Microgrid Modeling Approaches for Information and Energy Fluxes Management based on PSO

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Abstract: In order to improve the reliability, stability and economy of power supply of a microgrid, some fundamental work on microgrid energy management method is carried out. Firstly, models of microgrid components under steady state are established in MATLAB/SIMULINK. Secondly, an operation cost function of microgrid is proposed, together with the constraint conditions. Then, in order to solve the energy management problem, Particle Swarm Optimization (PSO) is declared by using m-files programming. The algorithm will be explained in chart flow and pseudo code. Finally, a simulation scenario is designed to show the good performance of this control method.

1 INTRODUCTION

As the global energy crisis and environmental problems are becoming more serious, much attention has been paid to renewable energy generation such as wind power, solar power, etc. Safety stability problems will be likely to occur if these power resources are directly connected to the power grid. In order to make full use of renewable energy generation, the microgrid (MG) is generated in the field of distributed generation. In general, a microgrid can be defined as a combination of Distributed Energy Resource (DER) units, which include Distributed Generation (DG) units and Distributed Storage (DS) units, and loads.

Microgrid is an independent and controllable system and can achieve flexible conversion between the grid-connected mode and the stand-alone (or islanded) mode. A microgrid is able to switch between these two modes. In the grid-connected mode, the main grid can provide the compensation of power short supply to the microgrid and take up the excess power from the microgrid. A trade between the microgrid and the main grid will be taken to maintain the power balance. In the stand-alone mode of operation, the power, whatever the real and reactive power, should be kept in balance with the local loads demands. A microgrid can be disconnected from the main grid under two conditions: 1) Pre−planned islanded operation: If any events in the main grid are presented, such as long-time voltage dips or general faults, among others, islanded operation must be started; 2) Non-planned islanded operation: If there is a blackout due to a disconnection of the main grid, the microgrid should be able to detect this fact by using proper algorithms.

If the microgrid can be managed effectively, the reliability, stability and economy of power supply will be improved effectively. The microgrid energy management and strategy is one of the core problems in microgrid research. A centralized Energy Management System (EMS) for isolated microgrids is proposed by Olivares, D.E, etc. Model predictive control technique (MPC) is used to solve a multi-stage MINLP problem iteratively. Fuzzy multi-objective optimization model is set for a microgrid taking the uncertainties of microgrid into account like stochastic net load scenarios and uncontrollable micro-sources. A system wide adaptive predictive supervisory control (SWAPSC) approach, which smooth the output of PV and wind generators under intermittencies, maintains bus voltage by providing dynamic reactive power support to the grid, and reduces the total system losses while minimizing degradation of battery life span, is proposed for a microgrid with multiple renewable resources. The energy management for microgird should also reach some kind of goals or meet economic benefits. A

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social benefit cost made up of total generation cost, maintenance cost of DGs and ESSs is given by Xiang, Y. Another cost function composed of battery, new power resources and exchange with grid is given by Han, L. A more complex expression is shown by Nikmehr, N, which includes four parts. The first part is composed of the operation and maintenance cost of generator, the second part only consist the installation cost, the third part is the cost of money cost by energy consumption and the forth part is the emission cost of exhaust gas.

In this paper, an effectively way to management microgrid will be discussed. The chapter 2 will list the models of different microgrid components used in the research. Chapter 3 will briefly give some information about the system configuration. Chapter 4 is the operation design which includes the description of objective functions and condition constraints. The algorithms of PSO will also be talked about in chapter 5. Chapter 6 is the simulation and chapter 7 shows the future.

2 MODELING OF MICROGRIDS

Firstly, different parts of a typical microgrid containing PV panel, wind turbine, battery, load, diesel generator and corresponding converters are modelled. There are two basic roles that have to be mentioned:

- All the components' modelling is under steady state
- Power flow transitions are the only things this paper cares

The first role steady-state means the dynamic process is not taken into considering. During every time step, the only thing that needs to be considered is the initial value and final value. For example, if the process of one certain time interval is a first-order response, the actual curve used in this report just a step. The second role means power output is the main variable considering in energy management system. Parameters like voltage, current are not considered.

