Optimal Load Management of a Microgrid with an Electric Boiler and Renewable Generation

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Abstract

Renewable energy penetration into power grid keeps on increasing due to environment issues and fossil fuel shortage in the past several years. The scale of wind power generation has grown significantly in the past 30 years. However, power curtailment of renewable generations happens frequently due to the limitations of existing power transmission infrastructure amongst other reasons such as load fluctuations. This brings a great challenge to the development of renewable energy and the penetration levels of renewable energy.

To deal with renewable power curtailment problem in a microgrid equipped with renewable generation, an electric boiler and a thermal energy storage (TES) tank, this thesis proposes a model to control the power flows within the microgrid so that the electric boiler, together with the TES tank, can absorb surplus renewable generation. The microgrid can also make power exchange with the external power grid. That is, if the renewable generation cannot meet the energy demand, it will purchase electricity from the external power grid; if there is surplus renewable energy, the redundant renewable generation can be sold or converted to heat to be stored in the TES. Power flows between the grid, renewable sources, boiler, and the remaining electric load of the microgrid will be controlled. The eventual target of the control model is to minimize the electricity cost of the user while at the same time maintain necessary thermal comfort.

For the electric boiler and TES, temperature control is used to regulate the outlet water temperature by changing the electric power supply. The electric boiler under consideration can operate on different taps, and each tap position corresponds to a specific rated power. If renewable energy is larger than the electric load other than the boiler in the microgrid, the electric boiler may operate on high tap and produce redundant heat energy stored in TES for delayed thermal load. The electric boiler may also operate on low tap or OFF position and the TES tank provides further heat flux if the renewable energy is lower. The exact operation schedule of the electric boiler depends on the solution of the optimal control model which can operate differently from the above observations due to the time-dependent load, renewable generation, electricity tariff and feed-in tariff.

In order to verify the efficiency of the proposed model and control schemes, simulation studies have been worked out using MATLAB. The operational cost and the customers' discomfort level are considered in the mathematical model. Genetic algorithm (GA) is applied to find the optimal solution of case studies. Simulation results demonstrate that the proposed model can deal with renewable energy curtailment problem effectively with lower operational cost, so as to improve the penetration levels of renewables.

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Chapter 1

Introduction

1.1 Background

Renewable energy, especially wind energy, has increasingly penetrated into the power grid due to environment issues and fossil fuel shortage in the past several years [1, 2]. The scale of wind power generation has grown significantly in the past 30 years [3]. The power generated by wind is transmitted through transmission and distribution networks to the end users. However, wind plants are usually located in remote areas, and it is difficult to send the wind energy to end users through long distance transmission lines because of the limitation of existing power transmission infrastructure [4]. The improvement of infrastructure will need huge investment. Larger production of wind plants and lower load in the night happen frequently [5]. This imbalance between renewable generation and load demand makes renewable power curtailment happens frequently, and it is necessary to minimize renewable curtailment so as to improve the utilization of renewable energy.

Energy storage is used to support renewable electricity generation and thus can minimize power curtailment [6]. Heat is easy to store and can be generated by electric power [7]. More than 30% of residential customers use electric water heating in Europe, which accounts for 8.1% of the total electric power consumption [8]. The use of electric boiler for thermal load containing spacing heating and hot water will continue increase for the high efficiency [9]. Microgrid attracts a great interest due to the flexible ability of power exchange with the grid which can also promote renewable energy [10, 11]. Thus, this project aims to establish a model of microgrid including renewable energy and electric boiler to deal with power curtailment problem.

1.2 Objective of research

Power curtailment of renewable power generations happens frequently under the increasing penetration of renewable energy. Two main reasons result in the phenomenon, namely 1) the limitation of existing power transmission; 2) larger production and lower load demand in the night, such as wind power. The electricity is difficult to store despite of the use of electric energy storage systems due to the limitation of capacity and low efficiency, while heat is easy to store and electricity can be converted to heat with high efficiency.

Thus, this research work proposes a model to control the power flows within a microgrid which consists of an electric boiler, a thermal energy storage tank, a PV system and a wind turbine. In this model, renewable energy can be consumed locally by electric load and boiler for thermal load in the microgrid. The redundant renewable energy can be absorbed by the electric boiler or be sold to the external power grid. The electric boiler converts the power energy to heat and stored in TES, which could be used to supply the thermal load when low production or high electric load happens. The approach can deal with the power curtailment problem efficiently, and thus reduce carbon dioxide emissions.

1.3 Literature review

Demand side management, microgrid system, and general energy management can improve the flexibility of the power grid. Their characteristics provide the potential to dissolve the power curtailment problem. A simple review of existing research on these topics is introduced in the section.

1.3.1 Demand side management

Demand side management (DSM) has been investigated for a long time. The main approach of DSM is to shift and monitor load to improve the performance of power grid, energy efficiency, customers' benefits, and penetration of renewable energy.

Reference [8] proposes an optimization algorithm for demand side management of electric storage water heaters, which can achieve a control strategy to create a flat load profile and increase the performance of the power system. References [12-15] investigate the application of electric boilers in demand side management by developing the energy demand model of boilers. The objective of the research is to cut down the load peaks to improve the performance of power system. Demand side management is implemented by considering power management and control as a multi-objective optimization problem where the objective is to minimize total electricity generation cost and greenhouse gas emissions [16]. The influence of dispersed heat pumps with a thermal storage as demand side management in a low voltage distribution grid is analyzed in [17]. Reference [18] investigates the optimal control of the domestic hot water heater as price-driven DSM. Reference [19] looks into the potential demand manipulation that can be achieved from existing control mechanism and its value to the security of supply, investigates the potential contribution to network security from greater demand side management and the requirement for additional control mechanism to achieve the full potential benefit. A simple DSM strategy which moves some energy consumption from the peak hours to off-load is used to improve the development of distributed generation in power grid by easing the voltage rise problems in [20]. Reference [21] shows that demand side management plays an important role as an effective solution to support the access of renewable energy sources in grid coordinated with conventional generation. The effect of dynamic and non-dynamic demand side management on the use of wind power is analyzed in [22]. Reference [23] analyzes the effect of the growing renewable generation on demand side management and illustrates that DSM should be dispatched for the development of renewable power. The optimal demand response is considered with energy storage and the concept of disutility is introduced to control the power consumption within an appropriate range in [24]. Reference [25] creates an electricity demand model, which is used to determine the appropriate size of a community for implementation of an effective and non-disturbing load shifting demand side management. The model is then utilized to quantify the potential benefits of applying load shifting demand side management with a variable severity level. Reference [26] presents a fast distributed algorithm for DSM based on the social welfare maximization problem under the dynamic pricing scheme, introduces the dynamic game to illustrate the interaction between the utility company and its consumers, which eventually leads to an equilibrium point, and considered a smart grid environment with multiple users with renewable energy and energy storage devices equipped with smart meters and energy management devices (EMD). A novel EMS for a microgrid including renewable power by providing on-line information for generation unit and demand side management is presented in [27]. Reference [28] provides an operational decision making method for increase efficiency of energy in the microgrid by scheduling production and demand side at the same time.

Also research on intelligent technologies to develop the performance of demand side management have been carried out. An intelligent demand side management system to respond to various factors is designed in [29], which can provide consumers a best choice to use electricity and achieve intelligence autonomization. Intelligence autonomization means that users will know which factor affects the electricity consumption and choose the best electricity plan. The state of the art about smart metering communication standards relevant to the smart grid and smart house concepts is analyzed in [30] with an architectural overview of the existing information and communication technologies (ICT) standards related. Reference [31] presents a demand side management strategy based on load shifting technique for demand side management of future smart grids with a large number of devices of several types. Algorithms and architecture models for a home energy management system is presented in [32], and it is based on customers' behavior that is modeled by a decision-making chain, and smart appliances' use for demand side management. Reference [33] introduces a differential game to formulate two decentralized control schemes for decentralized control in smart grid based on the availability of communication. In [34], the scheduling strategy in the MAC layer of wireless networks comprises of smart meters is investigated, which assumes that the information used to decide the policy is collected via wireless communication. In addition, the energy storage system has been used to determine the demand-side management. In [35], the communication information is assumed to be always available between two houses and focused on the data that predicts the output of a photovoltaic power system. Reference [36] proposes a model comprising the grid connected system with photovoltaic and energy storage system for power backup and insights a perspective to address the optimal load management on the basis of consumer set demand priorities, renewable energy generation, and energy storage to reduce peak demand for residential end user.

1.3.2 Microgrid systems

Microgrid is a distributed energy system to produce heat, cool and power for end users in residential applications [37]. Microgrids can operate in isolated mode (disconnected from the distribution network) and grid-connected mode [38]. And Microgrid attracts a great interest due to the flexible power exchange with the grid [10] and has been proved the ability to promote renewable energy [11]. The scheduling problem of microgrid is more complex because of the presence of several kinds of renewable energy resources, smaller units, complex load demand and load mismatches [39, 40]. A multi-agent system is proposed for real time operation of a microgrid considering generation and demand side management [41]. Reference [39] also investigates the optimal size of energy storage system in a microgrid. Reference [5] analyzes the optimal operating strategies of microgrid with distributed energy resources and energy storage system to obtain minimum energy cost and maximal output of renewable energy considering the power exchange with power grid.

Usually the demands for electricity and heat are not synchronized in residential buildings [42]. A micro combined heat and power (CHP) system can recycle the "waste heat" by gas engine, fuel cell or Stirling engines for space and domestic water heating instead of electricity [43]. Thus, the CHP system in microgrid is investigated to deal with the mismatch problem between electricity and heat demands. The CHP system can operate during the period of high electric load and store the heat and to satisfy the thermal load in electric off-peak hours. Micro combined heat and power (CHP) technologies become more interesting with the increasing demand for less polluting forms of energy [43].

Germany has issued special legislation such as feed-in tariffs and bonus payments to encourage the adoption of micro CHP system [43]. Reference [43] also investigates two alternative micro CHP systems (gas engine and fuel cell) from economic and environmental and shows that it is an effective way for energy saving and carbon emission reduction. Reference [44] establishes a mathematical model of the Distributed Energy Supply System (DESS) using the natural gas including building and network level and analyzes the positive effect of micro-CHP for primary energy reduction.

References [42, 45-47] analyze the influence of a thermal storage system on micro-CHP systems and these results show that thermal storage can make a significant contribution to the development of renewable energy. Reference [45] analyzes the profitability of residential application by using an integrated CHP system, which consists of a prime mover, an electric energy storage (EES) system, a thermal storage system and an auxiliary boiler. The results show that proper sizing of the prime mover, EES and TES is beneficial to primary energy saving and profitability. Reference [46] presents general guidelines to design proper prime mover technology and size and size of thermal storage for micro-CHP system. The effect of the thermal energy storage on the performance of micro-CHP in residential building applications is investigated, and several prime movers are considered in [37] and the selection method of thermal storage size presented in [46] is used. Reference [47] carries out the research on cogeneration of micro-CHP coordinated with TES in the University of Parma Campus, by establishing a simplified lumped capacity model and providing operation strategy. Also the proper size of thermal storage is given by the simulation results.

1.3.3 Electric boiler, water heater and other energy system management

The boiler can be divided into two categories, namely electric boiler and gas boiler, which are used for thermal load including spacing heat and hot water. And the boiler can be domestic or central [8], and the efficiency of the electric boiler for converting electricity to heat is almost 100% [9]. Different from boilers, water heater usually provides hot water only for domestic [7]. However, both of them have great deal of energy consumption and their storage tank/geyser can provide energy storage capacity for demand side management purpose [8, 12-15]. Thus, the optimal control of boiler/water heater is beneficial to energy saving and the promotion of renewable generation.

An optimization algorithm has been proposed in [8] to manage electric boiler to smooth the load profile. A diversity model of hot water demand is presented in [12]. Reference [13] investigates a Monte Carlo simulation model for multi-boilers and provided different control strategies for load. References [14, 15] also investigate the control of boilers to cut down the load peaks. A model of a central heating electric boiler combined with a stand-alone wind generator presented in [9], where the wind power is only used to supply the boiler for water heating but not connected to the grid. Reference [10] shows the use of electric boilers in district heating grids coordinated with CHP plants and fossil fuel boilers in Germany. The results show electric boilers can reduce the power generation cost and carbon dioxide emissions and improve the penetration of renewable energy sources.

Reference [7] considers the aggregated electric water heaters (EWHs) to control the load shifting and provide desired balancing reserve instead of fossil fuel-based power plants for renewable generation. The paper also analyzes the economic benefit for the customers and their comfort level. The technique includes two algorithms named Operator algorithm (OA) and load algorithm (LA) are proposed in [48] to provide regulation and load leveling according to a reference temperature signal by minute-to-minute regulations. The results indicated electric water heaters can dissolve fluctuations of renewable energy and load forecast error and are effective for load peak shaving. Electric water heaters have been controlled for ancillary services for regulation services [49, 50]. Heat Pump Water Heaters (HPWHs) are used to deal with the frequency fluctuation in power grid with large penetration of renewable energy sources due to their flexibility [51, 52]. A mathematical model of a domestic hybrid solar-electric water heater is established in [53]. Reference [54] analyzes the benefits and bidding strategies by users under the premise of electric water heaters can be dispatched and users can participate in electricity market. Also the control of water heaters can reduce the energy demand [55]. An optimal control for the domestic water heater to achieve lower electricity cost and discomfort level is provided in [56]. The research on optimal control of the domestic hot water heater as a DSM support is also presented in [18].

Research on energy management also has been carried out to optimize the use of energy and improve the utilization of renewable energy. Wind energy, with its inexhaustible potential, increasingly competitive cost, and environmental advantage, is one of the best technologies available today to provide a sustainable supply to the world development [57]. Reference [58] proposes a demand management strategy within the community micro-grid. On the premise of individual preferences, the paper regulates the supply and demand which contains electric vehicle charging and energy storage to reduce the peak load. References [59-62] investigate the benefits for load shifting and cutting down peak load by the use of thermostatically-controlled appliances. References [59] and [60] cannot provide satisfactory comfort level for some customers. And the papers did not consider the price signal in load shifting. Conventional power plants should increase the amount of available reserve to meet the increasing penetration of renewable energy sources to the power grid, and reference [63] provides an approach to quantify reserve demand. Also it is necessary to provide balancing reserves and large-scale energy storage, storing the excess power generated by renewable generation, to prevent the power curtailment [6]. Reference [64] analyzes the operation and performance of large-scale energy storage devices integrated with the variable renewable generation. Reference [65] presents a method to size the energy storage system by minimizing the operating cost of the microgrid.

1.4 Research contribution

From the above analysis, power curtailment of renewable power generations happens frequently under the increasing penetration of renewable energy. This brings great challenge to the development of renewable energy and the penetration levels of renewable energy. The main contribution of the thesis is to propose a microgrid load management model to deal with the power curtailment problem and to improve the development of renewable energy. The novel aspects of the thesis are:

- This thesis proposes a model to control an electric boiler integrated with renewable generation in microgrid to deal with the power curtailment problem. The microgrid can make power exchange with the external power grid. Two case studies are implemented to demonstrate the effectiveness of the model.
- The thesis investigates control schemes for the microgrid, the electric boiler and power exchange with the external power grid.
- This thesis analyzes the heating process of the electric boiler system. The mathematical models of the electric boiler and TES and power exchange of the external power grid are established.
- This thesis analyzes the impact of renewable power on operating strategy.

Chapter 2

Development of model and methodology

2.1 Chapter introduction

In this chapter, the model of the proposed microgrid is presented. The operation principle and process are introduced. Also models of the elements in the microgrid are described too. The objective function and constraints are showed and in the end the optimal process based on genetic algorithm is implemented.

2.2 Model of the proposed microgrid

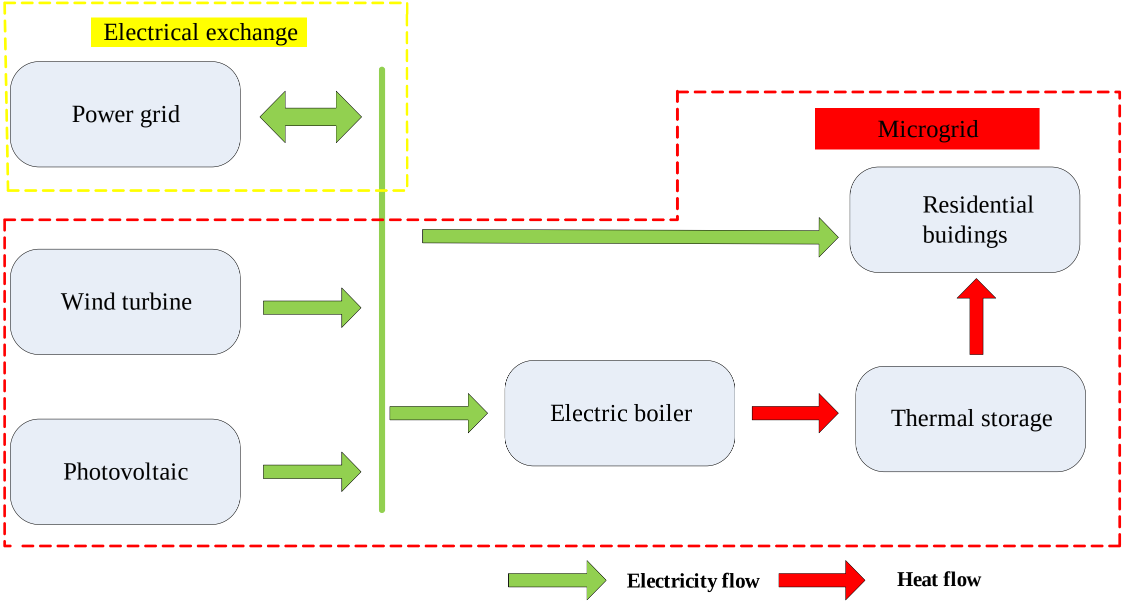


Figure 2-1 Structure of microgrid with renewable energy resources

The layout of the integrated microgrid system under investigation in this thesis is presented in Figure 2-1. The main components and energy flows of the proposed system are shown in the dashed box. The green line represents the electricity flow, and the red line stands for heat flow. The presented system aims at satisfying the electric and thermal load demand of residential buildings. It consists of (i) a photovoltaic (PV) system, (ii) a wind turbine system, (iii) an electric boiler, (iv) a thermal energy storage system (TES) and (v) an external power grid. The electric load is mainly made up with electric applications in residential buildings and electric boiler. The thermal load is space heating in residential buildings while hot water is not supplied by the manager of the microgrid.

A microgrid system is usually interconnected with the external power grid. The electricity buyback is considered in this thesis. In the proposed system, the energy flow process can be divided into two types: electricity flow process and heat flow process which are shown in Figure 2-1. The heating system consists of the electric boiler and a thermal energy storage tank. The electric power supply consists of the photovoltaic, wind turbine and the external power grid.

Electricity flow process: Electricity is generated by wind turbine and photovoltaic and transmitted to electric boiler and residential buildings. Electricity is also exchanged between microgrid and the external power grid.

Heat flow process: Heat is produced by electric boiler and transmitted to TES and then to residential buildings.

The renewable energy is used primarily for electrical and thermal load. The redundant renewable energy can be absorbed by two ways, namely 1) converted to heat by the electric boiler and stored in the TES, and 2) sold to power grid. The thermal load is supplied by three possible ways, namely 1) electric boiler alone, 2) TES alone, and 3) both of them. When the electric and thermal load is satisfied, the redundant renewable energy can be converted to heat by the electric boiler and stored in thermal energy storage system, and it can be released for further thermal load. By this way, the utilization of renewable energy can be improved.

