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Research Article

Optimal Economic Operation of Islanded Microgrid by Using a Modified PSO Algorithm

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An optimal economic operation method is presented to attain a joint-optimization of cost reduction and operation strategy for islanded microgrid, which includes renewable energy source, the diesel generator, and battery storage system. The optimization objective is to minimize the overall generating cost involving depreciation cost, operation cost, emission cost, and economic subsidy available for renewable energy source, while satisfying various equality and inequality constraints. A novel dynamic optimization process is proposed based on two different operation control modes where diesel generator or battery storage acts as the master unit to maintain the system frequency and voltage stability, and a modified particle swarm optimization algorithm is applied to get faster solution to the practical economic operation problem of islanded microgrid. With the example system of an actual islanded microgrid in Dongao Island, China, the proposed models, dynamic optimization strategy, and solution algorithm are verified and the influences of different operation strategies and optimization algorithms on the economic operation are discussed. The results achieved demonstrate the effectiveness and feasibility of the proposed method.

1. Introduction

In recent years, microgrid has received considerable attentions to improve the reliability and economy of power system [1]. Researches and practices show that islanded microgrid integrated with renewable energy sources (RES), the synchronous generators, and energy storage system has been an effective approach to solving the power supply problem in small rural or remote regions, where these communities do not access the utility grid due to the technical and economical reasons [2–4]. However, incorporation of renewable energy sources and other distributed generations (DG) poses a big challenge to the economic operation problem of islanded microgrid [5].

Economic operation is a very important problem to be solved in the planning and operation of power system, and optimal modeling, optimization, and simulation have received considerable attentions in the literature [6–8]. Reference [9] presents a novel energy management system (EMS) to coordinate the power forecasting, output power of different generators, and energy storage to minimize the total operation cost. Reference [10] proposes a multiobjective linear programming methodology to determine the operating levels of various generation units by minimizing two objectives of annual energy cost and annual CO_2 emissions. Similarly, a differential evolution algorithm is used to minimize the total cost comprising the emission cost and the operation and maintenance costs of microgrid in [11]. Clearly, the operation strategy has a significant influence on the actual performance of islanded microgrid system. Reference [12] proposes an idealized predictive dispatch strategy as a benchmark in evaluating simple, nonpredictive strategies, based on assumed perfect knowledge of future load and wind conditions. Reference [13] proposes an optimal dispatch strategy, considering the battery wear cost and the diesel fuel consumption cost, to determine the optimum values of set points for the starting and stopping of the diesel generator as to minimize the total operation costs of islanded microgrid. The optimum control algorithm based on combined dispatch strategies is developed to achieve the optimal unit cost of islanded microgrid [14].

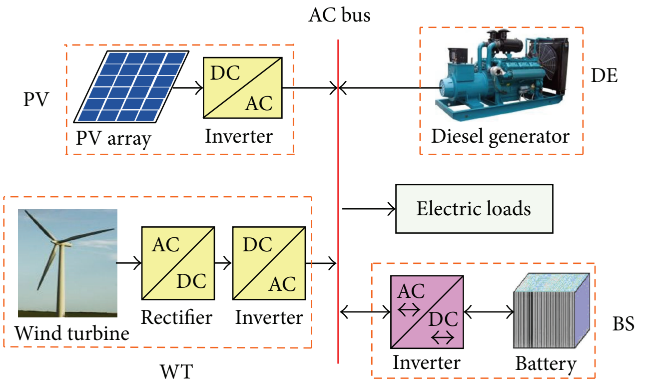


Figure 1: Structure of islanded microgrid.

From the literature survey exposed above, the economic operations of islanded microgrid in those studies are performed under the preset control strategies for minimizing operation cost. In addition, it can be clearly inferred that the cost of islanded microgrid depends on two factors: the unit generating cost of various distributed generation units and the operation strategy. In fact, there are two distinct levels in the operation control of islanded microgrid system: (1) dynamic control, which deals with control of the frequency and magnitude of the output voltage of the system; (2) dispatch control, which deals with the energy flow management from the various sources to load for cost minimization. Thus, the master-slave control strategy is popularly adopted to deal with the control of system frequency and voltage, as well as the energy flow management of islanded microgrid.

This paper presents a joint-optimization of operation strategy and cost reduction to allocate the load demand among various generation units in an economic, stable, and reliable way for islanded microgrid, which is integrated with wind turbine generator (WT) and solar PV generator (PV), the diesel generator (DE), and battery storage system (BS). Considering two different control modes where DE or BS acts as the master unit to guarantee stable operation of islanded microgrid, a novel dynamic optimization process integrated with a modified PSO (MPSO) algorithm is developed to find both optimal operating strategy and optimal cost optimization scheme for the practical economic operation problem of islanded microgrid.

2. Microgrid Operation Strategy

Figure 1 shows a typical system structure of hybrid energy sources islanded microgrid, where PV, WT, DE, and BS units are all connected together to supply power to the electric load through the AC bus. As we know, WT and PV both have a remarkable drawback of their unpredictable nature and dependence on weather and climatic conditions, and their intermittent output powers will cause the system power fluctuation [15]. BS has great advantages of peak shaving and energy buffer to improve RES fluctuation, but the existing big bottleneck of higher cost and shorter lifetime causes the small size of BS in islanded microgrid [16]. DE is still necessary and important to improve the system reliability in case of bad weather conditions that will cause little or zero RES power; however its higher fuel cost and pollution emission are still main concerns of economic operation in islanded microgrid.

The main concerns of islanded operation are to guarantee the system operation stability and reliability, as well as consider economic cost requirement of microgrid. Combining the system operation requirement and control characteristics of various DGs, the master-slave control method is a popular and preferable choice for islanded microgrid to achieve an optimal objective of stable operation and minimum generating cost [17]. In the master-slave control strategy, the controllable microsource is selected as the master unit to track the power fluctuation as to guarantee the stability of system voltage and frequency, and the other microsources do not follow the system power fluctuation [18]. As shown in Figure 1, DE and BS units both are qualified to act as the master unit, but the larger difference of their control response characteristics causes them not to operate as the master unit at the same time [19]. Thus, there are two different operation control modes as below.

