ENERGY MANAGEMENT IN MICROGRID

Y.Nandini[1], Dr.CH.PadmanabhaRaju[2]
[1]PG Scholar, [2]Professor
[1] Dept. of Electrical and Electronics Engineering,
[1] P.V.P.Siddhartha Institute of Technology, Kanuru, 520 007, Vijayawada, India ,

Abstract : Micro-grid is a grid formed by renewable sources. A microgrid is a low voltage and small-scale network containing both distributed energy resources and load demand. The microgrid consists of a fuel cell, microturbine, photovoltaic, wind turbine and energy storage system. Among the other renewable power sources, wind and solar have recently consummated a precipitate growth around the world. The objective of the optimization model is to meet the load demand and to scheduling generation of DER's in each hour on the next day. Considering the dynamic performance of battery as Energy Storage System, the model is proposed to be solved by using the Advanced Dynamic Programming (ADP) method. Moreover, since wind and solar generation is a stochastic process affected by weather changes, the proposed optimization model is performed hourly to track the weather changes. Therefore, it is necessary to manage the energy from this type of distributed energy resources to optimize its usage in an optimal manner.

***IndexTerms* - Micro grid, Energy management and storage, DER**

I. INTRODUCTION

Recently, the increase of fuel price and the development of renewable energy technologies give more opportunities for using the renewable sources in micro grid. In order to increase the economic efficiency and reliability of the micro grid, energy management system (EMS) is necessary to be taken into account [1]. Micro grid is considered as a isolated controllable system that impart both power and heat to its local area. A micro grid can operate as part of the system grid or in islanded mode. An Energy Management System (EMS) is a computer-aided tool used by power system operators to monitor, control, and carry out the optimal energy management [2]. The purpose of EMS is to produce demanded power with least cost and least environmental effect.

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, biogas etc, which are noncontrolled Energy sources with diesel generator, fuel cell, micro-turbine, and energy storage system (ESS). As compared to a large power grid, a single and small DER is considered as a non-regulated energy resource. If such a 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 an MG concept is introduced. In energy management system of an 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, curtail harmful gas effusion, improve energy usage efficiency, increase MG operation profits under divergent operational conditions.

As clean energy is promoted in distribution grid and microgrid for building a green and sustainable environment, ESS gains more and more concentration than before due to its coordination with DERs, which can improve the energy utilization efficiency and stabilize the system voltage and frequency [3]. Various types of ESS such as the flywheel, supercapacitor, battery and so on, the battery is the most used one due to its low cost and its convenience of installation and maintenance. A fact emerges in microgrid energy management model that the battery state of charge (SOC) in each hour depends on the SOC in the previous hour. Hence, the battery SOCs in every two adjacent hours are coordinate and the optimization model is constrained by a dynamic programming.

1.1 BASIC SYSTEM CONFIGURATION

A microgrid is a low-voltage and small network connected to a distribution grid through the point of common coupling (PCC) and contains both distributed generations and loads. Several types of distributed energy resources are used in a microgrid, such as a microturbine, fuel cell and energy storage system as controllable units. Renewable energy, such as wind energy and photovoltaic, are also included in a microgrid as non-controllable units.

The microgrid operates in a stand-alone mode, the power generation produced within the microgrid is required to satisfy its local load demand. In this paper, the optimization model of EMS in a microgrid is to plan a generation schedule for each unit in each hour on the next day with the objectives shown below:

- Minimize the fuel cost.
- Minimize harmful gas emissions.
- Improve energy utilization efficiency.