The electric boiler in this microgrid is different to electric water heaters. Electric water heaters can only be on or off while the electric boiler in this mircogrid can be operated between 0 tap (off) to the maximal tap corresponding to different power. The power changes evenly between two adjacent tap positions, that is when the tap position is changed to an adjacent position, the power is increased or decreased by a fixed value, which is denoted by P_{bd}. The electric boiler can be operated with different taps in different power and electric load conditions:

1) When the renewable energy is much higher than the sum of electrical load of residential buildings and the thermal energy storage capacity, operating status of the electric boiler depends on the control decision;

2) When the renewable energy is a little larger than the electrical load of residential buildings and the thermal energy storage can meet the thermal load, the electric boiler is operated in low taps or switched off;

3) When the renewable energy is equal to or less than the electrical load of residential buildings and the thermal energy storage can meet the thermal load, the electric boiler is switched off;

4) Under conditions of 2) or 3), if the thermal energy storage cannot meet the thermal load, the microgrid will purchase electrical from the external power grid and the electric boiler is operated in suitable tap;

When the renewable production is not equal to the consumption, electricity exchange with the external power grid will happen. If the wind and PV power cannot meet the electricity load and heat demand in the microgrid, the manager in the microgrid must buy electrical power from the external power grid. If the wind and PV power is much larger than the load demand, it can be sold to the power grid act as income. In other situation, the microgrid can buy or sell electrical power which depends on the optimization results. Then the external power grid can be treated as an electric storage system.

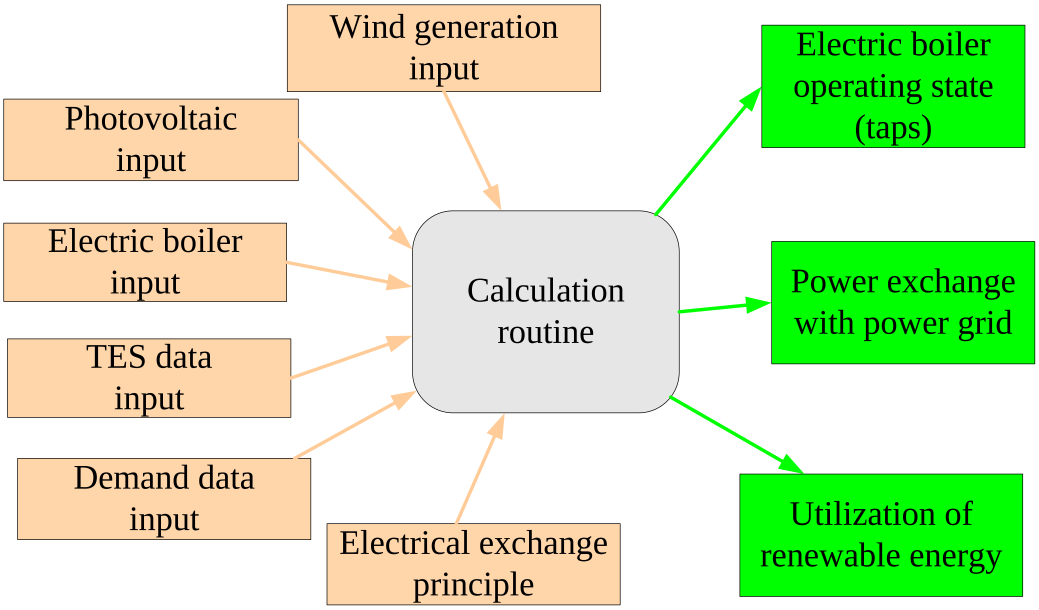


Figure 2-2 Calculation program of the microgrid with input/output data

On the basis of the above presented microgrid system, the calculation program of the microgrid with input and output data is shown in Figure 2-2. More in details, the main inputs of the program are:

(1) wind generation (wind power profile);

(2) photovoltaic (photovoltaic power profile);

(3) electric boiler input design data (total rated electric power, the rate electric power per tap, the maximal taps);

(4) TES data input design data (size, heat transfer coefficient etc.);

(5) demand data input (electric load and thermal load profiles);

(6) principle of electrical exchange (upper limit, price).

The main outputs of the program are:

(1) the electric boiler operating state (operating taps);

(2) power exchange with the external power grid;

(3) utilization of renewable energy (wind and PV power).

The proposed calculation procedure is implemented in MATLAB using genetic algorithm. Objective function and constraints will be illustrated in the following section. All the input data are obtained from a real microgrid in certain region of northern China.

2.3 Model of electric boiler and TES

2.3.1 Operational scheme of different heat supplying systems

In this subsection the model of electric boiler and TES tank is introduced. Electric boiler can be divided into two different types, which are used for direct and storage heating electric boiler. In this thesis, the electric boiler is considered as storage heating electric boiler. The electric boiler is used for space heating in residential building and the hot water is supplied by customer themselves in the microgrid.

The operational scheme of the space heating systems is shown in Figure 2-3. The operational scheme of the proposed microgrid is shown in Figure 2-3 (a). The heat is produced by electric boiler, and then it is delivered to TES, and at last the heat is transmitted to the residential building. The heat energy is stored in TES, and then TES provides heat flux to heating load. In the process, the on/off status of electric boiler depends on the thermal load and the renewable energy generation:

(1) if the thermal load is higher than capacity of TES, the electric boiler will be on and provide thermal energy to the absent thermal load;

(2) if the TES can fulfill the thermal load and the renewable energy generation is low, the electric boiler will be off or on depending on the control decision;

(3) if renewable energy generation is much higher than the electric load, the electric boiler will be off or on depending on the control decision.

Figure 2-3(b) illustrates the operational scheme of CHP systems which is different to Figure 2-3(a) studied in this thesis. Generally, a CHP system (operating parts for thermal load) consists of a CHP prime mover, a TES device and an auxiliary boiler. The features of CHP operational scheme is:

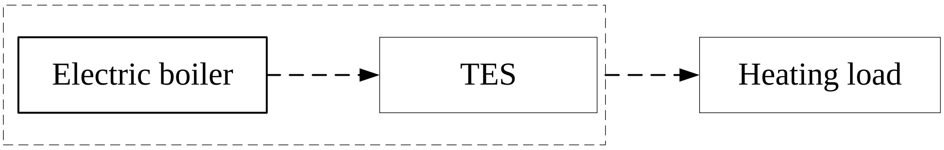
(1) the CHP prime mover generates heat energy and provides for heating load;

(2) if there is surplus heat (the heat generated by prime mover is larger than thermal load), the excess heat energy will be stored in TES device;

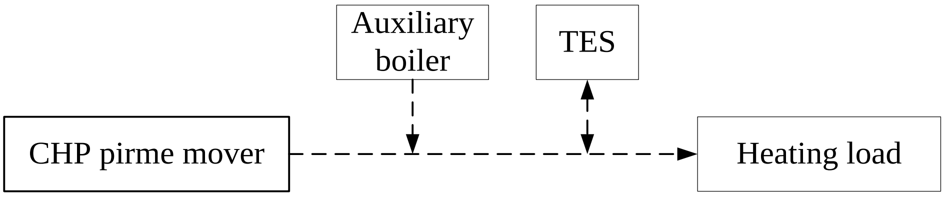
(3) if the CHP prime mover can fulfill the thermal load, TES will provide further heat flow;

(4) if the CHP prime mover and TES can fulfill the thermal load, the auxiliary boiler will be used to provide the further heat.

Except for the operational scheme, other differences exist between the two heat supplying systems. The system presented in this paper has no pollution to the environment due to the electric boiler is driven by electricity. The CHP prime mover will generate CO_x, SO_x and other pollutant emissions due to the use of gas or oil. Also electric power is generated together with thermal energy in the CHP, therefore, if the thermal load is high, there might be surplus electric power, which will result in energy waste if the electric power cannot be stored or sold to the grid. However, this phenomenon will not happen in the system in Figure 2-3 (a) as the electric boiler is driven by electricity. The operating status of the boiler can be adjusted flexibly along with the thermal load and the production is purely heat energy.



(a) The operational scheme of the space heating in this paper in northern China



(b) The operational scheme of the space heating in other studies [48, 50]

Figure 2-3 The operational scheme of the space heating with different types

2.3.2 Schematic of the proposed heat supplying system

The schematic of the proposed heat supplying system is presented in this subsection. The schematic diagram of the proposed heat supplying system is shown in Figure 2-4. In the heat supplying system, both of hot water and water vapor can be flexibly used to transfer heat energy. The main difference between them is the highest temperature of water is 100 ℃ while that of water vapor can be several times of 100 ℃ which depends on air pressure. And both of them can be stored in the tank. However, the water vapor flux in the heater pipe may easily lead to the burst of the heating equipment, which is dangerous to persons. So in the investigated microgrid, hot water is selected to transfer heat energy.

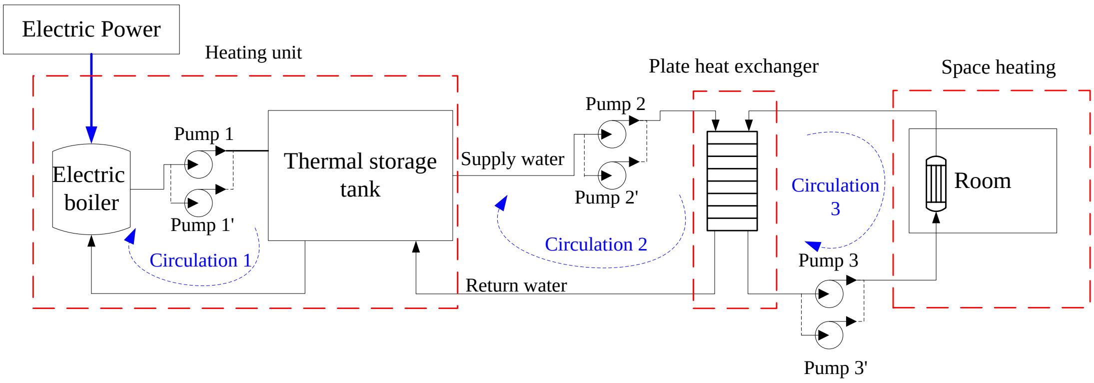


Figure 2-4 The schematic diagram of the proposed heat supplying system

The heating supplying system consists of an electric boiler, and thermal storage tank, a plate heat exchanger and six pumps. It can be clearly seen that there are three circulations in the proposed heat supplying system. There are two pumps in each circulation and the two pumps are parallel to guarantee the flow of the hot water. Take Circulation 1 as an example, generally speaking, Pump 1 works for the water flow while Pump 1' is OFF, and when fault occurs in Pump 1, Pump 1' can startup quickly for the normal operation of the circulation, namely Pump 1' is the standby of Pump 1.Also Pumps 2' and 3' are standbys of Pumps 2 and 3.

Details of the circulations and heating process are introduced as follows:

Circulation 1: Heating unit.

Step 1 Generate heat energy: Electric power is used by the electric boiler to heat water. In this step, the electric power is converted to heat energy.

Step 2 Transfer hot water to TES: The hot water in the electric boiler is transferred to thermal storage tank by Pump 1. The heat energy is stored in thermal storage tank in this step.

Step 3 Return water: The water in thermal storage tank is returned to the electric boiler to heat.

In this circulation, the water will be heated following the above three steps. The electric boiler is close to the thermal storage tank and the pipeline linked them is very short which is about two meters, so there in no delay between them.

Circulation 2: Heat exchanger

Step 1 Transfer hot water: The hot water in thermal storage tank is transferred to plate heat exchanger by Pump 2.

Step 2 Heat exchanger: After the hot water is delivered to plate heat exchanger, the thermal energy in the hot water is transferred to the water flux in the space heating area by plate heat exchanger.

Step 3 Return water: After plate heat exchanger and the thermal has been transferred, the water will be returned to the thermal storage tank.

Circulation 3: Space heating. The hot water in plate heat exchanger will be delivered to the residential buildings by Pump 3 for space heating. The low temperature water will be returned to plate heat exchanger for heating.

In this circulation, the plate heat exchanger can control the supply temperature for the residential buildings.

The temperature of the room mainly depends on the mass flow rate of hot water, the supply water temperature (namely the outlet temperature of TES) and the return water temperature of the system. Assuming the demand temperature of the rooms is $Dr(t)$ at time t and the return water temperature is T_i, then the outlet temperature has the minimum $T(t)_{\min}$ at time t. Namely, heat demand can be satisfied when outlet water temperature is not less than $T(t)_{\min}$. The plate heat exchanger/radiators will affect the temperature in the residential buildings to some degree, and it controls the supply temperature to be close to the expected temperature.

2.3.3 Mathematic model of electric boiler and TES

The mathematic model of electric boiler and TES is introduced in this subsection. Existing models are reviewed and then the model needed in this thesis is analyzed.

1) Boiler thermal dynamics

Classical fuel powered boilers consume gas, coal or diesel, while the electric boiler consumes electric power. However, their thermal dynamics are essentially the same. The thermal dynamic equation of a classical fuel powered boiler considers the energy supplied and the heat consumed [66, 67]:

$$\frac{dT_{boiler}}{dt} = \frac{1}{C_{boiler}}[Q_{heat} - vc_w(T_{boiler} - T_i)] \tag{2-1}$$

where,

T_{boiler} is the water temperature (outlet temperature) in the boiler (℃);

C_{boiler} denotes the specific heat capacity of boiler (J/℃);

Q_{heat} denotes the energy supplied (W);

v denotes the mass flow rate of hot water (kg/s);

c_w denotes the specific heat capacity of water (J/(kg ·℃));

T_{boiler} indicates the inlet temperature (return water)in the boiler (℃).

This boiler model does not consider the energy loss to the environment, even though energy loss is not significant. To consider the energy conservation and guarantee the integrity of the boiler model, the modified model [68, 69] is shown in equation (2-2).

$$\frac{dT_{boiler}}{dt} = \frac{1}{C_{boiler}}[Q_{heat} - vc_w(T_{boiler} - T_i) - K(T_{boiler} - T_a)] \tag{2-2}$$

where,

K represents heat transfer coefficient of tank’s external walls (W/(m^2 ·℃));

T_a represents ambient temperature(℃).

This modified model is applied to the electric boiler in this thesis.

2) Model of TES

The TES with heat exchangers is treated as a whole device. The model contains the energy loss to the environment can be expressed as [47]

$$\frac{dT_{TES}}{dt}=\frac{1}{C_{TES}}[n_1K_{s-c}(T_s-T_{TES})+n_2K_{s-l}(T_d-T_{TES})-K_{s-e}(T_{TES}-T_a)] \quad (2\text{-}3)$$

where,

C_{TES} is the specific heat capacity of TES (J/℃);

coefficients n_1 and n_2 are 0 or 1, depending on if TES is exchanging heat with CHP prime mover (n_1) and the thermal load (n_2);

K_{s-c}, K_{s-l} and K_{s-e} are conductance (W/(m^2·℃));

T_s, T_d and T_{TES} are the temperature of heat supplied, thermal load and water in TES, separately (℃).

3) Model of the heating unit (combine of electric boiler and TES)

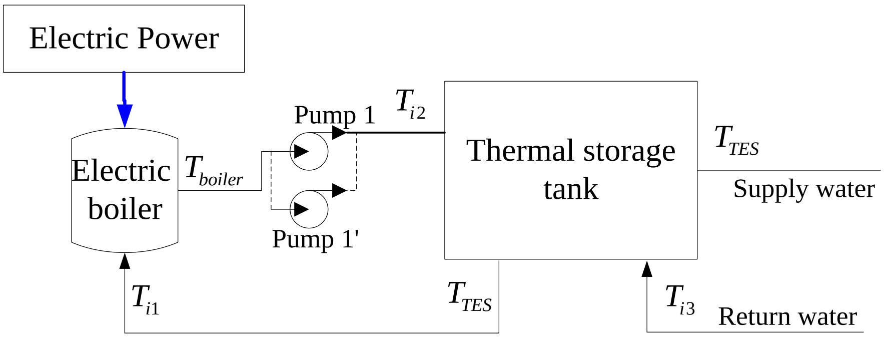


Figure 2-5 The schematic diagram of electric boiler and TES

The schematic diagram of the electric boiler and TES is shown in Figure 2-5 and the several kinds of water temperature have been shown by T_x. However in the case study of this thesis, TES is only a tank without any heat exchanger. The hot water in TES is come from electric boiler and both of them are connected directly without any heat exchanging unit. Then the mathematic model of the electric boiler and TES can be expressed as equations (2-4) and (2-5) respectively:

$$\frac{dT_{boiler}}{dt}=\frac{1}{C_{boiler}}[Q_{heat}-v_1c_w(T_{boiler}-T_{i1})-K_1(T_{boiler}-T_a)] \tag{2-4}$$

$$\frac{dT_{TES}}{dt}=\frac{1}{C_{TES}}[v_1c_w(T_{i2}-T_{TES})-v_2c_w(T_{TES}-T_{i3})-K_2(T_{TES}-T_a)] \tag{2-5}$$

where,

v_1 and v_2 are the mass flow rate of hot water in circulations 1 and 2 (kg/s);

K_1 and K_2 represent heat transfer coefficient of external walls (W/(m^2 ·℃)).

As the electric boiler is close to the thermal storage tank and the pipeline linked them is very short which about two meters, and the water flows continuously in the pipeline, there is in no delay between them. So $T_{i1}=T_{TES}$ and $T_{i2}=T_{boiler}$, then equations (2-4) and (2-5) can be modified as follow respectively:

$$\frac{dT_{boiler}}{dt}=\frac{1}{C_{boiler}}[Q_{heat}-v_1c_w(T_{boiler}-T_{TES})-K_1(T_{boiler}-T_a)] \tag{2-6}$$

$$\frac{dT_{TES}}{dt}=\frac{1}{C_{TES}}[v_1c_w(T_{boiler}-T_{TES})-v_2c_w(T_{TES}-T_{i3})-K_2(T_{TES}-T_a)] \tag{2-7}$$

From equation (2-6), it can be observed that the energy losses of electric boiler consist of two parts: flow to TES and dissipate to the environment. From equation (2-7), it is clear that energy supplied to the TES comes from electric boiler and energy losses also consist of two parts: delivered to end users' plate heat exchanger/radiators and dissipate to the environment.

The energy supplied is converted by electric boiler, so Q_{heat} can be described by equation (2-8)

$$Q_{heat} = 1000\eta u P_{bd} \tag{2-8}$$

where,

η represents the operation efficiency of the electric boiler (efficiency of electric power converted to thermal energy);

u is the operating tap of the electric boiler, $u = 0$ represents OFF;

P_{bd} is the rated power of each tap of the electric boiler (kW).

From the above analysis of the structure and the energy flow of the heating unit, it can be learned that the electric boiler and TES can be treated as a whole system when C_{boiler}=C_{TES} (this is generally correct). Then T_{TES}=T_{boiler}. To simplify notations and expressions, the heating process within the electric boiler and TES can be simplified by combining equations (2-6), (2-7) and (2-8). Let *T* represent the outlet hot water temperature of the combined heating system which consists of the boiler and TES, then T=T_{TES}=T_{boiler}. So the mathematic model of the electric boiler and TES can be simplified as

$$\frac{dT}{dt} = \frac{1}{C_{boiler}}[1000\eta u P_{bd} - vc_w(T - T_i) - K_1(T - T_a) - K_2(T - T_a)] \tag{2-9}$$

where, $v = v_2$, $T_i = T_{i3}$.

