Multi-objective Optimization Scheduling Method for Islanded Micro-grid with PV, Wind Turbine, Diesel Generation and energy storage system

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Abstract. The optimization scheduling method for islanded micro-grid operation is studied in this paper. The typical structure of islanded micro-gird and function of each component are introduced. Based on the analysis of operational characteristics of PV, wind turbine generation and energy storage system, the mathematical model of the multi-objective optimization scheduling is proposed by considering diesel generation and energy circulation of energy storage system. Such constraints as the range of the charging/discharging power, SOC (state of charge) of the energy storage system, the value scale of power generated by diesel and the balance of system power are built. Then the multi-objective optimization model is solved by NSGA-II algorithm. For a test case under the situation of different solar radiations and wind levels, several Pareto solution sets are obtained, from which typical dispatching schemes are selected to verify the model's rationality by analyzing power flow of each component.

1. Introduction

China has a long coastline and many islands. Safe and reliable power supply is the basic guarantee of island construction and residents' daily life. With the development of distributed power supply and micro-grid technology, solar energy, wind energy and other renewable energy resources of island can form a variety of complementary energy island model, which is one of the effective ways to solve the problem of island power supply [1, 2].

As an important part in the study of integration control and energy management of micro-gird, economic operation optimization can meet the load demand and optimize comprehensive cost, which is the key to the representing of micro-grid economic benefit [3]. The research of micro-grid is mainly about the cost optimization of traditional controllable power generation, and includes no storage loss in the system. Although the initial construction investment is not high, the running cost of batteries in energy storage system is the most expensive component in the whole system with frequent replacement [4]. Therefore, the service life of the energy storage system should be considered in the study of independent micro-grid operation optimization, reducing the cycle of energy storage power as much as possible.

A mathematical model is established to research multi-objective optimization scheduling method of independent island micro-grid system with reducing the cost of diesel generation and energy circulation of energy storage system.

2. Mathematical Model of Multi-objective Optimization Scheduling

2.1 System Structure

Independent micro-grid system includes PV, wind turbine, diesel generation, storage batteries and control center.

2.2 objective functions

The first goal is to minimize power generation cost of diesel engine.

$$C = P_D \sum_{i=1}^{24}(P_{Di}\Delta t_i) \tag{1}$$

Where P_{Di} is the average power of diesel generation at the time i; Δt_i is the length of stage i; P_D is unit price of diesel generation.

$$P_{Di} = \begin{cases} P_{Li} + P_{Bi} - P_{PVi} - P_{WTi}, & P_{Li} + P_{Bi} - P_{PVi} - P_{WTi} \geq 0 \\ 0, & P_{Li} + P_{Bi} - P_{PVi} - P_{WTi} < 0 \end{cases} \tag{2}$$

Where P_{Li} is the average power of load at the time i; P_{Bi} is charging/discharging power of storage system and is the decision variable in this study; P_{PVi} is the power of PV power generation system; P_{WTi} is the power of wind turbine generation system.

The second goal is to minimize energy circulation of energy storage system [5].

$$\min E = \sum_{i=1}^{T}(P_{Bi}^*\Delta t_i) \tag{3}$$

$$P_{Bi}^* = \begin{cases} \frac{|P_{Bi}|}{\eta_{disc}} & , P_{Bi} < 0 \\ 0 & , P_{Bi} \geq 0 \end{cases} \tag{4}$$

2.3 constraint condition

The constraint of charging/discharging power of storage system and the range of SOC follow:

$$|P_{Bi}| < P_{Bn} \tag{5}$$

$$1 - D \leq SOC \leq 1 \tag{6}$$

$$SOC_i = \begin{cases} SOC_{i-1} + P_{Bi}(\Delta t_i/E_{Bn})\eta_c \\ SOC_{i-1} + P_{Bi}(\Delta t_i/E_{Bn})\eta_{disc} \end{cases} \tag{7}$$

Where P_{Bn} is the rated power of AC/DC converter; D is the maximum discharging depth of storage system; SOC_{i-1} is the charged state of storage system at the time i; E_{Bn} is the rated electricity of storage system; η_c and η_{disc} are the charging and discharging efficiency of storage system.

Diesel generation runs between maximum and minimum power restrictions.

$$P_{Dimin} \leq P_{Di} \leq P_{Dimax} \ or \ P_{Di} = 0 \tag{8}$$

Power balance of independent micro-gird system meets the relationship:

$$P_{Di} + P_{PVi} + P_{WTi} = P_{Li} + P_{Bi} \tag{9}$$

3. Solution of Optimization Model

The result of objective function is the basis of the fast non-dominated sorting of the individuals in the NSGA-Ⅱ algorithm population. Specific steps are as follows：

1) Predicted values of the output power of PV and wind power generation system P_{PVi} and P_{WTi} at each time in the future 24h are calculated according to historical data, weather forecast and prediction method.