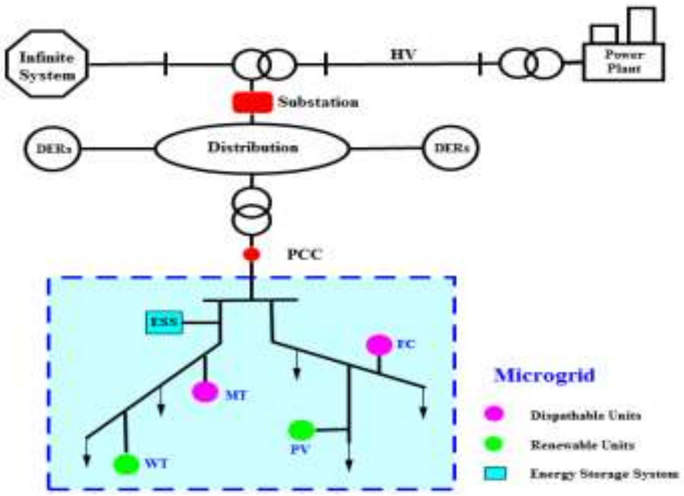


Fig. (1) A typical micro grid interconnected with the main grid

These objectives 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. A time interval is normally set to 15 minutes, 30 minutes or 1 hour. Some information should be known in advance for a day-ahead energy management, such as the DER parameters, 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. Then, the prepared data are sent to the EMS optimization engine as inputs. Finally, the outputs from the optimization engine show the best generation schedule for the next day.

2. OPTIMIZATION MODELING

The major difference between the energy management in a conventional power grid and a microgrid is the algorithms used within the optimization engine shown in fig (2). The hourly energy management model is implemented by using ADP algorithm and considering the dynamic performance of a battery.

The majority of the models work for day-ahead energy management and few discussed the hourly or real-time energy management in a microgrid. The inclusion of wind generation or solar generation brings stochastic events into the model, so a day-ahead model may lose accuracy due to the external weather changes, whereas an hourly rendition could lane the actual circumstances and mitigate the errors between the scheduled generations and actual generations of DERs.

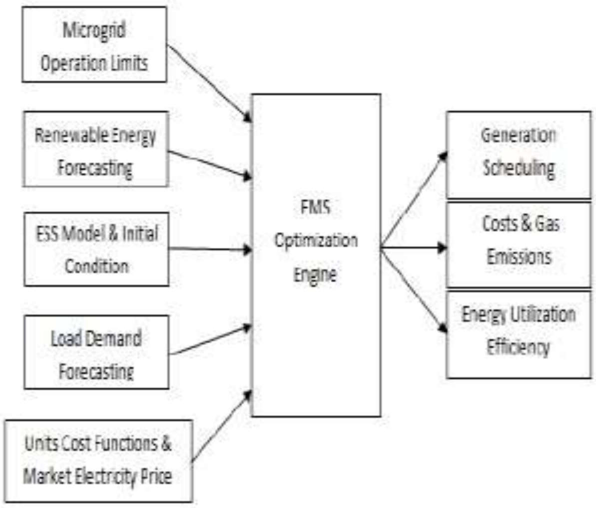


Fig. (2) EMS optimization in a micro grid

2.1 Photovoltaic (PV) System configuration

Photovoltaic (PV) is another clean energy source used in a power system, which absorbs the solar irradiation and converts it into electric energy. The utilization of PV in power system is able to reduce the fuel cost and gas emissions. In this paper, the silicon type PV is used in the microgrid.

$$I = I_{PH} - I_D - I_{SH} \quad (1)$$

According to [4] the shunt current can be expressed by equation (2):

$$I_D = I_0 . e^{\frac{qV_1}{A_0 kT} - 1} \quad (2)$$

Where I_{ph}: Generated current by absorbing solar energy; I_D: Current through the diode; Ish: Current through the shunt resistance; I0: Cell reverse saturation current; q: Electron charge, equals to 1.6e-19; 1V: Open circuit voltage; A0: Curve fitting constant; k: Boltzmann constant, equal to 1.38e-23; T: Temperature.

2.2 Wind generation forecasting

Due to the advanced technology of wind turbines, wind generators are widely used as a clean energy source in power systems. Doubly-fed induction generator (DFIG) is the most popular wind turbine used in current power industry due to its medium cost, high generation capacity and variable operational speed.

The generation of wind power depends on the wind speed. According to reference [5], the relationship between the active power generation and wind speed can be expressed by equation (3**).**

$$W_P = 0;\ E_{actual} < E_{cut-in}$$

$$W_p = aE_{actual}^2 + bE_{actual} + c;\ E_{cut-in} \le E_{actual} < E_{rated}$$

$$W_p = rated\ power;\quad E_{rated} \le E_{actual} \quad (3)$$

Where Wp: Wind turbine active generation; E_{actual}: Actual wind speed; E_{cut-in}: Cut in wind speed; E_{rated}: Rated wind Speed.

