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A Review to Economic Dispatch of Hybrid Microgrids

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Abstract: Hybrid Microgrids are being widespread for power generation in remote locations. The improvement in non-conventional energy sources and rise in the price of existing electrical energy production sources led to the advancement of hybrid renewable sources. Economic characteristics of these technologies are adequately capable to include in emerging power generation. Advances and research in solar, wind and other non-conventional energy sources are required to continue for improving their performance, creating techniques for exactly forecasting their outputs and reliably integrating with other conventional sources used for generation. Economic dispatch is being taken into consideration as the optimal output of the electricity generation facilities. These are to be met as per the load at the lowest possible cost. The problem on Economic Dispatch (ED) and different technical constraints considering power balance in the network satisfying the objective are to be formulated. This paper presents a brief review on economic dispatch of hybrid microgrids.

Keywords: Distributed Generation (DG), Hybrid Microgrid, Hybrid Energy Systems, Renewable Energy Sources, Economic Dispatch (ED).

1 Introduction

The power utilization is increasing rapidly due to the advancements in different technologies for the sophisticated human life. As the fossil fuels are becoming exhausted and are not able to meet the electric power demand requirements, the renewable energy sources have become more vital in the production of electrical energy. Distributed Energy Resources (DER) are decentralized which could help in serving to nearer load locations. The production of electrical energy at a smaller scale led to the Distributed Generation (DG). The DG helps to meet the electric power demand requirements. The DGs were firstly introduced as a source of production of DC power but later due to sudden changes in the technologies it later led to the rise of production of AC power using DGs [1]. DGs can be defined as the number of small grid connected devices which can be mentioned as DER for production of

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electrical energy. The increase in renewable energy utilization has been the most important as the fossil fuels are exhausting at a faster rate for production of electrical energy. The yearly gross electricity generation is also being increasing year by year and the statistics in India are being presented in **Table 1**.

Table 1

Yearly gross electricity generation by source [2].

Year	Fossil Fuel [GWh]	Nuclear [GWh]	Hydro [GWh]	RES [GWh]
2014 – 2015	878,320	36,102	129,244	61,780
2015 – 2016	943,788	37,413	121,377	65,781
2016 – 2017	994,230	37,916	122,313	81,869

A drastic rise of more than 20,000 GWh of electricity generation could be observed in India from 2014 – 2015 to 2016 – 2017 which explains the increasing importance of electricity generation using renewables and a fall in electricity generation using hydro can be observed.

Microgrids [3] came into existence combining different sources or small-scale non-conventional sources of energy (like solar, wind) along with energy storage systems (like flywheel, batteries, Superconducting Magnetic Energy Storage (SMES)) and loads are integrating through the Point of Common Coupling (PCC) which can operate in grid connected or disconnected mode. The microgrid with DGs could not meet the requirements of the power industry as the dependency has been increasing day by day on the electrical energy in the human life. In this context, the hybrid microgrid with DGs could satisfy the electrical power industry requirements. Hybrid in this context means that utilizing two or more sources (multiple sources) for production of electrical energy. So, the hybrid concept is to be taken into consideration where the DGs utilizing different sources (as shown in Fig. 1) can be used for continuous production of electricity energy.

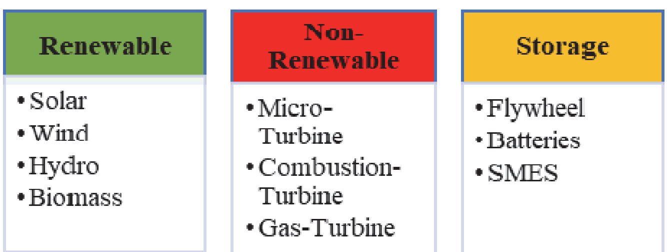

Fig. 1 – *Different sources of DGs.*

Different optimization algorithms or techniques have been used for the optimal operation in distributed networks. The hybrid energy system design is difficult due to the uncertain of supplying power by using renewable energy. These helped in bringing electrical energy production cost to a minimum as when compared to previous situations but utilization of different energy sources makes it still more optimal which leads to hybrid microgrids. These microgrids have many features like more sharing of power of renewable and other energy sources in islanded and grid-connected modes.

From Fig. 2, hydro when compared with Renewable Energy Sources (RES) indicates that the role of RES has been increased. There is more than 10,000MW rise of installed capacity in India when renewables are taken into consideration from 30th June 2017 to 30th June 2018 [2]. This states the importance and growth of RES in terms of contribution to generation of electrical power.

