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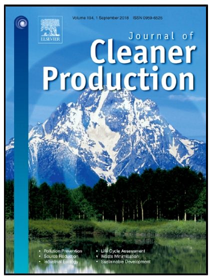

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Energy management of Smart Micro-grid with Response loads and Distributed Generation Considering Demand response

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ABSTRACT:

Governmental incentives to develop clean and renewable energy sources, and concerns about the increasingly serious environmental pollution problem, and the development of smart grid technology are the most important motivations for adding distributed generations to conventional power systems and carrying out the Demand Response program (DR). In these circumstances, it has become a key factor for the development of micro-grid to realize efficient and economical operation of smart micro-grid considering Demand Response strategy. In this paper, an intelligent park micro-grid consisting of photovoltaic power generation, combined cooling heating and power system, energy storage system and response load is modeled to study the optimal scheduling strategy of these units by taking into account the price-based demand response. To achieve this goal, an optimization model for the economic operation of micro-grid is established, and the model presented mainly aims to minimize the operating cost of micro-grid system and make full use of clean energy under the premise of considering distributed power generation and demand response. This operation optimization problem is solved by the Genetic Algorithm (GA) and the best solution on the best operating strategy is determined by the clean energy resources and demand response program. Finally, a micro-grid project in China was used to carry out optimization simulation in order to verify the accuracy and reliability of the established model. It is found that the operation optimization model of micro-grid with demand response can effectively reduce the operation cost of and improve the utilization rate of renewable energy sources.

KEY WORDS: Renewable energy; demand response (DR); micro-grid; distributed generation (DG); operation optimization; operation cost; utilization rate

1 Introduction

Following environmental pollution concerns, increasing clean energy demand, and rush in energy cost, special attention has been recently focused on micro-grid with response loads and distributed generation (Zao et al., 2018). As the energy crisis and environmental crisis become more and more serious, renewable energy has been widely concerned and applied to the field of power generation. However, the large-scale direct grid connection of distributed power supply will cause the instability of power system. Under such circumstances, smart micro-grid, as an efficient and safe way to use clean energy, has begun to be developed and applied on a large scale (Rawea et al., 2018).

Smart grid is a new type of power supply mode which integrates renewable energy power generation technology (wind power generation, photovoltaic power generation, biomass energy, tidal energy, etc.), energy management system (EMS) and distribution infrastructure (Wu et al., 2016). It can not only improve energy efficiency and the security of power supply, but also reduce the power loss and the impact on the environment. With the large-scale application of micro-grid technology in distribution system, advanced operation optimization technology has become an important guarantee for micro-grid operation. There are strict requirements for micro-grids access to existing power grids. The connection of the micro-grid cannot affect the stability of the existing power grid. At the same time, the micro-grid should have an independent control system, which can adjust its operation status according to the load and power grid signals independently (Hu et al., 2017).

In the traditional power system, most of the load is uncontrollable and the power consumption is not easy to be measured accurately, which results in that the system can only dispatch power generation resources. Micro-grid, as an efficient power supply mode, integrates distributed resources and loads into one system for dispatching (Husted et al., 2018). Demand Side Management (DSM) can enable different types of loads to actively participate in the optimal operation of the power grid, which is an important means to realize the optimal operation of the micro-grid. As an important way of DSM, Demand Response (DR) program guides users to participate in power grid dispatching through electricity price and incentive information, which makes the economy and stability of micro-grid be improved effectively (Wang et al., 2018). In (Jang et al., 2015) the response index is tested as an alternative to conventional load impact measures and a strong correlation between reductions and cost shares of electricity is identified. The reference (Sun et al., 2014) establishes a production-power dynamic control model for manufacturing system and explores the potential of power demand reduction of typical manufacturing system by studying Real-time electricity demand response for manufacturing systems. The reference (Sun et al., 2016) establishes the plant-level electricity demand response model considering manufacturing and HVAC systems, and it also models the relation between manufacturing operation and temperature evolution. The aim of the study is identifying an optimal demand response strategy with respect to both production schedule and HVAC control. In (Cominola et al., 2018) the heterogeneity of typical residential water-electricity demand profiles is introduced. Authors contribute a customer segmentation of over 1000 residential accounts in the Los Angeles County and propose recommendations to design customized water-electricity demand management actions. In (Shrouf et al., 2014) a mathematical model to minimize energy consumption cost at machine level is proposed. The proposed algorithm for the model has the potential capability to be integrated into the factory scheduling and its high scalability allows running the production schedule in real time. Authors in (Khan et al., 2018) propose the impact of demand response-DR and electrical energy storage-EES in energy-only market and analysis the impact of limited DR and medium-term EES on a capacity market-CM. Authors in (Lu et al., 2018) propose an artificial intelligence based dynamic pricing demand response algorithm and achieve uncertainty of customer's demand and flexibility of wholesale prices. In (Padmanabhan et al., 2018) a new mathematical model for a Locational Marginal Price (LMP) based, loss included, day-ahead, co-optimized, energy and spinning reserve market including DR provisions, is proposed. A repeated game-theoretic market is proposed in (Motalleb et al., 2018) for selling stored energy in batteries. Day-ahead price signal is improved through a real-time demand response market. The reference (Shahryari et al., 2018) proposes an improved IBDR program which is based on the concept of price-demand elasticity. The proposed method considers the elasticity as a function of consumption time, customer type and peak intensity.

The demand response links the load with the distributed resources, which makes the energy management of micro-grid more reasonable. For the energy management of micro-grid, demand response is only an important factor that needs to be considered. Operation optimization strategy is the necessary means to realize efficient and economical operation of micro-grid. In (Weitzel et al., 2018) model to include battery aging into Micro-grid scheduling problem is presented. Battery aging cost model reduced cycled energy by 37% and increased lifetime by 74%. Authors in (Bellido et al., 2018) state the main barriers to the entry of micro-grids in the world power sector and identify some constraints on promoting their development and participation in the Brazilian Power Sector. The results in (Zhou et al., 2018) show that heating energy saving potential from building envelope in China is 30.9%–66.1%. The reasons for high energy consumption are high indoor temperature and window opening. In addition, a new Energy Management Strategies (EMS) for hybrid electric vehicle (HEV) is proposed based on operation-mode prediction using a Markov chain in (Liu et al., 2018). It determines the on-line correction of torque distribution between the engine and the electric motor. In (Phurailatpam et al., 2018) DC micro-grid is considered for a village, residential and commercial building, which is optimization and comparison of results for various micro-grid configurations. In (Zhang et al., 2018) the multi-micro-grid (MMG) operation is formulated as a transaction commitment problem. Authors design a two-stage robust optimization based MMG coordinated operation approach and describe discrete feature of energy interaction behavior among multiple micro-grids. The reference (Moradi et al., 2018) proposes a novel optimization model to minimize operation of micro-grid and maintenance costs as well as emission costs. The reference (Cesena et al., 2018) proposes both dynamic reliability price signals with a stochastic approach and a MILP tool to co-optimize micro-grid behavior when facing conflicting signals. Micro-grid can provide users with energy, storage and reliability services. The reference (Vasak et al., 2018) is focused on the problem of controlling the energy storage, where the energy exchange between the storage and the remaining system is performed in the required amount with maximum efficiency. An optimal operation model for a multi-agent system (MAS) based micro-grid is proposed (Zheng et al., 2018). The aim of the model is to save the overall energy cost. In (Mehdizadeh et al., 2018) risk-based short-term generation scheduling of renewable micro-grid is proposed, and the effects of demand response program are investigated. Authors in (Sardou et al., 2018) propose a novel robust model for energy management of micro-grid and propose a validation method based on Monte Carlo simulation combining the advantages of both classic and heuristic methods. Reference (Netto et al., 2018) presents a framework to analyze the problem of real-time management of smart grids. Authors in (Ghasemi et al., 2018) study the energy management of an isolated rural micro-grid and propose a new stochastic optimization framework to keep generation and demand in balance. In (Nunna et al., 2013) an agent-based energy-management system is proposed to facilitate power trading among micro-grids with demand response. An index-based incentive mechanism is also proposed to encourage customers participating in DR based on frequency and size of the participation. A secondary demand response program is proposed in (Rezaei et al., 2015) to contribute into the micro-grid frequency aware energy management system. The reference (Liu et al., 2017) proposes a distributed energy management method for interconnected operations of combined heat and power (CHP)-based micro-grids with demand response (DR). Reference (Tabar et al., 2017) introduces portable renewable energy resource (PRER) and considers effect of them, where the multi objective and stochastic management are considered with various loads and sources.

Through the analysis of the existing research, it is obvious that smart micro-grid plays an important role in distributed power generation and power grid dispatching. At the same time, with the development of smart grid technology and the progress of demand-side management technology, demand response, as an important energy management method, is one of the key factors in micro-grid dispatching. Existing research has done a lot of research on the basic structure and conventional dispatching strategy of micro-grid, and some of them have also analyzed the basic principles and application methods of demand response in depth. However, under the background of large-scale application of intelligent power utilization technology and intelligent terminal technology, the role of

DR program in micro-grid dispatching will become more and more obvious. Renewable energy generation, load and demand response module are important components of smart micro-grid. The scheduling relationship and influence mechanism between them are the key factors to realize the economic operation of micro-grid. In order to make up for this gap, this paper and studies the energy management of smart micro-grid with response load and distributed power generation considering the DR program. In this paper, a smart micro-grid with distributed generation, load and demand response is constructed, and a mathematical model is established for each energy unit. According to the structural characteristics of the established micro-grid, an operation optimization scheduling strategy is also formulated. Based on the modeling of micro-grid, an operation optimization model suitable for smart micro-grid is established. The optimization model established takes the minimum operating cost of the micro-grid system as the objective function, and takes into account factors such as load reduction, load transfer and demand response electricity price. Based on load constraints, operation constraints, user satisfaction and other constraints, Genetic Algorithm (GA) is used to solve the operation optimization model. Then, a micro-grid project in China is used to carry out optimization simulation to verify the validity and accuracy of the model established in this paper. We simulate the dispatching strategy and load response of the micro-grid under three different demand response strategies, and discuss and analysis the system operation cost and the key factors affecting the cost under different strategies. Finally, Natural Gas (NG) price is used as a sensitive factor to influence the DR effect, and the results show that the fluctuation of NG price has a great influence on the DR effect.

