

# Optimization of Wind, Solar and Battery Micro-grid Capacity Allocation

Shijun Lu<sup>1</sup>, Hongfang Pan<sup>1\*</sup>, Chenyu Peng<sup>1</sup>, Xuan Li<sup>1</sup>, Zhigang Hu<sup>1</sup> and Lei Yan<sup>2</sup>

<sup>1</sup> Inner Mongolia Power Information & Telecommunication Center, Inner Mongolia Grid, Inner Mongolia, China

<sup>2</sup>School of Electrical & Electronic Engineering, North China Electric Power University, Beijing, China

\*Corresponding author

**Abstract**—As an important way to absorb clean energy, micro-grid is studied in this paper. Compared with photovoltaic or wind independent power supply system, wind-solar complementary system can better adapt to the change of environment. Coupled with the regulating function of battery, wind, solar and battery micro-grid system can make better use of clean energy and meet the load demand of the system. Taking the comprehensive cost of system investment, operation cost and maintaining system power supply reliability as objective functions, a multi-objective optimization function is constructed. In this paper, an improved differential evolution algorithm (IDE) is proposed to optimize the capacity allocation of wind, solar and battery micro-grid. This algorithm can improve the ability of global optimization and avoid falling into the local optimal. An example shows that this algorithm can quickly and reliably calculate the optimal capacity configuration of wind, solar and battery micro-grid system.

**Keywords**—wind power; solar power; micro-grid; differential evolutionary algorithm

## I. INTRODUCTION

With the increasing pressure of shortage of fossil fuel resources and environmental pollution, the development and utilization of renewable energy, such as solar power, biomass energy and wind energy, has become an increasingly important research and development subject. Wind and solar power can reduce fuel demand and reduce the pollution of the environment, which are important to reduce power loss and improve power supply reliability of distribution power grid. However, due to the large randomness and uncertainty of wind and solar energy, the large-scale access to a large power grid poses new challenges to the grid planning and stable operation.

The above problems can be effectively solved by connecting distributed renewable energy to distribution network in the form of micro grid. Micro-grid system consists of distributed power supply, energy storage device, energy conversion device, protection device and load, etc. It is a small power system that can realize self-control, protection and management. Micro-grid systems can operate in parallel with large power system or in isolated islands. Research on the application of wind, solar and battery micro-grid system can maximize the application rate of renewable distributed power, reduce environmental pollution, improve the reliability of

power supply, and is of great significance in the construction of smart grid.

Compared with a single photovoltaic or wind energy independent power supply system, wind-solar complementary power generation system makes use of the complementary characteristics of wind and solar energy, and its output power fluctuation is small. While the energy storage system can effectively solve the intermittently and fluctuation of wind-solar complementary power generation and the dislocation of "source" and "load" in the micro-grid. Literature [1]-[7] discussed the capacity optimal allocation method of independent operation of micro-grid. By establishing the objective function with the minimum economic cost of micro-grid, and considering constraints such as investment cost, maintenance cost and battery operating condition, different optimization algorithms were used to calculate the optimal allocation of each power source, which were all single-objective optimization methods.

In this paper, a method of multi - objective micro - grid capacity allocation optimization based on improved differential evolution algorithm (IDE) is proposed. This method takes the comprehensive cost including investment cost, operation cost and system reliability cost of the system as the objective function, uses the control parameter self-adaptive adjustment strategy, obtains the higher global convergence ability and the faster search efficiency.

## II. DESCRIPTION OF WIND, SOLAR AND BATTERY MICRO-GRID SYSTEM

Compared with photovoltaic or wind energy independent power supply system, photovoltaic and wind energy complementary hybrid power supply is more reliable and more adaptable to environmental changes. In this paper, the wind turbine, photovoltaic array and storage battery are comprehensively considered to carry out the modeling of each component of the micro-grid system, the characteristics of wind energy, solar energy, energy storage, load and their application in the micro-grid are studied, and the integrated micro-grid model of wind, solar and battery is formed. From the economic point of view and on the premise of meeting the basic performance indexes of the system, the comprehensive model aims at the lowest comprehensive costs and obtains the

optimal capacity allocation of wind, solar and battery micro-grid.