(1) Mode 1: BS is the master unit that employs V/f control method to follow the system power fluctuation and guarantee the frequency and voltage stability of islanded microgrid. DE is off or operates at full power to supply power to microgrid and BS as required.

(2) Mode 2: DE is the master unit that uses droop control method to maintain the operation stability of islanded microgrid. However, as the slave unit, BS just use PQ method to absorb RES power or inject power to assist DE to keep system power balance according to the instruction of microgrid energy management system.

3. Economic Operation Model

The economic operation problem of islanded microgrid is to allocate the load demands among the various distributed generation units in such a secure and reliable manner as to minimize the overall system generating cost subject to a set of equality and inequality constraints, while the controllable power sources such as DE or BS act as the master unit to follow system power fluctuation.

3.1. Objective Functions. The objective of microgrid economic operation is to determine generation levels of WT, PV, DE, and BS units to meet the load demand as to minimize the overall system generating cost, including the depreciation cost, the operation cost, the pollutant emission cost, and economic subsidies available for RES over the entire dispatch period $[0, NT]$, where T is the sampling time interval and N is the number of the time intervals. The operation cost comprises the fuel cost and maintenance and operating (M&O) cost:

$$\min C(P) = \sum_{t=1}^{N} \sum_{j=1}^{G} C_j\left(P_j^t\right), \tag{1}$$

where $C(P)$ is the total generation cost of microgrid to produce P during an entire dispatch period NT; G is the numbers of various distributed generation units j; $C_j(P_j^t)$ is the generation cost for unit j to produce P_j^t; P_j^t is the output power of generation unit j during the tth time interval $[(t-1)T, tT]$.

3.1.1. RES Generating Cost. The renewable energy sources of WT and PV units incur only investment costs and exhibit very little operating cost which can be expressed as a fraction of the corresponding initial capital costs [5]. The economic subsidies available for WT and PV units are expressed as their different price subsidies per unit power according to the local green energy generating policy. Thus, the generating cost of RES is formulated in the following:

$$\begin{aligned} C_{\text{RES},i}\left(P_i^t\right) &= C_{\text{DC},i}\left(P_i^t\right) + C_{\text{MO},i}\left(P_i^t\right) - S_{\text{ES},i}\left(P_i^t\right) \\ &= \frac{C_{\text{AIC},i}\left(1+\rho_i\right)}{E_{\text{APG},i}} \cdot P_i^t - k_{\text{ES},i} \cdot P_i^t \\ &= \left(\frac{C_{\text{AIC},i}\left(1+\rho_i\right)}{E_{\text{APG},i}} - k_{\text{ES},i}\right) \cdot P_i^t, \end{aligned} \tag{2}$$

where $C_{\text{DC},i}$, $C_{\text{MO},i}$, and $S_{\text{ES},i}$ are the depreciation cost, the M&O cost, and the economic subsidy for RES unit i to produce P_i^t, respectively; C_{AIC} is the annualized investment cost (¥); ρ is M&O cost coefficients; E_{APG} is the estimated total annual power generation (kWh) based on a typical historical data; k_{ES} is the proportionality coefficient of price subsidy (¥/kWh).

3.1.2. DE Generating Cost. The generating cost of DE is made up of the fixed cost and variable cost. The fixed cost is expressed as the depreciation cost; however the variable cost consists of the fuel cost, M&O cost, and emission cost. The M&O cost is assumed to be proportional with the produced energy. The fuel cost is expressed as an inverse proportion function about the relationship between the nominal power rating and actual output power [20]. The pollution emission costs (NO_x, SO_2, and CO_2) are gained by their proportional coefficients of the fuel cost [21]. The unit depreciation cost can be equal to the annualized investment cost divided by the estimated total annual power generation produced by DE. Thus, the overall generating cost of DE is formulated in the following:

$$\begin{aligned} &C_{\text{DE}}\left(P_{\text{DE}}^t\right) \\ &\quad = C_{\text{DC}}\left(P_{\text{DE}}^t\right) + C_{\text{MO}}\left(P_{\text{DE}}^t\right) + C_{\text{FC}}\left(P_{\text{DE}}^t\right) + C_{\text{EC}}\left(P_{\text{DE}}^t\right) \\ &\quad = \left(\frac{C_{\text{AIC,DE}}}{E_{\text{APG,DE}}} + K_{\text{MO,DE}}\right) \cdot P_{\text{DE}}^t \\ &\qquad + \left(0.146 + 0.05415 \cdot \frac{P_{\text{DE}}^{\text{RD}}}{P_{\text{DE}}^t}\right) \cdot \left(c_{fp} + \sum_{k=1}^{3} c_{E,k}\right), \end{aligned} \tag{3}$$

where $C_{\text{DC}}(P_{\text{DE}}^t)$, $C_{\text{MO}}(P_{\text{DE}}^t)$, $C_{\text{FC}}(P_{\text{DE}}^t)$, and $C_{\text{EC}}(P_{\text{DE}}^t)$ are the depreciation cost, the M&O cost, the fuel consumption cost, and the emission cost, respectively, for DE to produce P_{DE}^t; $C_{\text{AIC,DE}}$ is the annualized investment cost (¥); $E_{\text{APG,DE}}$ is the estimated total annual power generation produced by DE (kWh); $K_{\text{MO,DE}}$ is the M&O cost coefficient (¥/kWh); $P_{\text{DE}}^{\text{RD}}$ is the nominal power rating of DE (kW); c_{fp} is the fuel price for DE (¥/liter); $c_{E,k}$ is the environmental cost coefficient of pollution emission k of NO_x, SO_2, and CO_2 (¥/kg).

