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Dynamic economic dispatch of a microgrid: Mathematical models and solution algorithm

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ABSTRACT

Dynamic economic dispatch of a microgrid is better suited to the requirements of a system in actual operation because it not only considers the lowest cost in a scheduling cycle but also coordinates between different distribution generations (DGs) over many periods. So it is very significant to research the dynamic economic dispatch of a microgrid. Since wind energy and solar energy are subject to random variations and intervals, there is great difficulty in solving the dynamic economic dispatch. In this paper, we establish a combined heat and power (CHP) microgrid system which includes wind turbines (WT), photovoltaic arrays (PV), diesel engines (DE), a micro-turbine (MT), a fuel cell (FC) and a battery (BS). Comprehensively considering the operation cost and the pollutant treatment cost of the microgrid system, we choose the maximum comprehensive benefits as the objective function for the dynamic economic dispatch. At the same time, we establish the spinning reserve probability constraints of the microgrid considering the influence of uncertainty factors such as the fluctuation of the renewable energy, load fluctuation error, and fault shutdown of the unit. Also researched are four different operation scheduling strategies under grid-connected mode and island mode of the microgrid. An improved particle swarm optimization (PSO) algorithm combined with Monte Carlo simulation is used to solve the objective function. With the example system, the proposed models and improved algorithm are verified. When the microgrid is running under the grid-connected mode, we discuss the influence of different scheduling strategies, optimization goals and reliability indexes on the dynamic economic dispatch. And when the microgrid is running under the island mode, we discuss the influence of the uncertainty factors and the capacity of the battery on the dynamic economic dispatch. The presented research can provide some reference for dynamic economic dispatch of microgrid on making full use of renewable energy and improving the microgrid system reliability.

Introduction

In recent years, the whole world has been paying more and more attention to developing renewable energy sources such as wind energy and solar energy owing to the serious global depletion of energy and environmental problems. With the development of distribution technology, the microgrid [1–6] provides an effective way for the comprehensive use of renewable energy.

The economic dispatch of power system can be divided into static dispatch and dynamic dispatch [7–10]. Static economic dispatch determines the priority and operation mode of the power generating equipment based on the operating conditions of the system in each independent period.

The dynamic economic dispatch is better suited to the requirements of a system in actual operation because it not only considers the lowest cost in a scheduling cycle but also coordinates between the different distribution generations (DGs) over several periods. So it is very significant to research the dynamic economic dispatch. Renewable energy sources [11] are subject to randomness and interruptions, which makes it very difficult to solve the dynamic economic dispatch.

The power system which includes wind energy and solar energy have been developed so far in terms of dynamic economic load dispatch problem. An optimal economical dispatch model was established in [12], it developed a method to estimate the risk and to manage conventional power systems with wind power systems for the short-term operation. [13] proposed a stochastic model and a solution technique for optimal scheduling of the generators in a wind integrated power system considering the demand and wind generators uncertainties. The research in [14]

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proposed a new real-time dynamic economic dispatch method to meet the requirements of power system based on investigation of future circumstance, the research in [15] proposed dynamic economic dispatch based on the market price of power system, considering the uncertainties in deregulated energy and reserve markets. Recently, some studies about the dynamic economic dispatch of a microgrid have been published. Online optimization method developed in [16] used particle swarm optimization (PSO), however some issues need to be further investigated regarding the optimal operation for a number of DGs such as the WT, FC and BS. A dynamic economic dispatch model was proposed in [17], it compared the dynamic dispatch results with those of static dispatch, and reached the conclusion that dynamic economic dispatch for a microgrid could reduce the operation costs, however gas turbines and the randomness of renewable resources were not taken into account. On the other hand, they did not take into account that a microgrid has distinct operation modes, namely the grid-connected mode and the island mode. Generally, without the support of the grid, the effect of uncertainty factors on the operation of the system under island mode is more obvious than that under grid-connected mode, and the generating units participating in the economic scheduling are different. Therefore the study of dynamic economic dispatch should take into account the two different operation modes.

In fact, there are many kinds of DGs in a microgrid. The DGs will show different features in the dynamic economic dispatch under different operation modes and scheduling strategies. Randomness and interruptions will increase the difficulty of the economic dispatch. In this paper, mathematical models and an algorithmic solution of dynamic economic dispatch on a microgrid are presented. After formulating a combined heat and power (CHP) microgrid system which including wind turbines (WT), photovoltaic arrays (PV), diesel engines (DE), a micro turbine (MT), a fuel cell (FC) and a battery (BS), we choose the maximum comprehensive benefits as the objective function for dynamic economic dispatch. We also establish the spinning reserve probability constraints on the microgrid taking uncertainty into account. An improved particle swarm optimization (PSO) algorithm combined with Monte Carlo simulation is used to solve the objective function. Using an example, we discuss the various influences on the dynamic economic dispatch of different scheduling strategies, optimization goals, reliability indexes, uncertainty factors and the capacity of the battery.

