Review Article

A Review of Recent Research on Optimal Scheduling of a Microgrid with Renewable Energy Sources

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Received: 24/02/2017
Revised: 00-00-0000
Accepted: 29/06/2017

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Abstract:

The present paper attempts to bring focus on the work done and concept of optimal scheduling of microgrid with renewable energy sources and state of art different methodologies proposed for scheduling in microgrid integrating renewable energy sources. The attempt is to carry out review of optimal scheduling on microgrid with different types of renewable energy sources and energy storage systems. The intention is to evaluate the recent status, major barriers and present research efforts guided towards establishing optimal scheduling on microgrid. This review paper also evaluates the various methods of optimal scheduling for low operating cost, low maintenance and high reliability with its merits and demerits. The optimal scheduling justifies the cost of investment of a microgrid by allowing economic and reliable utilization of the resources.

Keywords: Microgrid, Optimal Scheduling, Renewable Energy Sources, Energy Storage System, Distributed Generators, Electric Vehicles, Smart Grid.

I. INTRODUCTION

The continuous and expanded growth and share of renewable energy sources (RES) have led to new effective approach for grid management i.e. smart grids and microgrid in order to make the electrical grid more reliable and secure. The new approach of microgrid is more robust and cost-effective compared to the conventional approach of centralized grids. They represent a promising prototype of next generation electric power systems which deals with the vital challenges of power system reliability, stability, security and integration with RES due to the growing idea of green energy resources and environmental awareness.

Microgrid defined as localized group of distributed energy resources (DER)(such as distributed generators (DG), storage devices, or controllable loads) and loads linked by a distribution system, generally at low or medium voltage, and can work connected to the main grid or disconnected and function autonomously as physical and/or economic conditions dictate(connected or islanded mode of operation) [1]. Microgrid connect different energy sources in the finest probable way to gratify to local loads with the capability to operate either connected or disconnected with the main grid. It can be observed as a controllable subsystem to the utility generating power from the DER which are mostly renewable[2].DER technologies consists of power generation and storage resources typically located on an end use customer's premises and operated for the purpose of supplying all or a portion of the customer's electric load [3].

A smart grid entails technology applications that will allow an easier integration and higher penetration of renewable energy[4]. It enhanced grid operation management and keep balance among demand and supply. RES are non-dispatchable resources that are variable, intermittent and uncertain in nature.

The microgrid operation is currently in progressive manner all over the world. At low voltage level and medium voltage level the use of DER with RES increases in developing countries.[5] Microgrids have

its own independent existence which co ordinates the DER and RES in a more decentralized manner, to reduce the controlling action on main grid and providing benefits. Microgrid works safely and efficiently with its local network in both islanding and grid connected mode.

Some of the most significant features of microgrid affecting the optimal scheduling are [1],[6]:

- Microgrid has a high share of renewable sources, which makes it hard to determine the expected power obtainable at any moment in the advance.
- The weakly meshed low voltage architectures of microgrid are more liable to faults like over/under voltage or overloading during the load/generation alteration.
- The occurrence of storage devices and exchange of energy with the main grid makes microgrid operation flexible, but in addition it increases the solution space of the unit commitment (UC) problem.
- Microgrid involves small size of the generators which give feasibility to switch them on/off with a faster rate compare to the large power plants.

This volatility can cause major challenges in the operation of the microgrid. The need to deal with conventional energy generation and utilization based on the instantaneous variations of RE generation lead to demanding stability problems. Without optimal utilization of sources the cost of investment for a microgrid shall not be acceptable. Fig.1 shows the general structure of typical microgrid connected with different sources and loads.