2.3 Micro turbine modeling

The microturbine is a term for the gas turbine which has a small size and high speed. According to [6], the cost function of Microturbine is expressed as

$$C_{MT} = C_{ng} \sum_j \frac{P_j}{\eta_j} \quad (4)$$

C_{MT} : Cost of the microturbine generation; Cng: The natural gas cost deliver to the microturbine; Pj: The power output during time interval j; ηj: The efficiency of the microturbine at interval j.

2.4 Fuel cell modeling

The Fuel cell is one type of distributed energy resources which converting the chemical energy into electrical energy through an oxidation reaction. Based on reference [7], the cost function of fuel is shown in equation (5),

$$C_{FC} = C_{fuel} \sum_j \frac{P_j}{\eta_j} \quad (5)$$

Where C_{FC} : The cost of fuel cell generation; C_{fuel} : The fuel cost; Pj : The power output during time interval j; ηj: The efficiency of the fuel cell at interval j.

2.5 Energy storage system modeling

Energy storage system (ESS) is one of the devices to store the surplus energy and deliver the stored energy during the peak load periods. ESS is usually coordinated with a wind farm or a group of PV cells and stores the surplus energy. In this paper, the lead-acid battery is chosen and modeled. SOC stands for a state of charge and is a percentage value. To avoid over-use or overcharge, the SOC of a battery is set between 20% and 100%. The variation of SOC depends on the charging or discharging power, the charging efficiency and battery storing capacity. The SOC at time t+1 equals to the SOC at time t subtracting the SOC variation during this interval.
Hence, the SOCs of each two adjacent time intervals are related shown in equations (6, 7)

$$soc(t+1) = soc(t) - \frac{\eta_t P_{ess(t)}}{w_{ess}} \quad (6)$$

$$\mathrm{soc}^{\min} \leq \mathrm{soc}(t+1) \leq \mathrm{soc}^{\max} \tag{7}$$

Where η_t : Charging or discharging efficiency; Wess: Battery reserve capacity; Pess (t): Battery output power at time t.

3. Optimization model for energy management in micro grids

The load demands in a micro grid are satisfied by its local generation. Let S_i is a state variable involve in the power output of discharge units at time interval i; let v_i be a decision vector consisting of the planning generation for each dispatchable unit; function Θ_i is the cost function at time period i. To reduce the total cost, the recommended formulations are shown in equation (8):

$$\min \quad \Theta = \sum_i^{M-1} \Theta_i(s_i, v_i) + \Theta_M(s_M) \tag{8}$$

Transformation of formulations is:

$$s_i = [P_1(i) \quad P_2(i) \quad \ldots \quad P_m(i) \quad P_{ess}(i) \quad soc(i)]^{\mathrm{T}} \tag{9}$$

$$V_i = [\Delta P_1(i) \quad \Delta P_2(i) \quad \ldots \quad \Delta P_m(i) \quad \Delta P_{ess}(i)\ ]^{\mathrm{T}} \tag{10}$$

$$\Theta_i(s_i, v_i) = s_i^T z_i + s_i^T w_i s_i + J_i \tag{11}$$

$$\Theta_M(s_i) = s_M^T z_M + s_M^T w_M s_M + J_M \tag{12}$$

The dimension of the state vector is m+2, while the dimension of the decision vector is m+1. In the cost function Θi, the vector Zi, matrix Wi and constant are related to the cost functions of the DERs used in microgrid [8].

For a specific stage, it contains several system states determining the current stage's cost. Then, a set of decision variables acts on the current states and generates new system states for the next stage. This procedure repeats until the last stage. The overall purpose is to find the best path of states transitions leading to a minimal summation of costs of all stages.
MSDP can be formulated with equations (13, 14)

$$s^{k+1} = f^k(s^k, v^k), s^k \in S, v^k \in V, K \in \{0,1, \ldots . M-1\} \tag{13}$$

$$J^M(S^M) = \min_{V^0 \ldots V^M} [g^M(S^M) + \sum_{k=0}^{M-1} g^k(s^k, v^k)\ ] \tag{14}$$

where k : The number of time intervals; S^k: The state vector at stage k ; V^k: The decision vector at stage k ; f^k: The state transition functions; g^k : The cost function of the state and decision variables at stage k ;J^M : The summation of costs of all M stages.

The ADP method is determined to have a great execution for discrete-time optimal control constrained by dynamic programming and broadly applied into real guidance problems. In this paper, the ADP method is chosen as the tool for solving the proposed model. The parameters used in the microgrid are given in the below table.