The mathematical model of DGs

The model of an MT

The exhaust emissions of NO_x and CO_2 of MT is much lower than traditional technologies used in centralized power plants [18]. The mathematical model of an MT can be shown as follows:

$$Q_{MT} = P_{GT}(1-\eta_e-\eta_l)/\eta_e \quad (1)$$

$$Q_{he} = Q_{MT}K_{he} \quad (2)$$

$$C_{MT} = C_{nl} \times \left(\sum P_{GT}\Delta t/\eta_e L\right) \quad (3)$$

where Q_{MT} is the residual heat of the exhaust, η_e is the generating efficiency of the MT, η_l is the heat loss coefficient, P_{GT} is the output power of the MT during the calculation period Δt in kW, Q_{he} is the heat provided by the MT, K_{he} is the heat coefficient of the cooler, C_{MT} is the gas consumption cost of the MT, L is the net thermal value of the gas, 9.7 g/kW, and C_{nl} is the price of the gas, 2.05 ¥/m^3.

The model of the FC

The mathematical model of the FC can be shown as follows:

$$C_{FC} = C_{nl} \times \left(\sum P_{FC}\Delta t/\eta_J L\right) \quad (4)$$

where C_{FC} is the gas consumption cost of the FC, P_{FC} is the output power of the FC during the calculation period Δt in kW, η_J is the efficiency of the FC, L is the net thermal value of gas, 9.7 g/kW, and C_{nl} is the price of gas, 2.05 ¥/m^3.

The model of the BS

The state of charge (SOC) of the battery refers to the ratio of the residual energy to the rated energy. It is very important to predict the SOC of the battery accurately for controlling the charging/discharging process and the system economic dispatching.

The charging formula of the battery is described as follows:

$$SOC(t) = (1-\delta)SOC(t-1) - P_c\Delta t\eta_c/E_C \quad (5)$$

where P_c is negative, it represents the charging power, η_c is the charging efficiency, E_C is the total capacity of the BS during the calculation period Δt in kW, $SOC(t)$ is the SOC of the BS in period t, and $SOC(t-1)$ is the SOC of the BS in period $t-1$.

The discharging formula of the battery is described as follows:

$$SOC(t) = (1-\delta)SOC(t-1) - P_d\Delta t/(E_C\eta_d) \quad (6)$$

where P_d is positive, it represents the discharging power, η_d is the discharging efficiency, and δ is the self-discharge rate of storage in%/h.

The mathematical model for the dynamic economic dispatch of a microgrid

The objective function for the dynamic economic dispatch of a microgrid

The operating cost of the microgrid system

For the microgrid, the operating cost C_1 of the system can be described as follows:

$$C_1 = C_{Fuel} + C_{OM} + C_{DC} + M\left(\sum \lambda_t^r r_t^r + C_{GRID}\right) \quad (7)$$

where C_{Fuel} is the fuel consumption cost of the DGs, C_{OM} is the operation and management cost of the DGs, C_{DC} is the depreciation cost of the DGs, M indicates whether the microgrid is connected with the grid or not: when the microgrid is connected with the grid, $M = 1$, when the microgrid is in island mode, $M = 0$, C_{GRID} is the cost of interaction between the microgrid and the grid: it is being positive, represents that the microgrid is purchasing power from the grid, when it is negative, that represents that the microgrid is selling power to the grid. And because there are some uncertain factors, the spinning reserve capacity of the microgrid is limited by the DGs, so the microgrid needs to purchase some spinning reserve power from the grid, λ_t^r is the price of the spinning reserve, and r_t^r is the purchasing power of the spinning reserve.

C_{Fuel}, C_{OM} and C_{DC} can be described as follows:

$$\begin{cases} C_{Fuel} = K_{fc} * P \\ C_{OM} = K_{om} * P \\ C_{DC} = \frac{ADCC}{P_{\max}\times 8760\times cf} \times P \\ ADCC = InCost \times d(1+d)^l/[(1+d)^l - 1] \end{cases} \quad (8)$$

where P is the output power of the DGs, K_{fc} is the coefficient of fuel consumption, K_{om} is the coefficient of operation and management. $P_{\max}$ is the maximum power of the DGs, cf is a capacity factor, $ADCC$ is the depreciation cost per kilowatt-hour of the DGs, $InCost$ is the