The basic functions of different components are like: PV panels are tending to generate power from solar irradiation. Wind turbine will generate power when the wind bellows. Battery storage system will charge or discharge according to the power difference. Diesel generator serves a main power supply under all conditions.

2.1 Electronic Converters

In the microgrid system, all the converters are modelled as efficiency related to the input power and converter rated power. The bidirectional DC/DC converter efficiency the bidirectional AC/DC converter efficiency can be formulated by the Equation 1, 2:

$$\eta_{DC-DC} = \frac{100u}{0.007u^2 + 1.0017u + 0.004} \times 100\% \quad (1)$$

$$\eta_{AC-DC} = \frac{100u}{0.018u^2 + 1.002u + 0.004} \times 100\% \quad (2)$$

Where u is the input power ratio, defined by Equation 3:

$$u = \frac{input\ power}{converter(inverter)\ rated\ power} \quad (3)$$

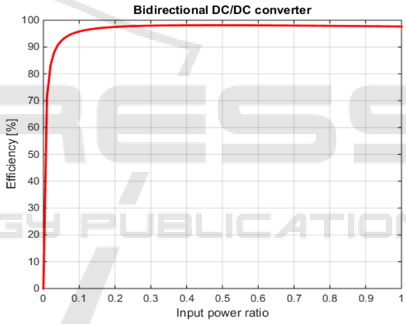

Figure 1: DC/DC efficiency curve.

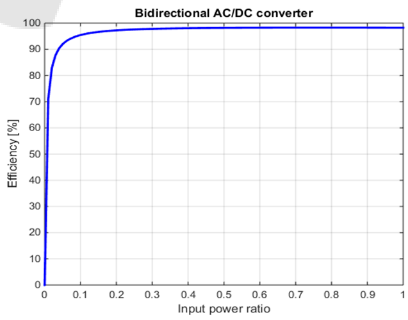

Figure 2: AC/DC efficiency curve.

Figure 1 and 2 shows the efficiency for bidirectional DC/DC converter and bidirectional AC/DC converter. It can be seen that the efficiency of all these converters are nearly 98%. So if necessary, the value of efficiency may be taken as 98% in the following work.

2.2 Solar Photovoltaic

A PV panel can be modelled in two ways: precise model and simple model. Compared to the precise one, the output of simplified PV model has connection with the panel surface, the ambient temperature, the solar irradiation and data from the manufacture. The power output of PV is considered at MPPT output, given by Equation 4:

$$P_{pv} = \eta_{pv} \cdot S \cdot G \tag{4}$$

Where P_{pv} is the output power of PV panel, S is the surface of a PV panel and G is the real solar irradiation received by PV panel. η_{pv} is the power transfer efficiency which is given by:

$$\eta_{pv} = \eta_0 \cdot [1 - \beta(T_{cell} - T_{ref})] \tag{5}$$

η_0 is the PV panel efficiency given by the producer. β is the temperature coefficient, usually taken as 0.0045. T_{ref} is the reference temperature. Cell temperature T_{cell} is deduced from ambient temperature and solar irradiation in Equation 6:

$$T_{cell} = T_a + (T_{cNOCT} - T_{NOCT}) \cdot \frac{G}{G_{NOCT}} \tag{6}$$

T_a is the ambient temperature. T_{NOCT} and G_{NOCT} are ambient temperature and solar irradiation under Nominal Operating Cell Temperature (NOCT) conditions, with 20 ℃ ambient temperature and 800 W/m^2 solar irradiation. T_{cNOCT} is the nominal operating cell temperature.