Equation (2-9) is equivalent to the combination of equations (2-6) and (2-7), however, (2-9) will simplify redundant computations in the relevant programming and computation, thus it is derived in the thesis.

Then the temperature in the electric boiler and TES (the outlet temperature) can be obtained:

$$T(t+1) = \\ T(t) + \frac{\Delta t[\eta 1000 u(t) P_{bd} - vc_w(T(t) - T_i) - K_1(T(t) - T_a) - K_2(T(t) - T_a)]}{C_{boiler}} \tag{2-10}$$

where,

$T(t+1)$ and $T(t)$ indicates the outlet temperature of the tank in (t+1)-*th* period and t-*th* period(℃);

$u(t)$ is the operating tap of the electric boiler in the t-*th* period.

2.4 Model of power exchange with power grid

Due to the intermittent nature of the wind and PV generation, the microgrid needs to be connected with the external power grid. The model of power exchange with grid is introduced. The details of the power exchange can be divided into two cases:

1) when the electric power generation in the microgrid is insufficient to meet its demand, the system will purchase electric power from the external power grid;

2) when there is surplus renewable energy generation in the microgrid, the system will sell electric power to the external power grid as income.

The specific model will be expressed as follows.

Case 1: Insufficient the electric power generation in the microgrid

In this case, the system will purchase electric power from the external power grid and the cost for purchasing power from power grid can be described as follow.

The power $P_p(t)$ that purchased from power grid at time t is described as bellow:

$$P_p(t)=\begin{cases} P_w^A(t) & if\ P_{load}(t)>P_w^A(t)+P_w(t)+P_{pv}(t) \\ P_{load}(t)-(P_w(t)+P_{pv}(t)) & if\ P_w(t)+P_{pv}(t)<P_{load}(t)<P_w^A(t)+P_w(t)+P_{pv}(t) \\ 0 & if\ P_w(t)+P_{pv}(t)>P_{load}(t) \end{cases} \tag{2-11}$$

where,

$P_{load}(t)$ is the total electric load at time *t* (kW), $P_{load}(t) = P_{eload}(t) + P_{bd}u(t)$;

$P_{eload}(t)$ is electric load demand at time *t* (kW);

$P_{bd}u(t)$ is the power of electric boiler at time *t* (kW);

$P_w(t)$ is wind generation power that dispatched at time *t* (kW);

$P_{pv}(t)$ is PV generation power that dispatched at time *t* (kW);

$P_w^A(t)$ is maximum that allowed purchasing from power grid (kW).

$P_w^A(t)$ is no more than 20% of the total electric load demand in the microgrid which is based on the policy in certain region northern China can be described as follow:

$$P_w^A(t) = [\max(P_{eload}(t)) + P_{bd}u_{\max}]\alpha \quad t \in [t_0, t_f] \tag{2-12}$$

where,

$u_{\max}$ is the max tap of the electric boiler;

α is percent of the total electric load demand, namely the upper limit coefficient of power exchange and $\alpha \le 0.2$.

The cost for purchasing power from power grid can be described as follow:

$$\begin{aligned}F_{\cos t} &= \int_{t_0}^{t_f} P_p(t)price(t)dt \\ &= \int_{t_0}^{t_f} [P_{load}(t)-P_w(t)-P_{pv}(t)]\mathrm{sgn}(P_{load}(t)-P_w(t)-P_{pv}(t))\,price(t)dt \\ &= \int_{t_0}^{t_f} \{P_w^A(t)\,\mathrm{sgn}(P_{load}(t)-P_w(t)-P_{pv}(t)-P_w^A(t)) \\ &\quad +[P_{load}(t)-P_w(t)-P_{pv}(t)]\mathrm{sgn}(P_w^A(t)+P_w(t)+P_{pv}(t)-P_{load}(t)) \\ &\quad \mathrm{sgn}(P_{load}(t)-P_w(t)-P_{pv}(t))\}\,price(t)dt\end{aligned} \tag{2-13}$$

$$\mathrm{sgn}(x)=\begin{cases}1 & x>0\\ 0 & x\le 0\end{cases}$$

where，

$t_f - t_0$ denotes the time duration of the control, and it can be one day or one month;

$price(t)$ is the price to purchase electric power from power grid at time *t*, RMB/kWh.

The price of purchasing electric power from the external power grid is expressed as equation (2-14), which is based on electricity price policy in certain region northern China.

$$price(t)=\begin{cases}0.55\ \mathrm{RMB/kWh} & 8:00 \sim 22:00\\ 0.3\ \ \mathrm{RMB/kWh} & 0:00\sim 7:00,\, 23:00\sim 24:00\end{cases} \tag{2-14}$$

Case 2: Surplus renewable generation occurs in the microgrid

In this case, the system will sell electric power to the external power grid and the income for selling electric power to power grid can be described as follow.

The power $P_s(t)$ that sold to power grid at time *t* is described as bellow:

$$P_s(t)=\begin{cases}P_w^A(t) & if\ \ P_w(t)+P_{pv}(t)>P_w^A(t)+P_{load}(t)\\ P_w(t)+P_{pv}(t)-P_{load}(t) & if\ P_{load}<P_w(t)+P_{pv}(t)<P_w^A(t)+P_{load}(t)\\ 0 & if\ P_w(t)+P_{pv}(t)<P_{load}(t)\end{cases} \tag{2-15}$$

The income for selling power to power grid is described as bellow:

$$\begin{aligned} F_{income} &= \int_{t_0}^{t_f} P_s(t) price_f(t) dt \\ &= \int_{t_0}^{t_f} \{P_w^A(t)\operatorname{sgn}(P_w(t)+P_{pv}(t)-P_w^A(t)-P_{load}(t)) \\ &+[P_w(t)+P_{pv}(t)-P_{load}(t)]\operatorname{sgn}(P_w^A(t)+P_{load}(t)-P_w(t)-P_{pv}(t)) \\ &\operatorname{sgn}(P_w(t)+P_{pv}(t)-P_{load}(t))\} price_f(t) dt \end{aligned} \tag{2-16}$$

where, $price_f(t)$ is the feed-in-tariff at time *t*, RMB/kWh.

The price of selling electric power to the external power grid is expressed as equation (2-17), which is based on electricity price policy in certain region northern China.

$$price_f(t) = 0.40 \text{ RMB/kWh} \quad t \in [0, 24) \tag{2-17}$$

2.5 Objective function

In the research, two objectives are considered: the customers' discomfort level and the operational cost of the microgrid. The operational cost contains electricity exchange price and allowance on renewable energy. The costs of investment of wind generation, PV, electric boiler and TES are not considered because the microgrid already exists. The priority objective of the research is to provide operating strategy to minimize operational cost to deal with the power curtailment problem efficiently, and thus reduce carbon dioxide emissions. The customers' discomfort level for thermal load and the operational cost should be minimized and they are calculated bellow.

(1) Operational cost $F_{\cos t\_total}$. The operational cost function can be expressed as

$$F_{cost\_total} = F_{cost} - F_{income} - F_s \tag{2-18}$$

$F_{\cos t}$ and F_{income} have been introduced in the above. F_s is the allowance on the use of wind and PV power and expressed as follow.

$$F_s = F_w \int_{t_0}^{t_f} P_w(t)dt + F_p \int_{t_0}^{t_f} P_p(t)dt \tag{2-19}$$

where，

F_w is allowance of wind generation, RMB/kWh, $F_w = 0.6$;

F_p is allowance of photovoltaic power generation, RMB/kWh, $F_p = 0.42$.

The allowance standard is obtained from the allowance policy in certain region northern China.

It is noted that when $F_{\cos t\_total} < 0$ ($F_{cost} < F_{income} + F_s$), there will be a profit for microgrid, and when $F_{\cos t\_total} > 0$ ($F_{cost} > F_{income} + F_s$), there will be a deficit for microgrid.

(2) The customers' discomfort level for thermal load.

The customer’s discomfort level is evaluated by the difference between actual supplied water temperature and the expected demand temperature. It has been introduced that the supplied water temperature is affected by the outlet temperature of electric boiler and TES. It is difficult to obtain the real-time temperature in the room while it is easy to obtain the outlet temperature. So the customer’s discomfort level for thermal load can be indicated by the difference between real-time outlet temperature and the expected outlet temperature. The delay is considered from heating water in plate heat exchanger to realize space heating in residential buildings. The delay in circulation 3 can be considered as a constant.

The customer’s discomfort level for thermal load can be described as follow:

$$L = \int_{t_0}^{t_f} e[T(t) - D(t)]^2 \operatorname{sgn}[D(t) - T(t)]d(t) \tag{2-20}$$

where，

e represents the delay coefficient whose value is bigger than 1;

$T(t)$ is the supplying temperature (outlet temperature) at time *t*;

$D(t)$ represents the demanding temperature(the minimal outlet temperature) at time *t*. $D(t) = \text{constant} \quad t \in [0, 24)$.

(3) Objective function

The customers' discomfort level for thermal load and the operational cost should be minimized, and according above they are showed as bellow.

$$\min F = \min F_{\cos t\_total} + \mu L \tag{2-21}$$

where， μ is a weighting factor representing the tradeoff between operational cost and human comfort.

In next subsection, the constraints are implemented and used to the optimization of the proposed microgrid.

2.5.1 Equality constraint

(1) Electric power balance constraint

This constraint indicates that the total electric load power must be equal to the sum of wind generation power, PV generation power and the external grid power. The equation for the constraint can be expressed as follow:

$$P_w(t) + P_{pv}(t) + P_t(t) = P_{boiler}(t)u(t) + P_{eload}(t) \tag{2-22}$$

where $P_t(t)$ represents electric power traded with power grid at time *t* (kW).

If $P_t(t)$>0, purchasing power from power grid ($P_p(t)$), otherwise, feeding in power grid ($P_s(t)$).

2.5.2 Inequality constraint

(1) Supply constraints

The dispatched power of wind generation, PV generation and the external power grid is limited in the upper and lower bounds expressed as follow:

Dispatched wind power: $0 \le P_{w(t)} \le P_{wm}(t)$ (2-23)

Dispatched PV power: $0 \le P_{pv}(t) \le P_{pvm}(t)$ (2-24)

Traded electric power with power grid: $-P_w^A(t) \le P_t\ (t) \le P_w^A(t)$ (2-25)

where,

$P_{wm}(t)$ and $P_{pvm}(t)$ is the maximum power of wind and PV generation at time *t*(kW);

$-P_w^A(t)$ and $P_w^A(t)$ is the minimum and maximum power exchange between microgrid and the external power grid at time *t* (kW).

(2) Electric boiler and TES constraints

For a stable operation, electric boiler and TES are limited to the technical constraints expressed as follow:

Electric boiler switch: $u(t) \in \{0,1,...,u_{\max}\}$ (2-26)

Water temperature in TES: $60\,°C \leq T(\mathrm{t}) \leq 100\,°C$ (2-27)

where $u_{\max}$ is the maximum tap of electric boiler, $60°C$ and $100°C$ is the minimum and maximum temperature of water in TES.

2.6 Chapter summary

This chapter proposes a microgrid composed of a photovoltaic (PV), a wind turbine, an electric boiler, a thermal energy storage system and an external power grid. This chapter also investigates control schemes of the microgrid, the electric boiler, TES, and power exchange with the external power grid. The mathematic models of the heating unit and power exchange are established. The optimal model to minimize customers' discomfort level and the operational cost of the microgrid with several constraints is investigated.

Chapter 3

Solution algorithm

3.1 Chapter introduction

Genetic algorithm will be adopted to solve the optimization problem in this thesis. This section presents a simple description of genetic algorithm. Its optimization process is introduced and several genetic operators are described. The optimal process of the proposed model based on genetic algorithm is proposed.

3.2 Genetic algorithm and optimal process

The proposed microgrid control model is a nonlinear integer programming problem with a large number of discrete variables which makes the model quite complex. Traditional Newton based mathematical methods can hardly solve this problem; therefore, genetic algorithm (GA) from intelligent computing is adopted.

GA is an elitist optimization algorithm and has been used widely. The main idea of Genetic algorithm is to evolve solutions based on natural evolution laws**.** The basic idea is to present an evolving process with competition and mutation to maintain chromosomes [70]. GA was inspired by Holland in 1975 [71] and it is robust in nature and available to solve complex problem [72]. GA has been widely applied to deal with complex problems, such as unit commitment [73, 74], fuzzy subsets and rules [75], energy management in microgrid [76].

Each individual in the population is called a chromosome. Generations is the chromosomes evolve through successive iterations. To create the next generation, new chromosomes, called offspring, are form by either merging two chromosomes form current generation using a crossover operator or modifying a chromosome using a mutation operator.

There are several genetic operators in GA, selection, reproduction, crossover and mutation [72]:

(1) Selection uses Tournament selection and the selection pressure will be higher with competitors increasing.

(2) Reproduction is determined by fitness value, every individual has the chance to select for reproduction.

(3) Crossover is based on two populations. GA will implement one-point crossover twice independently among the room attribute in each period.

(4) Mutation in implemented in one population. Two values will be exchanged at random positions.

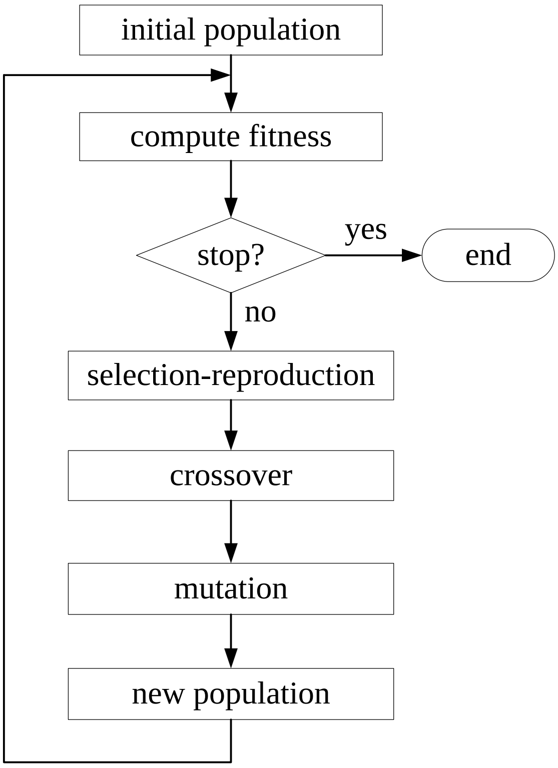


Figure 3-1 Basic flowchart of GA [72]

The basic flowchart of GA is shown in Figure 3-1. A simple GA works as follows [72]:

(1) Generate N chromosomes in a population, where N is the size of population, l–length of chromosome x.

(2) Compute fitness value of each chromosome x in the population.

(3) Repeat steps until N offspring's are produced:

1) A pair of chromosomes are chosen randomly from current population basing on fitness function value.

2) Generate an offspring y_i by crossover and mutation operators, where $i = 1, 2, ..., N$.

(4) Exchange current population from new one.

(5) Go to step (2).

The GA has attracted considerable attention considering their potential as an effective and novel optimization technique. When using the GA to resolve optimization problems, there are several major advantages:

1) GA is an excellent for solving complex problem and has an intricate solution and very larger search space [77].

2) GA does not ask for much mathematical models about the optimization problems. Ignoring the detailed inner process of problem, GA can still search for solutions effectively because of their evolutionary nature [78].

3) GA can carry out global search effectively due to the evolution operators [78].

4) GA can deal with discrete problems effectively.

5) GA is a build-in function in MATLAB, and therefore it is very convenient to be applied directly from computer programming perspective.

Considering the characteristics of the optimal problem in this thesis and the feature and advantages of GA, the algorithm will be applied to obtain the optimal solution.

The flowchart of the optimal process in this paper is shown below in Figure 3-2. The simple optimal process is illustrated as follow:

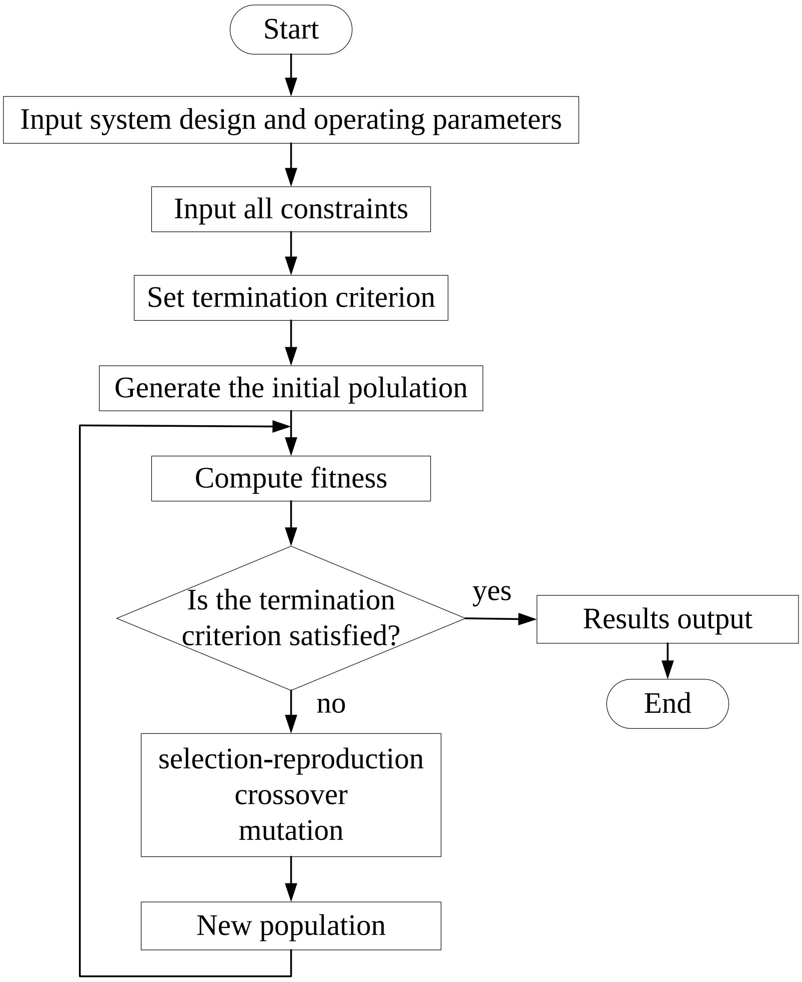


Figure 3-2 The flowchart of the optimal process

Step 1: Input system design and operating parameters, such as boundary conditions of the microgrid, population size, crossover rate, mutation rate and so on;

Step 2: Input all constraints that are composed of equality constraint (2-22) and inequality constraint (2-23)-(2-27);

Step 3: Set the termination criterion (convergence precision or the maximum generations);

Step 4: Generate the initial population;

Step 5: Calculate the fitness depending on equation (2-21);

Step 6: If the termination criterion is satisfied, output optimal results and end the process, otherwise, go to Step 7;

Step 7: Implement selection-reproduction, crossover and mutation;

Step 8: Generate new population and go to Step 5.

3.3 Chapter summary

This chapter investigates the basic theory and the procedure of GA. The characteristics and major advantages of GA are analyzed. GA is robust in nature and available to solve complex problem, especially can deal with discrete problems effectively. The optimal process of the proposed model based on GA is proposed.