#### A. PV Modeling

Solar radiation and temperature are important factors affecting the efficiency of photovoltaic cells. In addition, there are some methods to calculate the power output according to the inclination angle of photovoltaic array. In this paper, photovoltaic cell modeling is carried out according to the inclination angle of photovoltaic array and solar radiation amount. As the characteristic equation of photovoltaic cells is a transcendental equation without analytic solution, the maximum power point tracking method (MPPT) is used [8].

The total solar radiation [9] is calculated as follows:

$$I_{tt} = I_a + I_s + I_g \quad (1)$$

Where,  $I_{tt}$  is the total solar radiation amount on the photovoltaic panels,  $I_a$  is the direct solar radiation amount on the photovoltaic panels,  $I_s$  is the solar scattering amount on the photovoltaic panels, and  $I_g$  is the solar reflection amount on the photovoltaic panels.

According to MPPT method, the formulas of PV output power, solar radiation  $I_{tt}$  and inclination  $\beta$  are deduced

$$P_{pv} = f(I_{tt}, \beta) \quad (2)$$

Where,  $P_{pv}$  is the output power of photovoltaic panels,  $\beta$  is the tilt angle of photovoltaic panels.

#### B. Wind Turbine Modeling

In the micro - grid model, the relationship between the generator power and wind speed is usually used [10]. However, it is difficult to get accurate minute-level wind speed data, only statistical data such as monthly/annual average wind speed can be obtained. Generally, two-parameter Weibull distribution can be used to describe the distribution characteristics of wind speed:

$$F(v) = 1 - \exp[-(\frac{v}{c})^k] \quad (3)$$

Where,  $c$  and  $k$  respectively are scale parameters and shape parameters of the Weibull distribution, which jointly control the shape of the Weibull distribution curve. The former reflects the average wind speed of the wind field, and the latter reflects the peak value of the curve.

The relationship between the power generated by wind turbines and the wind speed is known as the output power characteristic curve, generally available from manufacturers [11]. In this paper, polynomial fitting curve is established,

which is close to the actual output power of the fan. The fitting curve adopted in this paper is as follows:

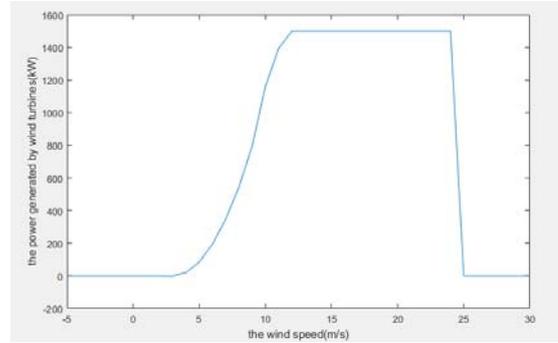


FIGURE 1. THE OUTPUT POWER CHARACTERISTIC CURVE OF WIND TURBINE(KW-M/S)

#### C. Battery Storage Modeling

In the integrated system, the energy of SB changes dynamically, and SB has two states of charge and discharge[12].The state of SB at time  $t$  can be determined by the state of SB at time  $t-1$  and the supply and demand relationship between time  $t-1$  and time  $t$ .In the integrated wind-wind load storage system, the load in this system is supplied by the total output power of PV and WG, except the battery[13].

The electric quantity of SB at time  $t$  is as follows:

$$P_b(t) = \begin{cases} P_b(t-1) \times (1 - z_1) + [P_t(t) - (P_{load}(t) / z_2)] \times z_3, & \text{if } P_t(t) - P_{load}(t) \geq 0 \\ P_b(t-1) \times (1 - z_1) - [(P_{load}(t) / z_2) - P_t(t)] \times z_3, & \text{else} \end{cases} \quad (4)$$

Where,  $P_b(t)$  is the storage energy of the battery at time  $t$ ,  $P_t(t)$  is the total energy available at time  $t$  for PV and WG,  $P_{load}(t)$  is the load at time  $t$ ,  $z_1$  is the number of self-discharge per hour of the battery,  $z_2$  is the inverter efficiency, and  $z_3$  is the battery charging efficiency.