2.3 Battery Storage System

For the battery, a lead-acid one with CIEMAT model may be used. The most important parameter state of charge (SOC) versus time can be described by:

$$SOC(t) = SOC(t - \Delta t) + \frac{P \cdot \eta_{cha} \cdot \Delta t}{3600 \cdot U_B \cdot C_n} \tag{7}$$

$$SOC(t) = SOC(t - \Delta t) - \frac{P \cdot \Delta t}{3600 \cdot \eta_{dis} \cdot U_B \cdot C_n} \tag{8}$$

Where η_{cha} is the charging efficiency equals to 0.85, taking as the round-trip efficiency provided by manufacture, and η_{dis} is the discharging efficiency equals to 1. C_n is the nominal capacity of the battery and the U_B is the nominal battery voltage. As this is a power battery model, the current and voltage may not be important. The constraint is normally described as:

$$SOC_{min} \le SOC(t) \le SOC_{max} \tag{9}$$

Where SOC_{min} and SOC_{max} are the maximum and minimum allowable storage capacity.

2.4 Wind Turbine

The relationship between wind speed and the output power of wind turbine can be described with piecewise function, such as quadratic piecewise function, linear piecewise function. A cubic piecewise function is implemented, shown in Equation 10, and the curve can be shown in Figure 3.

$$Pw = \begin{cases} 0, & v < v_{ci} \\ P_r \cdot \dfrac{v^3 - v_{ci}^3}{v_r^3 - v_{ci}^3}, & v_{ci} < v \le v_r \\ P_r, & v_r < v \le v_{co} \\ 0, & v > v_{co} \end{cases} \tag{10}$$

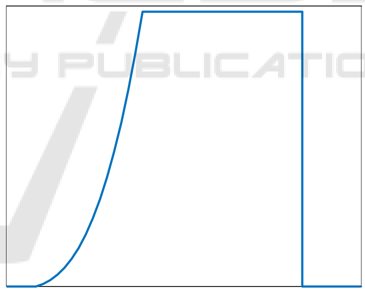

Figure 3: Typical wind turbine power curve.

Where :
Pw is the output power of wind turbine;
v is the real wind speed;
P_r is the rated power of wind turbine;
v_{ci} is the cut-in wind speed;
v_{co} is the cut-out wind speed;
v_r is the rated wind speed.

2.5 Diesel Generator and Load

The diesel generator is modelled as a power source without an upper limit but with a lower limit to meet the basic power consumption in microgrid.

The load is considered as power consumption component, varying with time.

3 SYSTEM CONFIGURATION

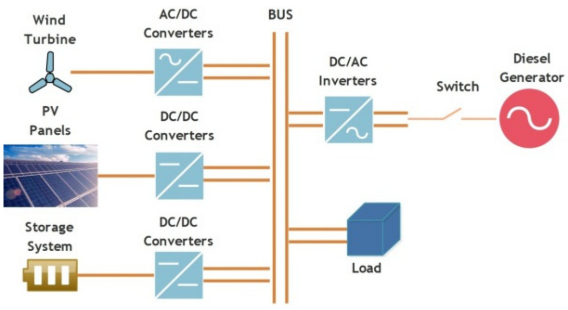

Figure 4: System structure.

The typical structure of research object is shown in Figure 4. The whole operation progress can be explained as followed: the load demand power varies with time. In order to keep the power balance on bus, different components (PV, wind turbine, battery, diesel generator) should provide power or absorb power. So essence of this problem is power distribution problem.

All the components are modelled in SIMULINK environment. For the algorithm suitable for this power distribution, a central controller using MATLAB FUNCTION block is established.

The total simulation will be set under one day-24 hours, and sample time is set to 1 hour. To be specific, it is a one-day-ahead plan, and the operation time interval is 1 hour. The load data and weather data is predicted and stored beforehand. So at each sample time load power demand is detected, all the components will send the power it can provide at this certain time separately, according to the ambient weather conditions. This power information will be sent to the central controller, together with the load demand. Then the central controller will decided the actual power that each component needs to provide.

A rule-based energy management strategy is firstly put forward. This method is simple and it comes from human experience. The central controller will ask PV, wind turbine, battery and diesel generator in sequence for power supply. The distributed power resources will give out power according to their maximum output power corresponding to the weather. And if possible, the new energy resources will charge the battery if there is abundant energy. Compared with this human-experience-based algorithm, an optimal distribution method using PSO will be discussed below.

4 OPERATION DESIGN

Economic optimization operation refers to the comprehensive consideration of system economic, environmental and technical benefits under the premise of meeting system power balance and various safe operation constraints, and optimizes the output of each output unit in the distribution network.