3.1.3. BS Wear Cost. The wear cost of BS is expressed as a proportion of the life cycle cost divided by the total discharging power in the whole life time. It is a simple and effective way to calculate in microgrid economic operation, compared with the method in accordance with the battery cycle times. Thus, the wear cost of BS is expressed as follows:

$$C_{\text{BS}}\left(P_{\text{BS}}^t\right) = \beta_{\text{BS}} \cdot P_{\text{BS,dc}}^t, \tag{4}$$

where $C_{\text{BS}}(P_{\text{BS}}^t)$ is the wear cost of BS to discharge P_{BS}^t at t time; β_{BS} is the unit wear cost coefficients of BS; $P_{\text{BS,dc}}^t$ is the discharging power of BS.

3.2. Constraint Conditions

3.2.1. System Power Balance. The balance between power supply and demand is necessary for islanded microgrid, so the equality constraint is expressed as follows:

$$\sum_{j=1}^{G} P_j^t - P_{\text{excessive}}^t = P_{\text{Load}}^t, \tag{5}$$

where $P_{\text{excessive}}^t$ is the system excessive power beyond the load demand; P_{Load}^t is the total system load demand.

3.2.2. Spinning Reserve Capacity. The necessary spinning reserve capacity of the controllable generation units available is necessary to follow the system net load power fluctuation as to guarantee the secure and stable operation of islanded microgrid; thus it is formulated as follows:

$$\begin{gathered} \sum_{g=1}^{R} P_{\text{CG,SR}}^t \geq \Delta P_{\text{MG,SR}}^t, \\ \Delta P_{\text{MG,SR}}^t = e_{\text{MG}} \cdot P_{\text{net-load}}^t, \end{gathered} \tag{6}$$

where R is the numbers of the controllable generation units; $P_{\text{CG,SR}}^t$ is the spinning reserve of the controllable generation unit (CG) available; $\Delta P_{\text{MG,SR}}^t$ is the required spinning reserve of microgrid (MG); e_{MG} is the deviation ratio between the predictive value and the actual value of system net load; $P_{\text{net-load}}^t$ is the system net load, which equals the system load minus RES power.

3.2.3. Power Generation Limits of Microsources. As for various generating units such as WT, PV, DE, and BS, their output power ranges are subject to the functional roles in islanded microgrid.

(1) Master Unit. The master unit is responsible for tracking the power fluctuation as to guarantee the stability of system voltage and frequency in islanded operation of microgrid. Thus, its output powers are subject to the following constraints:

$$P^t_{Mh,\max} \le P^t_{Mh} \le P^t_{Mh,\min}, \tag{7}$$

$$\begin{aligned} P^t_{Mh,\max} &= P^{\max}_{Mh} - \Delta P^t_{\mathrm{MG,SR}}, \\ P^t_{Mh,\min} &= P^{\min}_{Mh} + \Delta P^t_{\mathrm{MG,SR}}, \end{aligned} \tag{8}$$

where P^t_{Mh} is the output power of h master unit (Mh) during tth time interval; $P^t_{Mh,\max}$ and $P^t_{Mh,\min}$ are the output power upper and lower limits, respectively; $P^{\max}_{Mh}$ and $P^{\min}_{Mh}$ are the technical maximum and minimum power limits, respectively.

(2) Slave Unit. The slave unit can operate within its technical maximum and minimum power limits, as it does not need to follow system power fluctuation. Thus, its output power is subject to the following inequality constraint:

$$P^{\min}_{S,l} \le P^t_{S,l} \le P^{\max}_{S,l}, \tag{9}$$

where $P^t_{S,l}$ is the output power of l slave unit during tth time interval; $P^{\min}_{S,l}$ and $P^{\max}_{S,l}$ are the technical operation power upper and lower limits of l slave unit, respectively.

3.2.4. Start-Stop Time Constraints. The minimum start-stop time constraint such as DE or WT cannot be less than a certain number:

$$T_{\mathrm{rs},j} \ge T^{\min}_{\mathrm{rs},j}, \tag{10}$$

where $T_{\mathrm{rs},j}$ is the running/stop (rs) time of j generation unit; $T^{\min}_{\mathrm{rs},j}$ is the minimum continuous running or stop time of j unit.

3.2.5. BS Storage Capacity Limits. In order to avoid any deep discharge to decrease battery lifetime [22], this paper selects four key nodes of $\mathrm{SOC}_{\min}$, $\mathrm{SOC}_{\mathrm{low}}$, $\mathrm{SOC}_{\mathrm{high}}$, and $\mathrm{SOC}_{\max}$ to divide the battery energy storage capacity into 4 interval ranges. The maximum SOC ($\mathrm{SOC}_{\max}$) is fully charged (100% of the SOC), and the minimum SOC ($\mathrm{SOC}_{\min}$) is recommended by the manufacturer below which they should not operate:

$$\mathrm{SOC}_{\min} \le \mathrm{SOC}_{\mathrm{low}} \le \mathrm{SOC}(t) \le \mathrm{SOC}_{\mathrm{high}} \le \mathrm{SOC}_{\max}, \tag{11}$$

where $\mathrm{SOC}_{\min}$ and $\mathrm{SOC}_{\max}$ are the minimum and maximum battery storage capacity limits; $\mathrm{SOC}_{\mathrm{low}}$ and $\mathrm{SOC}_{\mathrm{high}}$ are the low and high storage capacity limits of BS normal operation range.