### III. OPTIMIZATION OF CAPACITY ALLOCATION

#### A. Optimization algorithm

The study of capacity allocation of wind, solar and battery micro-grid should consider the input capacity of wind turbine, photovoltaic panels and energy storage, and involve the load characteristics of micro-grid. Under the basic operating conditions of the system, the economy of the micro grid is maximized, which is essentially an optimization problem. Mathematically, it is a complex multi-objective, multi-constraint, nonlinear, discontinuous and mixed integer optimization problem. Finding suitable optimization algorithm is the key of research.

Differential evolution algorithm (DE) [14]is an optimization algorithm based on random multidimensional data, which is suitable for global optimization of unconstrained continuous variables. This algorithm is known for its simple

parameter setting and fast convergence speed. It only needs to set a few parameters, and the same setting can be used for different problems, which shows its special value in solving optimization problems.

The basic idea of DE algorithm is that the difference vector of two vector parameters randomly selected is used as the random variation source of the third vector parameter, and then the new generation solution is obtained by mutation and selection.

Due to the strong individual competition in DE algorithm, it is likely to converge to the local minimum and lead to premature development. The traditional method to solve this problem is to adjust the scale factor or increase the size of the initial solution and make it evenly distributed. However, this will prolong the calculation time. The method of solution group transformation can better solve the problem of prematurity [15].

The idea of solution group transformation is as follows: the JTH gene of solution group is regenerated by the following formula:

$$x_{ji}^{G+1} = \begin{cases} x_{j_{best}}^{G+1} + \rho_1(x_j^{\min} - x_{j_{best}}^{G+1}) & , \text{if } \rho_2 < \frac{x_{j_{best}}^{G+1} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \\ x_{j_{best}}^{G+1} + \rho_1(x_j^{\max} - x_{j_{best}}^{G+1}) & , \text{else} \end{cases} \quad (5)$$

Where,  $x_{j_{best}}^{G+1}$  is the JTH gene of the individual with best fitness in G+1 generation solution group,  $x_j^{\max}$  and  $x_j^{\min}$  are the maximum and minimum boundary of variable  $x_j$ ,  $\rho_1$  and  $\rho_2$  are the random Numbers evenly distributed in [0,1].

Not every generation needs to carry out the transformation operation of the solution group. The following equation can be used to measure the dispersion degree of the solution group, and the solution can be transferred beyond the given limit to get rid of the local best advantages. Otherwise, the original search path will continue to search for the optimal solution.

$$U = \frac{\left[ \sum_{i=1, i \neq b}^{N_p} \sum_{j=1}^{N_p} \eta_{ji} \right]}{D(N_p - 1)} < \varepsilon_1 \quad (6)$$

$$\eta_{ji} = \begin{cases} 1, & \text{if } \left| \frac{X_{ji}^{G+1} - X_{j_{best}}^{G+1}}{X_{j_{best}}^{G+1}} \right| > \varepsilon_2 \\ 0, & \text{else} \end{cases}$$

Through the improved DE algorithm [15], when the given limit value is exceeded, the mutation operation will generate new individuals to get rid of the premature problem caused by

the local minimum, which is equivalent to the solution transfer to get rid of the local best advantage, so as to carry out global optimization.

### B. Objective Function

In this paper, the economy and power supply reliability of micro grid are fully considered and it aims to minimize the comprehensive cost of wind, solar and battery micro-grid system. Cost includes: initial construction cost, operation and maintenance cost, system outage loss cost, etc. The objective function is as follows:

$$\min C_{total} = \min \sum (C_{WG} + C_{PV} + C_{SB}) + C_{CS} \quad (7)$$

Where,  $C_{total}$  is the total system cost;  $C_{WG}$ ,  $C_{PV}$ ,  $C_{SB}$  are the total cost of fan, total cost of photovoltaic cell and total cost of battery, which have taken initial construction, operation and maintenance costs into account respectively;  $C_{CS}$  is the cost of system power failure loss.

$$C_{WG} = m_0(P_{WG}) \times \frac{R(1+R)^y}{(1+R)^y - 1} + m(P_{WG})$$

$$C_{PV} = m_0(P_{PV}) \times \frac{R(1+R)^y}{(1+R)^y - 1} + m(P_{PV}) \quad (8)$$

$$C_{SB} = m_0(P_{SB}) \times \frac{R(1+R)^y}{(1+R)^y - 1} + m(P_{SB})$$

Where,  $m_0(P_{WG})$ ,  $m_0(P_{PV})$ ,  $m_0(P_{SB})$  are respectively the fan cost, photovoltaic cell cost, battery cost,  $R$  is the discount rate,  $y$  is the depreciation life of the equipment,  $m(P_{WG})$ ,  $m(P_{PV})$  and  $m(P_{SB})$  are respectively the operation and maintenance costs of fan, photovoltaic cell and battery.