Fig.1. A General Structure of Typical Microgrid

Related work on optimal microgrid scheduling:

Several models and methods have been proposed to optimize various objectives in microgrid operation for different applications. Lucas Bolívar Jaramillo et al. design the model of optimal microgrid scheduling by peak load reduction with use of a fuel cell, electrolyzer and flexible loads to reduce the operational cost and ecological effect. The systems make use of the flexible demand and the hydrogen storage system to circumvent high grid peak power. The hydrogen storage converts the available electricity in hydrogen production via an alkaline electrolyzer and reconverts it into electricity via a fuel cell. The paper has discuss four reference cases for simulations like full set of constraints, without battery electric vehicle, without the peak power constraints and without photo voltaic production. From the simulation result it is concluded that the peak variables in the objective function has a big impact on the program's run time; it takes less time to reach solution when it runs through without variables [5]. The concern of the peak restriction gives the importance of use of a storage system. In the offered method, the storage primarily gives the reduction of supply drawn from the grid and so keeping away higher power peaks. The same results are confirms with the ones accounted by other authors. [7] - [9].

Hugo Morais et al. gave a detailed analysis on optimal operation technique of microgrid in an isolated area with use of mixed integer linear programming to optimize the performance of power supply by applying the right timing. In analysis virtual power producer can optimal manage the generation units and secured the high-quality functioning of equipment together with maintenance, operating cost and generation measurement and control. A central control at system allows a virtual power producer to manage the load and generation control. Virtual power producer reduce the operation cost of the isolated system and increase its efficiency [10].

Muhammad Khalid et al. developed the methodology to minimize the energy cost for microgrid which is integrated with conventional generation and RES using battery storage system. The author developed optimization algorithm utilized the constraint-based controlled operation of the battery energy storage system (BESS) to minimize the total cost and also to accomplish the power demand at a certain geographical area. The method is useful mostly to an Island or a far isolated region via RE resources linked with the BESS and a microgrid. This paper concentrates mostly on the BESS but its investment returns, battery

degradation, aging cost and operational and maintenance cost is not consider in this paper [11].

N. Jayalakshmi et al. identifies some more issues such as islanding constraint with energy storage system with minimizing operating cost and the losses of energy storage system. The problem is divided into grid connected operation as master problem and the islanded operation as sub problem, solved by benders cut method. In this paper optimization tool gives merely the local solution, combining additional constraints are also probable for future scope of work[12].

Wencong Su et al. developed a two stage stochastic microgrid energy management model in inter connected mode with minimizing operational cost, power losses. The developed model is optimally dispatching the plug in electric vehicle (PEV) charging load and scheduling DG and distributed energy storage devices (DESD) with taking into account battery degradation cost. By considering more uncertainties such as load and customer behavior to this model will be good future scope of work [13].

Abdorreza Rabiee , et al. developed a methodology for simultaneous scheduling of electrical vehicles and responsive loads to reduce operating cost , increase the incentives of the owner of electric vehicle and emission while the uncertainties related to wind and PV are compensated. Author developed a two stage model to find operating cost. In first stage generation and reserve power costs are minimized while in the second stage the wind and pv units with its uncertainties condition and unit scheduling changes the associated cost are minimized. Solution methodology is simulated by Particle swarm optimization (PSO) method. Proposed scheduling method in the paper explain the electrical vehicles used for load curve correction and peak shaving, while the responsive loads useful to deliver a part of the required grid reserve to balance wind and PV uncertainties. The simulation outcomes give the clear cut effect of the proposed method in the operation costs and emission reduction [14]-[16].

M. Zein Alabedin, et al. developed a day-ahead UC problem in a microgrid operated in both mode to perform generation scheduling in microgrid with uncertainties of power generation using mixed integer linear programming (MILP). The microgrid models handled forecast uncertainties with spinning reserve requirement and further load curtailment is required in the isolated mode to deliver the required spinning reserve [17].

Ango Sobu et al. have presented the dynamic optimal schedule management technique for connected and disconnected microgrid with renewable sources like wind power systems and PV systems. The dynamic programming and equal incremental fuel cost technique used to solved optimization problem of micro-turbine generators with electricity storage in Energy Management System (EMS) [18].

T. Logenthiran has described a three-step efficient method for the optimization generation scheduling of a microgrid in island operation. Solution is carried out by UC. At last it optimizes the renewable-thermal dispatch based on thermal UC results. By doing so it minimizes the operating cost with the help of the Lagrangian relaxation, genetic algorithm (GA). The successive dynamic programming method is used to resolve non- linear optimization with continuous variable[19].