4. MPSO-Based Dynamic Optimization

4.1. Dynamic Economic Optimization Concept. The economic operation of islanded microgrid is commonly regarded as a discrete cost optimization problem to sum up all minimum generation costs of sampling periods in the time domain [23]. The operation strategy and cost reduction are two main concerns to the economic operation problem of islanded microgrid. The operation strategy is mainly to select the master unit to maintain the system stable operation, as well as pay critical influence on the cost reduction [14, 24]. As shown in Figure 1, there are two different control modes of DE or BS as the master unit. In fact, during the whole dispatch period of islanded microgrid, DE and BS might alternate to operate as the sole master unit to maintain the system frequency and voltage stability. Thus, a novel dynamic economic operation optimization process is proposed based on two potential operation control modes as shown in Figure 2, which adopts a MPSO algorithm to find both optimum operation strategy and optimum cost minimization for the economic operation problem of islanded microgrid. This proposed operation strategy is called the dynamic operation strategy.

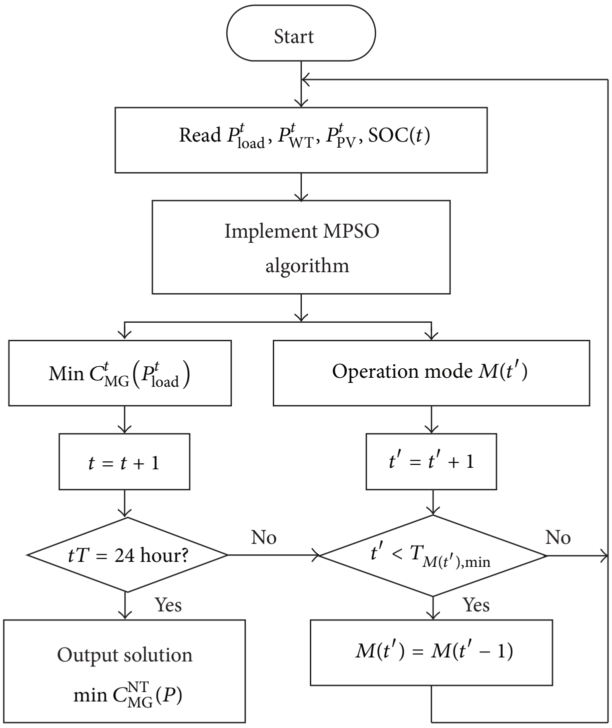


Figure 2: Dynamic economic optimization process.

In the proposed dynamic optimization process as above, there are two different time scales: t is for the cost optimization and t' is for the operation control mode or the type of master unit. It also indicates that the type of master unit will change during dispatch period, so the master unit $M(t')$ needs its own time-domain function ($t' = t' + 1$) to evaluate if its minimum start or stop time constraints are met or not. If the master unit is always fixed as DE or BS over the whole dispatch period or during the initial sampling periods, these two time scales are the same as $t = t'$. Moreover, MPSO algorithm is applied to get the optimal trade-off between the minimum generating cost ($C^t_{\mathrm{MG}}(P^t_{\mathrm{load}})$) for meeting load power (P^t_{load}) and the corresponding operation control mode that determines the type of master unit ($M(t')$) during tth sampling period.

4.2. MPSO Algorithm. Particle swarm optimization (PSO) is a stochastic population-based algorithm, which was originally introduced by Kennedy and Eberhart [25, 26]. Compared to other optimization techniques such as genetic algorithm (GA), PSO has the most outstanding advantages of few parameters to implement easily and faster convergence speed. In order to find a balance between accelerating the convergence speed and retaining the diversity of the particles, a MPSO with dynamic adaptive inertia weight is adopted to resolve the economic dispatch problem, for it has the improved convergence speed and solution accuracy [27]. In MPSO, a swarm contains a set of population members, which is called the particle. Every particle has both a position and a velocity, and the position represents a candidate solution in the multidimensional solution space, and the velocity moves it from one position to another over the solution space. For the economic operation optimization of islanded microgrid, each particle represents a candidate optimum operation solution.

In a D-dimensional solution space, the position vector of the mth solution is written as $X_m = (x_{m,1}, x_{m,2}, \ldots, x_{m,D})$, and the corresponding velocity vector is given by $V_m = (v_{m,1}, v_{m,2}, \ldots, v_{m,D})$. The position and velocity updating methods for the dth dimension of mth solution at the $(n+1)$th iteration step are expressed as the following equations:

$$x_{m,d}^{n+1} = x_{m,d}^{n} + v_{m,d}^{n+1}, \tag{12}$$

$$v_{m,d}^{n+1} = w \cdot v_{m,d}^{n} + c_1 r_1 \left(pb_{m,d} - x_{m,d}^{n}\right) + c_2 r_2 \left(gb_d - x_{m,d}^{n}\right), \tag{13}$$

$$w = w_0 - h_m^n \cdot w_h + s_m^n \cdot w_s, \tag{14}$$

$$h_m^t = \left| \frac{\min\left(F\left(pb_m^{n-1}\right), F\left(pb_m^n\right)\right)}{\max\left(F\left(pb_m^{n-1}\right), F\left(pb_m^n\right)\right)} \right|, \tag{15}$$

$$s = \left| \frac{\min\left(F_{n\text{best}}^n, \overline{F}_n\right)}{\max\left(F_{n\text{best}}^n, \overline{F}_n\right)} \right|, \tag{16}$$

where x_m^n and v_m^n are vectors representing the position and velocity of the mth particle, respectively; $d \in 1, 2, \ldots, D$ represents the dimension of the particle; w is a dynamically adaptive inertia weight determining how much of particle's previous velocity is preserved; c_1 and c_2 are two positive acceleration constants; r_1 and r_2 are two uniform random sequences sampled from $U(0,1)$; pb_m is the personal best position found by the mth particle; gb is the best position found by the entire swarm; w_0 is the initial value of w; h_m^n is the speed factor; s is the aggregation degree factor; w_h and w_s are two constants typically within the range $[0,1]$; $F(pb_m^n)$ is the fitness value of pb_m^n; $\overline{F}_n$ is the mean fitness value of all particles in the swarm at the nth iteration; $F_{n\text{best}}^n$ is the best fitness value achieved by the particles at the nth iteration.