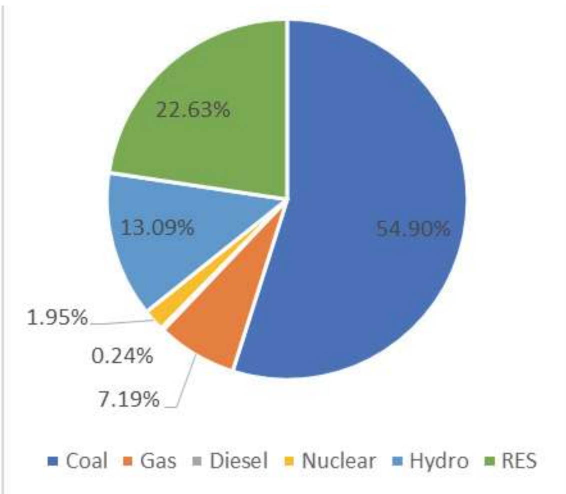

Fig. 2 – *India Installed Generation Capacity by Source (as on 30 November 2018)* [4].

In the next section, economic dispatch of hybrid systems or microgrids is discussed in detail considering several constraints.

2 Economic Dispatch of Hybrid Systems / Microgrids

Economic dispatch challenge is to minimalize the cost of generation. Due to the growing needs of electricity, the generation capacity is also increasing rapidly.

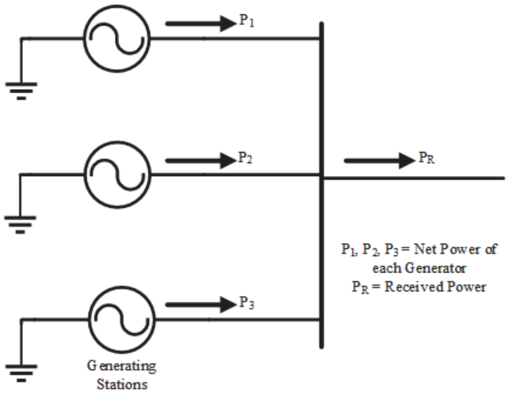

Fig. 3 – *Illustration of economic dispatch.*

Fig. 3 illustrates the basic idea of economic dispatch. The receiving end power, P_R is to be equal to the total sum of the generating stations power to satisfy the load as well as the economic dispatch constraints. Mathematically the relation from Fig. 3 can be represented as

$$P_1 + P_2 + P_3 = P_R .$$

But the increase in loss in terms of heat or in terms of electrical constraints makes the system unbalance and does not meet the economic dispatch criteria. To satisfy these constraints many factors are to be taken into consideration.

MATLAB or commercial optimization softwares are being utilized for many algorithms but are not validated against detailed power flow simulation of microgrid system. The components in the distribution system of microgrid are to be modelled in detail. This modelling includes phase imbalances, single and multiple-phases and physical specifications of transformers, conductors, voltage regulators etc. to confirm that power system constraints are within the safe operational range. The changes between actual power flow and set-points is to be corrected efficiently by the optimizer.

The economic dispatch of a hybrid system or microgrid begins with formulating of the objective function, constraints technically considered, power balancing constraints and additional constraints if any. In the next subsection, basic formulation of objective function is discussed.

2.1. Objective Function

But the primary objective of economic dispatch is to lessen the generation cost. Mathematically [5], to minimize total generation cost (F_T)

$$Min(F_T) = \sum_{g=1}^{N_{gen}} F_g P_g .$$

where F_g is the cost function of a unit g, P_g is the power generated by dispatchable unit g, and N_{gen} is the number of generating units.

The generated power should be as same as the load demand [5] in order to satisfy the economic dispatch

$$\sum_{g=1}^{N_{gen}} P_g = \sum_{d=1}^{N_{load}} LD_d \ ,$$

where N_{load} is the Number of loads and LD_d is Power Demand of the load d.

The negative values of cost function indicate the profit.

The generation, P_g is to be maintained within the minimum, $P_g^{\min}$ and maximum limits, $P_g^{\max}$ given by

$$P_g^{\min} \leq P_g \leq P_g^{\max} \ .$$

2.2. Technical constraints

The AC power is to maintain within the limits in a particular working interval. The DC power is to maintain within the microgrid power limits and the generated power is to be maintained within the range of generated power (maximum and minimum limits of generated power).

The battery state of charging and discharging is to be considered when battery is considered in hybrid system. The power of battery is to be maintained within the minimum and peak limits of discharging and charging.

The technical constraints considered are discussed in brief and are related to power balancing constraints also which is discussed in the next subsection.

