ENERGY MANAGEMENT IN MICRO-GRID WITH ENERGY STORAGE SYSTEM

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Abstract: Micro-grid (MG) is a grid formed by renewable sources. MG is a small scale network of low voltage also the renewable sources are distributed energy resources (DER). A MG gives clean energy. MG can have two operational modes, the islanded mode and grid connected mode. This paper reviews the optimal energy management for a MG under various constraints. The authors aims to optimize fuel cost, manage peak load and reduce gas emissions by scheduling generation of DERs in each hours or for time t. MG model includes battery as a storage device, hence the battery life is studied. DERs are wind and solar which are whether affected. The model is solved for time t and by deterministic approach to use to solve the models.

Index Terms: Energy Management and Storage, MG, DER.

I. INTRODUCTION

DERs are installed to establish green and smart distribution system with the use of renewable energy resources. The source mostly used in DERs are wind, solar, micro-hydro, bio-gas etc which are non-controlled energy sources with diesel generator, fuel cell, micro-turbine, and energy storage system (ESS) According to the US Department of Energy [1], relying on the advanced communication tools and power electronic control devices, the utilization of DERs is potentially in favour of increasing the energy utilization efficiency, mitigating the power flow congestion in distribution system, improving the system stability and reliability, providing more benefits in both economic and sustainability reasons, and strengthening the centralized control for grid operation.

As compare to large power grid, a single and small DER is considered as a non-regulated energy resource. If such source is integrated into the power grid, there are voltage fluctuations and it may affect power quality. Also if the fault occurs in the main grid single DER needs to be disconnected instantly. This is the main disadvantage and it limits the performance of DER to a large extent. Therefore a MG concept is introduced. In energy management system of a MG it needs to optimize the model in terms of cost also it needs to plan a Generation schedule for each unit in each hour on the next day, minimize harmful gas emissions, improve energy utilization efficiency, maximize MG operation profits under different operational conditions.

To achieve these goals the constraints are total power supply should be equal to the load demands in each time interval and each DER unit should operate within its minimum and maximum limits. A time interval is normally set to 15 minutes, 30 minutes or 1 hour. The state variables are the forecasted wind and solar generation in each hour on the next day, the forecasted market electricity price on the next day and also the load demand forecasting.

II. ENERGY MANAGEMENT IN A MG

DERs and energy saving system (ESS) provides clean energy in distribution grid and MG which can improve the energy utilization efficiency and stabilize the system voltage and frequency. There are several types of ESS such as the flywheel, super capacitor, battery and so on; battery is most commonly used one due to its low cost and its convenience of installation and maintenance. A fact
emerges in MG energy management model that the battery state of charge (SOC) in each hour depends on the SOC in the previous hour. Hence, the batteries SOCs in each two adjacent hours are correlated and the optimization model is constrained by a dynamic programming. The simplified expression of the model is as shown

Objective function

\[ F = f(x, u, d) \]  \hspace{1cm} (1.1)\\

Subjected to

\[ c_E(x, u, d) = 0 \]
\[ c_I(x, u, d) \leq 0 \]
\[ x_{i+1} = g(x_i, u_i, d_i) \]

where \( x \) is the state variables representing the active power output of all generators; \( u \) is the control variables such as the excitation current of a generator which can adjust the power output; \( d \) is the disturbance variables, such as the load changes or wind speed changes affecting wind turbines. \( F \) is the goal function minimizing the fuel cost, and the cost value is a function of state variables, control variables and disturbance variables; \( c_E \) is the equality constraint and \( c_I \) is the inequality constraint. The last constraint indicates that the current state vector is a function of the state variables, control variables and disturbance variables in the previous interval. The system states in time interval \( i \) and \( i+1 \) are correlated. In this case, the model is determined as a multi-parametric nonlinear programming constrained by dynamic programming, [2] for the optimization of MG energy management various algorithms were proposed [3-8].

In reference [4], the author clearly stated the model and cost function of each type of DER. GA-based algorithms and game theory is used to obtain the optimal solution. An MRC-GA optimization module was proposed for search optimal generation schedule in reference [5] and particle swarm optimization (PSO) technique was implemented in references [6-7]. A modified dynamic programming method was considered in reference [7], but the author simplified the model by replacing some important stochastic variables with fixed values. Since the development of MG is still in an initial stage, technologies related to the optimal energy management in MG are not matured and numerous researchers have contributed diverse and valuable ideas. In this model the dynamic performance of the battery is considered and the advanced dynamic programming (ADP) method is used to solve the model featured as multi-parametric nonlinear programming constrained by dynamic programming. In some cases the model consists of the performance of the battery, some researchers used heuristic algorithms to search the optimal solution which is slow and cannot guarantee the accuracy, while some references did not include the battery in their model. The ADP method was first proposed in 1999 by C. R. Dohrmann and R. D. Robinett [8], and later in 2005. This method was discussed in [9], and it is proved to have great results in the optimization of complex dynamic systems. In this model life of the battery is included so as to avoid overuse of battery, extend the battery service life and thus reduce the cost spent on batteries. In some papers only the capital cost of the battery is included, while in papers the optimization is done only to reduce the fuel cost and satisfy the load demand but the life of battery was neglected. The model is designed for the hourly management of energy using ADP algorithm and considering the dynamic performance of battery.