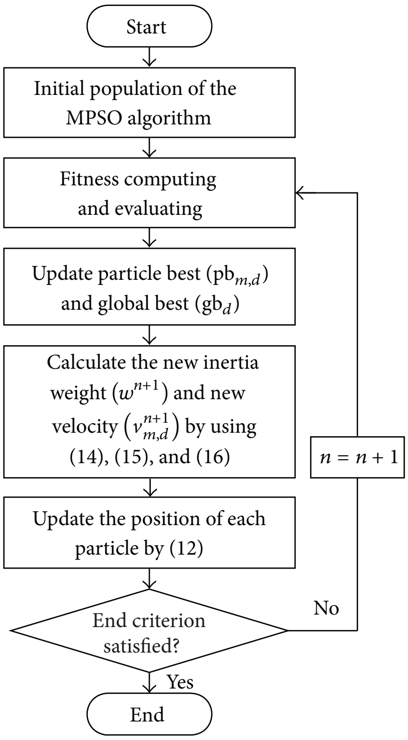


Figure 3: Flowchart of MPSO optimization algorithm.

4.3. The Process of the MPSO Algorithmic Solution. As shown in Figure 2, the MPSO algorithm was adopted to find both optimal operation strategy and optimal minimum generation cost of islanded microgrid. Thus, the algorithm process is shown in Figure 3.

The specific steps are described as follows.

Step 1. The first step includes the following: population initialization of MPSO parameters setting, the total number of the particles, the maximum number of the generations $k_{\max}$, the maximum velocity $v_{\max}$, two positive acceleration coefficients c_1 and c_2, initial inertia weight w_0, and two inertia weight coefficients w_h and w_s.

Step 2. Calculate and evaluate the fitness (1): evaluate the fitness of each particle in the population.

Step 3. Compare the particle's fitness value with $pb_{m,d}$ and gb_d. Update the $pb_{m,d}$ and gb_d according to the comparison result.

Step 4. Calculate the new velocity $v_{m,d}^{n+1}$ by using (15).

Step 5. Update the position of each particle by using (14).

Step 6. Calculate the variance of all particles' fitness functions (1) and check if the converge criterion is met. If it is met, go to Step 7; otherwise, go to Step 2.

Step 7. End and output the optimization result.

Table 1: System configuration of Dongao microgrid.

Generation unit	Power rating	QTY (set)
WT	750 kW	3
PV	250 kW	3
DE	1020 kW/1275 kVA	4
BS	500 kW × 6 h	1

Table 2: Control parameters of DGs.

Type	Parameter (p.u.)	Type	Parameter (p.u.)
$P_{\mathrm{MU}}^{\max}$	1 p.u.	$\mathrm{SOC}_{\min}$	0.2 p.u.
$P_{\mathrm{MU}}^{\min}$	0.2 p.u.	$\mathrm{SOC}_{\mathrm{initial}}$	1000 kWh
$P_{\mathrm{SU}}^{\max}$	1 p.u.	$T_{\mathrm{WT,min}}$	30 minutes
$P_{\mathrm{SU}}^{\min}$	0.2 p.u.	$T_{\mathrm{PV,min}}$	0
$\mathrm{SOC}_{\max}$	1 p.u.	$T_{\mathrm{DE,min}}$	20 minutes
$\mathrm{SOC}_{\mathrm{high}}$	0.90 p.u.	$T_{\mathrm{BS,min}}$	0
$\mathrm{SOC}_{\mathrm{low}}$	0.3 p.u.		

5. The Case of Study

5.1. The Example System. For the purposes of validating the proposed methodology, the simulations are executed in an actual islanded microgrid project, which was built to supply power for a new economic development experimental region in Dongao Island, China. The system configuration of Dongao microgrid is shown in Table 1, which was optimized based on the full consideration of the load demand and various distributed generation units such as WT, PV, DE, and BS based on the historical data. According to its practical operation performance, the unexpected problems have higher electricity costs and lower utilization of RES generations, when Dongao microgrid adopts an initial static operation strategy that just has the control mode 2 where DE always acts as the master unit, as discussed in Section 2.

In order to reflect the dynamic scheduling of microgrid better, this paper set the calculation cycle as 1 day, setting 5 min as a calculation period; then the whole day could be divided into 288 periods. The related parameters about MPSO were set as follows: particle population size was 50, dimensions were 30, and max iterations were 100 ($c_1 = c_2 = 2$, $w_h = 0.5$, and $w_s = 0.05$). Moreover, based on the developed models, the parameters for each distributed generation unit in Dongao microgrid project are given in Table 2.

5.2. Results and Discussion

5.2.1. Comparative Analysis of the PSO Algorithm. In order to analyze the influence of the MPSO algorithm and the traditional PSO algorithm on the microgrid operation, combined with the proposed dynamic optimization process as shown in Figure 2, the results of adopting these two different algorithms to calculate the optimal models are shown in Table 3, and the convergence curves are shown in Figure 4.

Table 3 shows that the calculation time of the MPSO is shorter than that of the traditional PSO algorithm, because the adaptive inertia weight effectively improves the convergence speed. It can also be seen from Figure 4 that the convergence rate of the MPSO is faster than the traditional PSO algorithm, and it converges at about 15th generation. Moreover, the MPSO obtained the optimum result compared to the traditional PSO algorithm. In conclusion, the MPSO algorithm has the more rapid convergence rate and more accurate convergence value to resolve the optimum operation of islanded microgrid.

Table 3: Result comparisons between the traditional PSO and the MPSO algorithm.

