Optimal Control of Ship Microgrid Based on Improved Genetic Algorithms

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Abstract. Wind energy and solar energy are natural clean energy. If wind power is used to generate electricity, rational allocation of wind turbines, photovoltaic cells, storage batteries, and diesel engines to supply the ship's electricity will be of great significance for energy conservation and emission reduction. This article proposes a specific research object, that is, research on the optimal configuration of the hybrid power generation system for small-scale barges berthed at the port, the establishment of a hybrid power system mathematical model of wind turbines, photovoltaic cells, batteries and diesel engines, and the use of improved genetic algorithms to the total cost of the system is the minimum. The power supply reliability of the system is the constraint condition to solve the mathematical model of the optimized configuration. Finally, the simulation results are analyzed in MATLAB.

1. Introduction

According to statistics, more than 66% of international trade depends on shipping. If the micro-grid connected with new energy can be applied on the ship, the power resources can be obtained, and the pollution can be reduced. At present, there are two methods to study the optimal configuration of micro-grid on the ship system. One is to use the algorithm to take the total cost of the ship hybrid power generation system as the objective function, the reliability and stability of the system as the constraints, and adopt non-linear intelligent algorithm to find the optimal solution [1-7]. Another is to use software, such as HOMER[8] and Hybrid2[9]. In the reminder of this paper, the power models are built firstly; Then the objective and constraints are established and the improved algorithm is used to solve the problem; At last, The ship power system based on clean energy is simulated, and the two algorithms are verified.

2. Microgrid modeling

2.1. The characteristics and modeling of Wind power generation

2.1.1. The value method of wind speed. The wind turbine calculation equation is shown in the equation (1). $A$ is the blade sweeping area; $C_p$ is the wind energy utilization coefficient; $\rho$ is the air density; and $v$ is the instantaneous wind speed. $c_p, \beta, \lambda$ satisfy equation (2).

$$P = \frac{1}{2} C_p A \rho v^3$$ (1)
\[ c_p = (0.44 - 0.0167 \beta) \sin \frac{\pi(\lambda - 2)}{13 - 0.3\beta} - 0.00184(\lambda - 2)\beta \quad \lambda = \frac{\omega_M R}{v} \]  

(2)

In the equation (3), \( R \) is the blade sweep radius, \( \omega_M \) is the angular velocity of the mechanical shaft output. In the equation (4), \( v_{ci} \) is the cut-in wind speed, \( v_{co} \) is the cut-out wind speed, \( v_r \) is the rated wind speed, and \( P_R \) is the rated power.

\[ T_M = \frac{P}{w_M} = \frac{1}{2} c_p(\lambda, \beta) \rho R^5 \frac{\omega_M^2}{\lambda^3} \]  

(3)

\[ P_W = \begin{cases} 
\frac{a}{v^3} - \frac{b}{P_R} & v_{ci} < v < v_r \\
0 & v_r < v < v_{co}
\end{cases} \quad a = \frac{P_R}{v_r^3 - v_{ci}^3} \quad b = \frac{v_{ci}^3}{v_r^3 - v_{ci}^3} \]  

(4)

The Weibull distribution is used to represent the statistical state of the wind speed. Its function is shown in the equation (5). Solving the distribution function, and the parameter value of \( k \) and \( c \) could be determined. If \( v \) and \( \sigma \) are known, \( k \) and \( c \) can be calculated.

\[ f(v) = \frac{k}{v} \left( \frac{v}{c} \right)^{k-1} \exp \left[ -\left( \frac{v}{c} \right)^k \right] \]  

(5)

2.1.2. The Model of fan shaft wind speed. When calculating the actual output power of the wind turbine, the wind speed value at the fan shaft is used, and the wind speed value we measured every day is obtained by the wind tower. Therefore, the wind speed value measured by the wind tower needs to be converted to the wind speed value at the fan shaft position, using Wind speed height transformation equation.

\[ v = v_0 \left( \frac{h}{h_0} \right)^\gamma \]  

(6)

In equation (6), \( v \) is the wind speed, \( v_0 \) is the wind speed value measured by the wind tower, \( h \) represents the height from the center of wind turbine’s wind wheel to the ground. \( h_0 \) is the height of the wind tower, \( \gamma \) is the wind shear coefficient. Its value is generally 1/7.