4.1 Cost Function

The main objective of energy management is to minimize the total cost of microgrid. The cost function can be described as:

$$min\, F_{cost} = min(F_{eco} + F_{env}) \tag{11}$$

F_{cost} is the total cost of microgrid, which can be divided into two parts: economic cost F_{eco} and environmental cost F_{env}.

The economic cost F_{eco} is described in Equation 12.

$$F_{eco} = \sum_{i=1}^{n} [C_F(P_i) + C_M(P_i)] \tag{12}$$

$$C_M = K_{omi} \cdot P_i \tag{13}$$

Where:

n is the number of microgrids units;

P_i is the power output of every unit;

$C_F(P_i)$ is the fuel cost of every unit;

$C_M(P_i)$ is the maintenance and operation cost of each unit, which is given by Equation 13;

K_{omi} is the coefficient of maintenance and operation of each unit.

When the microgrid is operating, there are some pollutants such as CO2. Taken the environmental benefit into consideration, the pollutants are converting into a certain proportion, which is the environmental cost. The environmental cost F_{env} is defined in Equation 14.

$$F_{env} = \sum_{i=1}^{n} \sum_{j=1}^{m} a_j \cdot EF_{ji} \cdot P_i \tag{14}$$

Where :

a_i Is the convert coefficient of pollutants;

EF_i is emission of unit product.

4.2 Constraint Conditions

In order to reach a certain result, some constraints must be added while solving the operation problem.

- Power balance constraints

$$P_L = P_G + P_{pv} + P_w + P_{Bat} \tag{15}$$

Where:
P_L is the power demand from load;
P_G is the output power of diesel generator;
P_{pv} is the output power of photovoltaic panels;
P_w is the output power of wind turbine;
P_{Bat} is the power exchange with battery.

- PV constraints

$$0 \le P_{pv} \le P_{pv,max} \tag{16}$$

$P_{pv,max}$ represents the maximum power output of PV panels under a certain weather condition (temperature and solar irradiation), which is usually considered as MPPT points. The real power output is smaller than the value, but bigger than zero.

- Wind turbine constraints

$$0 \le P_w \le P_{w,max} \tag{17}$$

$P_{w,max}$ represents the maximum power output of wind turbine under a certain weather condition (wind speed). The real power output is smaller than the value, but bigger than zero.

- Diesel generator constraints

$$P_{G,min} \le P_G \tag{18}$$

The output power of diesel generator must have a minimum output in order to meet the basic load demand.

- Battery constraints

$$SOC_{min} \le SOC(t) \le SOC_{max} \tag{19}$$

$$P_{bat,min} \le P_{bat}(t) \le P_{bat,max} \tag{20}$$

For a battery, the SOC should be restricted with a suitable range. The power exchange $P_{bat}(t)$ with other components during a certain sample time should also be limited.

5 OPTIMIZATION ALGORITHM

The operation design in previous chapter can be concluded in such a form:

$$s.t. \quad \begin{cases} minf(x) \\ g(x) = 0 \\ h(x) \le 0 \end{cases} \tag{21}$$

Where:
$f(x)$ is the objective function;
$g(x)$ are the equality constraints;
$h(x)$ are inequality constraints.

To solve such a nonlinear optimization problem, traditional optimization methods may not find the best result. Compared with other intelligent algorithm, Particle Swarm Optimization (PSO) is simple without too many parameters. Put forward by Eberhart and Kennedy in 1995, PSO serves as an effective method of optimization and has been widely applied in various fields. It is the ideological source of feeding the flock in the process embodied in the collective wisdom.

5.1 Introduction to PSO

In short, PSO algorithm is to simulate the feeding behavior of birds. Each bird is considered as a particle. All of the particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles.

The basic procedure of PSO algorithm is shown in Figure 5. PSO is initialized with a group of random particles (solutions) and the searches for optima by update generations. During every iteration, each particle is updated by following two 'best' values. The first one is the best solution (fitness) it has achieved so far, and this fitness value is also stored.) This value is called pbest. Another 'best' value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called gbest.