Chapter 4

Simulation studies and analysis

4.1 Chapter introduction

In this chapter, three case studies are implemented to estimate the performance of the proposed model. The operation data, such as electric demand, heat demand, wind power, PV power, are obtained from the actual microgrid in certain region of northern China. In the first and second case studies, the optimization results are composed of the absorption of renewable energy, the operation of electric boiler, TES and power exchange with power grid. The results are compared with those of the actual operating strategy.

4.2 Case study

In the selected region, the space heating cycle is from October to April the next year. Without loss of generality, a random day in the space heating cycle is selected as a case study. Also a month (February, 28 days) in the space heating cycle is considered as another case study to illustrate the effectiveness of the proposed model with large amounts of data. A full description of the microgrid system and load/power profile is presented in the next subsections.

4.2.1 Parameters of microgrid system

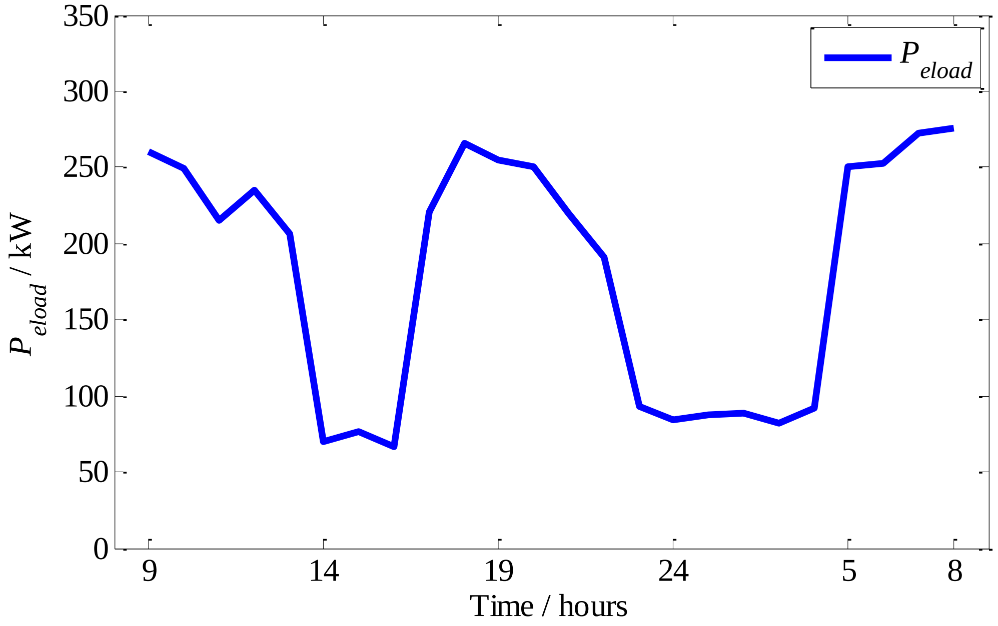
The microgrid system is composed of wind turbine, PV generation, electric boiler and TES, and rated power of these parts is obtained from the actual microgrid. Table 4-1 details these parameters and other operating parameters such as efficiency of electric boiler, volume of TES and so on. Let t_0=9 O'clock and t_f=24+t_0 in the case study of one day. The initial water temperature in TES is 85℃.

Table 4-1 Parameters of the microgrid system

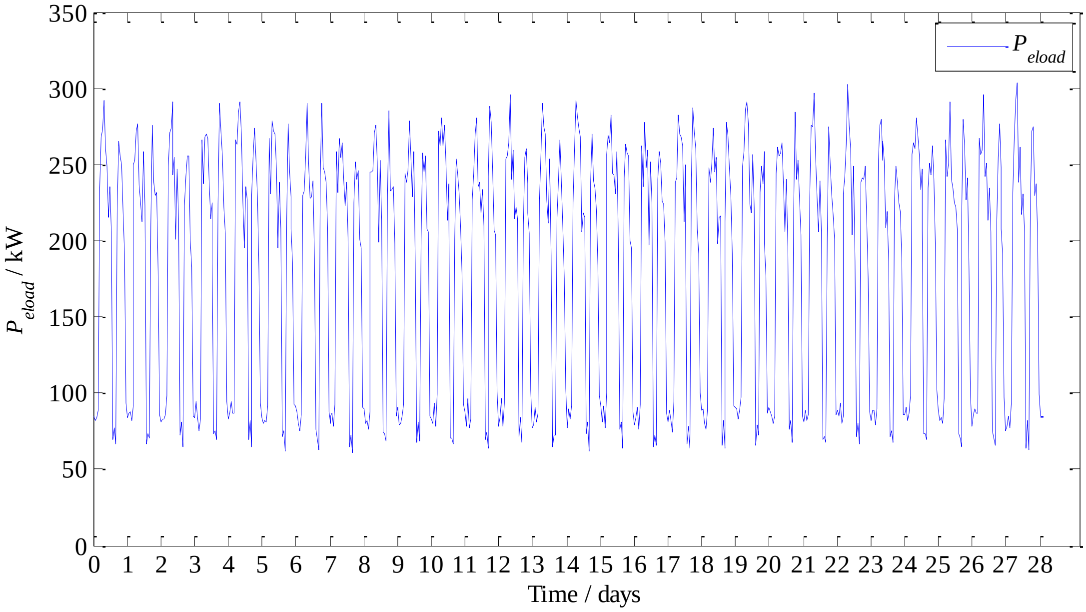
Description	value
Rated power of wind turbine (kW)	8×80
Rated power of photovoltaic generation (kW)	60
Maximal tap of electric boiler $u_{\max}$	20
Rated power of each tap of electric boiler P_{bd} (kW)	20
Operation efficiency of the electric boiler η (%)	90
Volume of TES V (m^3)	$9\times6.2\times3.2$
Return water temperature T_i (℃)	60
Demand temperature (Minimal outlet water temperature) $D(t)$ (℃)	80
Ambient temperature T_a (℃)	20
Delay coefficient e	5
Upper limit of power exchange α (%)	15
Coefficient μ	100
The specific heat capacity of water C_w (J/(kg ·℃))	4180
The specific heat capacity of boiler C_{boiler} (J/℃)	1.8×10^5
The mass flow rate of hot water v (kg/s)	1
Heat transfer coefficient K_1 (W/(m^2 ·℃))	8.4
Heat transfer coefficient K_2 (W/(m^2 ·℃))	0.0018

4.2.1.1 Load demand profile

Load demand in this microgrid consists of electricity load demand and heat demand. Heat demand can be satisfied when outlet water temperature is no less than 80℃. Electricity load demand illustrates the diurnal variations in the residential buildings. Figure 4-1 (a) and (b) show the electricity load demand profile in the residential buildings (P_{eload}) for one day and one month respectively which are obtained in the actual microgrid.



(a) Electricity load demand for one day



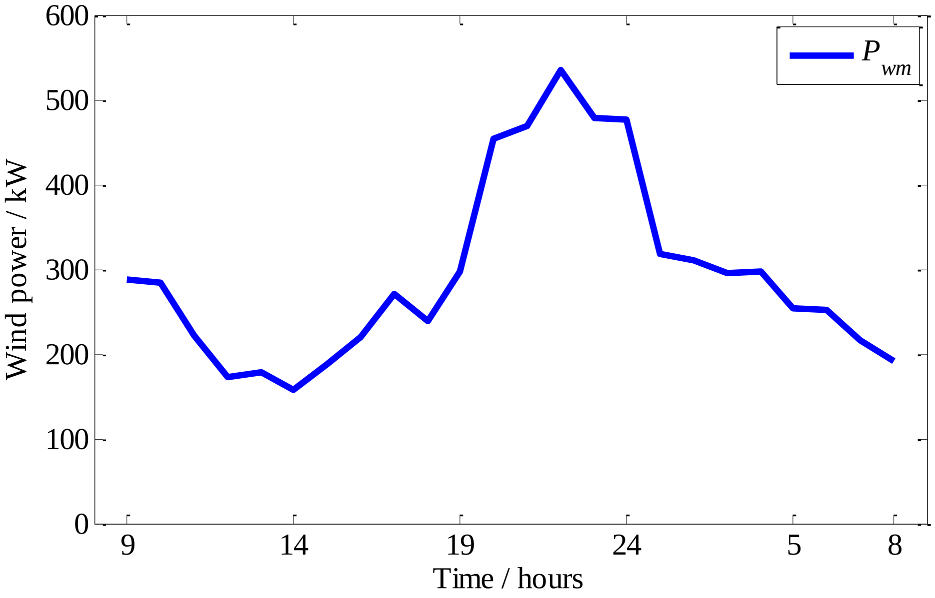
(b) Electricity load demand for one month

Figure 4-1 Electricity load demand in residential buildings

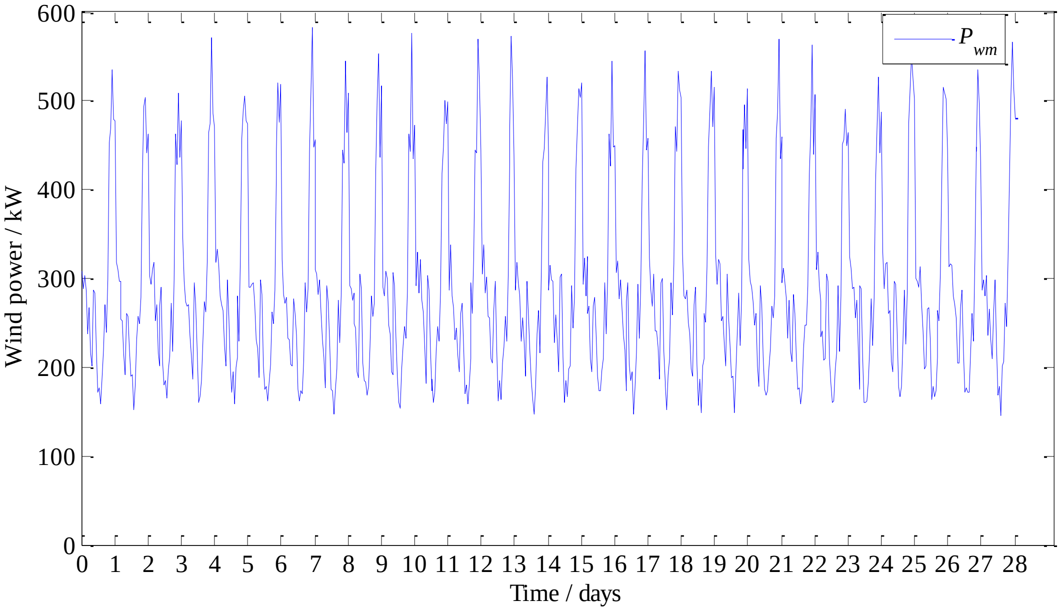
4.2.1.2 Available renewable power

Renewable power in this microgrid consists of wind and PV power, and the available power of them depends on wind speed and solar radiation. The available profile of wind and PV power is obtained in the actual microgrid. Figure 4-2 (a) and (b) show the available hourly wind power (P_{wm}) for one day and one month, respectively. Figure 4-3 (a) and (b) show the available hourly PV power (P_{pvm}) for one day and one month, respectively.

Table 4-2 indicates the data of electricity demand and available renewable power of the microgrid for one day.

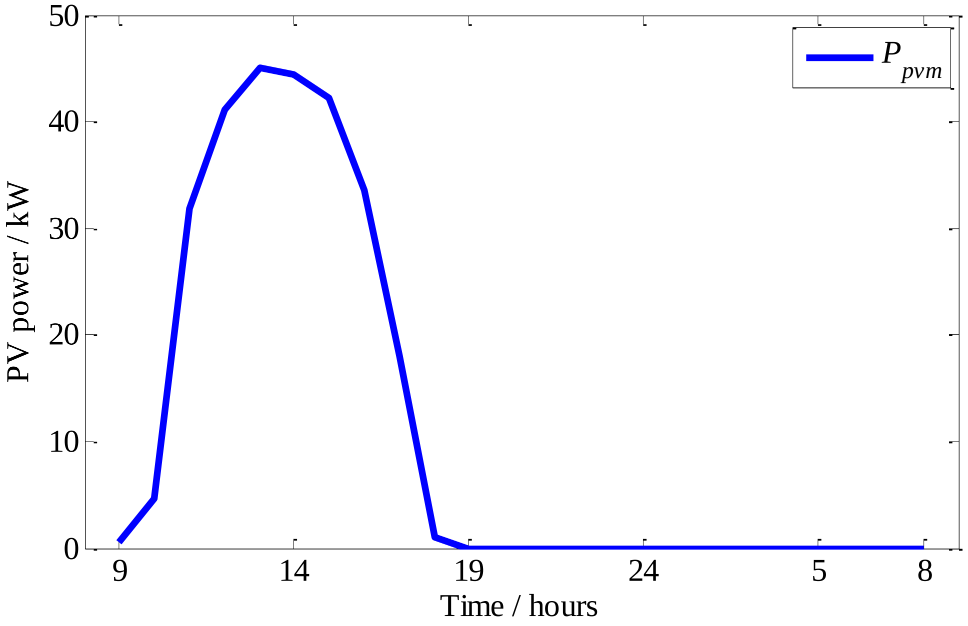


(a) Available wind power profile for one day

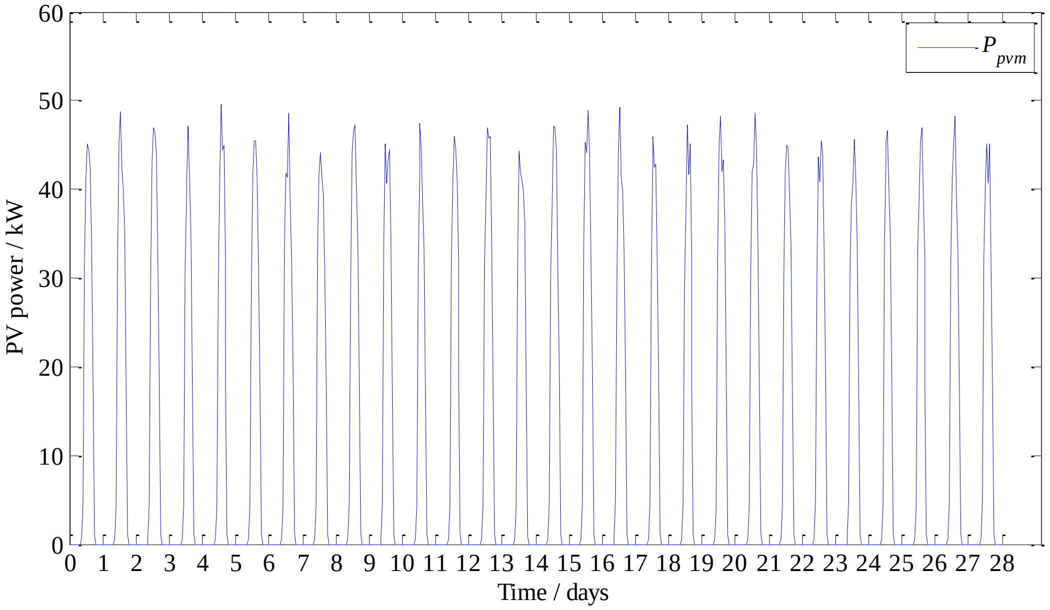


(b) Available wind power profile for one month

Figure 4-2 Available wind power profile



(a) Available PV power profile for one day



(b) Available PV power profile for one month

Figure 4-3 Available PV power profile

Table 4-2 Electricity demand and available renewable energy power of the microgrid for one day

Time (hour)	Electricity load demand (kW)	Wind power (kW)	PV power (kW)
9	260.26	287.3014	0.58
10	248.765	283.9317	4.58
11	215.04	221.382	31.85
12	235.365	172.3122	41.14
13	205.98	177.4732	45.09
14	69.66	158.3371	44.42
15	86.67	187.9151	42.25
16	81.055	219.7395	33.51
17	220.92	270.01	17.99
18	265.45	239.48	1.09
19	255.09	297.56	0
20	250.236	453.22	0
21	219.294	468.71	0
22	191.16	534.46	0
23	93.42	479.05	0
24	83.88	476.99	0
1	87.12	318.07	0
2	88.08	310.33	0
3	81.6	295.94	0
4	91.68	296.36	0
5	249.96	253.56	0
6	252.96	252.37	0
7	271.92	215.13	0
8	276.24	191.28	0

4.2.1.3 The external power grid tariff and limit

When the demand is high or low in the microgrid, the external power grid may absorb or supply some power. Table 4-3 shows the electricity power trade tariff of the external power grid. Figure 4-4 shows the upper limit of power exchange (P_{gm}) of everyday in the month.

Table 4-3 The external power grid real-time price

Time (hour)	Selling price (RMB/kWh)	Feed-in price (RMB/kWh)
8:00~22:00	0.55	0.4
0:00~7:00, 23:00~24:00	0.30	

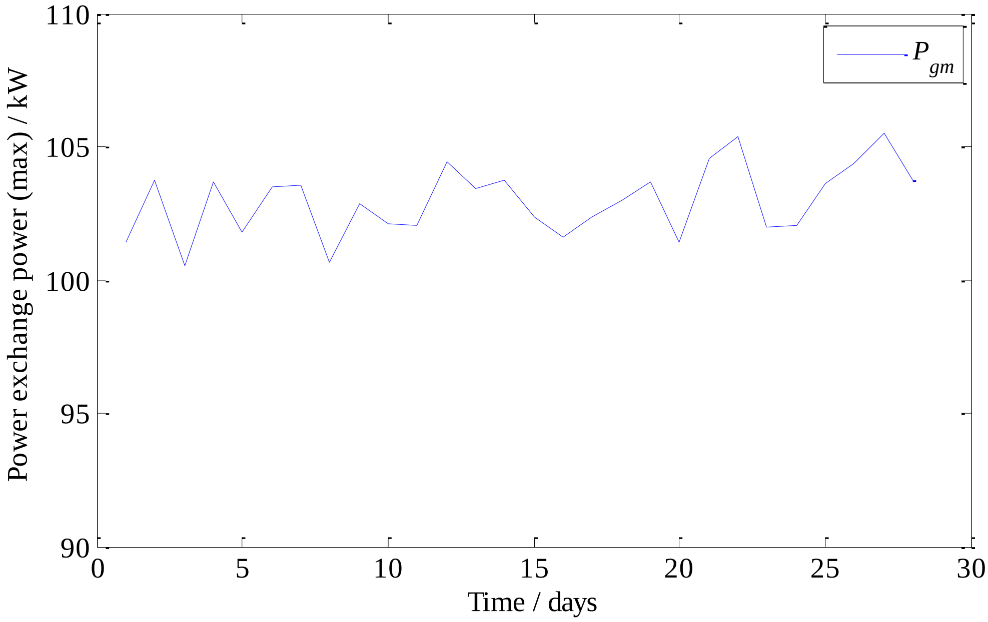


Figure 4-4 Upper limit of power exchange of everyday in the month

4.2.2 Simulation results and discussion

The parameters of GA are set as follows: population size = 100, generations = 500, crossover fraction = 0.8, mutation rate = 0.2 and precision = 10^{-3}. When the number of generation or the precision is reached, the optimization process will stop. Then experiments are simulated via MATLAB R2014a on a computer with an Intel(R) Core(TM) i7-4650U CPU @ 1.70GHz 2.30GHz 8G RAM. The case studies are optimized under the objective function defined in Section 2.5, namely minimizing customers' discomfort level and the operational cost. The simulation results and discussion will be analyzed in the next subsections.