2.2. The model of photovoltaic cell

2.2.1. Photovoltaic battery equivalent circuit analysis. In the equation (7), \( R_s \) is a series resistor, \( R_{sh} \) is a shunt resistor and \( I_D \) is a dark current. \( V \) is the external load voltage of the battery output. \( A \) is the diode quality factor, \( K \) is the Boltzmann constant, \( 1.38 \times 10^{-23} \text{J/K} \), \( T \) is the surface temperature of solar cell, \( q \) is the unit electron charge, \( K_i \) is the short-circuit current temperature coefficient, and \( \lambda \) is the light intensity. \( E_g \) is the forbidden broadband value, \( I_{OR} \) is the dark saturation current under the reference temperature \( T_{OR} \).

\[ I = I_{PH} - I_D - I_{sh} = I_{PH} - I_0 \left\{ \exp \left[ \frac{q(V + IR_s)}{AKT} - 1 \right] \right\} - \frac{V + IR_s}{R_{sh}} \]  

(7)

\[ I_o = I_{OR} \left( \frac{T}{T_R} \right)^3 \exp \left[ \frac{qE_g \left( \frac{1}{T_R} - \frac{1}{T} \right)}{BK \left( \frac{1}{T_R} - \frac{1}{T} \right)} \right] \]  

(8)
2.2.2. The model of Photovoltaic battery power output. The main factors affecting the output power of photovoltaic cells are temperature and light intensity. The output power of the photovoltaic cell is usually calculated simply by the equation (9).

\[
P_{PV} = P_{PVR} f_{PV} \left( \frac{I_T}{I_S} \right) \left[ 1 + \alpha_p \left( T_c - T_{c,STC} \right) \right] \tag{9}
\]

In equation (9), \( P_{PVR} \) is the rated capacity of photovoltaic cells, \( f_{PV} \) is the derating factor, \( I_T \) is the radiation amount kw/m² of the current panel, \( I_S \) is the radiation amount under standard test conditions, \( \alpha_p \) is the temperature coefficient of power, \( T_{c,STC} \) is the temperature of the photovoltaic cell under 25 °C, \( T_c \) is the surface time of the photovoltaic cell at some time. \( T_a \) is the installation temperature and \( NOCT \) is the temperature of photovoltaic cells.

\[
T_c(t) = T_a(t) + \frac{NOCT - 20}{800} \cdot I_T(t) \tag{10}
\]

2.3. The model of Battery and Diesel generators

The energy storage component is used to ensure the stability and reliability. In equation (11), \( R_i \) is the internal resistance, \( I_c \) is the current, \( U_i \) is the terminal voltage, \( D_i \) is the self-discharge rate, and \( K_i \) is the charge-discharge rate.

\[
SOC(t + dt) = SOC(t) \cdot (1 - D_i dt) + K_i (U_i I_n - R_i I_n^2) dt \tag{11}
\]

The power generation cost of a diesel generator is related to the output power. And the \( k_1, k_2 \) and \( k_3 \) are the parameters corresponding to the diesel generator cost function.

\[
C = k_1 P_{df}^2 + k_2 P_{df} + k_3 \tag{12}
\]

3. The Improved genetic algorithm based on constraint grading

3.1. The Improved genetic algorithm

The processing of genetic algorithm constraints is improved, and it is embodied in the three principles of feasible solution, infeasible solution and comparison. The feasible is selected firstly, then the solution with the least cost and the solution with less constraint at last.

3.2. The Objective function

In the optimized configuration, it has the lowest construction and maintenance costs while meeting the demand and \( x \) is the decision vector, \( x=(N_{PV}, N_{WG}, N_{BAT}, N_{Dsl}, N_{Ch}, h) \). The following equation (13) and (14) are the objective function, \( N_{PV}, N_{WG}, N_{BAT}, N_{Dsl}, N_{Ch} \) represent the number of photovoltaic cells, wind turbines, batteries, diesel engines and inverters respectively, \( J \) is the cost, \( C \) is purchase cost, \( k \) is the service life, \( M \) is the maintenance cost, \( Q \) is the installation cost, \( Y \) is the number of replacements, and \( h \) is the height of the machine.

\[
J(N_{PV}, N_{WG}, N_{BAT}, N_{Dsl}, N_{Ch}) = J_{PV} + J_{WG} + J_{BAT} + J_{Dsl} + J_{Ch} \tag{13}
\]

\[
\begin{align*}
J_{PV} &= N_{PV} \cdot \left( C_{PV} + kM_{PV} + Q_{PV} \right) \\
J_{WG} &= N_{WG} \cdot \left( C_{WG} + kM_{WG} + Q_{PV} \right) \\
J_{BAT} &= N_{BAT} \cdot \left[ C_{BAT} (Y_{BAT} + 1) + M_{BAT} (k - Y_{BAT} - 1) + Q_{BAT} (Y_{BAT} + 1) \right] \\
J_{Dsl} &= N_{Dsl} \cdot \left( C_{Dsl} + kM_{Dsl} + Q_{Dsl} \right) \\
J_{Ch} &= N_{Ch} \cdot C_{Ch} + N_{Ch} \cdot kM_{Ch} + N_{Ch} \cdot Q_{Ch}
\end{align*} \tag{14}
\]
3.3. The constraints
There are two constraints, one is energy constraint, the other is quantity constraint.

