

Research on Multi-Objective Optimization Operation of Microgrid

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Abstract: Since the microgrid with distributed power supply has the advantages of flexibility and cleanliness, it has become an important part of the smart grid. In order to achieve the economy and environmental protection multi-objective optimal operation of the microgrid system, the optimization strategy is used to solve the multi-objective optimization problem under the constraints of the system. The multi-objective function model for optimal operation of the microgrid is established. The subpopulation hybridization operation is added into the particle swarm optimization algorithm, which makes it suitable for solving multi-objective optimization problems and applies it to the optimization operation of the microgrid. The power generation cost and environmental cost are used as the sub-objective function to carry out simulation verification. The simulation verification results show that the algorithm can achieve multi-objective optimization operation of microgrid.

1.Introduction:

With the further development of microgrid technology, it has become an important technical means for the construction of the smart grid. However, in terms of microgrid optimization operation, how to realize the economic value and environmental benefits of micro-grid nowadays has become a research hotspot of micro-grid technology[1-2]. Scholars at home and abroad have achieved some theoretical results for this kind of hot issue. In document[3], the operating costs and pollutant emission costs of microgrid economic dispatching model, and uses the genetic algorithm to solve the microgrid economic dispatch model.

In the microgrid multi-objective optimization operation problem, the literature[4] considers the economic cost of the microgrid system, adopts the linear weighted summation method to convert the multi-objective function into a single objective function with lowest comprehensive cost. However, its essence cannot be called multi-objective optimization problem. In[5], the author studies the economical efficiency of the microgrid when it is in orphaned network operation and networking operation, and uses the improved genetic algorithm to solve it more numerically. In document[6], multiple methods of population initialization in genetic algorithms are used to optimize the multi-objective optimization of microgrid operation.

This paper constructs a multi-objective mathematical model for the optimal operation of microgrids. With the goal of minimizing the costs of economic and environmental, the multi-objective particle



swarm optimization (*MOPSO*) is used to study issues of the multi-objective optimization.

1.1 The basic model of each unit of the system

1.1.1 Wind turbine model

The specific calculation formula for the output power of wind turbine [7] is as follows:

$$P_{wt} = \frac{1}{2} \rho \pi R^2 v^3 C_p \quad (1)$$

Among them, ρ is the air density; R is the fan blade radius; v is the tip wind speed; C_p is the fan's wind energy utilization coefficient.

1.2 Photovoltaic Battery Model

Taking into account the randomness of lighting, ambient temperature, intermittent factors, the photovoltaic cell output power is:

$$P_{pv} = P_s \frac{S_A}{S_0} (1 + k(T_c - T_r)) \quad (2)$$

In the formula: P_{pv} is the output power of the photovoltaic cell; P_s is the maximum output power under standard conditions; S_A is the ambient light intensity; S_0 is the light intensity under standard conditions; k is the power temperature coefficient; T_c is the operating temperature of the panel; T_r is the temperature.

1.3 Energy Storage Battery Modeling

There is a close relationship between the battery charge at time t , ($t-1$) and the supply and demand of system energy from time ($t-1$) to t . The model ignores the hourly self-discharge rate of the battery and then assumes a battery discharge efficiency of 1.0. By the time the total power generated by the system is greater than the load, the battery is in a charged state. The charge of the battery at time t is:

$$S_B(t) = S_B(t-1) + (S_{GA}(t) - S_L(t)) \alpha_{Bat} \quad (3)$$

In the formula: $S_{B(t)}$ and $S_{B(t-1)}$ are the charge of the battery at the time t and ($t-1$) respectively; $S_{GA(t)}$ is the total energy provided by the system at time t ; $S_{L(t)}$ is the load of electricity at time t quantity; α_{Bat} is the battery charging efficiency. When the total power generated by the system is less than the power consumption of the load, the battery is in a discharged state. At t , the charge of the battery is:

$$S_B(t) = S_B(t-1) + S_{GA}(t) - S_L(t) \quad (4)$$

1.4 Diesel generator model

Diesel generators are usually used as a backup power source. The fuel cost is a function of its consumption characteristics and the fuel cost can be expressed as:

$$f_{DE} = a + bP_{DE} + cP_{DE}^2 \quad (5)$$

In the formula: f_{DE} and P_{DE} are the fuel cost and the output power of the diesel generator, respectively; a , b , and c are the fuel cost factors.