2.3. Power balancing constraints

The power injected by main grid along with sum of the generated power by different generation sources should be same as the power demand of all the loads [5]. Mathematically, given as

$$\sum_{g=1}^{N_{gen}} P_g + P_{Main} = \sum_{d=1}^{N_{load}} LD_d \ ,$$

where P_{Main} is the power injected by the main grid.

The power is to be balanced considering generation and load side of the system.

In addition to the power balancing constraints, various additional constraints are to be taken into the consideration which is discussed in next subsection in brief.

2.4. Additional constraints

The microgrid operating in islanding mode can happen during contingency and shutdowns. The AC grid parameters and variables are to be removed from optimization during grid outage at the AC side. The microgrid interface parameters and variables are to be removed from optimization during outage of local microgrid. The outage of both AC grid and local microgrid make the microgrid to operate in isolated mode with the help of available DGs and storage systems.

3 Literature Survey on Economic Dispatch of Hybrid Systems / Microgrids

The cost of operation was reduced by simulating with the help of MATLAB. PSO was implemented in the simulation of the hybrid solar, wind and energy system used for storage [6]. The solar PV as well as wind power output were predicted under different typical weather conditions and results obtained were compared with the proposed optimization method to lessen the cost of operation. The voltage, line flow constraints and reactive power flow limit were considered for every minute sub-interval taking wind, solar and load demand for a forecasting period [7]. The proposed economic dispatch approaches were tested on IEEE 118 and 30 test bus systems with the consideration of non-conventional energy sources variability and load demand.

The economic MPC was utilized to limit the cost while safeguarding forecasting objectives and other constraints to be satisfied [8]. The storage level objectives and energy exchange were met by effectively rejecting scheduling errors over a 24-hour interval by utilizing the proposed strategy for dispatch. Economic dispatch in islanded mode for a microgrid utilizing reduced gradient method was implemented using MATLAB [9]. By limiting the cost function of the system with the contrast between different micro-sources meeting the electrical load demand, the optimization was obtained. Mixed integer linear programming and genetic algorithm was utilized to develop for forecasting economic dispatch of the microgrids [10].

A simple and easy method with the help of reduced gradient method for the analysis of dispatch of the rate of power for isolated microgrid considering wind and solar is considered [11]. The optimal solution considering various practical aspects was found as the total generation costs effects with solar and wind inclusion into the microgrid. The relationship between investment and function cost and energy forecasting of fluctuant solar and wind resources was discussed. The benefits of considering the solar panel renewable energy credits were also discussed. The solution to economic dispatch was proposed using Ant Colony Optimization (ACO) for multiple environments [12] for solving dispatch problem on the generation side. The emission levels and operation cost were minimized by satisfying the load demand of microgrid with the help of combined cost optimization. The dispatch problem was implemented on with and without wind, solar with the help of MATLAB.

A seven-bus microgrid was considered to evaluate the proposed distributed lambda iteration. A new distributed approach for optimal power dispatch was proposed to organize the operation of many micro-units in the microgrid [13]. The distributed consensus algorithm was used for multi-agents and lambda iteration algorithm was utilized for the proposed seven-bus microgrid for economic dispatch problem. The proposed algorithm was used for online as well as offline calculation to survive failures.

The problems and solutions in microgrids pertaining to power quality, distributed generation and hybrid microgrids have been discussed [14]. STATCOM with distributed sources along with storage systems was utilized for compensation of reactive power in the microgrid for the improvement of the power quality. Energy storing systems have dynamic energy and power formulations which effects the overall management of energy and control of the microgrids. Harmonic and voltage compensation control methods for the microgrids were discussed. The economic emission load dispatch problem in present power system was solved by proposing a parallel hurricane optimization algorithm [15]. By protecting the constraints of the system within the range, generating units operating conditions and the transmission line operating above congestion limits were taken into consideration as well. In economic as well as in technical point of view, the proposed algorithm improved the economic operation of the system within the acceptable range of emissions.

A dynamic economic dispatch for each agent was proposed and developed in a community microgrid [16]. The price and demand estimations were considered for each and every agent for optimal dispatch of energy. MATLAB model was utilized for every agent. Linear programming was also utilized for finding the changeover cost based on battery level power dispatch. After the modelling of the microgrid, dynamic economic dispatch for each agent is developed and finally the simulation results proposed showed the effects by reducing the operating costs of active and passive agents. The main objective was to reduce the cost of the fuel when economic dispatch is considered during grid mode operation [5]. The constraint considered to fulfil this objective is by reserving the difference in load demand and difference in the non-dispatching DGs power outputs. Also, the flow limits in the adjacent areas are considered and the power reserve for the islanded mode was considered. The adjustable and fixed droop power-sharing principles were considered for stable islanded mode of operation of the microgrid.