At first, some nomenclatures used in the comparison between the optimization strategy and the actual strategy are defined in Table 4-4.

Table 4-4 Nomenclatures

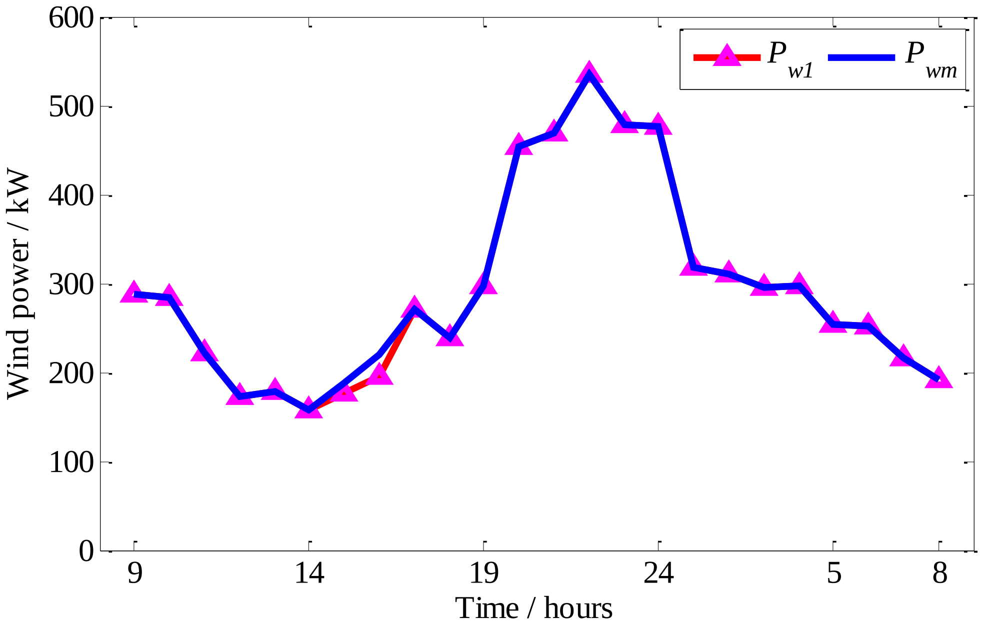
Description	Optimization strategy	Actual strategy
Wind power	P_{w1}	P_{w2}
PV power	P_{pv1}	P_{pv2}
Tap of electric boiler	u_1	u_2
Outlet water temperature (water temperature in TES)	T_1	T_2
Power exchange with external power grid	P_{g1}	P_{g2}

4.2.2.1 Optimization results of renewable energy

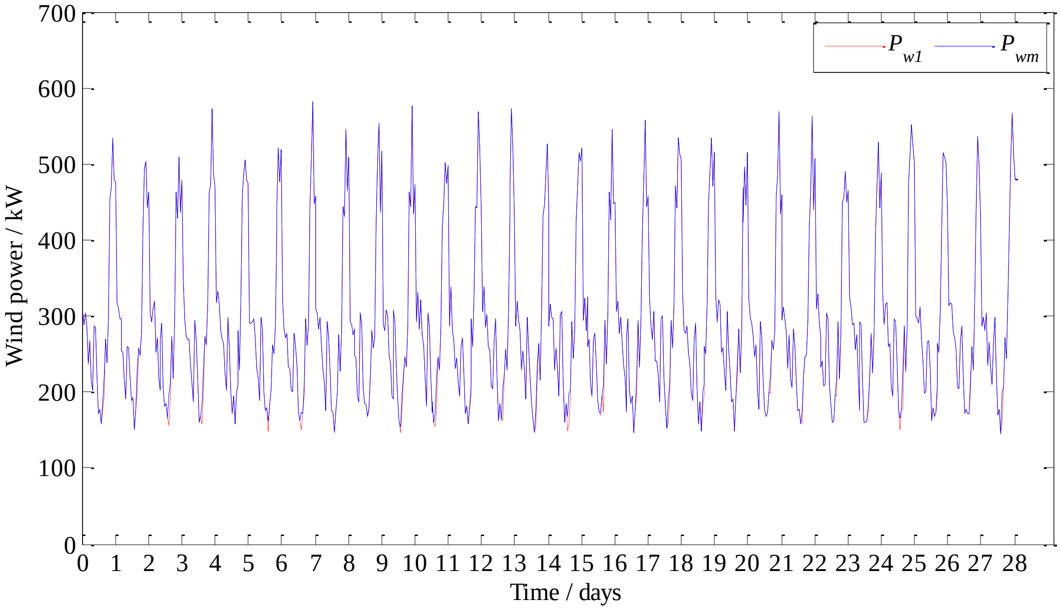
In this subsection, optimization results of wind and PV power that absorbed by the microgrid and external power grid is described in a graphical way.

Figure 4-5 (a) and (b) show the optimization results of wind power that can be absorbed for one day and one month, respectively. Figure 4-5 shows that only a little wind power cannot be absorbed in period 15:00-17:00 in Figure 4-5 (a). Figure 4-5 (a) also shows there is no waste in the peak period of wind power when wind generation is very high. The same conclusion can be achieved from Figure 4-5 (b): only a little waste of wind power occurs in some period in the afternoon and all the wind power in the peak period can be adsorbed.

Figure 4-6 (a) and (b) show the optimization results of PV power that can be absorbed for one day and one month, respectively. Only during the daytime the PV power is not zero. As the rated power of PV generation is small, the PV power can be used to supply the microgrid all the time as shown in Figure 4-6.

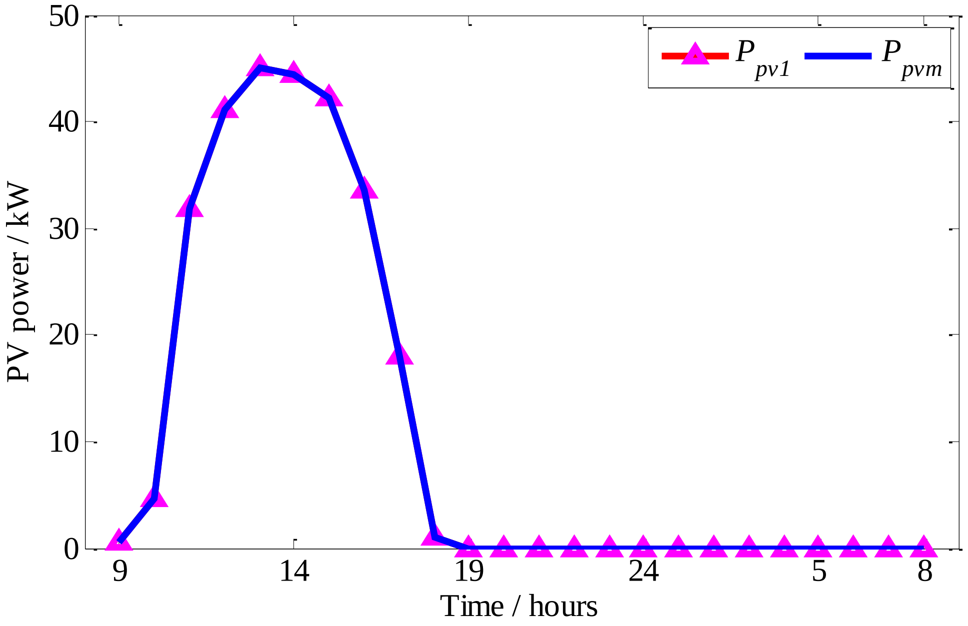


(a) Optimization results of wind power for one day

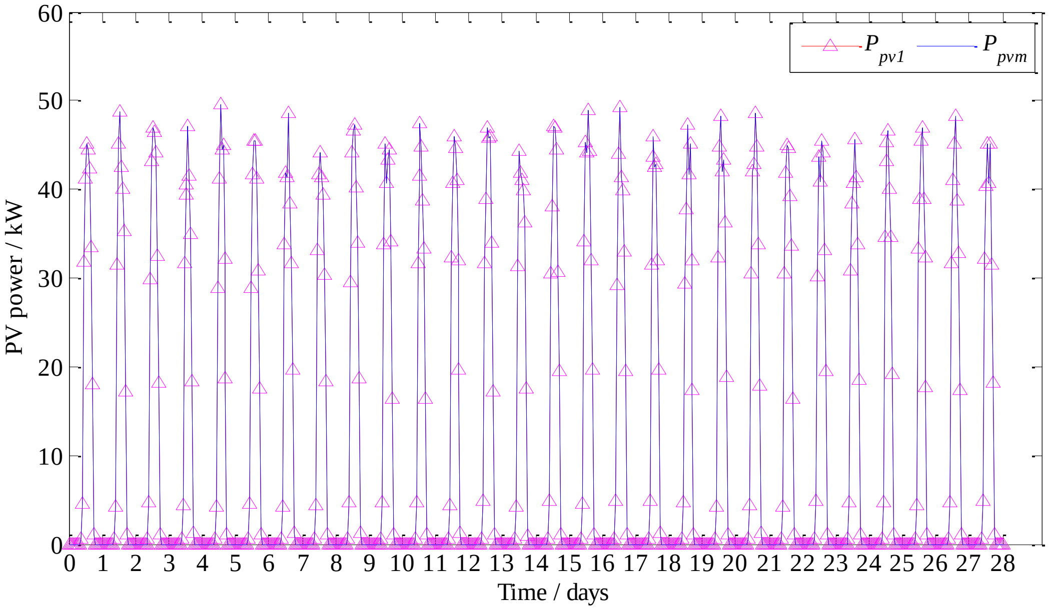


(b) Optimization results of wind power for one month

Figure 4-5 Optimization results of wind power



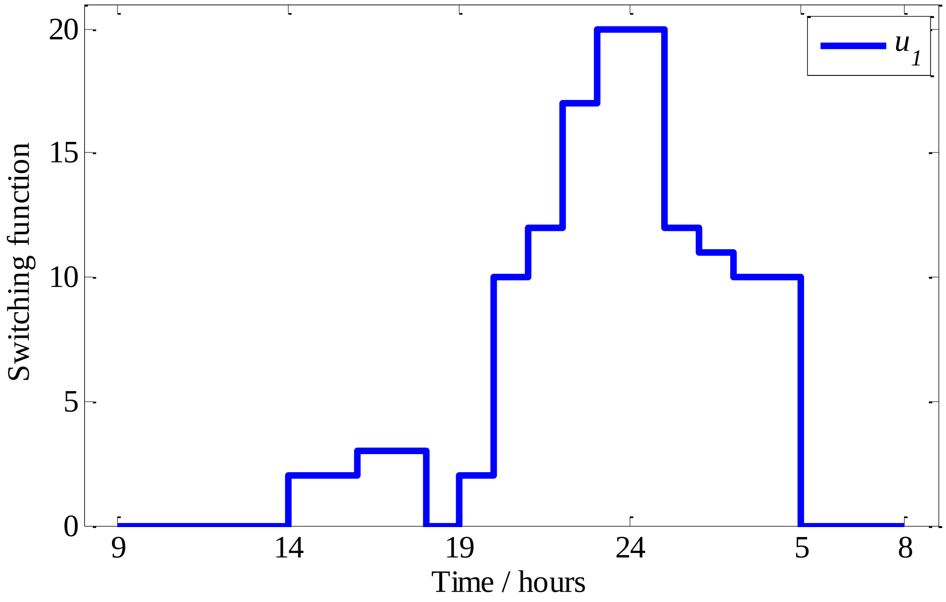
(a) Optimization results of PV generation for one day



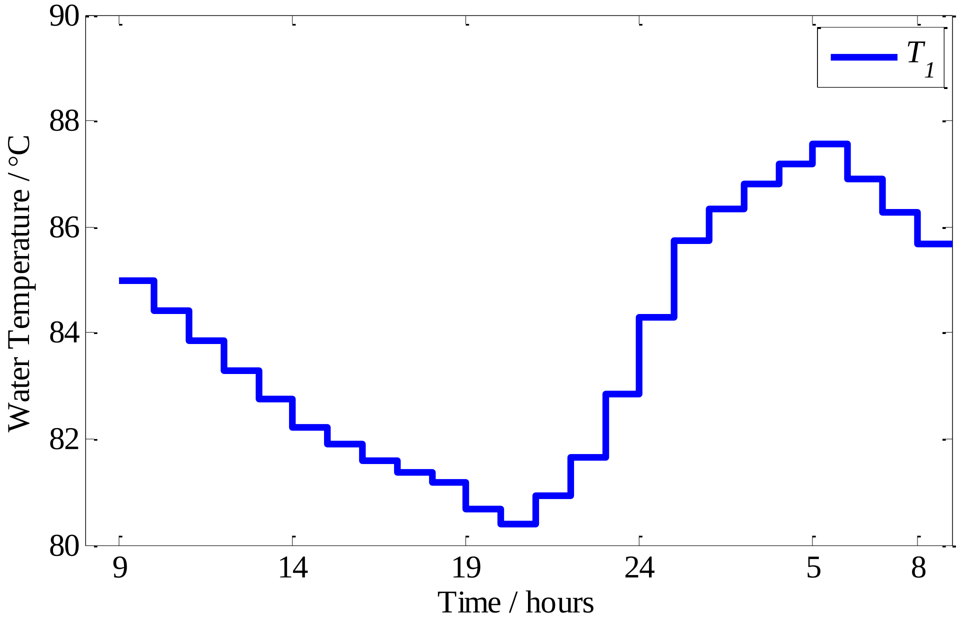
(b) Optimization results of PV generation for one month

Figure 4-6 Optimization results of PV generation

4.2.2.2 Optimal strategy of electric boiler and TES

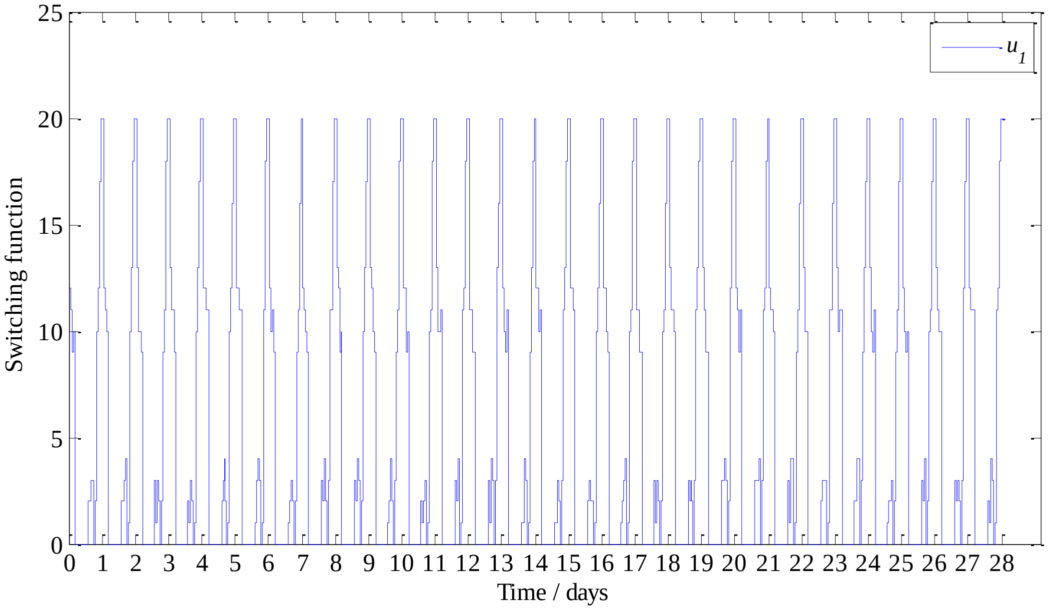


(a) Optimization results of operating strategy of electric boiler for one day

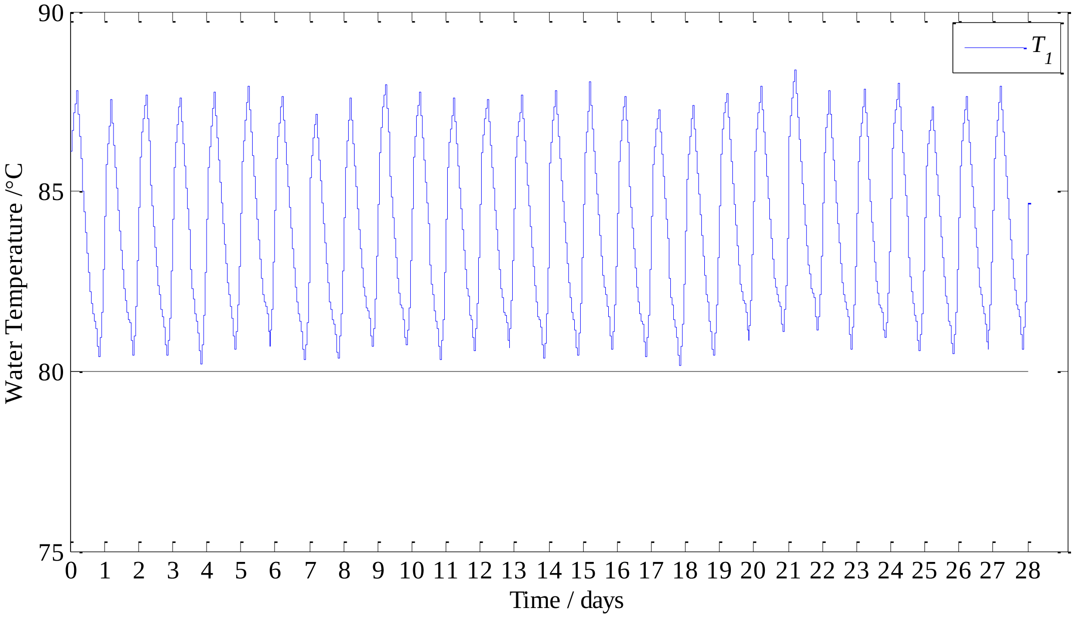


(b) Optimization results of water temperature variation in TES for one day

Figure 4-7 Optimization results of operating strategy of electric boiler and water temperature variation in TES for one day



(a) Optimization results of operating strategy of electric boiler for one month



(b) Optimization results of water temperature variation in TES for one month
Figure 4-8 Optimization results of operating strategy of electric boiler and water temperature variation in TES for one month

The optimization results of operating status of the electric boiler and variation of outlet water temperature of TES is analyzed in this subsection.

Figure 4-7 (a) and (b) show the optimization results of operating strategy of electric boiler and water temperature variation in TES for one day, respectively. It can be clearly seen that in the period 9:00-14:00, 18:00 and 5:00-8:00, the operating status of the electric boiler is OFF. In the period, the renewable energy generation power (especially wind power) is small and the electricity load demand in residential buildings is bigger than other hours. During the daytime some renewable energy power is sold to the external power grid which can reduce the peak generations of the energy suppliers in the external power grid.

The electric boiler is operated with high taps at night, especially in the period 23:00-24:00 and 0:00-1:00 operated with the max tap. At night wind power increases rapidly, the redundant wind power can be sold to the external power grid or used by the electric boiler for producing heat. The optimization results indicate the redundant wind power has been absorbed by the electric boiler to convert to heat energy stored in TES as shown in Figure 4-7 (a) and (b).