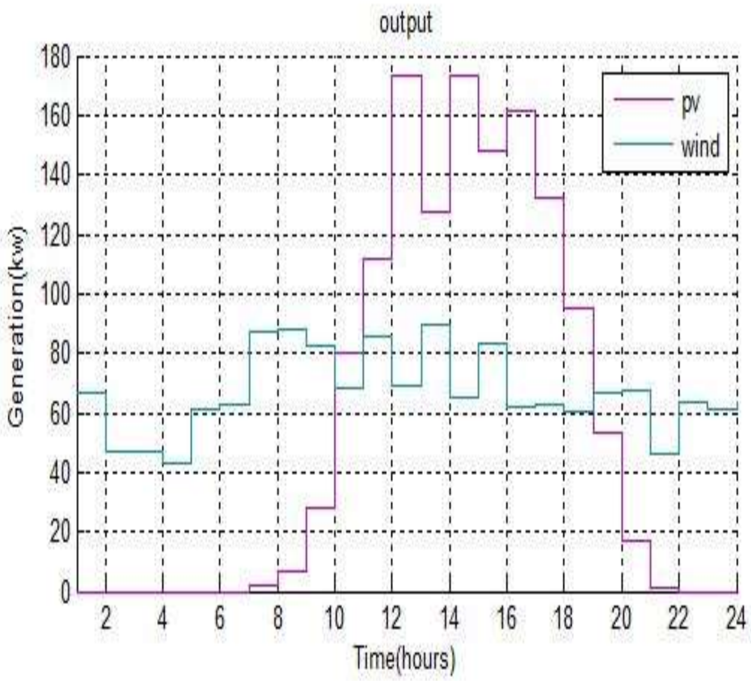
TABLE 3.1 Installed Distributed Generations

Unit Type	Min Power (kw)	Max Power (kw)
Photovoltaic	0	200
Micro turbine	1	10
Wind turbine	0	100
Fuel cell	1	10
ESS	-20	20

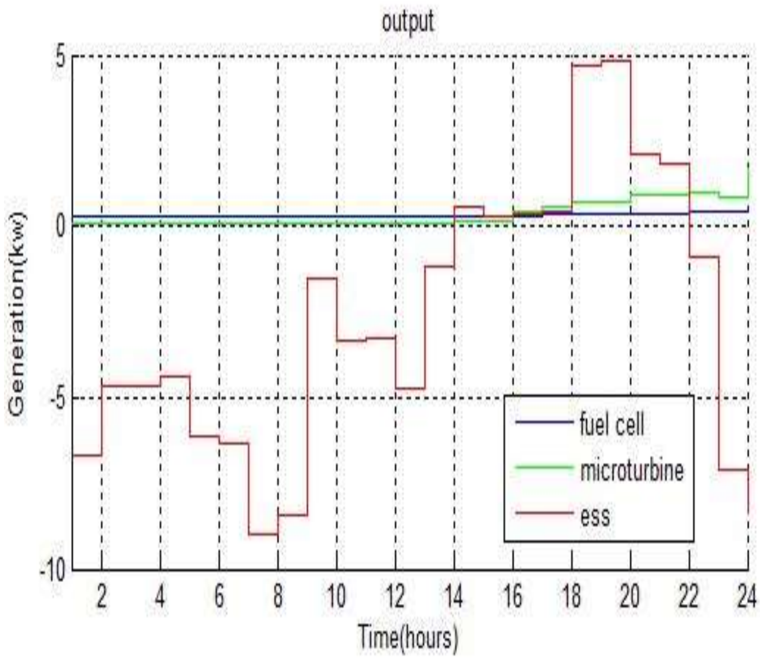
The variation between the day-ahead model and the hourly model is that the next 24hours wind generation should be forecasted persistently in each hour and the optimization engine is passing in each hour. The wind generation is calculated by the forecasted wind speed, and the forecasted wind speed for the next 24 hours can be examined abruptly from the website resource [9].