3.3.1. The energy constraints to Guarantee system power supply. The \( P_g \) represents wind turbines, photovoltaic cells, batteries, diesel engines, inverters

\[
\sum P_{g,i} N_D \geq P_{load}
\]  

(15)

3.3.2. The number of \( P_g \). In extreme cases, assuming that the wind power and the battery are not working, the consumption of the load is all dependent on the photovoltaic battery.

\[
N_{PV_{max}} = \frac{P_{load}}{P_{PV}}
\]  

(16)

4. Simulation

4.1. The resources and load data
The light radiation, the wind speed, the ambient temperature and the load of the ship are shown in figure 1, figure 2, figure 3 and figure 4.

4.2. The parameters of Hybrid power generation system
The parameters of Wind turbine, Photovoltaic cell, Battery and Inverters are shown in table 1.

| Wind | \( V_{ci} \) | \( V_{co} \) | \( V_r \) | \( P_R \) | diameter | Purchase | Maintenance | Installation |
|------|-------------|-------------|-------------|-------------|----------|----------|-------------|-------------|

Table 1. The parameters of Wind turbine, Photovoltaic cell, Battery and Inverters.
### turbine

| Capacity | NOCT | $\alpha_p$ | $f_{PV}$ | Purchase | Maintenance | Installation |
|----------|------|------------|----------|----------|-------------|--------------|
| 3        | 28   | 12         | 2400     | 4.5m     | 5400 yuan   | 54 yuan      | 540 yuan     |

### Photovoltaic

| Capacity | V  | Year | Model     | Purchase | Maintenance | Installation |
|----------|----|------|-----------|----------|-------------|--------------|
| 110      | 43 $^\circ$C | -0.0052 | 0.8    | 1518 yuan | 15 yuan    | 152 yuan    |

### Battery

| Capacity | V  | Year | Model     | Purchase | Maintenance | Installation |
|----------|----|------|-----------|----------|-------------|--------------|
| 600 Ah   | 12 V | 3    | Hopck6OPS60 | 4350     | 260 yuan    | 435 yuan    |

### Inverter

| Power level | Purchase | Maintenance | Installation |
|-------------|----------|-------------|--------------|
| 5 kW        | 35800 yuan | 750 yuan     | 750 yuan     |

### 4.3. Analysis of Simulation

The improved genetic algorithm is used to solve the model. In order to meet the daily load of ships, this paper adopts wind, photovoltaic and battery hybrid power generation system. The decision variable at this time is $x=(N_{PV}, N_{WG}, N_{BAT}, N_{Dsl}, N_{Ch}, h)$. The classic genetic algorithm takes 50 initial populations and 400 generations, runs the two algorithms 10 times each. The feasible solutions of the them are shown in figure 5.

![Figure 5. The solutions for algorithms](image1)

![Figure 6. The result of algorithms](image2)

It can be seen from figure 5 that the number of feasible solutions of the classical genetic algorithm fluctuates greatly, and the number of feasible solutions is always less than 50, while
the feasible solution of the improved genetic algorithm is maintained at 50. The less feasible solution means that the probability of obtaining the lowest feasible solution is lower, which shows that the classical genetic algorithm is not as reliable as the improved genetic algorithm. The results obtained by the two algorithms are compared as shown in the figure 6.

**Table 2. Comparison of the two algorithms**

|          | Time  | Average | Value   | Convergence | Feasible Solution |
|----------|-------|---------|---------|-------------|-------------------|
| Classical| 19.32s| 349965  | 348550  | 3           | 34.6              |
| Improved | 15.77s| 348952  | 348550  | 1           | 50                |

Table 2 shows that the improved algorithm has a shorter running time and smaller average. It is less likely to fall into local optimum and has better robustness. When the cost is 348,550 yuan the model has become optimal, then, \( x=\{35,1,6,0,1,14.1265\} \). It includes 35 photovoltaic cells, 1 wind turbine, 6 batteries, 0 diesel engines, 1 inverter. The tower height is 14.1265 m.

5. Conclusion
This paper takes a small microgrid based on clean energy as the research object, and applies it to the ship. Firstly, the calculation model of its output power are expounded, and the mathematical model of the microgrid is constructed. Secondly, an improved genetic algorithm is proposed to solve the optimization problem. Finally, the simulation results show the effectiveness of the algorithm in solving this problem.

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