The main contributions of this paper are as follows:

(1) Presenting an optimization model based on Demand Response mechanism for micro-grid energy scheduling with response loads and CCHP as well as PV units and ES.

(2) Employing the TOU tariff and RTP tariff to implement demand response planning for response loads in micro-grid to realize economical and efficient operation of micro-grid and improve

the utilization level of clean energy.

(3) Considering the operation cost under different electricity price policies as the objective function.

(4) Using the GA approach for minimizing objective functions and determining the best operation strategy by the clean distributed generation resources and demand response program.

2 Micro-grid with distributed generation

2.1 System architecture

Micro-grid is an autonomous system that can realize self-control, protection and management. it can operate in conjunction with the external power grid or in isolation. The main function of micro-grid is to realize flexible and efficient application of distributed power generation and to solve the problem of grid connection of a large number of Clean distributed power sources in various forms (Kirchhoff et al., 2016). Compared with smart grid, the traditional grid is a rigid system. The transmission of electric energy and the connection of power supply in the traditional grid are inflexible, lacking of composability and dynamic flexibility. And the self-healing and recovery ability of the system completely depend on entities. Moreover, the traditional grid is simple in service and lacks information sharing. Due to the imperfect information and weak sharing ability, the traditional power grid system is a local and isolated automation system, which can't form an organic and unified power supply system (Moreno-Garcia et al., 2017). Table 1 shows the differences between smart grid and traditional grid in different aspects.

Tab.1 Differences between smart micro-grid and traditional grid

Parameter	Traditional power grid	Smart micro-grid
Communication	Information from power grid to users; No information interaction	Bidirectional communication; Information interaction
Measuring	Electric meter reading power information	Information interaction through intelligent meter
Equipment management	Manual management; equipment failure causing direct power interruption.	Remote intelligent monitoring; Self-protection during failure; Self-healing of power restoration
Control	Centralized power generation and control	Coexistence of centralized control and distributed control

Decision support	Operators make decisions through experience	The operator makes decisions through intelligent control system and experience.

From table 1, it can be seen that smart micro-grid is more flexible and organic than traditional power grid. The advantages of smart micro-grid in power grid structure, communication technology, power grid dispatching technology and information interaction make it conform to the necessary conditions for implementing the demand response program. Figure 1 is a structural diagram of a typical Demand Response smart micro-grid.

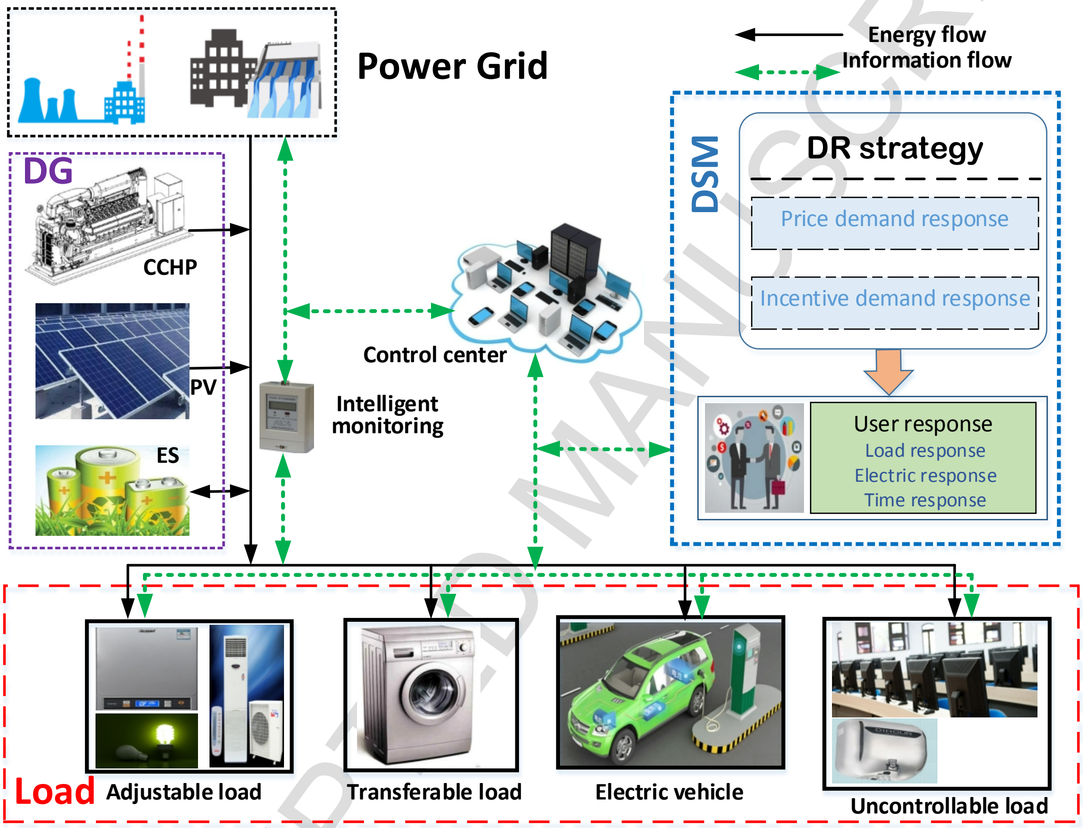

Fig. 1 Structural diagram of a typical Demand Response smart micro-grid

As can be seen from Figure 1, smart micro-grid mainly includes four modules: Distributed Generation, load, power grid, and Demand Response. Traditional demand response resources are mainly different power loads on the user side. In smart micro-grid, demand response resources include not only loads but also distributed power generation resources. The demand response load in micro-grid mainly includes adjustable load, transferable load, uncontrollable load and electric vehicle. Distributed power generation resources mainly include photovoltaic power generation, wind power generation and distributed energy storage.

2.2.1 Photovoltaic power generation (PV)

The distributed photovoltaic power generation system mainly includes solar photovoltaic modules, grid connected inverters, energy storage batteries, inverters, electric energy meters and so on. Photovoltaic power generation system has many advantages, such as easy installation, less maintenance, and no pollutant emission during power generation (Krauter et al., 2018). The actual output power of PV panels is related to the actual light intensity, the ambient temperature and the output power under rated conditions. The power model is shown below.

$$P_{PV}(t) = P_{stc} \frac{I(R_b, k_t, I_{0t})}{I_{stc}} \left[1 + \alpha_T (T_t - T_{stc})\right] \quad (1)$$

Where P_{stc} is the output of the solar panel, kW; I_{stc} is the intensity of solar radiation, W/m^2; $I(R_b, k_t, I_{0t})$ is the total solar radiation after considering the solar radiation, sun index, photovoltaic tracking type and other factors; T is the degree of atmosphere; α_T is the power temperature coefficient.

2.2.2 Combined Cooling, Heating and Power system (CCHP)

Distributed CCHP (combined cooling, heating and power) system is a new type of energy system built around the local or nearby. It is a multi-power supply system based on the concept of energy cascade utilization, which integrates refrigeration, heat production and power generation. The CCHP system has realized the cascade utilization of Natural Gas high temperature combustion heat energy. It uses high grade thermal energy to generate electricity and uses low-grade heat energy to refrigerate and heat up. The CCHP system can not only enable users to become an energy supply system, but also operate in parallel with the urban power grid (Mehrpooya et al., 2017). The system working principle of typical CCHP is shown in the Figure 2. And the operation process model of the CCHP system is shown in the formula (2) ~ formula (3).

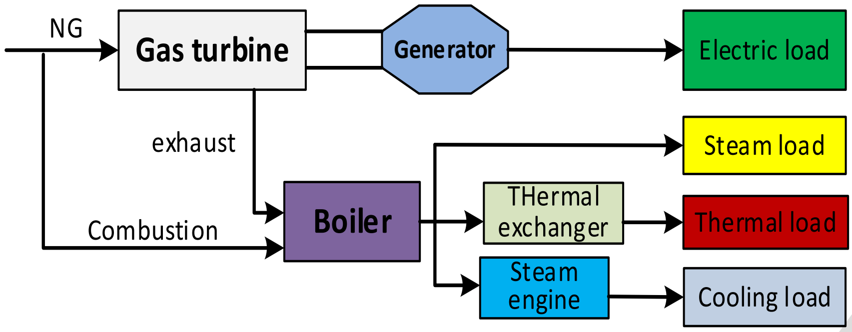

Fig. 2 Schematic diagram of typical CCHP system working principle

$$\eta = \frac{Q_h}{Q_e} \tag{2}$$

Where η is the rated thermoelectric ratio of the system, Q_h, Q_e are the heat and power production of gas turbine respectively.

The power generation efficiency of the CCHP is related to the output power, and the amount of Natural Gas consumed and heat generated by the gas turbine is calculated as follows:

$$\begin{cases} Q_{CCHP}(t) = \dfrac{P_e(t)(1-\eta_e(t)-\eta_l)}{\eta_e(t)} \\ V_{MT} = \dfrac{\sum P_e(t)\Delta t}{\eta_e(t)\times LHV_{NG}} \end{cases} \tag{3}$$

Where $Q_{CCHP}(t)$ is the exhaust residual heat of the CCHP, kW; $P_e(t)$ is the output of the CCHP, kW; $\eta_e(t)$ is the power generation efficiency; η_l is the heat loss coefficient; V_{MT} is the Natural Gas consumption, Nm^3/h; LHV_{NG} is the low calorific value of Natural Gas, kWh/m^3.

2.2.3 Energy storage system (ES)

Energy storage is an important technology to achieve distributed renewable energy applications. The use of energy storage can achieve the smooth fluctuation of the power generation power of renewable energy, and make the renewable energy generation stable and controllable output, and meet the need of large-scale access of renewable energy and electricity to the grid. Battery energy storage system has three states: discharge, charging and outage, and state of charging (SOC) is the most critical state (Hu et al., 2018). Based on the charging and discharging power of ES system, this paper studies the mechanism of energy storage participating in the operation optimization of micro-grid. According to the SOC and charging and discharging power, the mathematical modeling of battery energy storage system is as follows (Zou et al., 2017).