Figure 4-7 (b) shows the outlet water temperature is higher than 80℃, so the heat demand can be satisfied. When the electric boiler is OFF during the period 9:00-14:00, TES will release heat energy to meet heat demand and so the water temperature in TES will reduce continuously. The water temperature in TES will rise due to the obtained heat energy at night when the electric boiler is operated at high taps. After 5:00 am, the electric boiler is OFF, TES provides further heat energy with reduced water temperature.

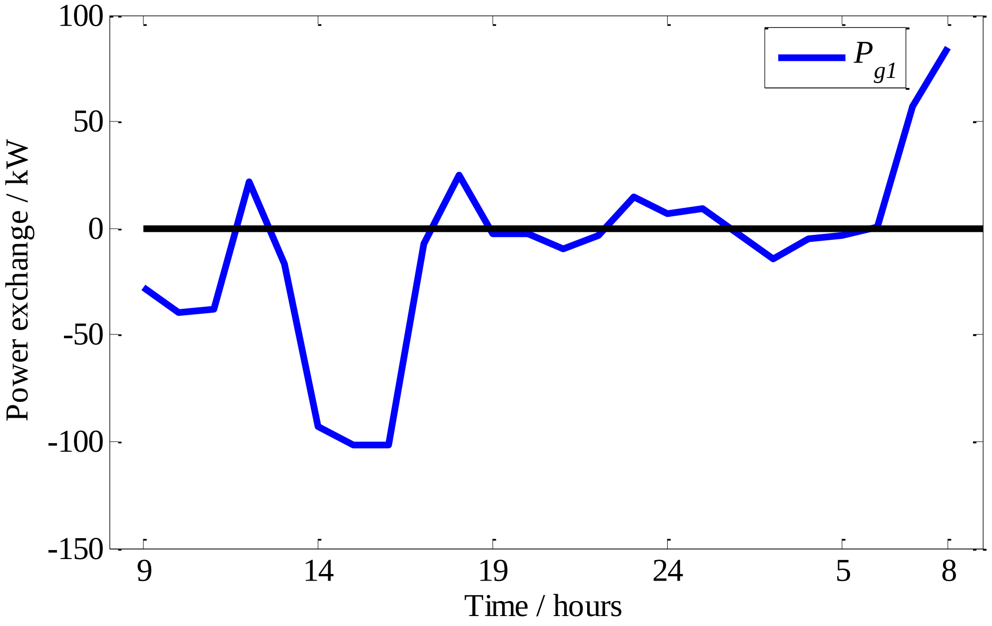
Figure 4-8 (a) and (b) show the optimization results of operating strategy of electric boiler and water temperature variation in TES for one month, respectively. It can be learned that the electric boiler is always operated with high taps at night to absorb the redundant wind power and operated with low tap or OFF when the wind power is small. The TES will store and release heat energy to absorb wind power and meet the heat demand.

4.2.2.3 Optimization results of power exchange with external power grid

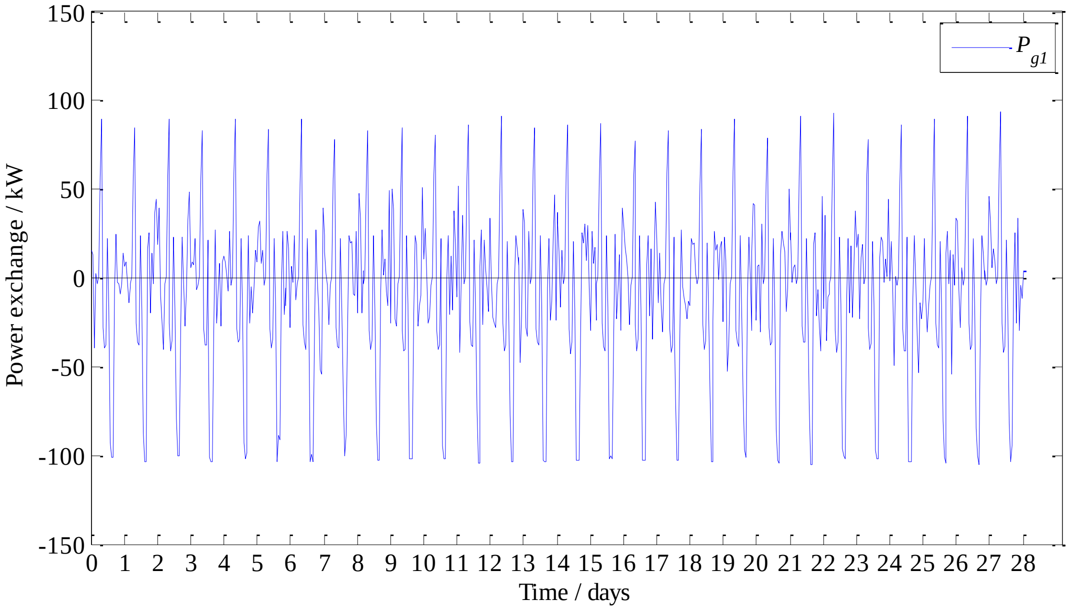
Optimization results of electricity power trade with the external power grid are analyzed in this subsection. Figure 4-9 (a) and (b) show optimization results of power exchange with the external power grid for one day and one month, respectively.

It is noted that when $P_{g1} > 0$, the microgrid purchases electricity power from the external power grid and when $P_{g1} < 0$, the microgrid sells electricity power to the external power grid. Figure 4-10 (a) shows in the period 9:00-11:00 and 14:00-16:00 the microgrid sells electricity power to the external power grid, and especially it reaches the upper limit in 14:00-16:00. In this period the electricity load demand in microgrid is low and the electric boiler is OFF or operated with low tap. In 7:00-8:00 the microgrid purchases electricity power from the external power grid to meet the electricity load demand. The trade between the two parts is close to zero or exactly equals zero in other hours. When the wind power is much bigger at night, it is used by electric boiler instead of selling to the external power grid because the feed-in tariff is lower than the electricity purchase price.

Figure 4-9 (b) shows optimization results of power exchange with the external power grid for one month. Similar conclusions to the optimization results of one day can be observed. It should be pointed out that at night the trade between the microgrid and the external power grid is close to zero. The wind power is used by the electric boiler to produce heat energy which will be stored in TES to provide further heat supply in the day time. By this way, the purchase of electricity with high price from the external power grid will decrease, which can reduce the operational cost of the microgrid. And furthermore, the microgrid can sell electricity in the daytime to earn income.



(a) Optimization results of power exchange with external power grid for one day



(b) Optimization results of power exchange with external power grid for one month

Figure 4-9 Optimization results of power exchange with the external power grid

4.2.2.4 Discussion

In order to illustrate the effectiveness of the proposed model, the comparison between the optimization strategy and the existing actual microgrid operations (actual strategy) has been analyzed in this subsection, such as the total operational cost, the operating status of the electric boiler system, the utilization of renewable energy, the impact of the microgrid on the external power grid.

4.2.2.4.1 Case 1: Discussion on comparison results of one day

Table 4-5 Optimization strategy of the microgrid for one day

Time (hour)	Wind power (kW)	PV power (kW)	External power grid (kW)	Tap of electric boiler
9	287.30	0.58	-27.62	0
10	283.93	4.58	-39.75	0
11	221.38	31.85	-38.19	0
12	172.31	41.14	21.91	0
13	177.47	45.09	-16.58	0
14	158.34	44.42	-93.10	2
15	185.85	42.25	-101.43	2
16	208.97	33.51	-101.43	3
17	270.01	17.99	-7.08	3
18	239.48	1.09	24.88	0
19	297.56	0	-2.47	2
20	453.22	0	-2.98	10
21	468.71	0	-9.42	12
22	534.46	0	-3.30	17
23	479.05	0	14.37	20
24	476.99	0	6.89	20
1	318.07	0	9.05	12
2	310.33	0	-2.25	11
3	295.94	0	-14.34	10
4	296.36	0	-4.68	10
5	253.56	0	-3.60	0
6	252.37	0	0.59	0
7	215.13	0	56.79	0
8	191.28	0	84.96	0

Table 4-6 The actual strategy of the microgrid for one day

Time (hour)	Wind power (kW)	PV power (kW)	External power grid (kW)	Tap of electric boiler
9	287.30	0.58	-7.61704	1
10	283.93	4.58	0.25012	2
11	221.38	31.85	1.8106	2
12	172.31	41.14	21.91119	0
13	177.47	45.09	23.42163	2
14	158.34	44.42	6.898512	7
15	187.92	42.25	6.87466	8
16	135.00	33.51	-101.43	0
17	270.01	17.99	-7.08219	3
18	239.48	1.09	24.88258	0
19	297.56	0	57.52672	5
20	453.22	0	-22.9839	9
21	468.71	0	10.58083	13
22	534.46	0	16.70475	18
23	414.85	0	-101.43	11
24	425.31	0	-101.43	12
1	318.07	0	-90.946	7
2	310.33	0	-22.251	10
3	283.03	0	-101.43	5
4	296.36	0	-84.6831	6
5	253.56	0	-3.6021	0
6	252.37	0	0.591	0
7	215.13	0	56.7895	0
8	191.28	0	84.9645	0

Table 4-5 shows the optimization strategy of the microgrid for one day and Table 4-6 shows the actual strategy of the microgrid for the same case study. Table 4-7 shows the comparison results between the two strategies.

For the case study of one day, the operational cost and absorption of renewable energy is -4413.50 RMB and 7310.57 kWh respectively as shown in Table 4-7. Compared to the actual strategy, the optimization strategy makes the operational cost 72.5 RMB smaller (profit 72.5 RMB larger) and the absorption of renewable energy 200.69 kWh more. The discomfort levels of the two strategies are equal to zero, which indicate both of them can meet the heat demand.

Table 4-7 Comparison results between optimization and the actual strategy

		Optimization strategy	Actual strategy
One day	Operational cost (RMB)	-4413.50	-4341.00
	Discomfort level	0	0
	Absorption of renewable energy (kWh)	7310.57	7109.88

From the comparison results between the two strategies as shown in Table 4-7, it can be learned the performance of the optimization strategy is better than that of the actual strategy with lower operational cost and higher utilization of renewable energy. A more detailed analysis will be carried out in a graphical way below.

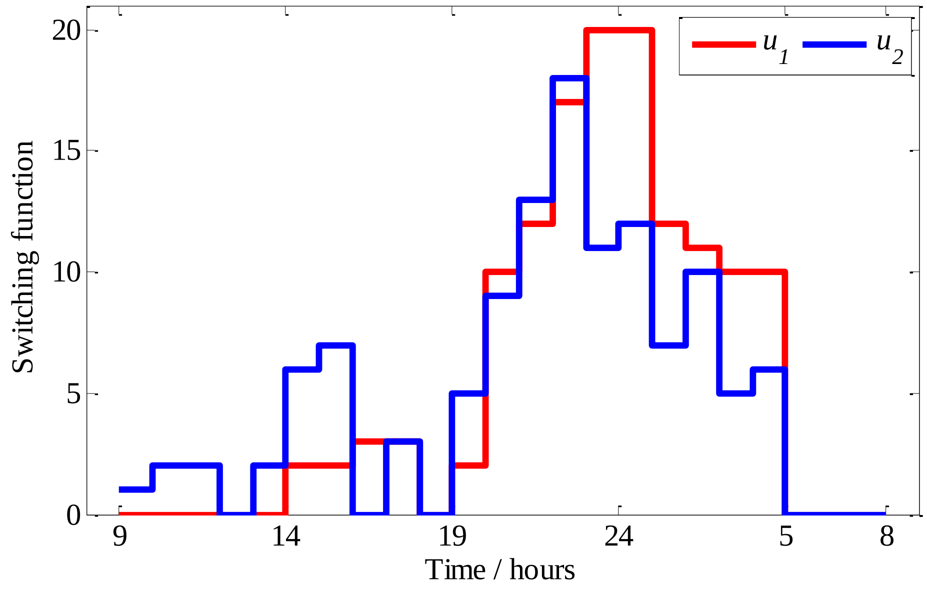


Figure 4-10 Comparison results of operating state of electric boiler and TES for one day

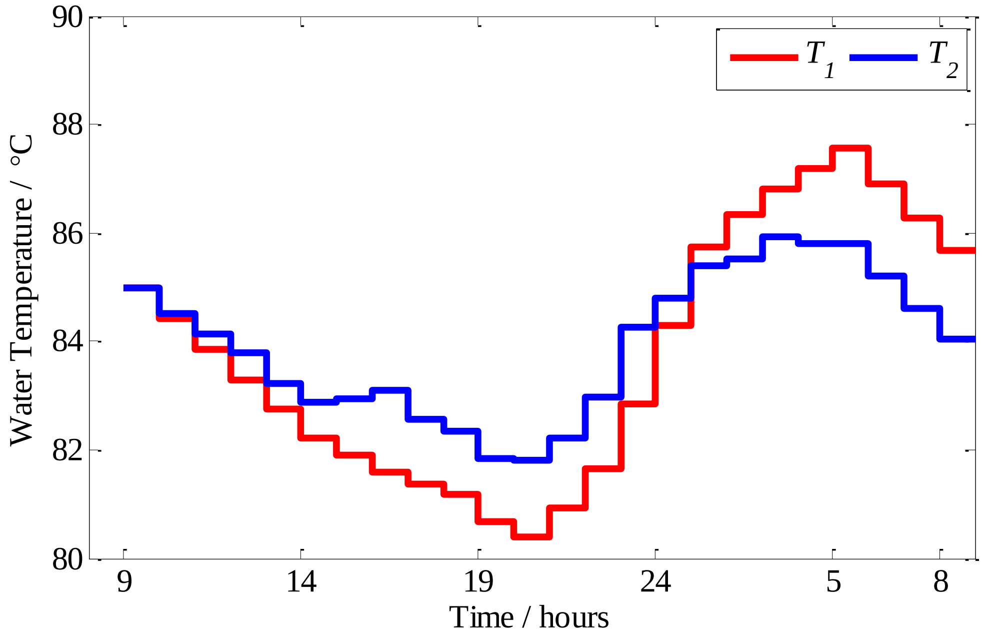


Figure 4-11 Comparison results of water temperature variation in TES for one day

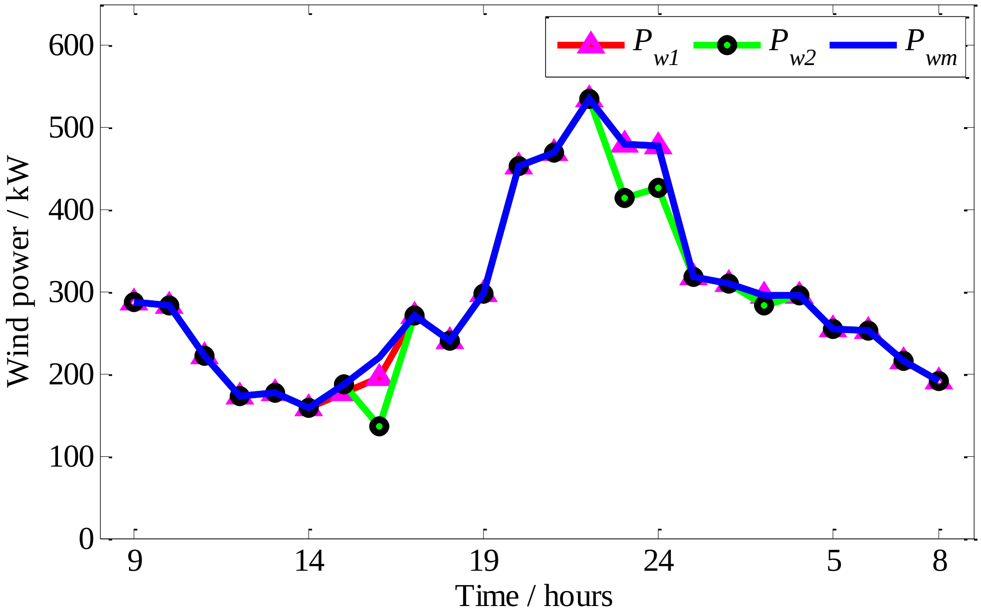


Figure 4-12 Comparison results of wind power for one day

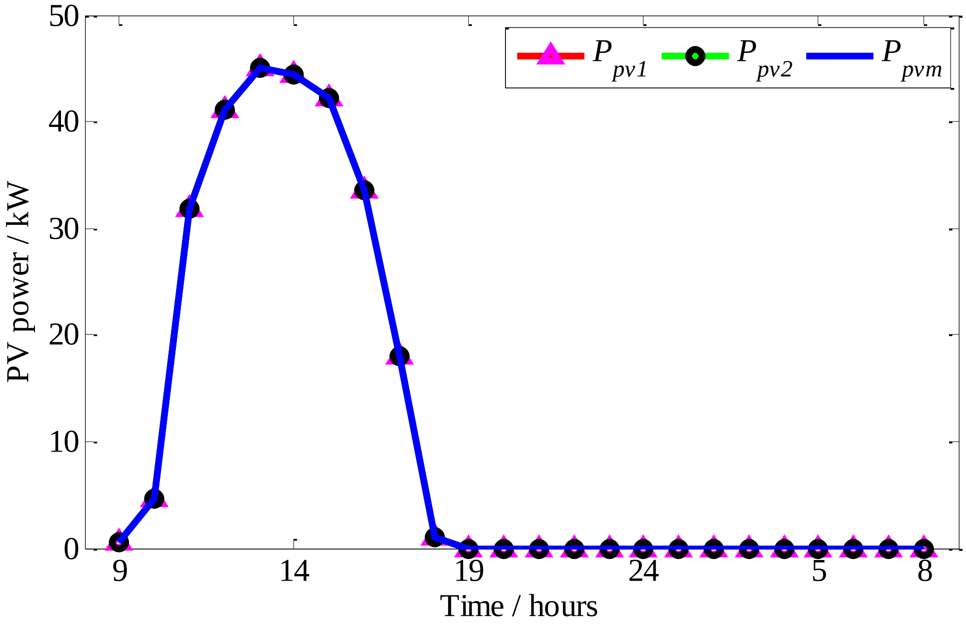


Figure 4-13 Comparison results of PV power for one day

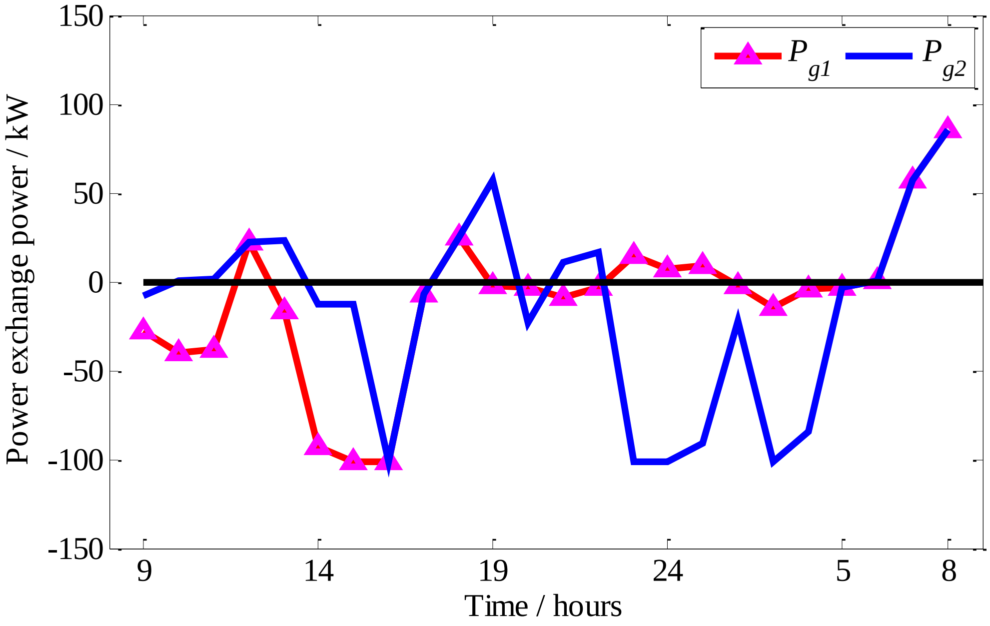


Figure 4-14 Comparison results of power exchange with external power grid for one day

1) Renewable energy absorption analysis

Figure 4-10 shows that the operating taps of electric boiler of the actual operating strategy in daytime is higher than that of the optimization strategy and is lower than that of the optimization strategy at night. The actual strategy also confirms to the general knowledge to operate the boiler with lower taps in daytime and higher taps at night. It can be seen graphically from Figure 4-11 that both of the two strategies can meet the heat demand. Figure 4-11 also shows the water temperature in TES of the actual strategy is lower than that of the optimization strategy.