2. Mathematical model for optimal operation of microgrids

2.1 Objective function

2.1.1 Cost of power generation

The cost of power generation mainly includes the fuel cost ($C_f(t)$), the operation and maintenance costs ($C_{OM}(t)$) and the on-off costs ($C_{onoff}(t)$).

$$\begin{cases} C_G(t) = C_f(t) + C_{OM}(t) + C_{onoff}(t) \\ C_f(t) = \sum_{i=1}^n F_i(P_i(t)) \\ C_{OM}(t) = \sum_{i=1}^n k_{OMi} P_i(t) \\ C_{onoff}(t) = \sum_{i=1}^{n_c} I_i(1 - I_i(t-1)) c_{onoffi} \\ c_{onoffi} = \delta_i + \sigma_i(1 - e^{-T_{offi}(t)/\tau_i}) \end{cases} \quad (6)$$

Where: $C_f(t)$ is the sum of the fuel costs for each micro-supply for t period; $F_i(t)$ is the fuel cost function for the i -th micro-supply; $P_i(t)$ is the active power output of the i -th micro power supply in t period; n is the number of micro power supplies; $C_{OM}(t)$ is the maintenance and operation cost of the micro power supply in t period; k_{OMi} is the unit cost operation and maintenance cost coefficient of the i -th micro power source; $C_{onoff}(t)$ remarks the controllable micro-power start-stop cost for period t ; $I_i(t)$ is the start/stop state of the i -th micro-power source; 1 is the running state; 0 is the outage state and n_c is the number controllable type of micro-power supply; c_{onoffi} represents the starting and stopping unit price of the i -th micro-power supply ; δ_i , σ_i , τ_i are the start-stop cost coefficients for the i -th micro-supply; $T_{offi}(t)$ is the time for the i -th micro-supply to stop at t .

2.1.2 Environmental costs

It is considered by converting environmental value of pollutants emitted by microgrid power generation and the environmental costs[8] of emission penalty. The formula is as follows:

$$C_e(t) = \sum_{i=1}^n \sum_{j=1}^m ((a_j + b_j) \lambda_{ij} P_i(t)) \quad (7)$$

Where: $C_e(t)$ is the sum of the environmental costs of the microgrid in t period; a_j is the environmental value of the j th pollutant; b_j is the fine for the j th pollutant; λ_{ij} remarks the i -th micropower unit the amount of pollutants discharged; m is the type of pollutants.

2.2 Constraints

$$\begin{cases} \sum_{i=1}^n P_i(t) + P_{grid}(t) = P_{load}(t) - P_L(t) \\ P_{i,min} \leq P_i(t) \leq P_{i,max} \\ P_i(t) - P_i(t-1) \leq R_{up,i} \\ P_i(t-1) - P_i(t) \leq R_{down,i} \\ P_{grid,min} \leq P_{grid}(t) \leq P_{grid,max} \end{cases} \quad (8)$$

Constraints include: the microgrid power balance constraints, the micro-power output power constraints, the micro-power ramp power constraints, microgrid and external network transmission power constraints.

In the formula(8): $P_{i,min}$, $P_{i,max}$ are the minimum and maximum output of the i -th micro-power supply respectively ; $P_i(t)$ is the output of the i -th micro-power supply at t ; $R_{up,i}$ and $R_{down,i}$ are the upper and lower ramp power limits for the i -th micropower supply respectively. $P_{grid,min}$ and $P_{grid,max}$ are the minimum and maximum transmission power of the microgrid and the external network.