Charging process:

$$SOC(t) = (1-\delta)SOC(t-1) + P_c \Delta t \eta_c / E_c \quad (4)$$

Discharge process:

$$SOC(t) = (1-\delta)SOC(t-1) + P_d \Delta t / E_c \eta_d \quad (5)$$

where E_c is the rated capacity of the battery, kWh; P_c is the charging power, kW; P_d is the discharging power, kW; $SOC(t)$ is the remainder of the battery after the T period; $SOC(t-1)$ is the remaining amount of electricity of the battery after the T period; η_c, η_d is the charge and discharge efficiency of the battery, respectively,%; δ is the battery's own discharge rate,%/h.

2.2 Scheduling strategy

According to the analysis of the characteristics of the structure of the smart micro-grid, the scheduling of the micro-grid includes not only the conventional power supply module, but also the load resource on the user side. On the one hand, PV, CCHP, and ES in the micro-grid system are the normal dispatching objects in the power system, which provide power supply to the system. On the other hand, load, as a new scheduling resource, will respond to system scheduling and management in time. Through the interaction of DGs, ES, load and power grid, the optimal operation of micro-grid system could be realized. In the operation optimization scheduling strategy designed in this paper, the optimal scheduling cycle of Demand Response is set to 5 minutes (T=5 minutes), and the total time of scheduling is one day (1440 minutes). Firstly, the power exchange between the system and the grid is considered. According to the power supply and demand situation of the system, there are two kinds of operation states.

Operation state 1: One way transmission of the power

$P_{grid} > 0$, the energy demand in the micro-grid is larger than that in the energy supply. The power from Distributed Generations and ES can't meet the power demand in the micro-grid, the micro-grid system must purchase some electricity from the power grid.

Operation state 2: Two-way transmission of the power

$P_{grid} < 0$, the energy supply in the micro-grid is larger than that in the energy demand. The power from Distributed Generations and ES could meet the power demand, and there is more electricity in the system that can be sold to the urban power grid.

On the premise of considering the above two operation states, the operation state of ES is controlled and scheduled, and finally the operation strategy of DGs and the response of load are considered. And the dispatching strategy of micro-grid based on Demand Response program is shown in Figure 3.

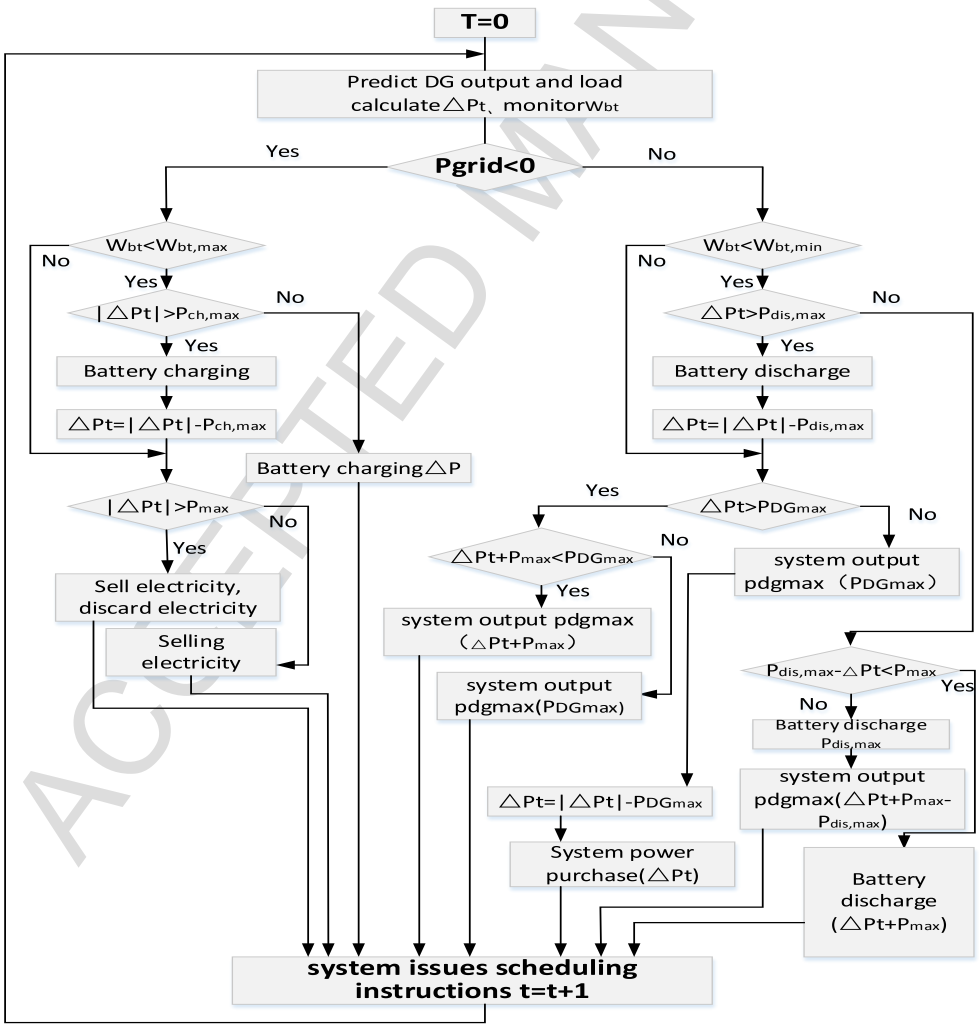

Fig. 3 The dispatching strategy of micro-grid based on Demand Response program

Where ΔP_t is the difference between the load and the power of DGs in the micro-grid, kW; $P_{\max}$ is the upper limit of power exchange between micro-grid and power grid, kW; $P_{ch,\max}$ and $P_{dis,\max}$ are the maximum charging and discharging power allowed by the battery, kW; $W_{bt,\max}$ and $W_{bt,\min}$ are the maximum and minimum electricity of the ES, kWh; $P_{DG,\max}$ is total power of distributed power supply, kW.

3 Energy management modeling

3.1 Objective function

According to the structural characteristics of the micro-grid established in this paper, the micro-grid mainly includes distributed generation, energy storage and load. In the process of micro-grid operation, the main operation cost of the system comes from the operation cost of the distributed power supply, the cost of fuel and the cost of buying electricity from the micro-grid to the urban power grid. At the same time, the micro-grid can also sell part of your excess power to the urban power grid according to its own energy balance. In the process of the energy exchange between the micro-grid and the urban power grid, the micro grid system can participate in the demand response according to the actual situation of the power market, and use the demand response to deal with the electricity price. According to the above analysis, this paper establishes an optimization model of micro-grid operation based on demand response price. The model takes the minimum operating cost of the micro-grid as the target function. The objective function is composed of distributed generation cost, energy storage operation cost, electricity cost and natural gas cost. In addition, due to the fast speed of CCHP response system scheduling, the scheduling cycle is set to 5 minutes. The model of the minimum cost of micro-grid operation in this paper is shown below.

$$F = \min C_{op} = \int_0^T \left(\sum_{i=1}^{n} C_i P_i + \frac{P_{fuel} V}{60} + C_{bat,dep} + C_{B\text{-}grid} \right) \tag{6}$$

$$C_{B\text{-}grid} = \begin{cases} K_b P_{grid} & , P_{grid} > 0 \\ K_s P_{grid} & , P_{grid} < 0 \end{cases} \tag{7}$$

where C_{op} is the operation cost of Micro-grid system, yuan; T is a response period, minute; C_i is the operation cost of Distributed Generation systems，yuan/kW; P_{fuel} is gas price，yuan/m^3； V is the gas consumption, Nm^3/h; P_i is the output of DG during the response period, kW; $C_{bat,dep}$ is the charge /

discharge depreciation cost of ES, yuan/kWh; C_{B-grid} is the electricity cost of the micro-grid, yuan/kWh; K_b is the purchase price, yuan/kWh; K_s is the selling price of micro-grid, yuan/kWh; P_{grid} is the exchange power between urban power grid and micro-grid, kW.

3.2 Constraints

3.2.1 Response load constraints

According to the micro-grid model established in this paper, the user side resources involved in Demand Response program are mainly distributed generations (DGs) and response load. The main constraints of DGs are the power constraints of the distributed generation unit, and the constraint of response load is mainly the constraint of load reduction and load transfer time.

1）Output constraint of DGs

During the operation of Distributed Generators, the output power of the unit is constrained by the equipment model. The maximum power and minimum power of the generator set are determined, and the actual output power must meet this range. (Kakran et al., 2018):

$$P_{GDs}^{\min}(t) < P_{GDs}(t) < P_{GDs}^{\max}(t) \tag{8}$$

where $P_{DGs}(t)$ is the output of DGs, kW; $P_{GDs}^{\max}(t)$ and $P_{GDs}^{\min}(t)$ are the maximum and minimum values of the output power of DGs, kW.

2）Interruptible load constraint

According to the Demand Response strategy, the interruptible load can be interrupted at any time, and the interruptible load has no specific restrictions on the total power consumption (Jang et al., 2015).

$$P_{IL}^{\min}(t) < P_{IL}(t) < P_{IL}^{\max}(t) \tag{9}$$

Where $P_{IL}(t)$ is the actual power of the interruptible load, kW; $P_{IL}^{\min}(t)$ and $P_{IL}^{\max}(t)$ are the minimization and maximum power of interruptible load, kW.

3）Adjustable load constraint

The adjustable load can be cut down according to the scheduling strategy in the demand response execution process, and the load reduction can't exceed the allowable reduction load.

$$\mu_{CUT}(t)P_{CUT}^{\min}(t) < P_{CUT}(t) < \mu_{CUT}(t)P_{CUT}^{\max}(t) \quad (10)$$

Where $P_{CUT}^{\max}(t)$ and $P_{CUT}^{\min}(t)$ are the upper and lower limits of the curtailable load reduction, kW; $\mu_{CUT}(t)$ is the state of the load at time t, $\mu_{CUT}(t)=1$ indicates load is cut, $\mu_{CUT}(t)=0$ indicates that the load is not cut; $P_{CUT}(t)$ is the reduction of the curtailable load at time t, kW.

4） Transferable load constraint

Transferable load is a load with no definite restrictions on power consumption, which can be moved according to scheduling strategy in a certain period of time. In the scheduling process, the transferable load can be transferred in a relatively relaxed period. And the transferable load must be moved within this limited time.

$$T_{\text{tr}}^{\alpha} \le T_{\text{tr}} \le T_{\text{tr}}^{\beta} \quad (11)$$

Where T_{tr}^{α} is the starting time, h; T_{tr}^{β} is the ending time, h. The starting and ending time of the transferable load is determined by the user's electricity habit.