RESULTS

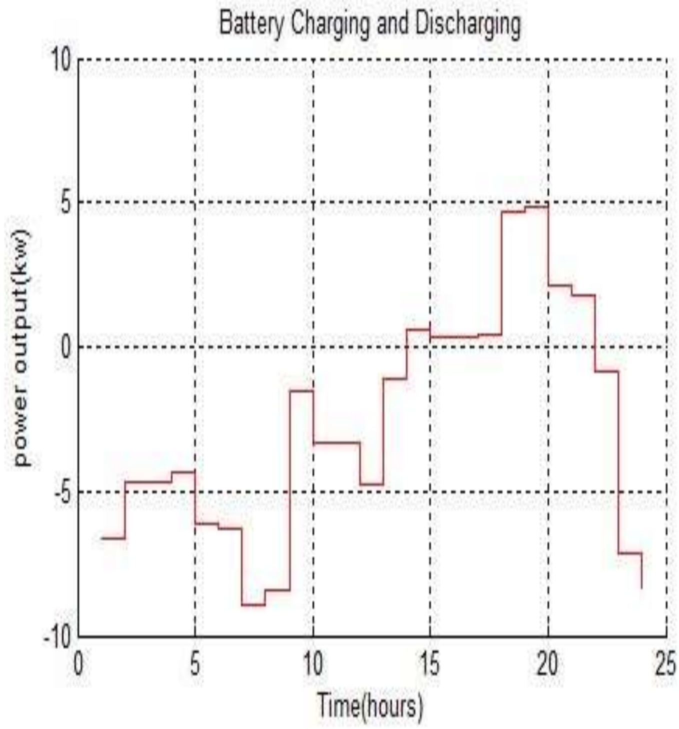
1) Hourly scheduling results



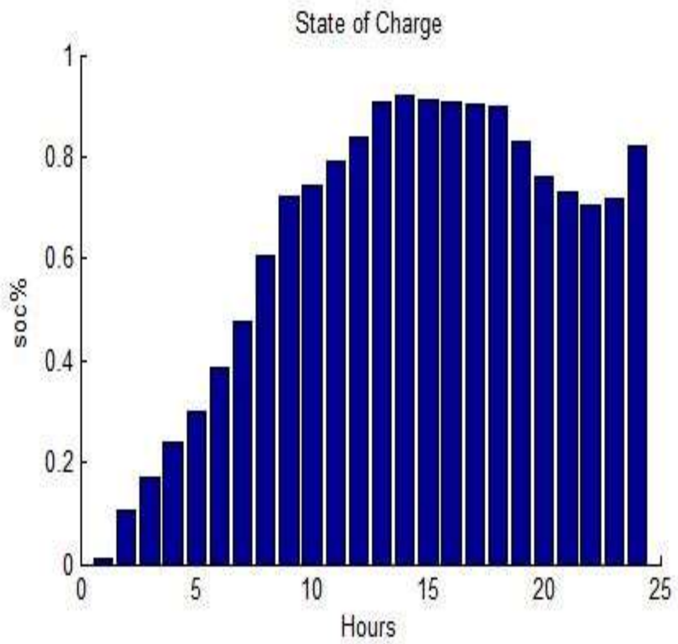
a) PV and Wind Results of hourly model



b) Results of Actual generation for DERs



c) Battery discharge and charge rate



d) Battery state of charge

CONCLUSION

The optimal energy management for a microgrid is studied. The aspiration is to schedule the generation for every unit in every hour on the following day in order to unite the load demand without any omission and to minimize the fuel cost, mitigate gas emissions and improve energy usage efficiency. The microgrid operates in stand-alone mode. The load demand on the system is less, the battery stores the energy, most of which comes from the photovoltaic and wind turbine. When the load demand is more, the battery discharges power to the microgrid and liberate the generation essence of fuel absorb units. From the results it can understand the battery charging and discharging frequency is mitigated in order to maintain a good utilization sequence and avoid over-use. During 2:00 am to 6:00 am, the battery reserves power from the wind generation; from 7:00 am to 9:00 am when the load is steadily rising and the solar generation is less, the battery discharge power; from 10:00 am to 5:00 pm when the solar generation is more, the battery hibernates; during 7:00 pm to midnight when the load demand is low and the solar generation is lost, the battery charge power. The ADP algorithm is used to solve the energy management model presented as multi-parametric nonlinear programming constrained by dynamic programming. The ADP algorithm works efficiently for the microgrid energy management problem. This algorithm is demonstrated to be efficient, fast and easy to converge.

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