### III. DISTRIBUTED ENERGY RESOURCES IN MG

Smaller energy sources in a MG are called as Distributed Generation (DG) units, and form part of the Distributed Energy Resources (DER). Generally non-conventional energy sources such as solar, micro-hydro and wind sources are most commonly used. Stand alone units are already in operation at many places even availability of solar, water and wind is continuous. Islanding operation is costly and not reliable. Hence hybrid energy system is formed. A system with combination of different sources provides balance and reliable and stable supply. The
main aim is to provide 24h quality power in remote areas. In this system solar photovoltaic (PV) array, wind system and micro-hydro system is considered along with the battery as a energy storage system (ESS). Different system developments in hybrid energy system are published in [4]. A simple numerical algorithm was used for unit sizing and cost analysis of stand-alone wind, solar PV system is explained in [5]. In [6] linear programming techniques was developed for optimal design of hybrid system. In [8,9] various aspects of hybrid power system including optimal sizing and operation is detailed. A probabilistic performance of stand-alone Solar PV, wind energy system with several wind turbines with same and different sizes and PV models with battery storage system has been presented [10]. A hydro-based system in synchronism with wind energy was discussed in [11].

Methodology

The objective of the system is to minimize the fuel cost, minimize harmful gases, and improve energy efficiency by providing reliable and quality power. These goals are subjected to the constraints that the total power supply should be equal to the load demands in each time interval and each DER unit should operate within its minimum and maximum limits. There are different energy management systems (EMS) that give optimized model of the MG system to fulfil the goal. EMS system is Zhou Xue et.al. Has explained hybrid control method for whole micro-grid and systematic control design of micro-sources in grid connected mode and islanded mode. Control approach is by Finite hybrid Automata (FTA) for micro-grid system For single micro-grid different control strategies are used to maintain stable output, such as PQ control, Droop control etc.[12] J.Toyoda et.al. Discusses the DG grouping in order to harmonized the investment of assets, quality of power supply and the co-operation of the existing power grid. [13] discusses security enhancement of the multiple DGs by harmonized grouping. S.Ashok gave optimized model for energy component for rural community by minimizing the life cycle cost. This model helps in sizing the hybrid energy system. H.M. Khodr and et.al. presents the methodology approach to formulate and solve the problem of determining the optimal resource allocation applied to a real case study in Budapest Tech’s. The problem is formulated as a mixed-integer linear programming model (MILP) and solved by a deterministic optimization technique CPLEX-based implemented in General Algebraic Modelling Systems (GAMS). The problem has also been solved by Evolutionary Particle Swarm Optimization (EPSO).[15]

Optimal Power System

The hybrid system is complex because of uncertain renewable supplies, load demand, nonlinear characteristics of components. The operation methods and sizing of hybrid system are interdependent. This calls for an optimization of the hybrid system.

A. Sizing of System

S. Ashok suggested unit sizing by numerical algorithm, which minimizes the capital cost \(2^n-1\) combinations of renewable sources. For this the constrained that are considered here are, availability of energy sources, load-demand supply balance, minimum and maximum operating limits of the units.

In this paper the system uses micro-hydro, wind and solar as renewable sources. To minimize the capital cost the equation is [14].

\[
C_c = \sum_{h=1}^{N_h} C_h + \sum_{w=1}^{N_w} C_w + \sum_{s=1}^{N_s} C_s + \sum_{b=1}^{N_b} C_b
\]

Where \(C_c\) is the total capital cost and \(N_h, N_w, N_s, N_b\) are total number of micro-hydro, wind, solar and battery units respectively.

The equations for micro-hydro unit is

\[
P_h = \eta_{hyd} \cdot \rho_{water} \cdot g \cdot H_{net} \cdot Q
\]

Where \(\eta_{hyd}\)the hydro efficiency is can be obtained from manufacturer’s datasheet. \(\rho_{water}\) is density of water, \(g\) is the acceleration due to gravity, \(H_{net}\) is the effective head, \(Q\) is the flow rate.
The wind power output is
\[ P_w = \eta_t \times \eta_g \times 0.5 \times \rho_a \times C_p \times A \times V_r^3 \]
Where \( V_r \) is the wind velocity, \( \rho_a \) is the air density, \( C_p \) is the power coefficient of wind turbine, \( A \) wind turbine rotor swept area, \( \eta_t \) and \( \eta_g \) are the wind turbine and generator efficiency respectively.