3.2.2 System power balance constraint

In the process of micro-grid operation, the power supply and demand in the system must satisfy a certain balance relationship, which is mainly reflected in the balance relationship between the input power and the output power (Tabar et al., 2017).The power balance of the system is as follows.

$$\begin{aligned} &P_{loss} + P_{core} + P_{load} \\ &= \sum_{k=1}^{N} P_{k-i}(t) + P_{gird}(t) + P_{storage}(t) \end{aligned} \quad (12)$$

$$P_{load} = \sum_{i=1}^{M} P_i(t)x_i(t) \quad (13)$$

Where $P_i(t)$ is the active power of the load, which mainly refers to the controllable load in the system, kW; P_{core} is the core load power（kW）; P_{load} is the controllable load power involved in Demand Response in the system, kW; P_{loss} is a lost load in the process of electric energy transportation, kW; $P_{gird}(t)$ is the power absorbed by the system from the grid, kW; $P_{storage}(t)$ is the charging and discharging power of ES, kW.

3.2.3 ES constraint

Battery life is an important factor affecting the operation of Energy Storage. In the process of the ES system, the charge and discharge power of the battery is strictly restricted. If the battery power exceeds the specified range for a long time, the battery life will be accelerated. And the energy storage system must meet the maximum charge discharge power constraints and charge state constraints during the operation process, while improving the service life of the battery and saving the maintenance cost (Zou et al., 2017).

$$|P_{storage}(t)| \le \begin{cases} P_{dis-\max} & P_{storage}(t) > 0 \\ P_{ch-\max} & P_{storage}(t) < 0 \end{cases} \tag{14}$$

$$SOC_{\min} < SOC(t) < SOC_{\max} \tag{15}$$

Where $P_{dis-\max}$ is the maximum discharge power, $P_{ch-\max}$ is the maximum charging power, kW; $SOC_{\max}$ and $SOC_{\min}$ are the upper and lower limits of the remaining capacity.

3.2.4 Customer comfort constraints

Users are the main participants in demand response, and the corresponding means for users to participate in the DR program is to adjust the operation state of the electrical equipment. When the user adjusts the running state of the equipment, it should not only respond to the dispatch of the power grid, but also ensure that the comfort of its own electricity is not affected greatly. In the DR model established in this article, temperature and power consumption are used to evaluate users' comfort degree before and after response to demand (Sun et al., 2016).

1）Temperature constraint

$$T_{\min}(t) < T(t) < T_{\max}(t) \tag{16}$$

Where $T(t)$ is the temperature in the room, °C; $T_{\max}(t)$ and $T_{\min}(t)$ are the upper and lower limits of user's temperature demand for temperature control equipment, °C.

2）Operating time constraint

The DR load runs continuously in a certain time, and the running time constraints are as follows.

$$x_i(t) = \begin{cases} 1 & t_{on}(X_i) \le t \le t_{on}(X_i) + \Delta t(X_i) \\ 0 & t < t_{on}(X_i) \quad or \quad t > t_{on}(X_i) + \Delta t(X_i) \end{cases} \tag{17}$$

Where $x_i(t)$ is the operational state of the transferable load; $t_{on}(X_i)$ is the time the device starts running; $\Delta t(X_i)$ is the device scheduling period.

3.3 Solution method

The optimization model established is a single objective mixed integer programming problem. According to the characteristics of the optimization model, the model solution can be realized by the intelligent optimization algorithm. Considering the accuracy of the model solution and the practicability of the intelligent algorithm, the Genetic Algorithm (GA) is used to solve the operation optimization model of the micro-grid based on the Demand Response scheduling strategy. Genetic algorithm is a method of searching the optimal solution by simulating the natural evolution process. It has the characteristics of organization, adaptability and learning. It can use the evolutionary characteristics of the population to search for information by itself, and use the rule of probability change to determine the search direction. It has been widely used in the field of electric power planning and operation (Liu et al., 2016). In the process of using GA to solve the optimal model, we take the load, the power of the distributed power, the electricity price as the input data, and solve the minimum operating cost of the system through the established optimization model. The flow chart of the model solution is shown in Figure 4. The implementation steps of solving the operation problem of micro-grid system based on Demand Response through Genetic Algorithm are as follows:

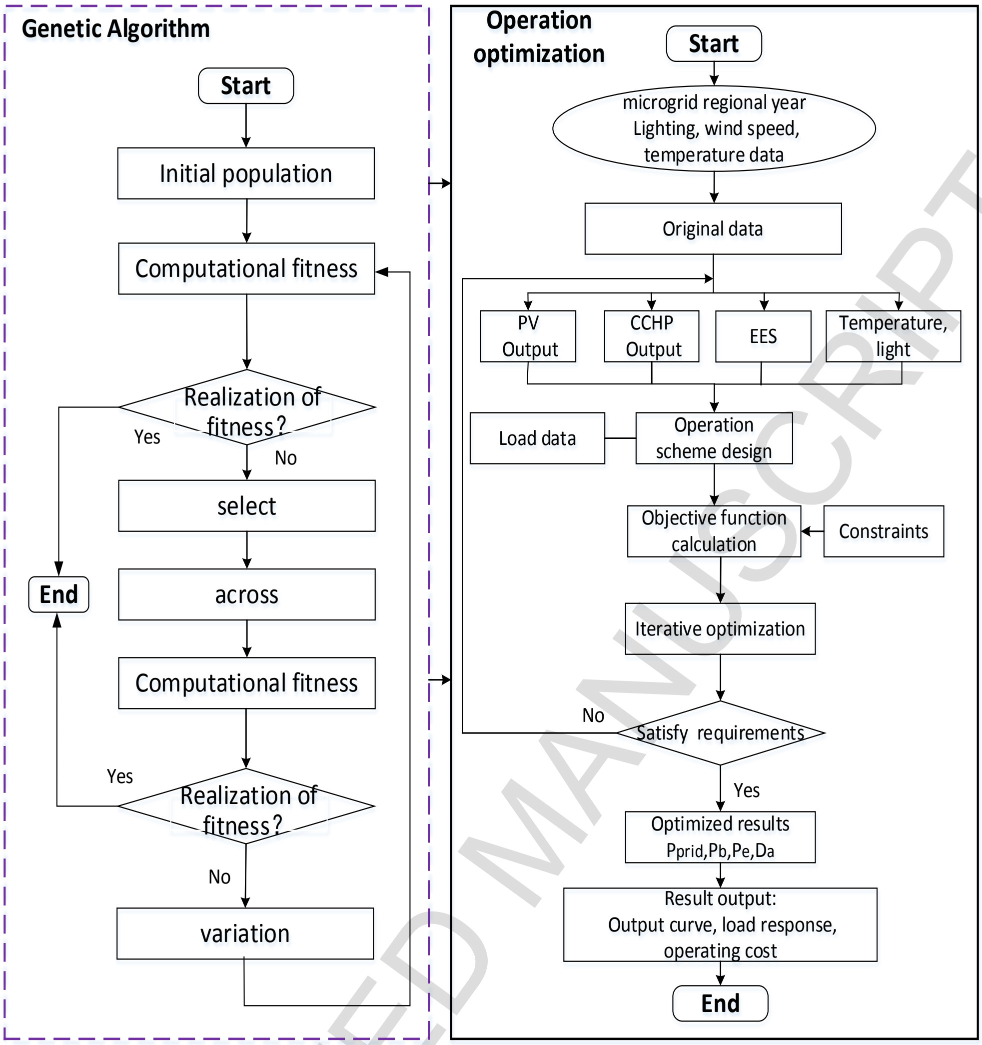

Fig. 4 Implementation process of genetic algorithm based on demand response strategy

Step 1: Parameters. The initial parameters of the input system mainly include the power of DGs (P_{DGs}), the charging and discharging current of the storage battery (P_b), discharge depth of ES (D_a), the power of CCHP (P_e), the exchange power between the micro-grid and the power grid (P_{grid}) and electricity price.

Step 2: Input the basic data of case analysis. Optimization objectives, scheduling strategy, optimization period (T=5min), optimization time interval ϖ, DDs in the micro-grid system, parameters of ES, the initial optimization time ($t=0$).

Step 3: Operation simulation. According to the original load data (1440 minutes) and basic parameters, the operation process of micro-grid under three Demand Response strategies is simulated.

Step 4: Objective function calculation. According to the load and price parameters, the optimal value of the objective function is calculated under the constraint of system constraints.

Step 5: Result. The simulation results of output optimal decision mainly include the power of each generation unit, the minimum cost and the load response of the micro-grid.

4 Data, Simulation, Results and Analysis

4.1 Data

In this section, a building micro-grid system is used for simulation analysis to verify the effectiveness of the operation optimization model established in this paper. In this micro-grid system, both DGs and response load resources are included. The capacity of each dispatching unit in the building micro-grid is shown in the Table 2. The daily load (1440 minutes) of electrical load data in a year, the typical day load curve and the NG load curve are shown in Figure 5.

In addition, because the micro-grid system has more advanced intelligent power monitoring equipment, and the load type is more comprehensive, it has the conditions to participate in the Demand Response program. The response load in the micro-grid system is shown in Table 3. According to users' participation in Demand Response, there are three alternative pricing strategies, Fixed electricity price (FEP=1.02 yuan/kwh), Real-time price (RTP) and Time-of-use price (TOU). And the electricity price curve of micro-grid under different Demand Response strategies is shown in Figure 6.