The economic dispatch problem for a microgrid or a hybrid microgrid can be analysed by taking the short-term optimization. A controller can also be considered if required depending upon the parameters involved during analysing the economic dispatch of the system. The short-term optimization module gets the input from the power forecasting and operation selection modules [17]. The operation selection module tries to identify the modes of operation. The different modes of operation are islanded and grid connected modes. The economic dispatch is performed on a nano-grid taking Multi-Port Electronic Interface (MPEI) into consideration.

HOMER Software was utilized to present the techno-economic analysis of the microgrid working under islanded mode [18]. Hybrid system comprising of wind, solar and battery were considered for the analysis of the microgrid. The net present cost and energy cost were presented to study the system performance. The reliability and economic performance of the proposed hybrid system was also analysed by considering the sizing of the wind turbine and PV panels along with the capacity of the battery banks which helped to evaluate the complexity of the economic analysis. Cooperative control and distributed economic dispatch modules were used for each and every bus for the optimization of output of active power for many generators in the distribution network. The active power reference output was calculated for each and every generator utilizing distributed economic dispatch module [19]. The generation constraints are satisfied by receiving the power from the cooperative control module to minimize the cost of operation and generation to demand was balanced. The simulation studies demonstrated the proposed approach effectively.

The economic dispatch was adopted by using bi-level planning method with the objective of reducing the load loss probability, daily fixed cost of investment and excess energy rate for the best placement of microgrid [20]. Also, cost of pollutant disposal and cost of operation taking as another objective to determine the distributed generation output power. Hybrid weighted and modified adaptive genetic algorithms together were proposed to satisfy the multi-objectives and found the optimal solution. The economic dispatch in the microgrid was optimized by using Particle Swarm Optimization (PSO) for the microgrid in grid-connected and stand-alone modes of operation [21]. The main aim of optimization was to minimize the microgrid operating cost by maintaining real power in the grid-connected mode. The load and battery were limited by maintaining real power supply reliably in islanded mode for distributed energy resources.

Deng, Dezheng, and Gengyin Li proposed was to reduce the cost of operation and to minimize the emissions of the DGs [22]. The hybrid system comprising of wind, solar, micro-turbine, battery and fuel cell were considered for the economic operation of the DC microgrid. The aim was fulfilled by improved hybrid PSO for solving and also by considering DC microgrid characteristics like environmental and economic cost, net loss, and various constraints. The multi-microgrids economic concept was considered to formulate as a problem for optimization [23]. A probabilistic and stochastic modelling of energy resources under small scale and load demand at the microgrids was performed. Based on the minimum cost, the transaction of power between main grid and microgrids was done to govern the best economic operation of the microgrid. The cost function was minimized using PSO as an algorithm to optimize. Also, the total operation cost of distribution network in the future was reducing due to the power sharing between the main grid and the microgrids. The habitat immune genetic algorithm was used to increase the convergence speed accuracy when compared to other optimization methods to calculate the optimal economic dispatch of microgrid [24]. The DGs utilized here are wind, photovoltaic, micro gas turbine, gas turbine, fuel cell and water turbine considering in both the modes of operations of microgrid which are: grid connected and standalone mode.

The main objective was to formulate the economic dispatch considering hybrid system comprising of solar and energy storage system to ensure in meeting the daily load demand [25]. With the help of MATLAB based quadratic programming, dynamic economic dispatch was carried out on the hybrid system in direction to encounter the daily load demand. Zhang, Ying, et al proposed was for scheduling effectively the energy sources to minimize the cost of operation to satisfy the electrical load demand [26]. The uncertainties in generation of electricity using renewable due to climatic conditions and the load demand and the highest pricing scheme were considered. The randomized and deterministic algorithms were used for evaluation in case of generators. Experimental evaluations with real-world suggestions showed that the online algorithms used were achieving nearly offline best performance.

The economic benefit is maximized by reducing the utilization cost of the storage system using Model Predictive Control (MPC) [27]. Many concepts like degradation and lifetime costs, start-up/off costs and maintenance & operation costs of the hybrid energy system used for storage are considered. Long-term scheduling is performed on the hybrid system in grid connected mode of operation. Mixed logic dynamic framework is utilized to model both discrete as well as continuous dynamics and also the switching between different operating conditions. MPC problem was solved by using Mixed Integer Quadratic Programming taking integer variables into account. The hybrid wind, solar systems along with battery banks were considered to ensure the annual cost of the system and the essential power supply loss probability was satisfied [28]. The decision variables comprised during the optimization were PV module slope angle and number, wind turbine installation height and number and battery capacity.