In the optimization strategy, the electric boiler almost does not work in 9:00-16:00 and the heat demand is mainly supplied by the TES as shown in Figure 4-11, so the water temperature decreases rapidly within the TES. And by this way the microgrid can sell the redundant renewable energy as income as shown in Figure 4-14.

Figure 4-10 shows that the electric boiler is operated with high taps at night in both of the two strategies. Wind power increases rapidly at night and the electricity demand in residential buildings is low, so a surplus wind power will occur. The electric boiler operated with high tap can absorb the redundant wind power to produce heat energy which will be stored in TES. The process can be seen clearly in Figure 4-11 that the water temperature increases continually at night in the two strategies.

Table 4-8 Comparison results of renewable absorbed by electric boiler and the external power grid between two strategies for one day

		Daytime		Night		Amount Exchanged
		Absorbed by electric boiler	Sold to external power grid	Absorbed by electric boiler	Sold to external power grid	
Optimization strategy	Renewable energy(kWh)	240	427.65	2409.69	40.58	3117.92
	Percentage(%)	7.70	13.72	77.29	1.30	100.00
Actual strategy	Renewable energy(kWh)	503.22	116.13	1792.71	528.76	2940.82
	Percentage(%)	17.11	3.95	60.96	17.98	100.00

Table 4-8 shows that the renewable energy absorbed by electric boiler and TES and the external power grid. It can be seen it is 3117.92 kWh in optimization strategy which is 177.1 kWh more than that (2940.82 kWh) of actual strategy. It also can be seen that the electric boiler under the optimized strategy absorbs more renewable energy at night and release heat energy during daytime. In the optimization strategy, 2649.69 kWh (84.98%) renewable energy is absorbed by electric boiler and TES and only 468.23 kWh (15.02%) is sold. For the actual strategy, the amount of sold renewable energy reaches 644.89kWh (21.93%), and 2295.93 kWh (78.07%) is absorbed by electric boiler. This indicates that electric boiler is an effective way to absorb renewable energy. It also can be learned that the more renewable energy is absorbed by electric boiler at night, the more renewable energy absorption can be achieved in the whole day.

Figure 4-12 shows the comparison results of wind power for one day of the two strategies. It can be clearly seen that the most wind power can be absorbed by the microgrid and the external power grid in Table 4-5 and Figure 4-14. There is more wind power curtailment in the actual strategy than that in the optimization strategy. At night all the wind power can be consumed by electric boiler under the optimization strategy. In the actual strategy, the electric boiler is operated in lower taps and the redundant wind power is larger than the upper limit of power exchange at night and 16:00, so more wind power curtailment occurs.

Also some wind power curtailment occurs in period 15:00-16:00 under the optimization strategy. In the period the sold wind power has reached the upper limit (the case study sets the upper limit of power exchange $\alpha = 15\%$). At 15:00, the electric boiler is operated with tap 2 and the wind power curtailment is 2.07 kWh. At 16:00, the electric boiler is operated with tap 3 and the wind power curtailment is 10.76 kWh. The operational cost in the period can be expressed as (only the wind power is considered due to all the PV power can be absorbed):

$$-101.43 \times 2 \times 0.4 - 185.85 \times 0.6 - 208.97 \times 0.6 = -318.04 \text{ RMB},$$

which consists of the allowance on the use of wind power and income of selling wind power, and the negative value indicates an income of 318.04 RMB from the selling of wind power.

The redundant wind power in period 15:00-16:00 can be absorbed by the electric boiler. Then the electric boiler will be operated with tap 3 and tap 4 at 15:00 and 16:00, respectively. As the rated power of each tap of electric boiler is 20 kW, 17.93 kWh and 9.24 kWh should be purchased from the external power grid at 15:00 and 16:00, respectively. The operational cost in this condition can be expressed as (only the wind power is considered due to all the PV power can be absorbed):

$$(17.93 + 9.24) \times 0.55 - 101.43 \times 2 \times 0.4 - 187.91 \times 0.6 - 219.74 \times 0.6 = -310.80 \text{ RMB}.$$

The negative value indicates an income of 310.80 RMB from the selling of wind power. Comparing the operational cost of two operating method, it can be learned that the condition with no wind power curtailment will increase the operational cost with 7.24 RMB (reduce the profit by 7.24 RMB). The model takes minimizing operational cost as an objective, so the wind power curtailment occurs.

From the above analysis we can learn that the microgrid has the ability to absorb all the redundant wind energy with a little more operational cost. The operational cost is composed of the allowance on the use of renewable energy and cost on renewable energy trading (selling and buying). The more the renewable energy is absorbed, the more allowance can be achieved. The cost on renewable energy trading mainly based on the selling and buying price. The selling price is 0.4 RMB. The buying price is 0.55 RMB at daytime and 0.3 RMB at night. To minimize the operational cost there are three ways: 1) increasing the use of renewable energy to achieve more allowance; 2) increasing selling electricity power; 3) reducing buying electricity power, especially during the daytime. 1) and 2) will result in more renewable energy can be absorbed. It requires the TES stores more heat energy at night to meet 3). This will absorb more renewable energy at night. So to minimize the operational cost can improve the penetration of renewable energy.

However, the upper limit of power exchange will lead to wind power curtailment. If the upper limit of power exchange is increased to 20%, there will be no waste of wind power in this case study. Even more, if there is no limit of power exchange, all the renewable energy will be absorbed by the external power grid.

Figure 4-13 shows that all the PV power can be absorbed under any of the optimization strategy or the actual strategy since the rated power of PV generation is small and also PV only generates power in the daytime. Figure 4-14 shows when the renewable energy is redundant or not enough, the microgrid will sell or buy electricity. The negative values represent the amount of power sold to the grid; the positive values are the amount of power purchased by the microgrid.

The external power grid cannot absorb all the redundant renewable energy due to the upper limit of power exchange. The above analysis shows that electric boiler is more effective on renewable energy absorption with lower operational cost. The optimization strategy can absorb more renewable energy with lower operational cost than the existing operating strategy.

2) Analysis on the impact of the microgrid to the external power grid

During the daytime, the electricity demand and the power generation are high in the external power grid. The redundant renewable energy can partially relieve the pressure of the grid. In the optimized strategy, the electric boiler almost does not work in 9:00-16:00 and the heat demand is mainly supplied by the TES. And the microgrid can sell the redundant renewable energy as income as shown in Table 4-5 and Figure 4-14. From Table 4-9 it can be seen 427.65 kWh electricity is sold in the optimization strategy, which is much higher than that in the actual strategy. Furthermore, most of the renewable energy is sold in the load peak period of the external power grid. However, in the actual strategy, the microgrid buys more electricity as shown in Table 4-9, which will increase the microgrid operational cost and the grid’s power supply pressure.

The electric boiler is operated with higher taps under the optimization strategy than that of the actual strategy as shown in Figure 4-10 and TES will achieve higher water temperature at night. 2409.69 kWh (77.29%) wind energy will be converted to heat energy which will be stored in TES and only 40.58kWh (1.30%) wind energy is sold to the external power grid under the optimization strategy as shown in Tables 4-8~4-9. On the contrary, 528.76kWh (17.98%) wind energy is sold and 1792.71kWh (60.96%) wind energy is converted to heat energy stored in TES under the actual strategy. In the actual strategy, much more renewable energy is sold and less is absorbed by electric boiler than those of optimization strategy at night. Furthermore, most of the renewable energy is sold in the load valley period of the external power grid.

Table 4-9 Comparison results of electricity trading between two strategies for one day

	Daytime (kWh)		Night (kWh)	
	Purchased from external power grid	Sold to external power grid	Purchased from external power grid	Sold to external power grid
Optimization strategy	188.55	427.65	30.90	40.58
Actual strategy	285.33	116.13	27.87	528.76

Figure 4-14 graphically shows the comparison results of power exchange with external power grid under the two strategies for one day. It can be clearly seen that the amount of traded electricity between the microgrid and the external power grid under the optimization strategy is much smaller than that of the actual strategy. Most of electricity sold to the external power grid from the microgrid is during the daytime and there is a little power exchange at night under the optimization strategy.

From the above analysis, it can be learned that the difference between peak and valley demand can be reduced by the optimization strategy when compared to the actual strategy. The optimization strategy not only can absorb more renewable energy with lower operational cost, but also is beneficial to the external power grid.

4.2.2.4.2 Case 2: Discussion on comparison results of one month

The case study of one month is also implemented in the research to verify the effectiveness of the proposed model. The optimization strategy and actual strategy of the microgrid for one month is shown in Table A1 in the Appendix.

Table 4-10 Comparison results between optimization and the actual strategy

		Optimization strategy	Actual strategy
One month	Operational cost (RMB)	-122148.31	-118445.25
	Discomfort level	0	0.1958
	Absorption of renewable energy (kWh)	202889.04	199003.75

The operational cost and the amount of absorbed renewable energy are -122148.31 RMB (i.e. a profit of 122148.31 RMB) and 202889.04 kWh respectively as shown in Table 4-10. Compared to the actual strategy, the optimization strategy makes an additional 3703.06 RMB profit and 3885.29 kWh more absorbed renewable energy. For the discomfort level, the value of the optimization strategy is zero while that of the actual strategy is 0.1958. The optimization strategy can satisfy with the heat demand all the time while the actual strategy cannot meet the heat demand sometimes. It can be learned that the optimization strategy has less operational cost, higher utilization rate of renewable energy and lower discomfort level than these of the actual strategy.

The comparison results of the optimization strategy and the actual strategy are graphically shown in Figures 4-15~4-19.

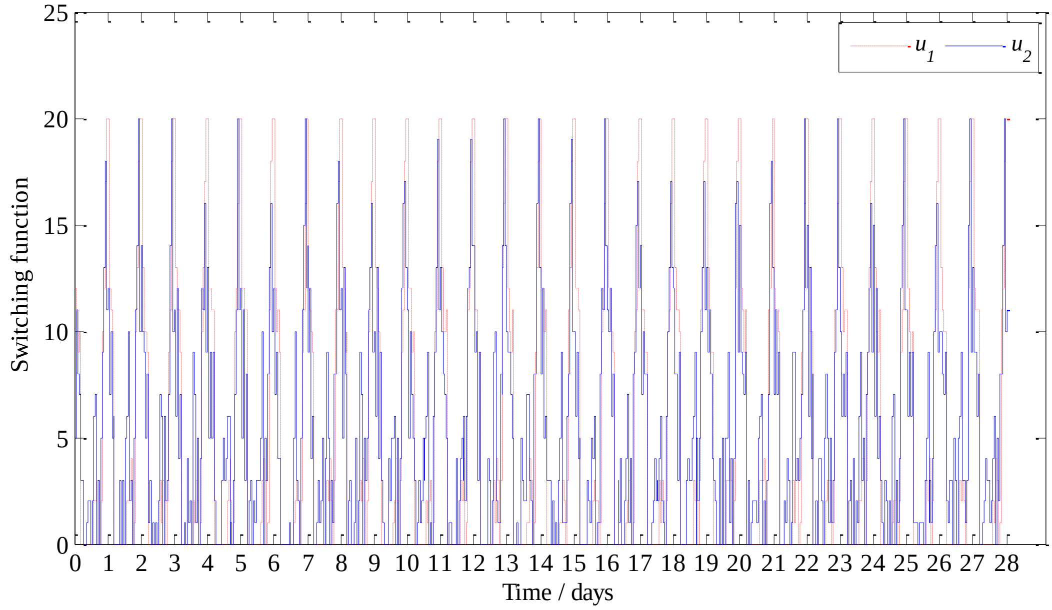


Figure 4-15 Comparison results of operating state of electric boiler and TES for one month

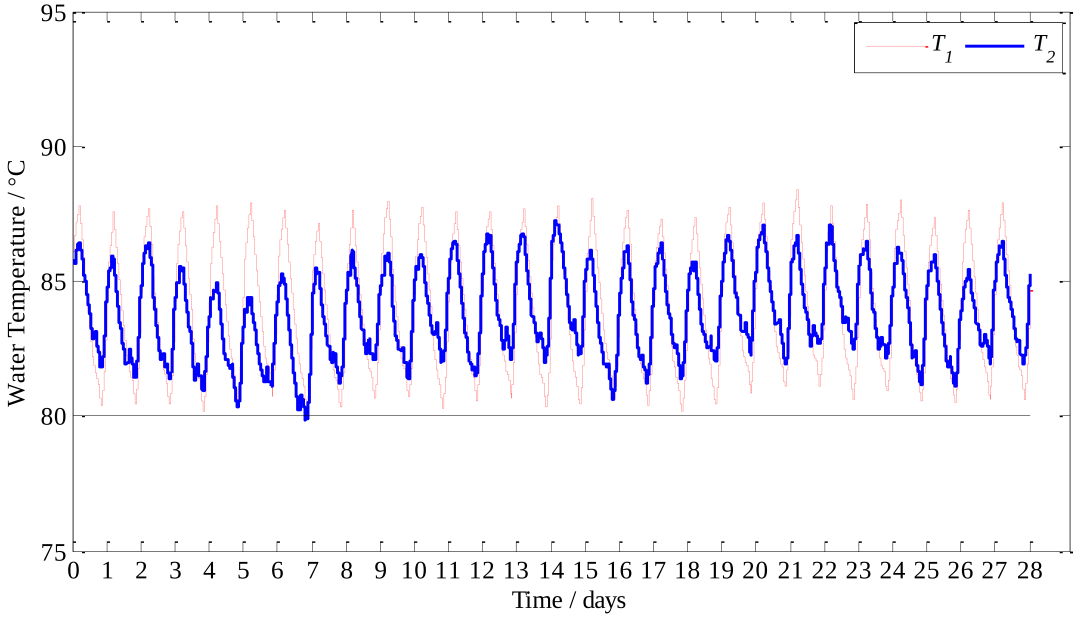


Figure 4-16 Comparison results of water temperature variation in TES for one month

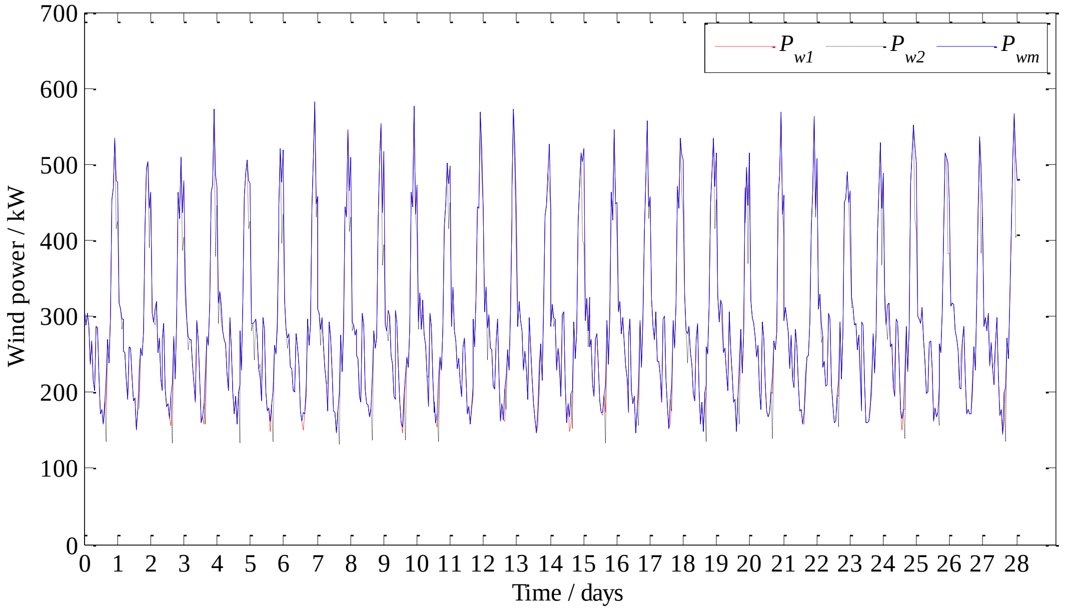


Figure 4-17 Comparison results of wind power for one month

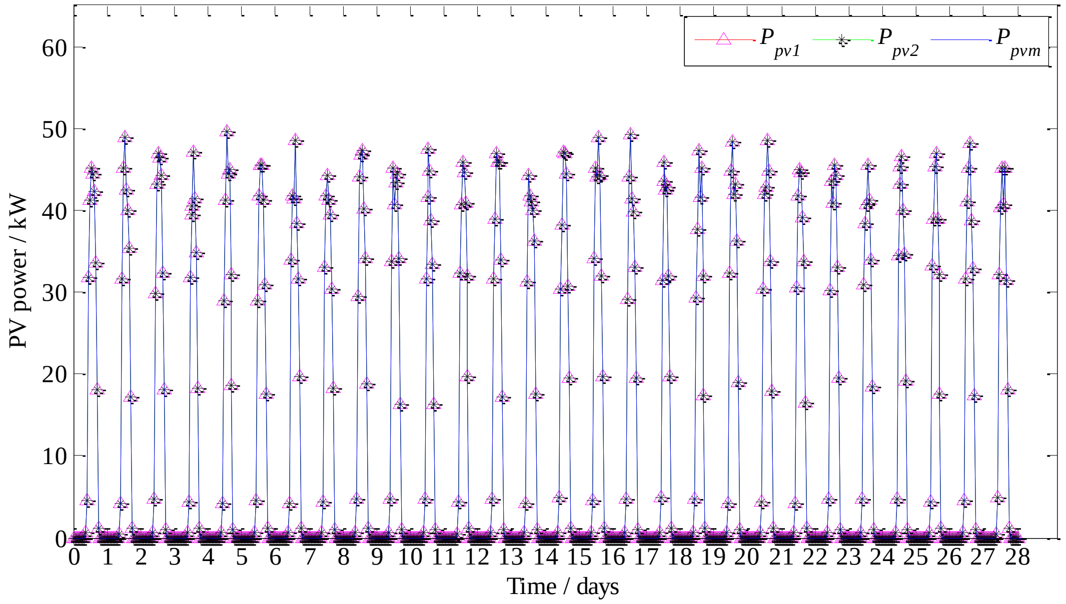


Figure 4-18 Comparison results of PV generation for one month

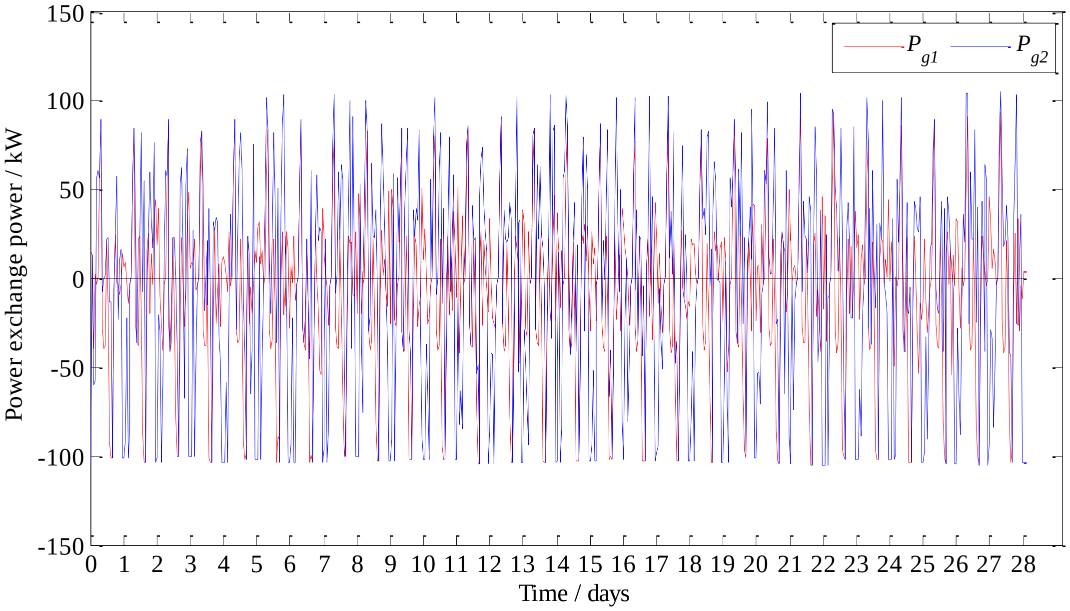


Figure 4-19 Comparison results of power exchange with external power grid for one month