Tab.2 Capacity of each dispatching unit in the building micro-grid

Scheduling unit	CCHP	PV	ES	Load
Capacity	1.5MW	400KWp	300kWh	667kW

Tab.3 Operation parameters of transferable load

Transferable load	Power/ kW	Single run time / h	Time windows	
			Start time/ h	Stop time / h
Washing machine	0.8	1	9	17
Rice cooker	1.5	2	16	20
EV	100	5	10	24

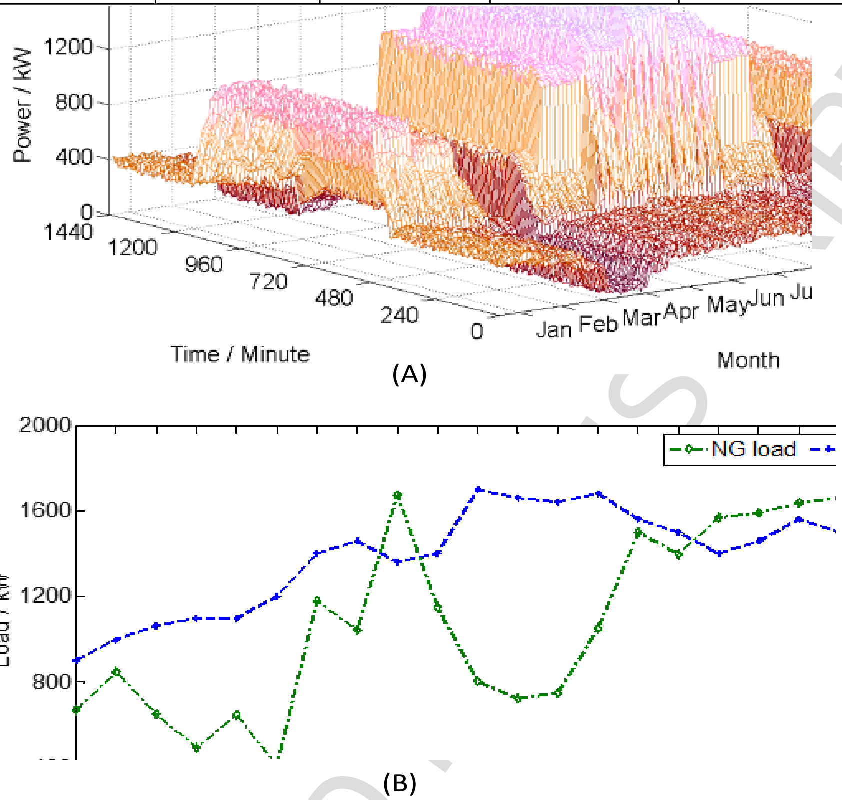

Fig. 5 Load diagram of the micro-grid. (A) Electrical load statistics of a micro-grid for a year; (B) Typical power load and gas load curves for micro-grids

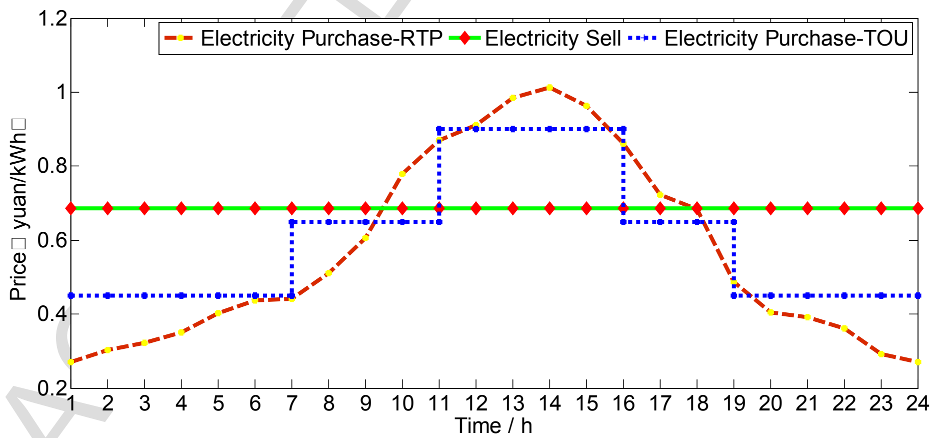

Fig. 6 Electricity price curve of micro-grid under different Demand Response strategies

In addition, in order to balance the fluctuation of PV output in the micro-grid, the system is also equipped with a 300 kwh lithium battery Energy Storage system. The actual cumulative throughput of the lithium battery is 1.99×10^{7} Ah .The parameters of the battery are shown in Table 4.

Tab.4 Main parameter of lithium battery (Chen et al., 2018)

parameters	Unit	value
Battery monomer capacity	Ah	180
Quantity	blocks	666
Maximum charge and discharge power	kW	65
Rated capacity	kWh	300
SOC operating range	-	0.25~0.95
SOC overcharge protection threshold	-	0.9
SOC over-discharge protection threshold	-	0.3
Charge - discharge conversion efficiency	%	90%
Self - discharge rate	%·s-1	0
Life	a	5~15
Cycle times	-	2000 (90%DOD)

In the building micro-grid, CCHP mainly provides electricity and heat. The operation cost of CCHP is mainly fuel cost (Natural Gas). The price of Natural Gas is 3.14 yuan / m^3. And the parameters of CCHP system are shown in Table 5.

Tab.5 Operation parameters of CCHP in different operating conditions (Mehr et al., 2018)

parameters	Unit	value		
Load rate	%	100	75	50
Electric power	kW	1490	1118	742
Output power	kW	1528	1146	765
Power factor	-	1	1	1
Voltage	V	400	399	403
Electric current	A	2146	1613	1064
Frequency	Hz	50	50	50

4.2 Simulation

According to the Demand Response scheduling strategy established in this paper, customers can respond to electricity price signals to participate in power grid dispatching according to power demand. This section takes electricity price as the research object, and designs three different scheduling scenarios. Through the simulation of the system operation under different price strategies, the influence of the electricity price strategy on the operation cost of the system and the output power of each unit of the system is studied.

Scene 1： In this scenario, users don’t participate in Demand Response project. The electricity price strategy is fixed price (FEP). The power generation units in the micro-grid are PV, CCHP and

ES, and there is electricity exchange between the micro-grid and the power grid.

Scene 2: In this scenario, users participate in Demand Response project. The electricity price strategy is time-of-use price (TOU). The power generation units in the micro-grid are PV, CCHP and ES, and there is electricity exchange between the micro-grid and the power grid. Users who participate in Demand Response can obtain benefits by load reduction according to the dispatching signal of the power grid.

Scene 3: In this scenario, users participate in Demand Response project. The electricity price strategy is real-time price (RTP). The power generation units in the micro-grid are PV, CCHP and ES, and there is electricity exchange between the micro-grid and the power grid. Users who participate in Demand Response can obtain benefits by load transfer according to the dispatching signal and Electricity habit.

4.2.1 Power output

According to the three simulation scenes set in this section, this section analyzes the operation of the system under different conditions. The operation results are shown in Figure 7.

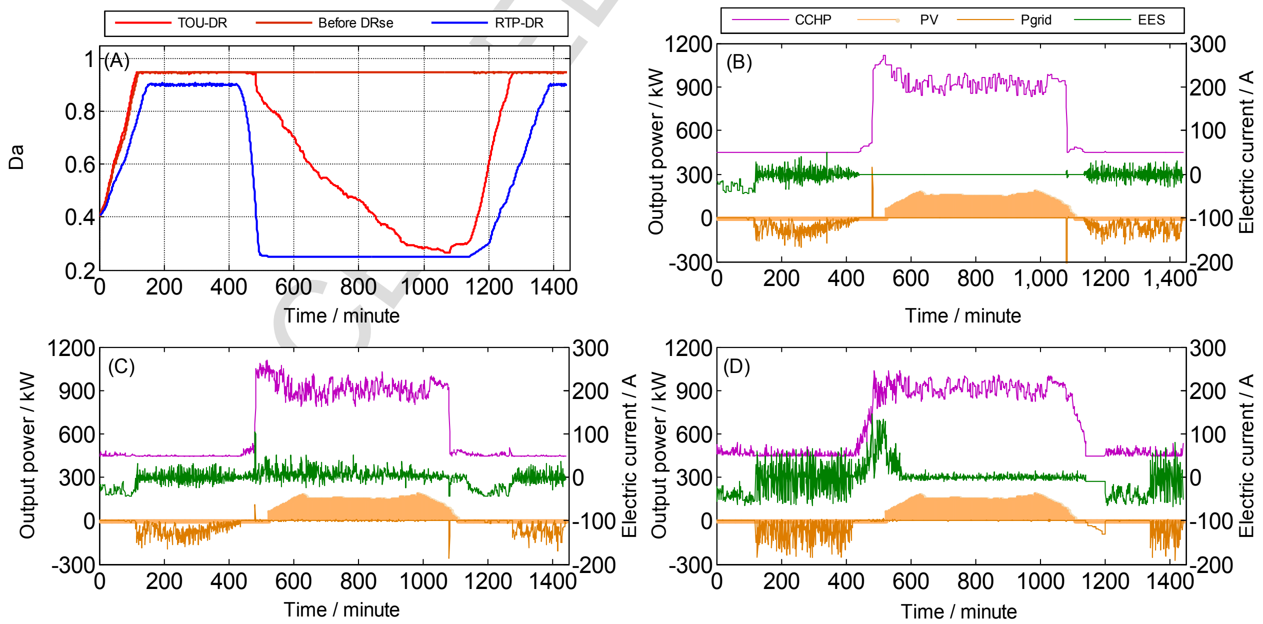

Fig.7 Operation results of micro-grid system under different demand response scenarios

According to the scheduling strategy established in this paper, the difference of the optimization results of the ES system in the three cases can be reflected by the discharge depth of the ES system, as shown in Figure (A). In scene 1, the discharge cost of the battery is very low in the actual situation, and when the load increases sharply, the battery discharge to the SOC protection threshold and then steady; in scene 2, the battery discharge slowly to the lowest point and no longer continues to discharge, the cost of the battery discharge increases; In scene 3, the battery discharge time is close to the upper limit of the rated cycle time, which causes the state of charging to remain unchanged during the day, so the discharge cost is very high.

In the three scenes, the output optimization results of each unit, the electricity exchange between the micro-grid and the grid are reflected in Figure (B), Figure (C) and Figure (D). Figure (b) is the initial state of system operation (scene 1). Users don't participate in Demand Response program, and electricity price is FEP. Users preferentially use DGs and ES, and sell surplus power to the power grid. When the power is shortage in the micro-grid, electricity can be purchased from the grid. Figure (C) shows the operation state of the system when users participate in the Demand Response program based on TOU price. In this scene, because of the ladder distribution of electricity price, the daily electricity price is higher. In order to save the cost of electricity purchase, the discharge degree of ES and the output of CCHP are enhanced compared with that of Figure (B). Figure (D) shows the operation state of the system when users participate in the Demand Response program based on RTP price. In this scene, the operation conditions of each unit of the system are more sensitive to the change of the electricity price because of higher electricity price and rising states, and the power of each unit, the change of power between the micro-grid and the grid are more obvious than the Figure (B) and Figure (C).