After finding the two best values, the particle updates its velocity and positions with Equation 22 and 23.

$$v(k+1) = \omega \cdot v(k) + c_1 \cdot r_1 \cdot (pbest - x(k)) + c_1 \cdot r_1 \cdot (gbest - x(k)) \tag{22}$$

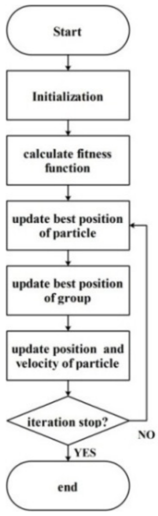

Figure 5: PSO algorithm chart flow.

$$x(k+1) = x(k) + v(k+1) \tag{23}$$

Equation 22 is the formula for velocity updating, and Equation 23 is the formula for position updating.

5.2 Modifications on PSO

However, due to the complexity of problem, the basic method cannot be applied directly. It has to be mentioned that some modifications are made to meet this problem.

- Simulation time is 24 seconds to represent 24 hours operating condition. The sample time is 1 hour which is using 1 second actually. So the optimization algorithm is put in the outside loop, which means the algorithm will be run 24 times, so that at each sample time an optimal result will reach.

$$\eta = \frac{P_{pv} + P_w}{P_g} \times 100\% \tag{24}$$

- As this is a multi-objective problem, after the traditional PSO is completed, a 'Pareto set' will appear. It means there are many optimal answers COUPLED. So, after the 'Pareto set' is reached, it has to be filtered to require the most wanted answer. The filtering method can be described in Equation 24. The efficiency η should be as bigger as possible. When η is bigger, it means PV and wind turbine provides more power, as a result, this answer is more environmentally friendly.

The specific parameters of PSO are shown in Table 1.

Table 1: Parameters for PSO.

Variables	Explanations	Values
N	Number of particles	50
W_max	Maximum inertia weight	1.05
W_min	Minimum inertia weight	0.1
C1	Personal confidence factor	2
C2	Swarm confidence factor	2
MaxIter	Number of iteration	100
v_max	Maximum velocity	1.05
v_max	Minimum velocity	-1.05

5.3 Pseudocode Description

The pseudocode of PSO is shown below.

```
Read the power information from components.
External loop for 24 hours {
    Initializing position, velocity, fitness function
    and Pareto set.
    Calculating fitness function initially.
    Firstly filtering of Pareto set.
    Inner loop for iteration {
        Updating velocity and position.
        Calculating fitness function.
        Updating pbest (best position of particles).
        Combining the previous Pareto set and
        pbest in a new set.
        Filtering new set.
    } End for iteration.
    Final Filtering and reserve the answer.
} End for External loop
Plot
```

6 SIMULATION AND RESULTS

In this part, a total simulation will be estimated. Firstly, the predicted weather data used are shown from Figure 6 to Figure 8. With these figures, the maximum output power under such ambient condition will be calculated using the steady state models from chapter 2.

Then a comparison between two strategies is shown in Figure 9 and Figure 10. In the two figures, the bar graph is the output power of a certain resources and the height of bar determines the quantity of power. The red line with star symbol is the predicted load demand. It can be seen that the algebraic sum of every bar-the power resources, equals to the load demand, which the power balance is met. It has to be mentioned that when the bar of battery is negative, it means the battery is under charge state, or under discharge state when positive.

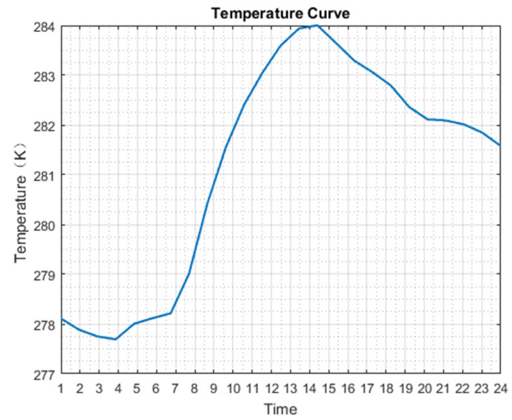

Figure 6: Temperature curve.