The output power of the solar PV array,
\[ P_{PV} = \eta_{PV} \times N_{pwp} \times N_{pv} \times V_{pv} \times I_{pv} \]
Where, \( \eta_{PV} \) the conversion efficiency of the PV module, \( V_{pv} \) and \( I_{pv} \) are the operating voltage and current of the PV cell, \( N_{pwp}, \) and \( N_{pv} \) are the parallel and series PV cells.

The state of battery is given by the equation

Battery discharging equation.
\[ P_b(t) = P_b(t-1) \times (1 - \sigma) - (P_h(t)/\eta_i - P_l(t)) \]

Battery charging equation.
\[ P_b(t) = P_b(t-1) \times (1 - \sigma) - (P_h(t) - P_l(t)/\eta_i) \times \eta_b \]

Where \( P_b(t-1) \) and \( P_b(t) \) are the battery energy at the beginning and the end of interval \( t \), respectively. \( P_l(t) \) is the load demand at the time \( t \), \( P_h(t) \) is the total energy generated by the Renewable sources at time \( t \). \( \eta_i \) and \( \eta_b \) are efficiency of inverter and battery.

The hybrid power generated at time \( t \) is [15]
\[ P_t = \sum_{h=1}^{N_h} P_h + \sum_{w=1}^{N_w} P_w + \sum_{s=1}^{N_s} P_s \]

Here, the objective function becomes, from eq.(1.1)
\[ F = f(x,u,d) \]

Where \( x \) is a state variable, i.e. output power of the renewable sources that are considered. \( U \) is the control variable, that is excitation current in generator etc, \( d \) is the disturbance factor, like wind speed, solar irradiations, Load demand etc.

Thus the cost function (either capital cost or operating cost) is a non-linear equation, contains state variable, control variable and disturbance variable with equality and inequality constrain, such as maximum and minimum power generation, charging time of battery, constant voltage irrespective of variable load demand, constant frequency, etc.

B. Optimal Operation

The combinations of various renewable generators with the constraints such as battery backup, load balancing, availability of resources should be such that, it should be able to dispatch power at minimum cost. The strategy should be such that, battery should charge when there is excess of renewable energy, and it satisfies the demand. And if load exceeds the renewable energy battery should discharge. S. Ashok suggested to minimize the operating cost based on the operating cost of the renewable sources for the interval \( t \) in a day and the battery units for the hourly interval \( t \) (\( t=1-24 \)) respectively. The operational costs are calculated on the basis of component characteristics, size and efficiency. Total annualized life cycle cost is summation of operating cost and capital cost. Yoash Levron et.al. suggested that instead of minimizing a function within a constraint, we can consider stored energy as a resource to be allocated. His view is to solve the problem as a allocation problem: energy is allocated in the time domain to optimize power import at the point of coupling. Stored energy is controlled to balance the power of loads and renewable sources, over the time domain, minimizing the overall cost of at the PCC[16]. For optimal operation, J.Toyoda,et.al has suggested harmonized grouping. The grouping discussed are 1. Isolated DG grouping for the concentrated demand, 2. Isolated DG grouping for the distributed demand. 3.Multiple DG plants to multiple demands through the utility network. H.M Khodr and et.al formulated linear model of optimal dispatch of power with two types of variables, continuous and binary. The problem is solved by two methods by mixed integer programming and evolutionary particle swarm optimization. Compared two results. Fernando A. Inthamoussou et.al uses Super capacitor as a energy storage system. He proposed an SM control strategy for bidirectional
dc/dc converter for energy storage system based on super capacitor in the context of micro-grid application with all operating conditions: start-up, constant power, and voltage limitation.[15]

IV. CONCLUSION AND FUTURE SCOPE

Various work has been done on renewable energy sources, micro-grid and energy storage system. Also various algorithms are introduced to minimize the cost function of micro-grid. Future work can done on optimal power flow in micro-grid and energy storage with non-deterministic approach. Battery charging and discharging can be controlled by different control system like Sliding Mode (SM) control, either by stochastic or heuristic approach to minimization of cost function of the DGs by considering the constraints as a random variable. In the connect-disconnect operation of DGs there should be communication protocols should deal with topology reconfiguration. In some case due to the topology change, the network resources (e.g. bandwidth) may need to be reallocated to optimize performance. Also smoothly updating the existing protocol is a challenge.

REFERENCES