Through the above analysis, we can see that after the Demand Response, the CCHP power, the discharge depth and the current of the ES change more obviously. During the operation of ES system, the main function of the ES is to charge at low power consumption at night and discharge at high power price during the day. Before Demand Response, the system calls the ES system in real time according to the power demand of the micro-grid and the power of DGs. The basic rule of dispatching is to charge at night and discharge in the daytime, but the electricity price is not taken into account. After the Demand Response, the system tries to sell more power to the grid when it meets the demand of power considering the economy. At the same time, the frequency of ES discharge is increasing, resulting in the fluctuation of current of ES.

As the important power source in the system, CCHP and PV must meet the power, cold and heat demand in the system, and then deliver the excess power to the power grid to achieve economic benefits. Before Demand Response, the main factor affecting CCHP is the electrical and heat requirements of the system. On the premise of meeting the requirements of heat load, CCHP supplies power to the micro-grid and sells excess power to the grid. After Demand Response, considering the economic operation of the system, the output power of CCHP increases gradually, as shown in Figure 7. In addition, it should be noted that the power of PV is fully used in the system, and the output of PV is not optimized.

4.2.2 Load response

After the implementation of the Demand Response program, users can respond to the market price according to their own electricity demand and power consumption habits, and adjust the mode of energy consumption and load demand. Figure 8 shows response state of EV users after the Demand Response program based on TOU price.

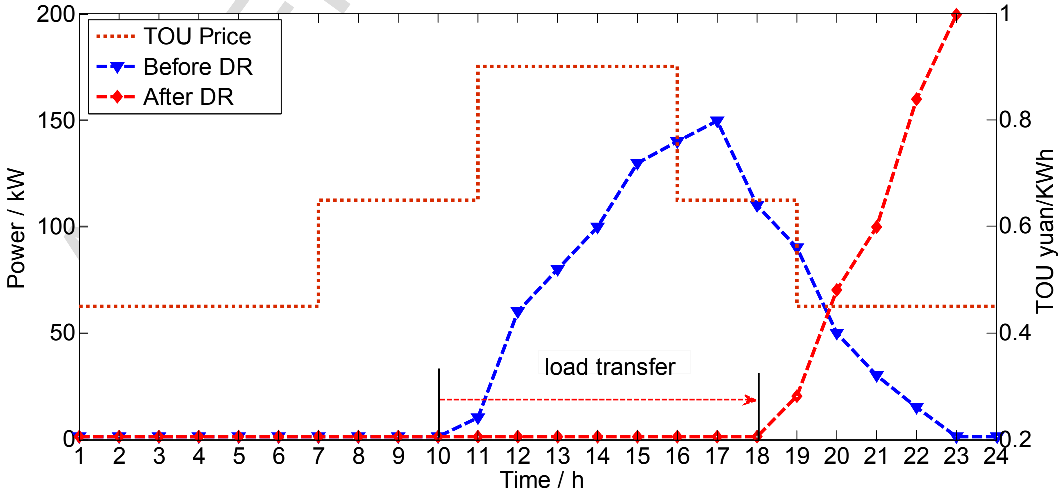

Fig.8 Changes of Electric Vehicle load before and after Demand Response (TOU)

According to the development of electric vehicle (EV) technology, it is known that the charging time of the EV is about 5~8 hours each time. If the vehicle adopts fast charging technology, it can be charged within 2 hours and the maximum mileage of the car can reach 300 kilometers (Xiong et al., 2018). From Figure 8, it can be seen that the running time of EV is mainly concentrated at 6:00~10:00, and the charging time is mainly at 20:00~24:00. Before the Demand Response, according to the change of charging time, it can be found that the charging time of EV is concentrated in the period of high electricity price, so the charging cost is more. After the Demand Response, the user changes the charging behavior to respond to the change of electricity price. The user has changed the charging time of the vehicle, and the charging time window is mainly concentrated in the evening (18:00~24:00). In this period, most users do not use vehicles, and the vehicles are basically in the charging state. The charging time after Demand Response is just the lower period of TOU price, so the charging cost is reduced.

In the commercial buildings, the electricity consumption is mainly for lighting and air conditioning in the building. According to the characteristics of commercial activities, the business hours are generally at 6: 00~21: 00, and buildings consume more electricity during this period. It is clear that the load of commercial buildings can't be adjusted before 6:00 and after 21:00. However, at 6:00~21:00, lighting load and air conditioning load could be adjusted according to RTP. Figure 9 shows the lighting load before and after Demand Response (RTP). Figure 10 shows the reduction of air-conditioning load after Demand Response (RTP).

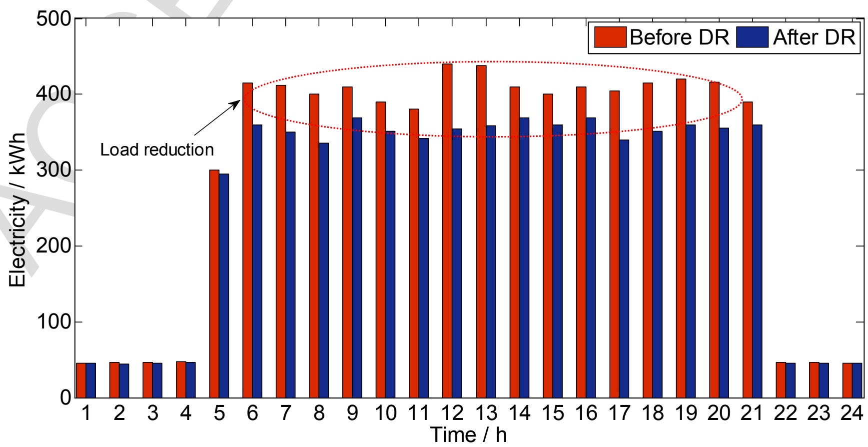

Fig.9 Lighting Load before and after Demand Response (RTP)

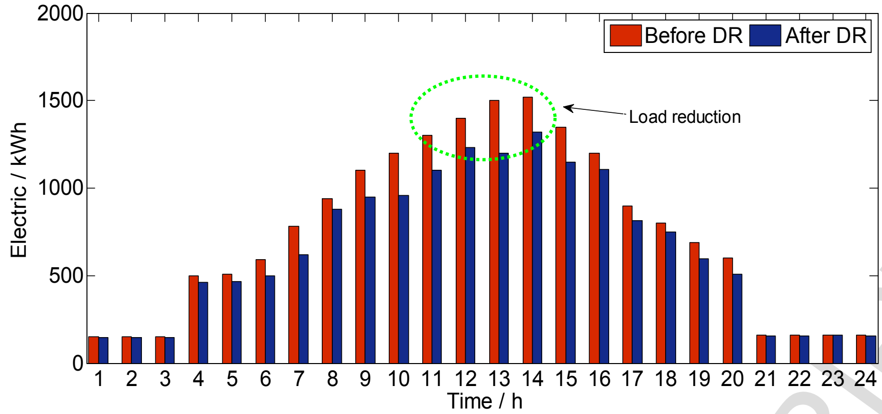

Fig.10 Air conditioner load before and after Demand Response (RTP)

In the urban power grid, more and more intelligent buildings have been built to meet the increasing energy demand because of the 40% power consumption of buildings. In addition, as the main power load, air conditioning and lighting are more closely related to the stable operation of the power grid and user comfort. Air conditioning load is an excellent resource for demand response. Reasonable adjustment of air conditioning can effectively alleviate the imbalance between supply and demand, and improve the comprehensive operation efficiency of power system.

By comparing the operation state of the building micro-grid before and after the Demand Response, it is obvious that the power consumption of the air conditioning system is reduced by about 16%, which reduces the peak load of the air conditioning, makes the electric power consumption relatively stable, and reduces the fluctuation compared with the situation that without participating in the Demand Response program. The optimization of the load of the lighting system is above 30% (10:00~16:00), the temperature and illumination meet the requirements. The demand response strategy of smart micro-grid can effectively save the cost of building electricity and effectively reduce peak load level.

4.3 Results and analysis

According to the three scenarios and simulation results set in this study, this section mainly analyzes the system operation results and objective functions of the micro-grid system in different scenarios. The cost of the system includes the operation cost of the power generation units, the cost of power purchase and sales, the cost of energy exchange and the total operation cost of the system.

Table 6 shows the results of system operation under different conditions.

Tab.6 System operation results in different scenarios

Scene			Unit	scene 1	scene 2	scene 3
CCHP	NG Consumption		m^3	3645.812	3773.154	3849.980
	Operation Cost		yuan	12170	12260	12510
PV	Operation Cost		yuan	1120	1120	1120
ES	Operation Cost		yuan	600	770	820
Electricity exchange	Purchase	Electricity	kWh	78.627	75.344	74.179
		Operation Cost	yuan	290	250	240
	Sell	Electricity	kWh	574.20	583.051	803.302
		Revenue	yuan	460	871	1200
Micro-grid	Operation Cost		yuan	13720	13530	13490

As can be seen from Table 6, the power exchange between micro-grid and power grid has undergone great changes under different operating conditions. After the Demand Response program was implemented, the power purchased by the system from the power grid changed little and remained at a low level. However, in response to electricity prices and profits, the micro-grid has delivered more power to the grid. The amount of energy exchange can reach 583.051kWh ~803.302 kWh. The influence of demand response is reflected when the price rises or the reliability of the system is threatened, the power users change their intrinsic mode of electricity to respond to the dispatching signal of the power grid actively, which is one of the solutions to the demand side management (DSM). In this study, the effects of Demand Response program include not only the reduction in electricity purchase, but also the increase in electricity sales. Before the Demand Response, the response of users to electricity prices is slowly, they only trade electricity according to their own electricity usage. However, in addition to the demand for electricity, the economy of electricity consumption is also one of the important factors for consumers to consider, after the demand response electricity price mechanism has been introduced. After the Demand Response, consumers can reduce the amount of electricity they want to buy at the peak of the electricity price, give priority to the use of DGs, and sell excess electricity to the grid to gain economic benefits. Compared with the state before Demand Response, the power consumption of micro-grid to the grid increased significantly after Demand Response. As shown in Table 6, before Demand Response, the micro-grid sold 574.2 kWh power to the grid. However, after the Demand Response, the power supply of the grid increased by 8.851 kWh and 220.251 kWh respectively under TOU and RTP.