2) Charging/discharge power P_{Bi} at each time is randomly generated within the constraint range of equation (5).The charged state of storage system at the time i is obtained by equation (7) with satisfying the constraint in equation (6).

3) Based on the power balance, the power of the diesel generation is calculated at each time. When the output power of diesel generation is greater than 0 and smaller than the minimum power, the output power of diesel generation and charging/discharging power of storage system should be corrected according to (10) and (11). Then, follow Step (2) to modify the charged state of storage system.

$$P_{Di} = P_{Dmin} \quad , if \ 0 < P_{Di} < P_{Dmin} \tag{10}$$

$$P_{Bi} = P_{Di} + P_{PVi} + P_{WTi} - P_{Li} \tag{11}$$

4) The cost of diesel generation is calculated by equation (1).

5) The energy circulation of energy storage system is calculated by equation (3) and (4).

4. Example Analysis

4.1 Research Object and Related Basic Data

There is one diesel generation in the system and its power ranges is 60kW~200kW; unit price of diesel generation is￥2/kWh; wind turbine generation capacity is 200kW; rated power of PV generation is 150kW; rated power of energy storage system is 300kWh; maximum discharging depth is 70%; maximum charging/discharging power is 50kW; charging and discharging efficiency of storage system are both 80%; starting electricity of batteries is 150kWh.

An example with different power of PV and wind turbine power generation in two weather conditions is given to optimize the operation as shown in Fig1.

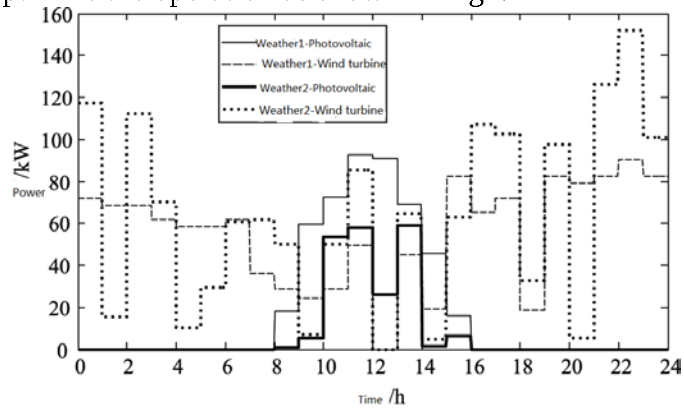


Fig.1 Power of PV and wind power generation in different weather conditions

4.2 Analysis of Optimization Results

The Pareto solutions are obtained in two weather conditions in Fig.2, which shows that with the increasing of energy circulation, the cost of diesel generation reduces. When energy circulation of energy storage system remains elevated, energy storage system has better regulating action with higher utilization of renewable energy.

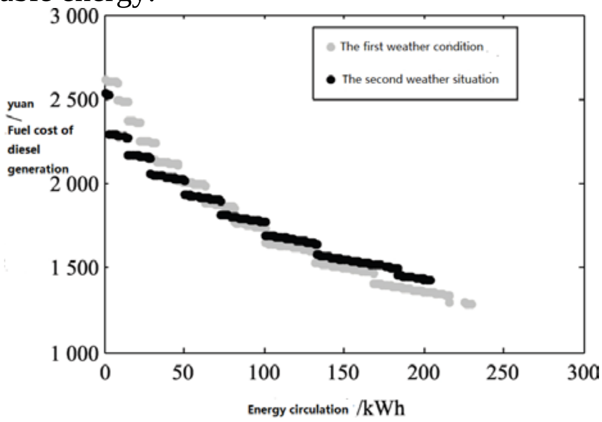


Fig.2 Optimization results in different conditions

1) The first weather condition.

Two optimal scheduling schemes are selected from the solutions in the first weather condition. The power variation of each component is shown in Fig.3 and Fig 4.