Juan P. Fossati et al. have proposed an algorithm for optimization scheduling of a microgrid with fuzzy logic controlled storage system. The proposed algorithm fulfills two main functions based on GA to optimize the microgrid operation. The first function determines the scheduling of microgrid by the status of generator and storage system and power exchange from main grid. The second function sets membership function for a Fuzzy Expert System (FES), which control the output power of storage system. FES has six different variables as input like state of battery, storage system charging status, actual time, energy price, wind power generation and load demand. The expert system gives the total power to store or drawn from the battery. Authors also identified that battery can deliver large amount of power during the last few hours of daytime, when the energy price at its highest. The discharge at the same time is more moderate to decrease the operating cost. The describe method evaluated with two technique. First, the battery is all the time charged or discharged at its highest permissible rate. In second technique the battery output is controlled by FES. The result shows the second technique of optimized FES lower the operating cost of the microgrid considerably [20].

Amin Khodaei has proposed a model for optimal scheduling based on resiliency oriented microgrid. The purpose of this model is to reduce the load shedding by skillfully scheduling the available resources when supply connected from main grid broken up for some time. The proposed model decayed the problem in two different parts, normal

operation and resilient operation. The normal operation problem is resolved by UC, adjustable load schedules and energy storage schedule. The solution of normal operation is employed in the resilient problem to examine the capability of microgrid to supply local load under islanded state. The model support minimum customer inconvenience, load shading, minimize the power mismatch between microgrid generation and load [21].

Binyan Zhao at el. have done the simulation in proposed method to achieve an competent performance with no loss of optimality and lower complexity. The proposed method also provides guidelines to decide the size of energy storage system to work the microgrid efficiently in islanding mode. Compare to other soft computing method the proposed method takes lesser processing time. For the demand and wind power forecast errors, a novel probability-based concept is projected to specify the possibility of the microgrid ability to operate in islanded mode, named "probability of self-sufficiency" (PSS).Paper results show that as microgrid works autonomously, the large amount of power to be generated to make sure self-sufficiency and to moderate demand and wind power forecast errors, so increase in operating cost. They have pointed out that as the forecasting gap time for wind is small, the more accurate the forecast records and the minor the inaccuracy. A duality-based approach has been established to an analytical characterization of the optimal UC and dispatch solutions for the DGs, which can be more proficient using a sub gradient-based algorithm [22].

Anil Khodaei has presented the methodology on optimal scheduling with the constraints by decomposing the problem in two part, one main problem grid connected mode and other is islanding mode. By taking Bender's cut model the mismatch between generation and demand will be reduced. The proposed model used two bender's cut on for UC and other for adjusting controllable load. By using this, solution based on iteration is optimized. Proposed method explained that the solution provides reliability in the system but the overall microgrid operating cost will be slightly increased. This is the scope of the future work how to reduce the operating cost [23]. Both [23] and [12] have moreover same methodology but [23] has used MILP method where [12] has used MATLAB for simulation.

A. M. Zein Alabedin et al. proposed two model one for grid connected mode and other in islanding mode solved by MILP to solve the day-ahead UC problem. Four cases for without renewable, with renewable and without considering its uncertainties, with renewable and its uncertainties are explained. They have also explained the optimal generation scheduling for dispatchable generators, renewable sources and spinning reserves to minimize the load shedding, microgrid operating cost and power curtailment in islanding mode [24].

Proposes energy management system for an isolated microgrid power-driven by a wind turbine and a photo voltaic array are incorporated with two storage systems: battery bank and a hydrogen storage system. Hydrogen systems used for long term storage as batteries are unsuitable due to their small storage density and inescapable self-discharge. A stochastic and the scenario tree method applied to cover the uncertainties of forecast weather and load. The relative analysis with the standard EMS is carried out for four different weather conditions – summer, autumn winter and spring. The reduction in operating cost is found because of the decrease in the operating hours of the hydrogen system. The main drawback of proposed method is high computational time and not optimized capacity of hydrogen storage system which leads to considerable rise in undelivered power [25].