It can be seen from the analysis that the electricity exchange between the system and the power grid is on the rise, and the profit of the system sale is increased after demand response. The benefits of micro-grid operation under different operating conditions are shown in Figure 11.

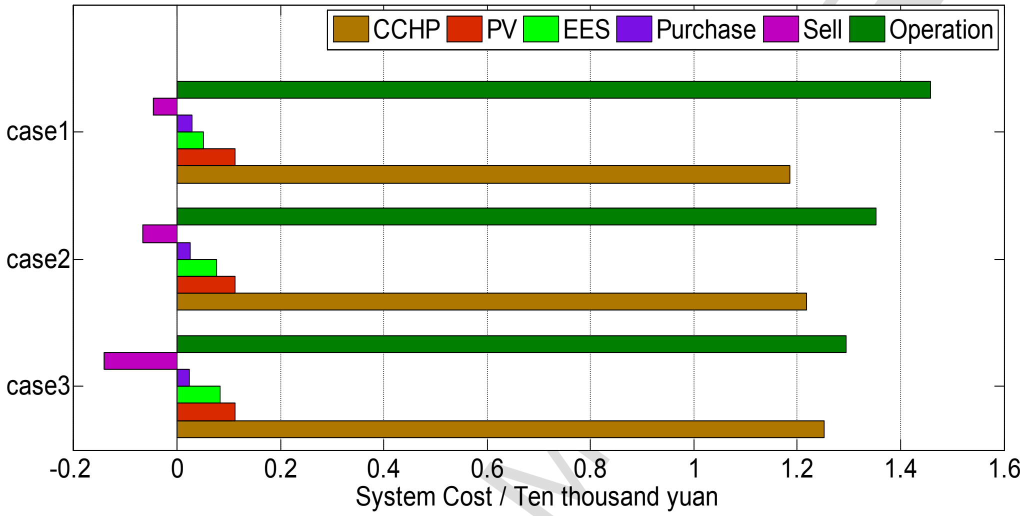

Fig.11 Daily operation cost of micro-grid under different Demand Response strategies

As shown in Figure 11, In scene 2 and scene 3, in order to match the price change, the power of CCHP and the charge and discharge of ES are improved, which leads to the increase of cost of CCHP generation and charge and discharge of ES. On the one hand, the increase of NG consumption in the CCHP system increased by 90 yuan and 340 yuan respectively, and the operation cost of ES system increased by 170 yuan and 220 yuan respectively. On the other hand, because the photovoltaic power is always used completely, the cost of the photovoltaic system is kept constant, and the DGs system can basically meet the demand for electricity, which makes the cost of power purchase change little and keep at a lower level. According to the optimization results, the total operation costs of the 3 scheduling schemes showed a downward trend, which were 13720 yuan, 13530 yuan and 13490 yuan respectively. Therefore, it is estimated that the monthly system operation cost savings rate is between 1.38% ~ 1.68% after the Demand Response,.

In addition, according to the actual operation of micro-grid system and the statistical results of system operation cost. The operation cost of CCHP accounts for 90% of the total cost of the micro-grid, while the fuel price (NG) of the CCHP system has a great impact on the total daily cost. In China, the price fluctuation of NG is an important factor affecting the economic operation of CCHP system.

On the one hand, the proportion of NG and standard coal is too high, which increase the proportion of coal supply, and reduce the proportion of NG supply. On the other hand, the price of NG is not appropriate. The price of industrial NG in the America and Germany is only 1/5~1/3 for resident gas, the proportion of Japan is 1/9. However, the NG price of industry generated by China is 1/2~2/3 for civilian NG price (Li et al., 2014). Therefore, on the basis of fixed NG price (3.14 yuan /m^3), this section appropriately adjusts the ratio of NG price change ($\pm5\%, \pm10\%$) to study the effect of NG price on the operation cost before and after the DR program. The sensitivity of daily operation cost of micro-grid to NG price is shown in the Figure 12.

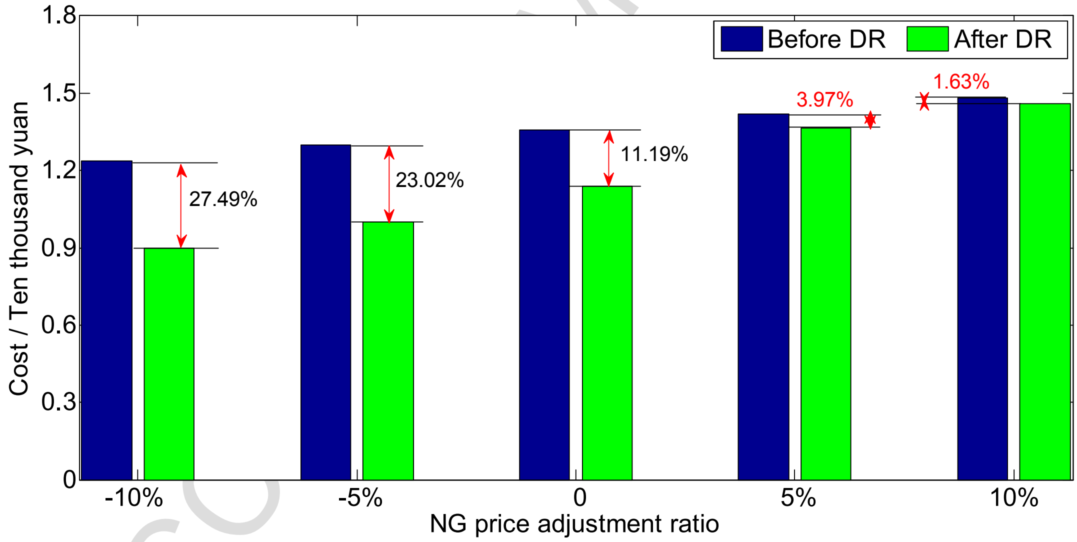

Fig.12 Sensitivity of daily operation cost of micro-grid to NG price

According to Figure 12, when the NG price increases, the system cost increases greatly. When the NG price declines by 10% from 3.14 yuan/m^3 to 2.826 yuan/m^3, the operation cost of the micro-grid declines by 16.3% after the Demand Response, and the cost before DR is 27.49% more than that after DR. However, when the NG price is raised by 10%, the operation cost of the system will increase sharply, and the cost after DR is only 1.63% less than that before DR. According to the cost curve, when the price of NG continues to rise, the operation cost difference before and after DR will gradually decrease. It can be seen that the change of NG price has a great influence on the effect of DR.

Through the analysis of the simulation results, it can be seen that the daily operation cost of the system is decreasing after DR, which shows that the implementation of the DR can effectively reduce the operation cost of the micro-grid and effectively improve the economic efficiency of the system operation. It can be seen from the Table 6 that the operating cost of the system increases after the DR, in which the cost of the NG and the operation cost of the ES are all increasing. The increase is due to the increase in the output of the CCHP and the charge and discharge frequency of the ES. With the stimulus of DR and electricity sales revenue, both the cost of ES and the electricity sales revenue are increasing, which is mainly because of the substantial increase in electricity sales to respond to the electricity prices at the peak of the power grid. It can be seen that the profit growth is far greater than the operation cost, which ultimately leads to the decline of the total operation cost of the system.

5 Conclusions

In this paper, the energy management problem of a smart micro-grid is studied in the context of renewable distributed energy generation and Demand Response program. Firstly, a typical intelligent micro-grid is introduced, and its modeling and scheduling strategy is studied. Then, on the basis of the scheduling strategy with the Demand Response, the operation optimization model of the micro-grid is established. The model takes the minimum operating cost as the objective function, and takes into account the multiple constraints such as load, power, electrical satisfaction and so on. Finally, the validity and practicability of the model are verified by the Genetic Algorithm and the simulation of a smart micro-grid project in China. Using the proposed energy management model of micro-grid has obtained several achievements as follows:

From the analysis of the structure and scheduling strategy of the micro-grid, it is found that the smart micro-grid is more diversified than the traditional power grid, and the system intelligence and self-control ability are more powerful. In the smart micro-grid scheduling, Demand Response and other market adjustment means play an important role, which makes the interaction between the power grid and the users enhanced, which makes the power grid scheduling more intelligent and vivid.

In micro-grid operation optimization modeling, Demand Response is a factor that can't be ignored. On the one hand, the implementation of Demand Response makes the choice of the system electricity price more optional. The system can choose different electricity price strategies according to the market conditions to achieve the goal of the minimum operating cost. On the other hand, the satisfaction and comfort of the users are also a heavy task in addition to the traditional constraints of the operation. System scheduling not only makes the cost minimum, but also has no negative impact on the user's power consumption experience.

From the case study of minimizing the operation cost considering electricity price strategy of Demand Response (FEP, TOU and RTP), it is found that different tariff strategies have great influence on the operation strategy and operation cost of the micro-grid system. At the same time, after the implementation of the Demand Response program, the smart micro-grid system can adjust the power consumption according to the market price and its own operating characteristics to respond to the scheduling. In addition, according to the composition of the operation cost of the micro-grid, the price of NG, one of the key factors affecting the operation cost of the micro-grid, is analyzed as a sensitive factor. And the sensitivity analysis shows that when the price of Natural Gas continues to rise, the effect of Demand Response program will be seriously weakened.

The focus of this paper is on the management of micro-grid energy based on Demand Response. The micro-grid studied in this paper is an intelligent modern power grid based on power consumption. In the future, with the development of energy technology and the emergence of the diversification of regional energy demand, the energy management of the micro-grid system will inevitably interact with the thermal supply system and the Natural Gas supply system. The energy management of micro-grid based on Demand Response should not only consider the influence of electricity price and subsidy policy on the power load, but also consider the response mechanism of the electricity load to Natural Gas price and thermal price. At the same time, the impact of NG load and thermal load on power load is also one of the factors that must be considered in the DR strategy of micro-grid.

Acknowledgments

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Reference

[1] Zao Z Y, Chen Y L. Critical factors affecting the development of renewable energy power generation: Evidence from China[J]. Journal of Cleaner Production, 2018.