Optimization type	PSO	MPSO
Calculation time (second)	35.058	16.235
Average convergence iteration	47	15
Convergence value (¥)	90684.3051	90632.5133

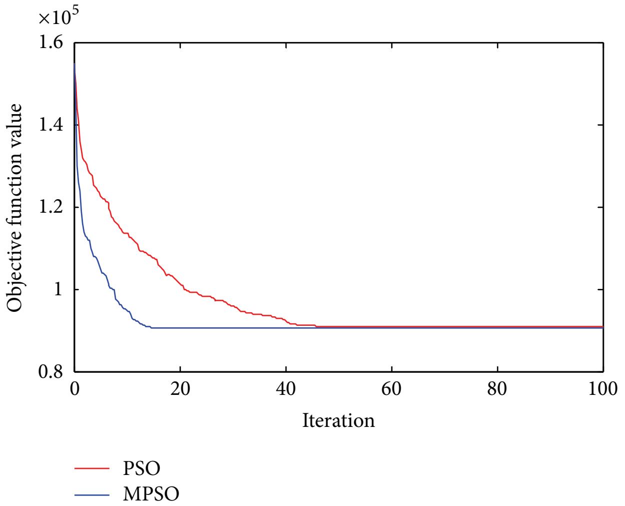
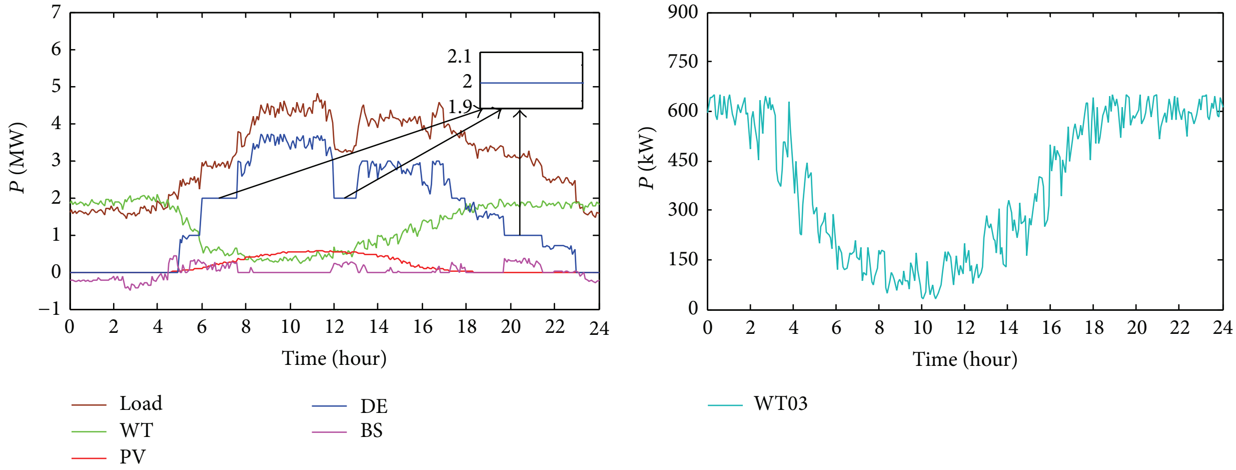


Figure 4: Convergence characteristics of PSO and MPSO.

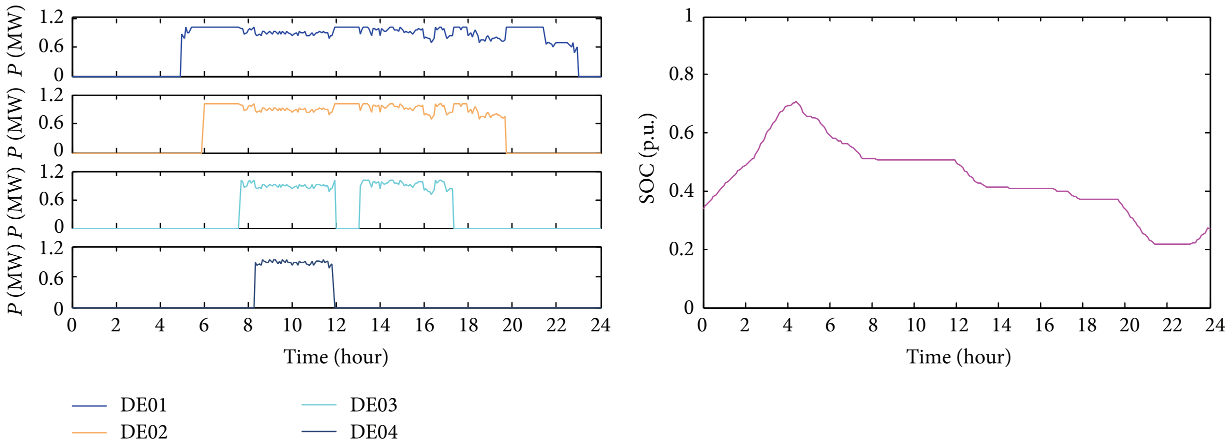
5.2.2. Comparative Analysis of the Operation Strategy. In this paper, we adopt the dynamic optimization strategy with mode 1 and mode 2 where DE and BS alternate as the sole master unit as to minimize the generating cost and improve RES utilization of islanded microgrid over the entire dispatch period. In order to analyze the impact of the proposed dynamic strategy on the economic dispatch of microgrid, the results of adopting both the proposed dynamic strategy and the original static strategy to calculate the model of scheduling are shown in Table 4, and their economic operation performances are demonstrated in Figures 5 and 6, respectively. Please note that the output power curves of WT01, WT02 and 3 sets of PVs are not shown because they are all absorbed or not changed during the economic operation.

We can see from Table 4 that when we adopt the dynamic operation strategy, the total cost is much less than that under the static strategy and the daily cost saving is RMB5047.5858. Thus, the annual cost reduction will be RMB181713.0888 because the ratio of similar weather is approximately 10%



(a) Performance under dynamic strategy

(b) WT03 power under dynamic strategy



(c) DE power under dynamic strategy

(d) BS SOC under dynamic strategy

Figure 5: Optimal economic operation under dynamic strategy.