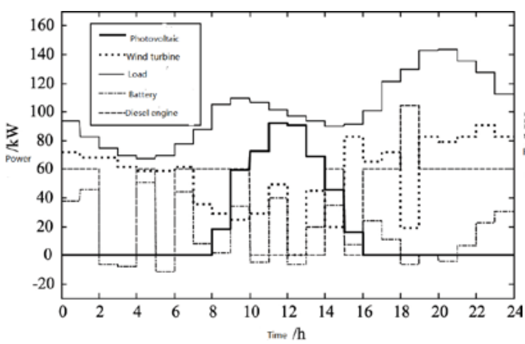


Fig.3 Energy circulation at 60kWh

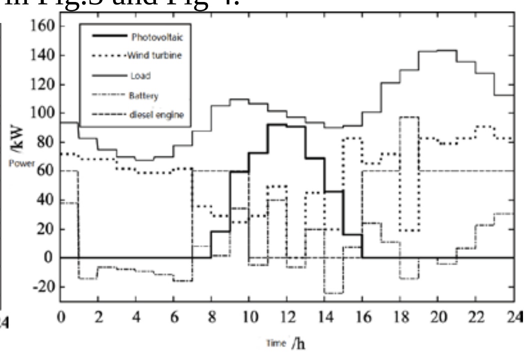
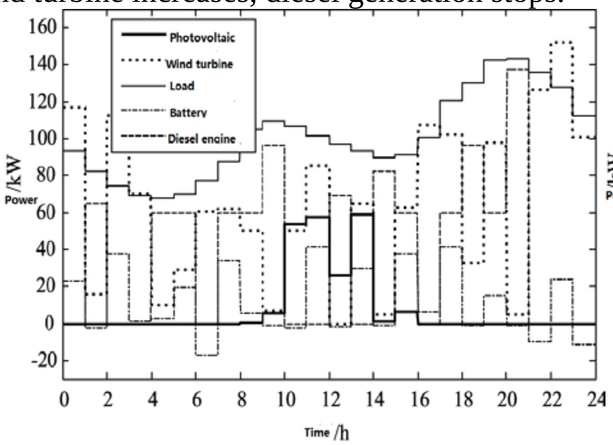


Fig.4 Energy circulation at 150kWh

It can be shown that when energy circulation is smaller, the regulating capacity of energy storage system is weaker. Meanwhile, the running time and start-stop frequency of diesel generation is more.

2) The second weather condition.

The power variation of each component in the second weather condition is shown in Fig.5 and Fig. 6. Because of the instability of wind turbine generation, diesel generation starts and stops more frequently: when the output of wind turbine decreases, diesel generation starts; when the output of wind turbine increases, diesel generation stops.



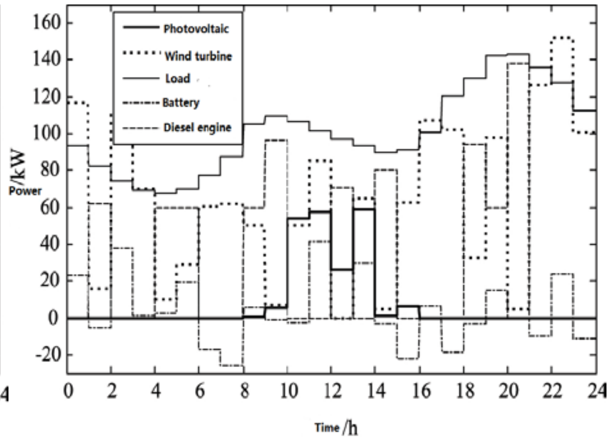


Fig.5 Energy circulation at 60kWh   Fig.6 Energy circulation at 150kWh

Appropriate scheduling schemes are selected according to actual situation. If the output power of PV and wind turbine generation is enough, energy circulation of energy storage system can be increased and the SOC remains at low levels. Otherwise, energy circulation of energy storage system should be decreased to reduce the loss of battery life.

5. Conclusions

The optimization scheduling model for islanded micro-grid operation with PV, wind turbine, diesel generation and storage batteries is established in this paper and the Pareto solutions are calculated with the objective functions of power generation cost of diesel generation and energy circulation of energy storage system. Typical dispatching scheme is selected to verify the model's rationality by analyzing power flow of each component.

In a real world application, optimization dispatching schemes can be decided by the initial state of SOC of energy storage system and sunshine, with energy circulation of energy storage system and cost of diesel generation considered.

Acknowledgments

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References

[1] Giatralcos G P, Tsoutsos T D, Mouchtaropoulos P G, et al, Sustainable energy planning based on a stand-alone hybrid renewable energy/hydrogen power system: Application in Karpathos island, Greece [J] ,Renewable Energy, 2009, 34: 2562-2570.

[2] Ahn S J, Moon S I, Economic scheduling of distributed generators in a microgrid considering various constraints [C]//Power ＆ Energy Society General Meeting, 2009. PES09. IEEE,2009: 1-6.

[3] Logenthiran T, Srinivasan D. Short term generation scheduling of a micro-grid [C]// TENCON 2009-2009 IEEE Region 10 Conference. IEEE, 2009: 1-6.

[4] Dunlop J, Farhi B. Recommendations for maximizing battery life in photovoltaic systems: A review of lessons learned [J]. Solar Engineering, 2001: 275-280.

[5] Zhou C, Qian K, Allan M, et al. Modeling of the cost of EV battery wear due to V2G application in power systems [J]. IEEE Transactions on Energy Conversion, 2011, 26(4): 1041-1050.