The probabilistic approach of economic dispatch was considered for islanded hybrid microgrids [29] at minimum operation cost. During analysis, battery was integrated and energy demand was investigated. The models and approach were tested utilizing different operations referring to test hybrid microgrid system. A genetic algorithm based multi-objective optimization technique is implemented towards techno-economic approach of the DC microgrid [30]. The wind-photovoltaic hybrid system with centralized battery backup is considered for the optimization. The cost and availability of the hybrid renewable energy systems provided a general model to quantify and were formulated to find the best solution. This method guaranteed a reliable supply of energy with least investment.

The operation of microgrid was optimized using smart energy management system which comprised of power forecasting, optimization modules and energy storage [31]. The distributed generators and storage systems for energy are considered to optimize the power production and for minimizing the operating costs of the microgrid. The economic dispatch was optimized using genetic algorithm based on matrix real-coded for reaching load management comprising operational policies and to produce diagrams of energy storage and distributed generation systems. The sharing of supply demand balance in a microgrid during uncertain conditions using Dynamic Economic Dispatch model (DED model) was developed [32]. The changes in contraction of tie-line flow between the microgrid and the utility grid is prevented by energy band operation. The over- & short-supply risks are prevented by chance-constrained approach caused by demands which are unpredictable in the microgrid. The operation cost versus ramping capability was determined with the help of this approach in microgrid under power demands which are uncertain.

The microgrid comprising of virtual power plant with configuration of lumped loads along with several types of Distributed Generation (DG) units were considered for economic operation of microgrid [33]. The main objective was to maximize the profit by minimizing cost of the electrical energy totally required for generation by DGs. The fuel cost, emission cost, operation and maintenance cost were considered as the main aim to minimize generation cost of each DG with the help of cuckoo search algorithm [34]. The results were compared with other algorithm like PSO for better global convergence to obtain a best optimal solution to reduce system emission and generation cost.

Virtual energy storage (VES) system model was proposed based on the buildings by using the stored heat ability of the building [35]. The VES model was then integrated with economic dispatch dynamically of hybrid energy microgrid to reduce the daily operation cost by adjusting the temperature within the building as per the customer comfort for temperature for managing charging as well as discharging of VES system. The best economic dispatch of microgrid in the grid connected mode comprising solar, wind and diesel power sources was proposed [36]. Demand response based on incentive was proposed for the optimal operation of microgrid in the grid connected mode which obtained limiting cost of the power during transaction transferred and the fuel cost of the generation by developing a mathematical model. Also, the sensitivity analysis was also performed on the system.

The global optimum was obtained without central coordinator considering interconnection of microgrids connected to each other [37]. The DED was handled flexibly presenting fully distributed algorithm for the economic dispatch locally but few information exchanges within the neighbouring microgrids. The numerically analysis was performed considering feasibility and adaptability in self-adaptive way.

Table 2
Different approaches for economic dispatch based on objective function.

Ref.	Objective	Constraints Considered
[5]	Reduce fuel cost	By reserving the difference in load demand and difference in the non-dispatching DGs power outputs
[7]	Economic dispatch in real time scenario	Voltage, line flow and reactive power limits for minute to minute intervals
[8]	Safeguard forecasting and power constraints	Battery State Of Charge (SOC) and battery temperature

Table 3
Different approaches for economic dispatch based on optimization.

Ref.	Objective	Method used	Constraints Considered
[6]	Reduce cost of operation	Particle Swarm Optimization (PSO)	Typical weather conditions of solar and wind
[10]	Meet the load demand and forecasting of microgrids	Mixed Integer Linear Programming and Genetic Algorithm	Equipment loading, unit constraints and voltages
[11]	Economic dispatch	Reduced Gradient Method	Solar and wind energy forecasting due to typical weather changes
[12]	Dispatch problem on generation side	Ant Colony Optimization (ACO)	Power generation satisfying load demand
[15]	Improve economic operation	Parallel Hurricane Optimization	Transmission line operating above congestion limits

The **Table 2** gives an overview on different approaches for economic dispatch based on objective function.

The **Table 3** gives an overview on different approaches for economic dispatch based on optimization.

4 Conclusion

This paper presents an overview of different methods of implementing economic dispatch using various optimization methods for a hybrid microgrid. The review is mainly focused on economic aspects of implementing hybrid microgrid with respect to electrical energy utilization concern. The various existing methods give an idea to the researchers for implementation of hybrid microgrid increasing by considering technical and additional constraints involved along with technical issues.

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