There are two main methods on power failure loss. One is to take into account the influence of various factors on power failure loss and estimate power failure loss through statistical investigation. The other method is to model the power failure loss and establish the power failure loss function. The accuracy and comprehensiveness of the statistical survey data are not high, and the establishment of power failure loss model can more accurately reflect the economic loss caused by power failure.

This paper calculates the power failure loss in the micro grid. The calculation method is as follows:

$$C_{CS} = \rho P_{EENS} \quad (9)$$

Where,  $P_{EENS}$  is the expected value of system electric quantity shortage,  $\rho$  is the unit power failure loss. By using the average price conversion multiple method and the electricity production ratio method, the estimated error of  $\rho$  is reduced by the weighted average of the two methods.

Power failure often occurs in the following situations: due to the limitation of power generation unit capacity and the constraint of line power flow, the micro grid cannot meet part of the load demand. Correspondingly, the stronger the power supply capacity is, the smaller the power failure loss will inevitably be. Therefore, the change of  $C_{CS}$  effectively reflects the influence trend of power supply configuration on power failure cost, and thus reflects the power supply reliability of the system.

### C. Constraint Conditions

Constraint conditions mainly include SB electric quantity change, WG quantity, PV quantity, SB quantity, PV solar panel inclination Angle constraint, etc., which meet the following forms:

$$x_{j,\min} \leq x_{i,j} \leq x_{j,\max} \quad (10)$$

Therefore, in the operation process of the improved DE algorithm, when the generated particles do not meet the constraint conditions, the following equation can be used for processing:

$$x_{i,j} = \begin{cases} x_{j,\max} & x_{i,j} > x_{j,\max} \\ x_{j,\min} & x_{i,j} < x_{j,\min} \end{cases} \quad (11)$$

### IV. MATHEMATICAL MODEL OF CAPACITY ALLOCATION OF MICROGRID

Through the improved DE algorithm, the optimal wind-landscape storage capacity is optimized, and the optimal wind-landscape storage ratio and the corresponding minimum comprehensive cost of micro-grid system are obtained. The algorithm flow chart is shown as follows:

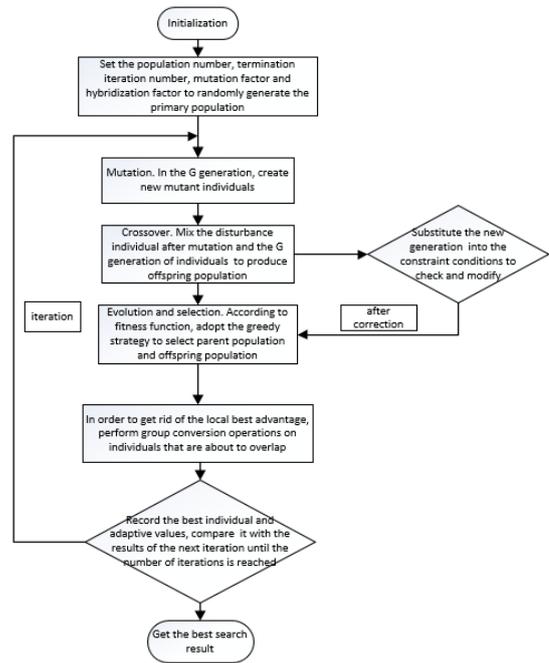


FIGURE II. THE OPTIMIZATION ALGORITHM FLOW

### V. THE SIMULATION EXAMPLE

Take a certain area ( $40^{\circ} 8'$ ) as an example to carry on the calculation example analysis. Sunshine data, wind speed data and system user load data are shown in the figure below.