2.3 Multi-objective optimization model

Based on the analysis obtained above, the global multi-objective optimization model for optimal operation of the microgrid can be expressed as:

$$\begin{cases} \min f_1 = C_f(t) + C_{OM}(t) + C_{onoff}(t) + C_{grid}(t) \\ \min f_2 = C_e(t) \end{cases} \quad (9)$$

3. Optimal operation optimization algorithm for microgrid

In the actual operation of the microgrid, the decision maker needs to select a satisfactory solution from the multiple solutions as the optimal solution. The idea of this paper is to use the multi-objective particle swarm optimization algorithm in order to find the multiple *Pareto* optimal solutions among multiple contradictory sub-objectives. Then according to the preference of different sub-objectives, the solution is sorted by normalization and the optimal solution is chosen.

3.1 The Multi-objective Particle Swarm Optimization Algorithm

The *PSO* algorithm regards each particle as a solution to the problem it seeks. All particles move at a certain speed within the feasible solution space and continue to follow the current optimal particle. On behalf of the search to get the optimal solution to the problem [10]. The disadvantages of the *PSO* algorithm in the later period of population diversity decrease, and it is easy to fall into the local optimal solution. In 2000, Lobvjeg et al. proposed to introduce the crossover operation in the evolutionary algorithm into the hybrid *PSO* model of *PSO*. According to this paper, the crossover operation is applied to the multi-objective particle swarm optimization algorithm. With the particle swarm optimization algorithm, subpopulation hybridization operation is added [11]. According to the number of sub-objective functions, the particle group is averagely divided into corresponding number of the subpopulations and each of the population corresponds into an objective function; the particles in each subgroup are optimized and updated according to the objective function of the subpopulation; Then the particles of each subpopulation randomly hybridize according to a certain hybridization probability to generate a new subpopulation. This usually allows the sub-targets to improve the population diversity through cross-subpopulation hybridization.

3.2 Algorithm flow

The following figure 1 is the flow chart of the particle swarm algorithm applied in this paper.

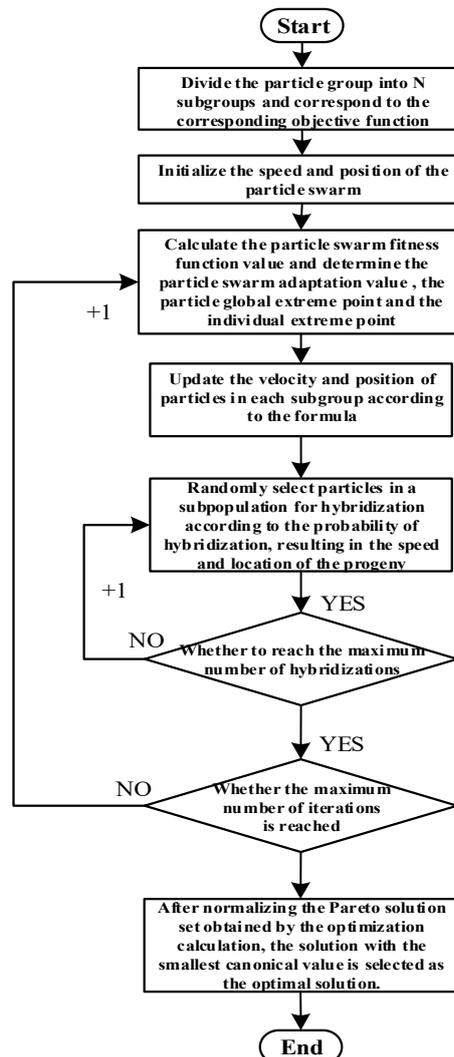


Figure.1. Improved multi-objective particle swarm algorithm flow chart

4.Example Analysis

The microgrid structure used in the example is shown in Figure2. The microgrid operates in an islanding state. The micro power supplies include a diesel engine (DE), a battery storage (BS), a wind turbine (WT), and a photovoltaic cell (PV). The micro power output power parameters are shown in Table1[12]. The micro-power pollution emission data, pollutant value standards, and fine levels are found in the literature [13]. The daily load forecasting curve for this microgrid is shown in Figure2.