Yifeng He et al. proposed on optimal scheduling by using electrical vehicles and its charging - discharging. Paper has explained the formulation of globally optimal scheduling scheme with minimization of total cost. The globally optimal scheduling method is practically impossible but it is required for the information of the forecast load and for the estimation of the future charging time of electrical vehicles in a day. The locally optimal scheduling method is expandable for large electrical vehicles and reliable for the future arrival electrical vehicles. From the simulation results author suggests that the locally optimal scheduling method is more precise compare to globally optimal scheduling method [26].

Johanna Salazar et al. presented a proposal for optimal control technique of renewable (solar energy) microgrid with energy storage system (lead acid battery bank, fuel cell and electrolyzer) based on simulations results. To minimize the operating cost prediction based control is used. The purpose of the control is to keeping a balance between produced power and consumed power. The main objective of the paper is to maximize the economic revenue and minimizing the energy imported from the grid under operational constraints [27].

Summary Table

Account of optimal scheduling methods studied in literature survey:

Table 1. Summary Table

Study label (Author)/Year of publication	Method of optimal scheduling	Objectives	Soft computing tool
Lucas Bolívar [6] 2016	By using electrolyzer and fuel cell as energy storage and flexible loads	-Peak load reduction -Reduction of operating cost	MILP
Hugo Morias [10] 2009	By using virtual power producer(VPP)	-Reduce the generation cost -Optimize storage charging/ Discharging time	MILP
Muhammad Khalid [11]2016	By using controlled BESS	-Minimize the total cost	Dynamic programming
N. Jaylaxmi [12] 2016	By considering the islanding constraints with the use of energy storage system, By Bender's cut decomposition method	-Optimize the power output -Minimize the total operation cost	MATLAB-Dynamic programming
Wencong Su [13] 2013	By optimally dispatching the controllable load PEV and DESD	-Minimize the operational cost and Power losses	Stochastic programming
Abdorreza Rabiee [16] 2015	By using simultaneous scheduling of PEV and responsive loads	-Reduce the generation and operation cost -Peak load shaving -Load curve modification -Reduce emission	PSO
Juan Fossati [20] 2014	By using fuzzy logic controlled storage system- FES	-Reduce operating cost	GA
Amin Khodaei [21]	By decomposing problem- normal (Connected with grid) and resilient problem (islanding mode)	-Minimize load curtailment -Improve Resiliency -Minimize consumer inconvenience	MILP
Binyan Zhao [22] 2013	By using duality based approach- PSS	-Decide the Energy storage system (ESS) size	Sub gradient based algorithm and mixed integer UC
Amin Khodaei [23] 2013	By using T-T islanding criteria, decomposing problem using Bender's cut method	-Minimize operating cost, both generating by DER and purchase from main grid	Mixed integer programming
Zein Alabedin AM [24] 2012	Generation Scheduling by using a day ahead unit commitment problem with uncertainties handling techniques,By using general algorithm modeling system (GAMS)	-Reduce the load shedding by using spinning reserve -Reduce the effect of uncertainties -Reduce operating cost	MILP
Giorgio Cau [25] 2014	By using novel EMS with the help oftwo different energy storage systems:Electric batteries and a hydrogen production & storage system.	-Utilize the renewable sources at their maximum power points and minimizing the Overall utilization costs.	MILP using Gurobi
Yifeng He [26] 2012	By using intelligent scheduling of charging and discharging of electrical vehicles(EV)	-Minimize the total cost of microgrid -comparison of locally optimal scheduling and globally optimal scheduling	MATLAB software for disciplined convex programming
Johanna Salazar [27] 2013-IEEE	Optimal Scheduling using Predictive controller with renewable and with mixed storage system (Batteries and hydrogen)	-Optimize operational cost -Maximize the economic revenue -Minimizing the energy imported from the grid under operational constraints	Mixed integer programming
Chen Changsong [28] 2009-IEEE	By using microgrid energy trading Model (METM).Power output prediction based on Neural network power forecasting	-Minimize purchase cost -Improve overall system operation -Provide mutual economic benefits among distribution networks	GA