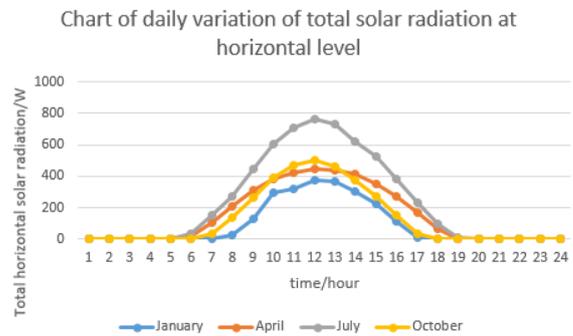


FIGURE III. THE CHART OF DAILY VARIATION OF TOTAL SOLAR RADIATION AT HORIZONTAL LEVEL

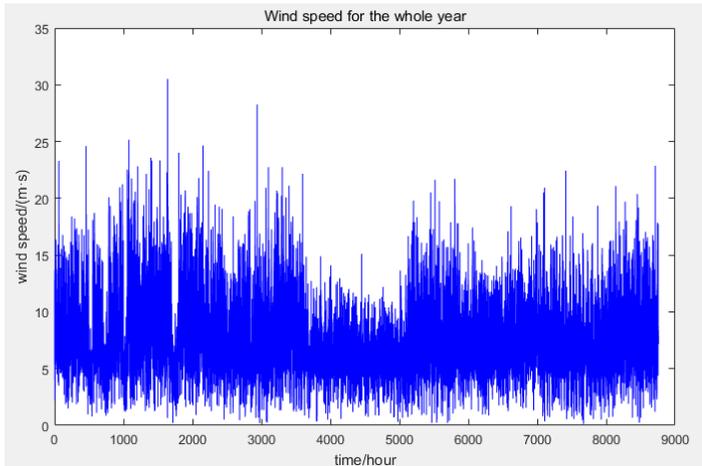


FIGURE IV. THE WIND POWER FOR THE WHOLE YEAR

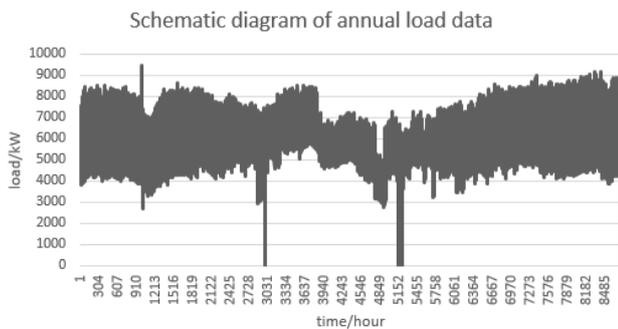


FIGURE V. ANNUAL LOAD DATA

The optimization process of the four variables-- angle of photovoltaic solar panel, number of fans, number of photovoltaic cells in parallel, and number of stored cells in the wind, solar and battery micro-grid system in the improved DE algorithm is shown as follows:

