testing and optimization not implemented
[33]	Artificial immune systems and particle swarm optimization	Cost improvement by using the DR technique for both utility and consumer	The integration of renewable sources is ignored
[16]	Modified cuckoo search algorithm	Wind and PV resources uncertainty are considered and the objective function is analyzed. The operating costs reduced by adaptive demand response programs	Small scale power network considered
[17]	Artificial bee colony (ABC), particle swarm optimization (PSO), and firefly algorithm (FA)	Optimal use of RERs, reducing the cost of production and market-clearing price	Solar power not considered
[18]	Genetic algorithm	Reduction in energy cost	Constraint-capturing mechanisms and the larger MG level not considered
[19]	Genetic algorithm	Generation cost is more without DSM compared to with DSM	MG for a large area not considered
[21]	Fuzzy logic	Residential DER operation cost-benefit ratio improvement	Computational complexity not discussed
[22]	Fuzzy logic	Management of power in the battery and scheduling of MG	Non-consideration of loss of power and time complexity for higher computation
[23]	Game theory	Entire energy cost reduction in the isolated microgrid system	Uncertainties not considered

(continued)

Table 2 (continued)

References	Approach	Contributions	Limitations
[24]	Game theory	Benefitting the grid by reducing the ratio of peak to average and reduction in load profile are smoothened which are caused by supply constraints	Hybrid micro-grid is not considered for the study
[25]	Fuzzy logic	Reduction in cost of energy, loss of power, peak demand and inefficiency of the grid	More renewable energy sources not considered
[26]	Markovian model	Reaching demand response targets as well as reduction in cost of operation	Computational complexity not discussed
[27]	Multi-agent system	This EMS increases levels of thermal comfort and consumer's electrical and reduces the operational cost of MG	Microturbine emission cost is ignored. Non-consideration of the operational cost of the battery
[28]	Neural network	Minimization of the overall cost of MG, a neural network used for forecasting and the results are compared with PSO	Non-consideration of battery operation cost and complexity of the time of computation
[29]	Stochastic programming	Minimization of CG battery cost of operation, trading of energy cost and cost of degradation with main grid	Discussion of complexity due to time in computation is not covered
[30]	Robust programming	Realization of performance of MG (imbalance cost), reliability of MG (loss of expected energy) and load expectation loss	DR not included in a residential district. Complex
[31]	Model predictive control	Static control issues addressing and elimination of load forecast errors and reduction in operations costs	Compensating residual forecast errors not discusses
[32]	Model predictive control	Power balance maintenance and the operation cost reduction	Computational complexity not discussed

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