Study label (Author)/Year of publication	Method of optimal scheduling	Objectives	Soft computing tool
Lian Lu [29] 2013-SIGMETRICS	Optimal scheduling by competitive online algorithm CHASE- competitive heuristic algorithm for scheduling energy generation	-Maximize the cost saving with local generations -Reduction of generating cost by integrating storage system during peak hours is the future scope work	Dynamic programming
K. Prakash Kumar [30]-2016 INDJST	By using two stage MAIMD algorithm.	-Optimize the generation cost -Overcome the drawback of AIMD -Extension of MAIMD algorithm with other real time application is for future work	AIMD
Chong Cao[31]-2016 SCRIP-SGRE	By using charging/ Discharging of of electrical vehicles	-Reduce customer cost -Minimize operating cost -Improve grid performance -Minimize power deviation	MILP

Chen Changsong et al. have proposed a microgrid energy trading model to find out the optimal scheduling of existing generators over a planning horizon so as to meet the constraints, the load and ancillary service demands. The power output of the renewable sources is strongly depending upon the weather, so power forecasting is required for the proposed model. In the proposed model genetic algorithm is utilized for microgrid scheduling. The model improves the overall system operation and reduces the cost of microgrid operation [28].

Lian Lu and Jinlong Tu et al. have developed an online algorithm called CHASE for energy generation scheduling in microgrid with renewable energy sources and cogeneration. Paper covered the UC problem which decides the on/off status of generation and economic dispatch problem which compute their output levels. The purpose of the paper is to minimize the overall operating cost. The future work can be done in this algorithm by including energy storage system to reduce additional operating cost. However the recent energy storage system is very costly, so it is critical to judge whether the combine strategy can reduce sufficient operating cost or not[29].

K.Prakash Kumar et al. proposed a two stage modified additive increase multiplicative decrease (MAIMD) algorithm to optimize the cost of generation in a microgrid with renewable sources in grid connected mode. In the two stage algorithm first stage is in offline process and the second stage schedules the generation among the available sources in microgrid. The algorithm is simple, fast computing, and requires least communication and less computation. The author has covered the drawback of original algorithm additive increase multiplicative decrease (AIMD) and proposed a new improved algorithm MAIMD. The drawback of AIMD is that when additive parameter is same, all generators schedule equal amount of power, this is not fair in renewable sources due to wide deference in cost. The other drawback is AIMD does not allow the priority based generation scheduling, and need more iterations to balance the load with generation[30].

Chong Cao et al. explain the optimal scheduling in microgrid by using renewable generation and electric vehicles to reduce gas emissions. The methodology developed for multi objectives like minimize operating cost, minimize power deviation from a pre-defined power and combine above both. The uncertainties of renewable like photo voltaic array by electric vehicles[31].

CONCLUSION

This review paper gives brief idea about different methods of optimal scheduling of a microgrid with RES. It also reviews and discusses the methodology utilized for developing optimal scheduling objectives and algorithms/software tools employed to optimize the cost effective system. A brief study on different methods for optimal scheduling of microgrid with including different renewable as energy sources is carried out. Current biggest issue of all energy system is the energy storage system. With new research and development the efficient and long life span energy storage systems have been employed. The study covers the optimal scheduling using different energy storage systems like fuzzy logic controlled storage, virtual energy storage system, hybrid storage, electrolyzer and hydrogen as storage. Out of all the methodology explained above for optimal scheduling in microgrid the decomposition problem methodology by bender's

cut has done generation side scheduling by UC and load side scheduling by controlled load. This methodology gets reliable solution with slightly increase operating cost. It may be included in future research work to optimize the operating cost more effectively. By charging and discharging electrical vehicles for the optimal scheduling to reduce operating cost is also promising technology revolution. The uncertainties of renewable sources are integrated with energy storage system and electrical vehicles as a controlled load for optimal scheduling of a microgrid presented. Further research will help to get better scheduling to defeat the shortfall of recent scenario.

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