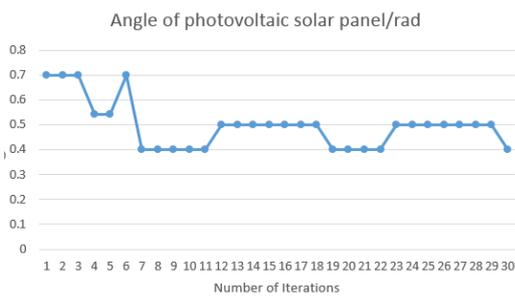


FIGURE VI. ANGLE OF PHOTOVOLTAIC SOLAR PANEL/RAD

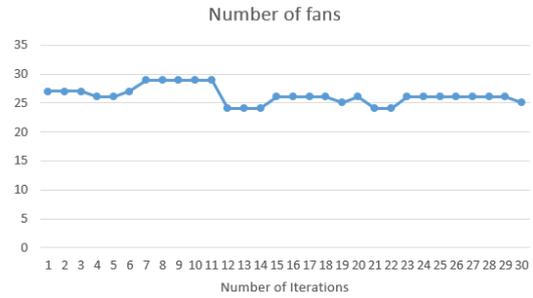


FIGURE VII. NUMBER OF FANS

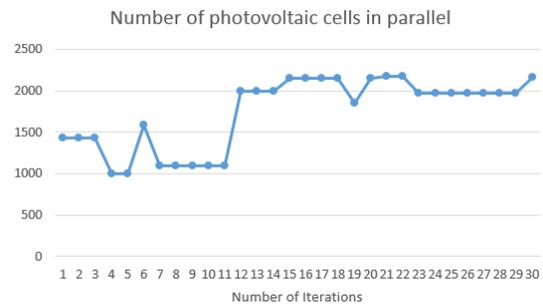


FIGURE VIII. NUMBER OF PHOTOVOLTAIC CELLS IN PARALLEL

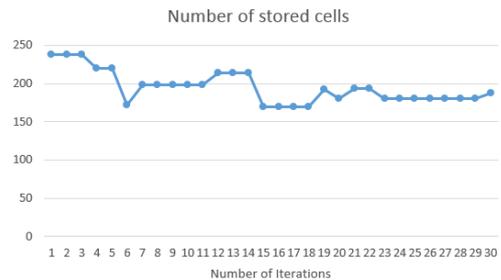


FIGURE IX. NUMBER OF STORED CELLS

After optimization, the optimal configuration scheme of this system is as follows.

TABLE I. TABLE TYPE STYLES

Scheme	WG	PV	SB	Angle of PV Solar Panels	Total Annual System Cost
the optimal configuration scheme	26	1968	181	22.5°	64119000

Through the optimal configuration scheme, the basic requirements of load power consumption can be met by WG. However, due to the mismatch between the actual distribution of wind energy and the change of load electricity consumption, WG power generation is very unstable. The pure wind power generation guarantees the load electricity consumption, and its reliability is low. By properly combining WG and PV arrays, the complementarity of wind and solar power in time distribution can be fully used. In addition, the effective complementary scenery can prevent SB frequent charge and discharge, improve SB life.

The above figure can reflect the evolutionary iteration process of the improved DE algorithm. The improved DE algorithm finds the optimal solution after about 20 generations and has certain fluctuations, indicating that the improved algorithm is conducive to maintaining population diversity and effectively avoiding it converges to local optimum.

The relationship between solar panel inclination Angle and total annual system cost can be obtained through optimization, as shown in the figure below.

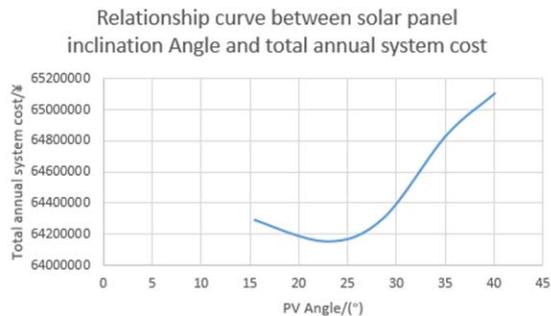


FIGURE X. THE POWER GENERATION BY WIND TURBINE(KW)

In many existing design schemes of wind-solar power supply system, PV inclination Angle is mostly designed as local latitude value. In the mixed system, the selection of inclination Angle is not only related to sunshine, but also closely related to wind speed, load and capacity of selected modules. The selection of optimal inclination Angle of photovoltaic solar panels directly affects the change of PV power generation. Meanwhile, in order to ensure the reliability of power supply, the number of SB must be increased. All these changes will increase the total cost of independent systems. Therefore, in this paper, the inclination Angle of photovoltaic solar panels is taken as a decision variable in the calculation. Through the calculation results, it is found that the relation curve between the two is a parabola, and the Angle corresponding to the minimum annual system cost is about 22.5°. The optimal inclination Angle obtained is different from the local latitude to some extent.

## VI. CONCLUSION

This paper studies the capacity configuration model of wind, solar and battery micro-grid system, taking into account the geographical location, load changes, hourly wind speed, sunshine, especially the inclination angle of photovoltaic solar panels, and other factors. Based on the weather data and load data of a certain area and considering the comprehensive cost of system reliability and economy, the capacity optimization configuration model is verified by the improved differential evolutionary algorithm, which provides a reference for the capacity planning of the system.

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