[2] Rawea A, Urooj S. Power Energy Management for Grid-Connected Hybrid Renewable Energy System in Yemen Using Fuzzy Logic[J]. 2018.

[3] Wu X, Hu X, Moura S, et al. Stochastic control of smart home energy management with plug-in electric vehicle battery energy storage and photovoltaic array[J]. Journal of Power Sources, 2016, 333:203-212.

[4] Wu X, Hu X, Teng Y, et al. Optimal integration of a hybrid solar-battery power source into smart home nanogrid with plug-in electric vehicle ☆[J]. Journal of Power Sources, 2017, 363:277-283.

[5] Husted M A, Suthar B, Goodall G H, et al. Coordinating microgrid procurement decisions with a dispatch strategy featuring a concentration gradient[J]. Applied Energy, 2018, 219.

[6] Wang J, Zhong H, Ma Z, et al. Review and prospect of integrated demand response in the multi-energy system ☆[J]. Applied Energy, 2018, 202.

[7] Jang D, Eom J, Kim M G, et al. Demand responses of Korean commercial and industrial

businesses to critical peak pricing of electricity[J]. Journal of Cleaner Production, 2015, 90:275-290.

[8] Sun Z, Li L. Potential capability estimation for real time electricity demand response of sustainable manufacturing systems using Markov Decision Process[J]. Journal of Cleaner Production, 2014, 65(4):184-193.

[9] Sun Z, Li L, Dababneh F. Plant-level electricity demand response for combined manufacturing system and heating, venting, and air-conditioning (HVAC) system[J]. Journal of Cleaner Production, 2016, 135:1650-1657.

[10] Cominola A, Spang E, Giuliani M, et al. Segmentation analysis of residential water-electricity demand for customized demand-side management programs[J]. Journal of Cleaner Production, 2018.

[11] Shrouf F, Ordieres-Meré J, García-Sánchez A, et al. Optimizing the production scheduling of a single machine to minimize total energy consumption costs[J]. Journal of Cleaner Production, 2014, 67(6):197-207.

[12] Khan A S M, Verzijlbergh R A, Sakinci O C, et al. How do demand response and electrical energy storage affect (the need for) a capacity market?[J]. Applied Energy, 2018, 214:39-62.

[13] Lu R, Hong S H, Zhang X. A Dynamic pricing demand response algorithm for smart grid: Reinforcement learning approach[J]. Applied Energy, 2018, 220:220-230.

[14] Padmanabhan N, Ahmed M H, Bhattacharya K. Simultaneous Procurement of Demand Response Provisions in Energy and Spinning Reserve Markets[J]. IEEE Transactions on Power Systems, 2018, PP(99):1-1.

[15] Motalleb M, Annaswamy A, Ghorbani R. A Real-Time Demand Response Market through a Repeated Incomplete-Information Game[J]. Energy, 2018, 143.

[16] Shahryari E, Shayeghi H, Mohammadi-Ivatloo B, et al. An Improved Incentive-based Demand Response Program in Day-Ahead and Intra-Day Electricity Markets[J]. Energy, 2018.

[17] Weitzel T, Schneider M, Glock C H, et al. Operating a storage-augmented hybrid microgrid

considering battery aging costs[J]. Journal of Cleaner Production, 2018.

[18] Bellido M H, Rosa L P, Pereira A O, et al. Barriers, challenges and opportunities for microgrid implementation: The case of Federal University of Rio de Janeiro[J]. Journal of Cleaner Production, 2018.

[19] Zhou Z, Wang C, Sun X, et al. Heating energy saving potential from building envelope design and operation optimization in residential buildings: A case study in northern China[J]. Journal of Cleaner Production, 2018, 174.

[20] Liu Y, Gao J, Qin D, et al. Rule-Corrected Energy Management Strategy for Hybrid Electric Vehicles Based on Operation-Mode Prediction &z.star;[J]. Journal of Cleaner Production, 2018.

[21] Phurailatpam C, Rajpurohit B S, Wang L. Planning and optimization of autonomous DC microgrids for rural and urban applications in India[J]. Renewable & Sustainable Energy Reviews, 2018, 82, Part 1:194-204.

[22] Zhang B, Li Q, Wang L, et al. Robust optimization for energy transactions in multi-microgrids under uncertainty[J]. Applied Energy, 2018, 217:346-360.

[23] Moradi H, Esfahanian M, Abtahi A, et al. Optimization and energy management of a standalone hybrid microgrid in the presence of battery storage system[J]. Energy, 2018, 147.

[24] Cesena E A M, Good N, Syrri A L A, et al. Techno-Economic and Business Case Assessment of Multi-Energy Microgrids with Co-Optimization of Energy, Reserve and Reliability Services[J]. Applied Energy, 2018, 210.

[25] Vasak M, Kujundžić G. A Battery Management System for Efficient Adherence to Energy Exchange Commands under Longevity Constraints[J]. IEEE Transactions on Industry Applications, 2018, PP(99):1-1.

[26] Zheng Y, Song Y, Hill D J, et al. Multi-Agent System Based Microgrid Energy Management via Asynchronous Consensus ADMM[J]. IEEE Transactions on Energy Conversion, 2018, PP(99):1-1.

[27] Mehdizadeh A, Taghizadegan N, Salehi J, et al. Risk-based energy management of renewable-based microgrid using information gap decision theory in the presence of peak load management[J]. Applied Energy, 2018, 211:617-630.

[28] Sardou I G, Zare M, Azad-Farsani E. Robust energy management of a microgrid with photovoltaic inverters in VAR compensation mode[J]. International Journal of Electrical Power & Energy Systems, 2018, 98:118-132.

[29] Netto R S, Ramalho G R, Bonatto B D, et al. Real-Time Framework for Energy Management System of a Smart Microgrid Using Multiagent Systems[J]. Energies, 2018, 11(3):656.

[30] Ghasemi A, Enayatzare M. Optimal energy management of a renewable-based isolated microgrid with pumped-storage unit and demand response[J]. Renewable Energy, 2018, 123.

[31] Nunna H S V S K, Doolla S. Energy Management in Microgrids Using Demand Response and Distributed Storage—A Multiagent Approach[J]. IEEE Transactions on Power Delivery, 2013, 28(2):939-947.

[32] Rezaei N, Kalantar M. Stochastic frequency-security constrained energy and reserve management of an inverter interfaced islanded microgrid considering demand response programs[J]. International Journal of Electrical Power & Energy Systems, 2015, 69:273-286.

[33] Liu N, Wang J, Wang L. Distributed energy management for interconnected operation of combined heat and power-based microgrids with demand response[J]. Journal of Modern Power Systems & Clean Energy, 2017, 5(3):1-11.

[34] Tabar V S, Jirdehi M A, Hemmati R. Energy management in microgrid based on the multi objective stochastic programming incorporating portable renewable energy resource as demand response option[J]. Energy, 2017, 118:827-839.

[35] Kirchhoff H, Kebir N, Neumann K, et al. Developing mutual success factors and their application to swarm electrification: microgrids with 100 % renewable energies in the Global South and Germany[J]. Journal of Cleaner Production, 2016, 128:190-200.

[36] Moreno-Garcia I M, Moreno-Munoz A, Pallares-Lopez V, et al. Development and Application

of a Smart Grid Test Bench[J]. Journal of Cleaner Production, 2017.

[37] Krauter S. Simple and effective methods to match photovoltaic power generation to the grid load profile for a PV based energy system[J]. Solar Energy, 2018, 159:768-776.

[38] Mehrpooya M, Sayyad S, Zonouz M J. Energy, exergy and sensitivity analyses of a hybrid combined cooling, heating and power (CCHP) plant with molten carbonate fuel cell (MCFC) and Stirling engine[J]. Journal of Cleaner Production, 2017, 148:283-294.

[39] Hu X, Cao D, Bo E. Condition Monitoring in Advanced Battery Management Systems: Moving Horizon Estimation Using a Reduced Electrochemical Model[J]. IEEE/ASME Transactions on Mechatronics, 2018, 23(1):167-178.

[40] Zou C, Hu X, Wei Z, et al. Electrothermal dynamics-conscious lithium-ion battery cell-level charging management via state-monitored predictive control[J]. Energy, 2017, 141:250-259.

[41] Kakran S, Chanana S. Smart Operations of Smart Grids Integrated with Distributed Generation: A Review[J]. Renewable & Sustainable Energy Reviews, 2018, 81.

[42] Jang D, Eom J, Kim M G, et al. Demand responses of Korean commercial and industrial businesses to critical peak pricing of electricity[J]. Journal of Cleaner Production, 2015, 90:275-290.

[43] Sun Z, Li L, Dababneh F. Plant-level electricity demand response for combined manufacturing system and heating, venting, and air-conditioning (HVAC) system[J]. Journal of Cleaner Production, 2016, 135:1650-1657.

[44] Liu D, Agarwal R, Li Y. Numerical simulation and optimization of CO 2 -enhanced water recovery by employing a genetic algorithm[J]. Journal of Cleaner Production, 2016, 133:994-1007.

[45] Chen L, Xinran L I, Huang J, et al. Effect Evaluation Method for Energy Storage System Participating in Frequency Regulation Based on Amplitude-frequency Characteristics[J]. Proceedings of the CSU-EPSA, 2018.

[46] Mehr A S, Mosayebnezhad M, Lanzini A, et al. Thermodynamic assessment of a novel SOFC

based CCHP system in a wastewater treatment plant[J]. Energy, 2018.

[47] Xiong R, Cao J, Yu Q. Reinforcement learning-based real-time power management for hybrid energy storage system in the plug-in hybrid electric vehicle[J]. Applied Energy, 2018, 211:538-548.

[48] Li R, Li P. Economical optimal operation of CCHP micro-grid system based on improved artificial fish swarm algorithm[J].Electrical Engineering,2014(6):63-68(in Chinese).

(1) Presenting an optimization model based on Demand Response mechanism for micro-grid energy scheduling with response loads and CCHP as well as PV units and ES.

(2) Employing the TOU tariff and RTP tariff to implement demand response planning for response loads in micro-grid to realize economical and efficient operation of micro-grid and improve the utilization level of clean energy.

(3) Considering the operation cost under different electricity price policies as the objective function.

(4) Using the GA approach for minimizing objective functions and determining the best operation strategy by the clean distributed generation resources and demand response program.