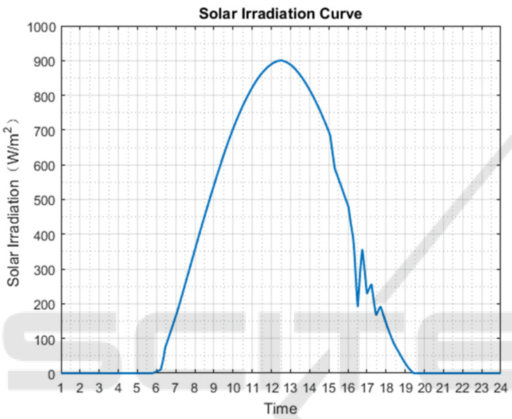

Figure 7: Solar irradiation curve.

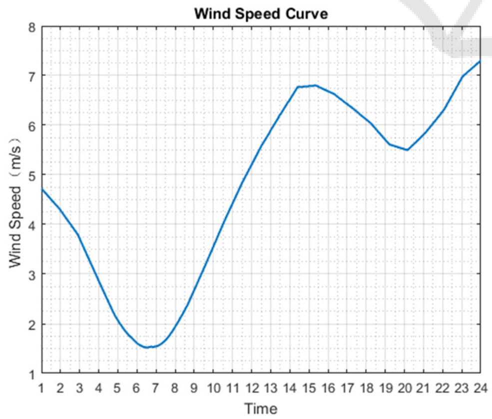

Figure 8: Wind speed curve.

By calculating the cost function of two strategies, shown in Figure 11, it can be seen that the cost using PSO optimization is smaller than the human-experienced-based strategy. The superiority of PSO has been embodied.

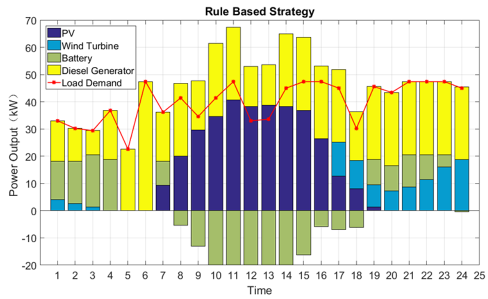

Figure 9: Rule based strategy.

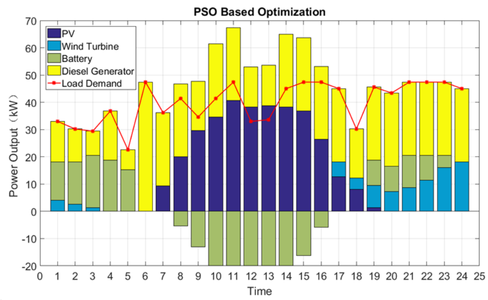

Figure 10: PSO based strategy.

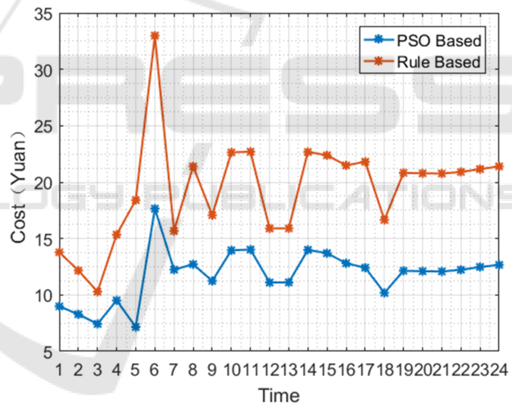

Figure 11: PSO algorithm chart flow.

7 CONCLUSION AND REMARKS

This paper makes effective energy management for the whole microgrid based on the particle swam optimization algorithm. In the optimization process, the economic and environmental aspects are considered comprehensively. A multi-objective is carried out with the lowest cost including economic cost and environmental cost, and the good performance of PSO is verified by an example.

For future work, here are some significant points:

- Multi-agent system can be designed to describe the controllers of each component.
- The PSO may be combined with other intelligent control method to reach a better performance of program running.

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