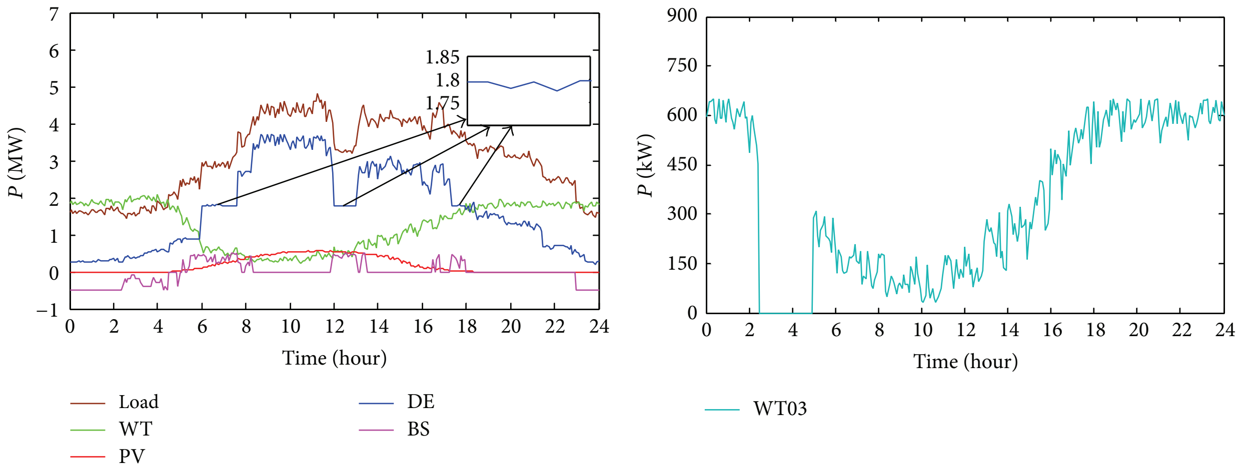
Table 4: Result comparisons between two operation strategies.

Optimization results	Dynamic strategy	Static strategy
Total cost (¥)	90632.5133	95680.099
RES utilization (%)	100%	96.59%
Cost saving (¥)	5047.5858	

calculated based on historical data collected on Dongao Island in 2013. Combined with Figures 5 and 6, it is easy to know the root cause of their different cost levels.

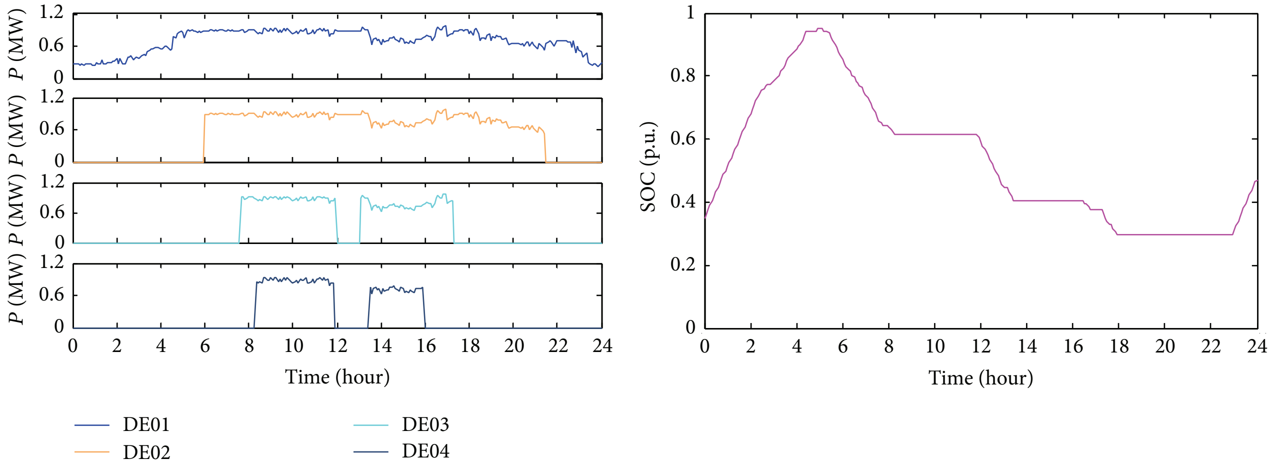
Figure 5 shows detailed operation performances of various distributed generation units under the proposed dynamic operation strategy, in which BS and DE alternate to operate as the master unit frequently according to different operation conditions. Figure 5(b) shows a continuous generation of WT, which means a satisfied RES utilization effect. Combining Figures 5(a) and 5(c), it is easy to know the following. (i) While BS runs as the master unit, it absorbs the surplus RES power when RES power exceeds the load demand during 0:00am–4:55am and 23:05pm–24:00pm, and accordingly DE is off. In addition, BS also runs the peak shaving function to meet buffer instantaneous fluctuations around the net load, and meanwhile DE operates at full power during 5:25am–7:35am, 11:55am–13:00pm, 17:20pm–17:55pm, and 19:45pm–21:25pm. (ii) While DE acts as the master unit during other time periods, it operates at the higher power level as to reduce fuel and emission, and sometimes it should get some necessary power supplement from BS if needed. The SOC curve of BS also shows this clearly in Figure 5(d). In short, the dynamic strategy achieves the higher RES utilization and the higher power level of DE, as well as reduction of DE run-time according to different conditions, which can further reduce the system generating cost.

Figure 6 demonstrates detailed operation performances under the original static strategy, in which DE always operates as the master unit. It is obvious to see that the static strategy causes the system to abandon/dump some wind power and to make DE run at lower power level in some times, which are shown in Figures 6(b) and 6(c). Moreover, combined with Figure 6(a), we also know that BS can assist DE to improve its output power level to a certain extent as to reduce fuel and



(a) Performance under static strategy

(b) WT03 power under static strategy



(c) DE power under static strategy

(d) BS SOC under static strategy

FIGURE 6: Optimal economic operation under static strategy.

emission. However, DE could not operate at the full power because of the necessary spinning reserve to cover system power fluctuation, indicated in (8). As a result, the higher system generating cost occurs, resulting from the lower RES utilization as well as the more fuel and emission of DE.