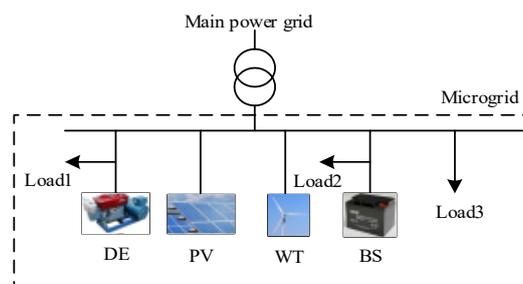


Figure.2. Structure of microgrid

Tab. 1 Output power parameters of microsources

Type	Power lower limit/kW	Upper limit of power/kW
DE	3	30
PV	0	10
WT	0	30
BS	4	30

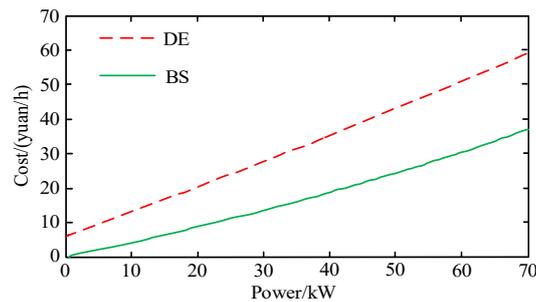


Figure.3.Relationship between power generation costs of microsources and their output power

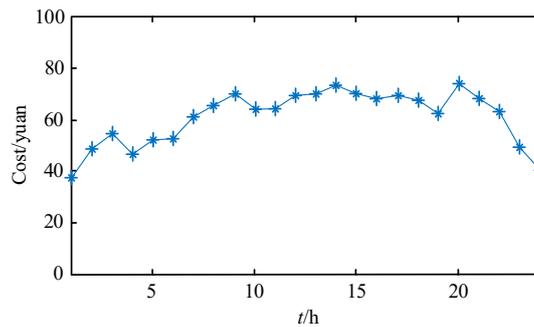


Figure.4. Total costs of microgrid

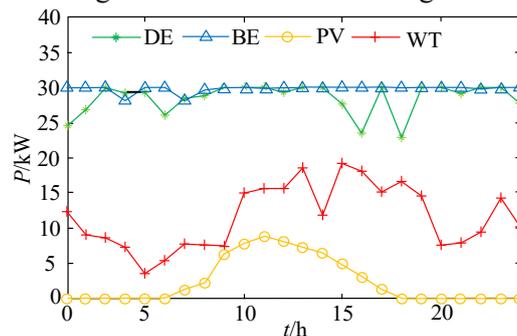


Fig.5. Output power of microsources

In the economic dispatch, the microgrid will increase the power generation cost due to the increasing of the diesel generator input cost and it will also increase the environmental cost with high pollutant emission. It can be seen from Fig. 5 that in the peak load period, since the photovoltaic array cannot provide electric energy, the load can only be supplied by the wind turbine, the diesel generator and the lead-acid battery group. The wind turbine and the photovoltaic cell are operated in the maximum tracking mode and have no power lower limit. From the figure 3, the power generation cost of the diesel engine is a little higher than the battery. The the battery storage shown in Figure.5 with low power generation cost and little environmental impact is almost always full.

5. Conclusion

In this paper, the multi-objective optimization model is established based on the economic and environmental protection of the microgrid optimization operation. Especially the improved sub-population hybridization operation enhances the global search ability of the algorithm and the improved particle swarm optimization algorithm can be applied to solve various multi-objective problems. This paper also simulates a microgrid example with multiple micro-power supplies in island operation mode. The results show that the algorithm can effectively achieve multi-objective optimization operation of microgrid, which makes the economic and environmental benefits of the microgrid are optimal.

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