Based on the above, it can be seen that the operating strategy has a critical influence upon the actual economic operation performance of islanded microgrid. Compared to the static strategy, the proposed dynamic strategy can maximize BS advantages to improve the RES utilization and help DE reduce run-time and run at higher power level correspondingly, further reducing DE fuel cost and emission cost so as to minimize the system generating cost of microgrid as far as possible. The root cause is to set BS as the master unit to further reduce system generating cost, which can not only just utilize RES power to meet load but also run the system peak shaving function as to minimize DE fuel and emission. In addition, the results show the following. (i) RES units have the lowest generating cost as to be priority scheduling, compared to DE and BS. (ii) There is a set point between the generating cost of DE and the wear cost of BS; when DE output power is higher than this set point, its generating cost is less than the wear cost of BS so as to be scheduled prior to BS. If not, BS has a higher priority than DE.

6. Conclusion

This paper proposes an optimal economic operation method for islanded microgrid to attain a joint-optimization of cost reduction and operation strategy that determine the type of master unit to maintain the stability of system frequency and voltage. The time-series dynamic optimization process is designed according to two different master units of DE and BS, as well as the discrete optimization characteristics of economic operation in islanded microgrid. The MPSO algorithm presented is capable of efficiently searching an optimum trade-off between the minimum generating cost and the corresponding control mode of islanded microgrid. The proposed models and MPSO-based dynamic optimization strategy are verified by case studies based on a real islanded microgrid in Dongao Island, China. The methodology presented effectively improves the RES generation utilization and the operational life of BS, as well as minimizing the fuel consumption cost and pollution emission cost resulting from DE.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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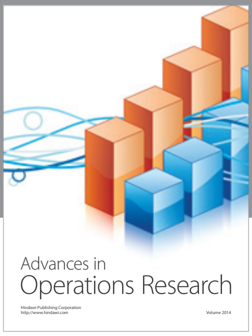
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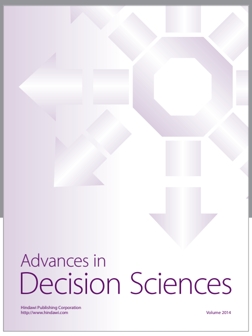
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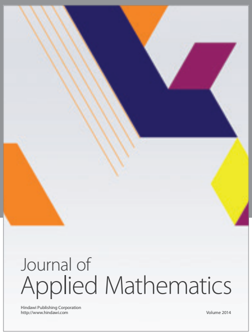
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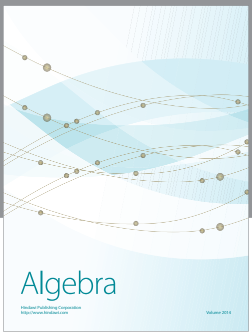
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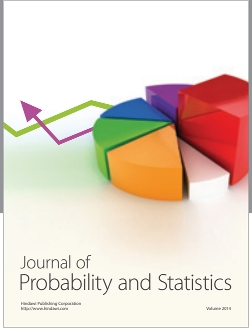
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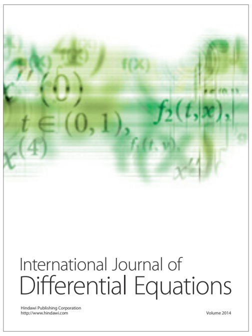
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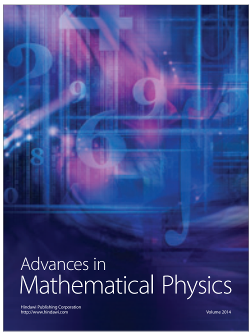
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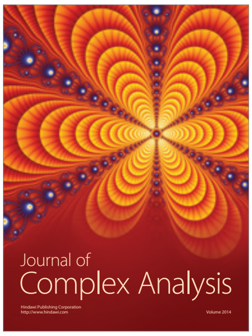
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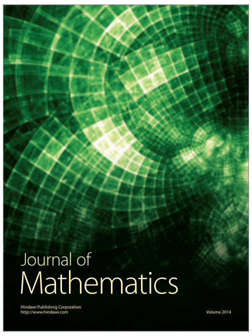
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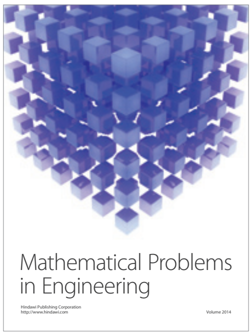
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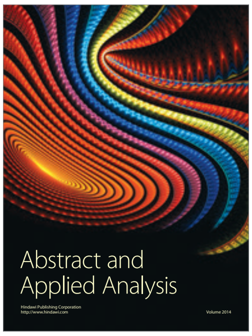
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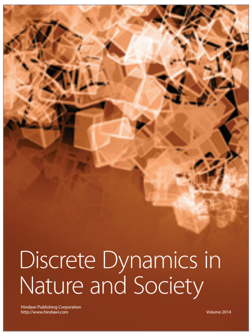
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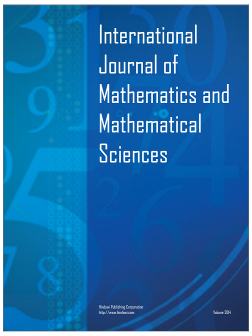
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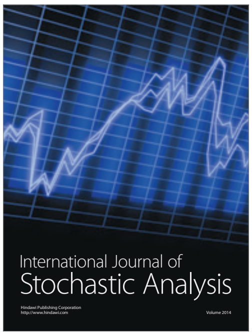
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