Table 4-11 Comparison results of renewable absorbed by electric boiler and the external power grid between two strategies for one month

		Daytime		Night		
		Absorbed by electric boiler	Sold to external power grid	Absorbed by electric boiler	Sold to external power grid	total
Optimization strategy	Renewable energy(kWh)	5204.23	12224.47	65580.95	2318.65	85328.30
	Percentage(%)	6.10	14.33	76.86	2.72	100.00
Actual strategy	Renewable energy(kWh)	11901.98	5277.45	51940.13	13317.20	82436.76
	Percentage(%)	14.44	6.40	63.01	16.15	100.00

Table 4-12 Comparison results of electricity trading between two strategies for one month

	Daytime (kWh)		Night (kWh)	
	Purchased from external power grid	Sold to external power grid	Purchased from external power grid	Sold to external power grid
Optimization strategy	3963.17	12224.47	4457.73	2318.65
Actual strategy	10370.45	5277.45	5247.27	13317.20

Table 4-11 shows that the electric boiler and external power grid are the main ways to absorb the redundant renewable energy. The electric boiler is more effective on renewable energy absorption than the external power grid in the case study. The optimization strategy can absorb more renewable energy as more wind power can be used by the electric boiler and TES at night.

Table 4-12 shows that in the optimization strategy sells less electricity power at night and more electricity power at daytime than those of the actual strategy.

Conclusions made for the one day control period also apply to the case of one month control period. The electric boiler is operated with higher taps to stored heat energy in TES, and the electric boiler is operated with lower taps during the daytime and TES provides thermal energy to the heat demand. The microgrid sells electricity power to the external power grid mainly during the daytime and it is little at night. The comparison results also indicate that the optimization strategy has better performance than the actual strategy.

4.2.2.4.3 Discussions on computational time

It has been verified that the proposed optimization strategy in this thesis has better performance than the existing control strategy. However, the optimization may be resolved online to produce optimal control input, and then the computational time must be very short. The computational time of different control time durations is analyzed in this subsection.

The parameters of GA are set as follows: population size = 100, generations = 500, crossover fraction = 0.8, mutation rate = 0.2 and precision = 10^{-3}. When the number of generation or the precision is reached, the optimization process will stop. Several scenarios are considered and the time duration to be optimized, i.e. $t_f - t_0$, is set to be 1h, 3h, 6h, 9h, 12h, 18h and 24h, respectively. Then experiments are simulated in MATLAB R2014a on a computer with Intel Core ™ i7-4650U CPU @ 1.70GHz 2.30GHz 8GB RAM. For each of these scenarios, the average computational time of 30 independent runs, the corresponding median, average and the standard deviation are shown in Table 4-13.

It can be clearly seen that the computational time average and median values of all the scenarios are second level in Table 4-13. When the optimization time duration is 1h, the average computational time is only 2.783229s. When the optimization time duration is 24h, biggest average computational time is reached with 17.50074s. With the increase of the optimization time duration, the average computational time increases. The standard deviation shows that the computational time is close to the average value.

From the above analysis, it can be concluded that the computational time of the optimization is quite short and the optimization can be solved online to produce optimal control strategy.

Table 4-13 Results of computational time for different scenarios

Optimization Time Duration (h)	Median (s)	Average (s)	Std. dev. (s^2)
1	3.062969	2.783229	0.584673
3	3.134793	3.058316	0.684447
6	3.523456	3.936187	0.891006
9	5.975020	6.426938	1.116237
12	8.001005	8.389770	1.064590
18	11.79507	12.12669	1.098222
24	17.62239	17.50074	1.154510

4.3 Case 3: Impact of renewable power to optimal operating strategy

From the analysis of the above studies, it can be learned that the renewable power can influence the optimal operating strategy, such as electric boiler tap positions, and the amount of electricity traded. This subsection will illustrate the impact of renewable power on the optimal operating strategy obtained in the optimization model. As the rated power of PV generation is small, its impact can be ignored, and therefore only wind power is considered.

In this case study the optimization over one day is taken as an example to investigate the impact of wind power. The other parameters of the microgrid system are same to those in Case 1 as shown in Subsection 4.2.1. The available wind power (P_{wm3}) is shown in Figure 4-20, which is different from P_{wm} (P_{wm} is the available wind power in Case 1).

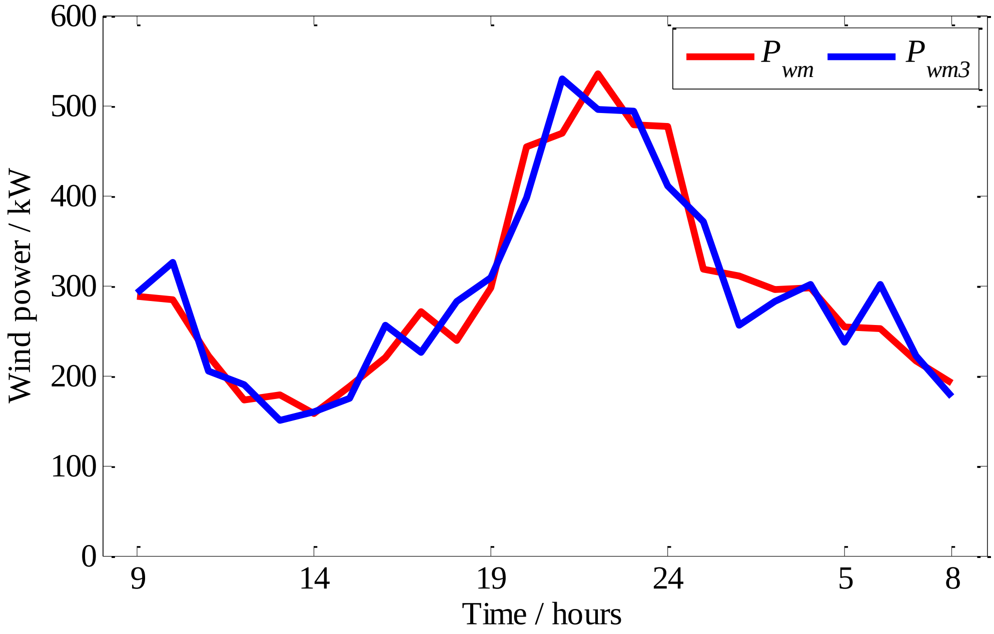


Figure 4-20 Available wind power profiles in this case study

The simulation results are compared with the optimization strategy in Case 1 and comparison results are shown in Figures 4-21~4-25. (u_3, T_3, P_{w3}, P_{pv3} and P_{g3} are strategies in Case 3)

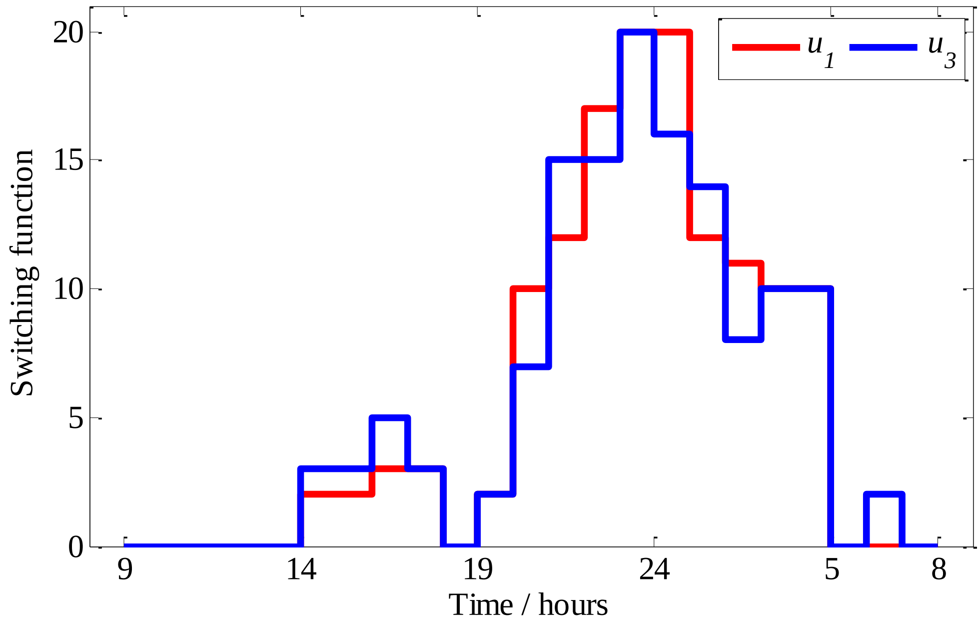


Figure 4-21 Comparison results of operating status of electric boiler

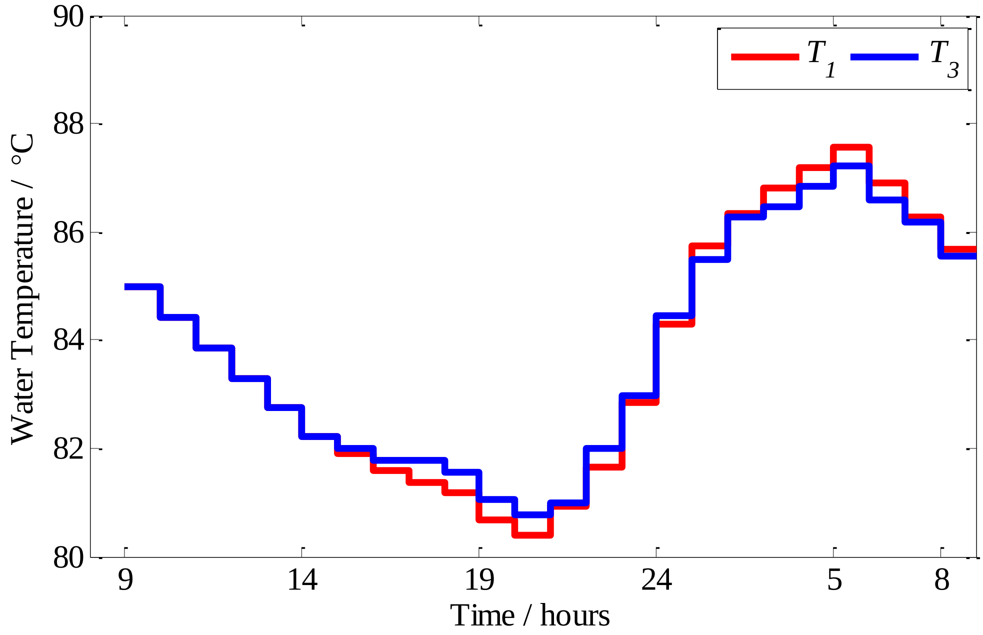


Figure 4-22 Comparison results of water temperature variation in TES

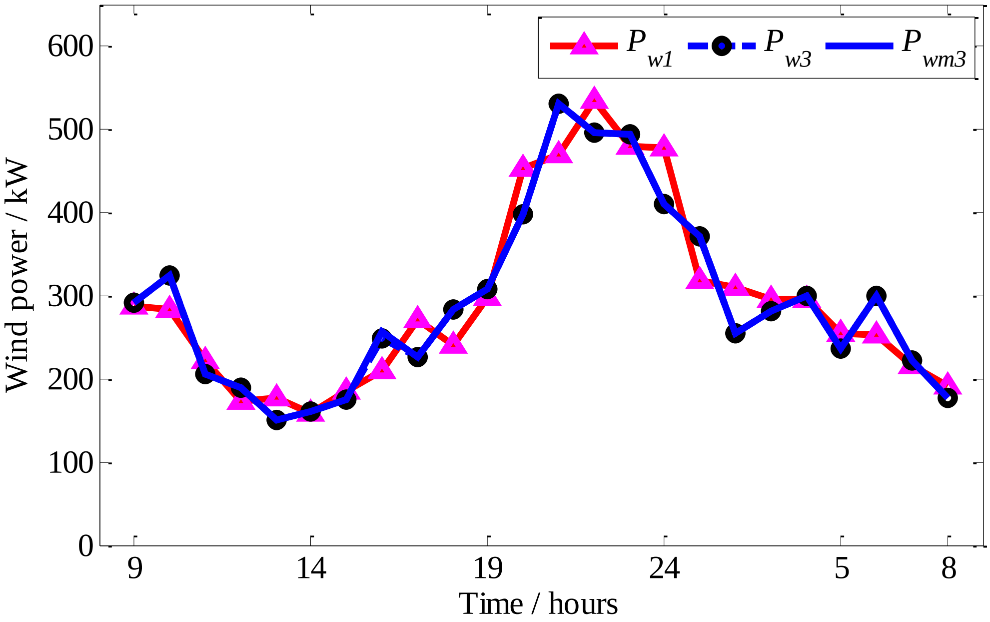


Figure 4-23 Comparison results of wind power

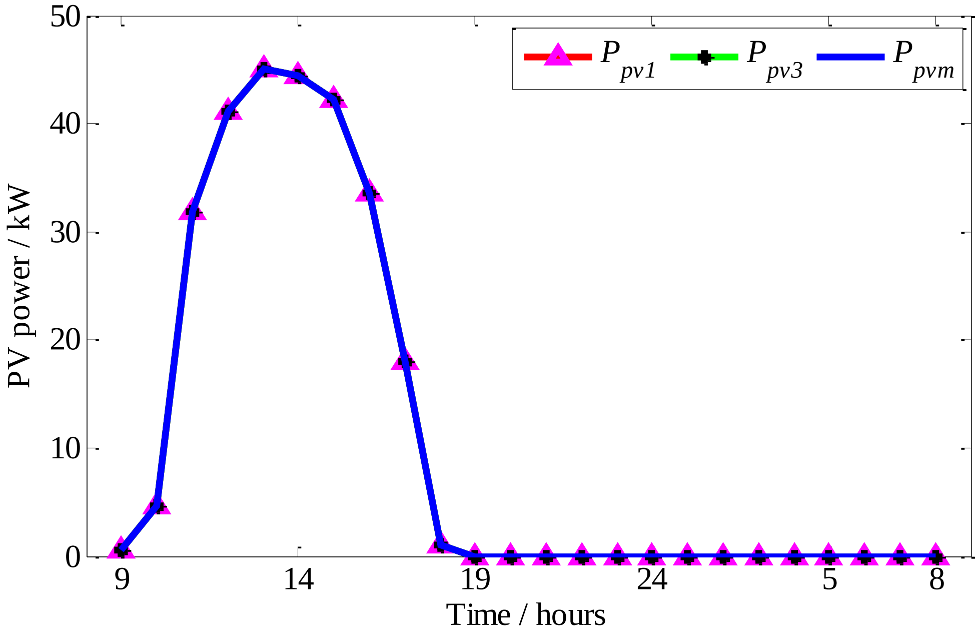


Figure 4-24 Comparison results of PV power

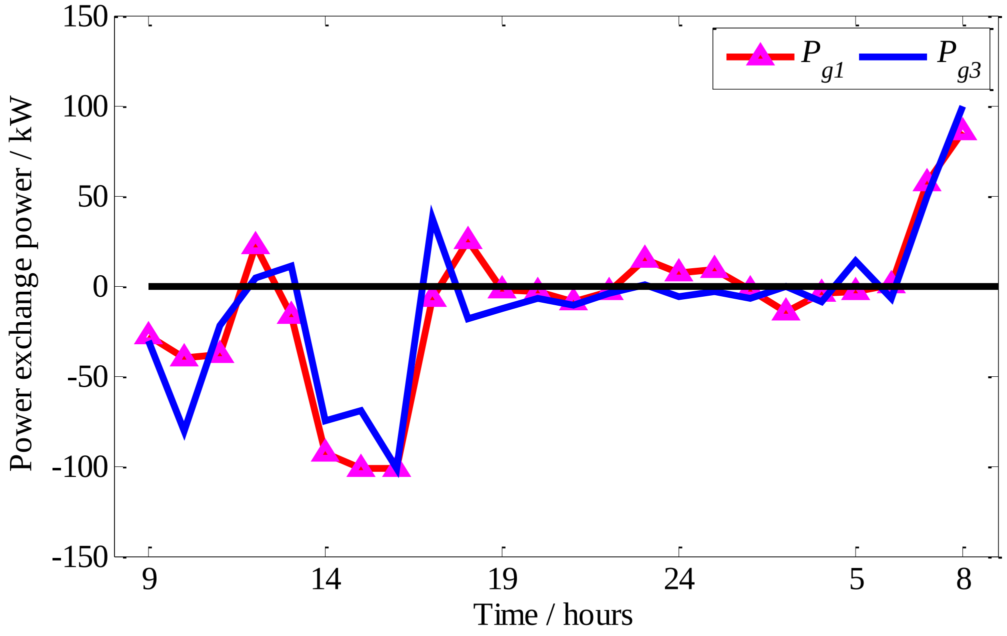


Figure 4-25 Comparison results of power exchange with external power grid

From the comparison results in the Figures, it can be clearly seen the operating strategy in Case 3 is different from that in Case 1. In Case 3, the electric boiler operates with high taps in period 14:00~16:00 and with low taps at night as shown in Figure 4-21. Figure 4-23 shows almost all the wind power is absorbed. There is no waste of PV power due to the small rated power as shown in Figure 4-24. Figure 4-25 describes the power trading with external power grid and the microgrid does not buy electricity power around 24:00.

Table 4-14 shows total renewable energy and renewable energy absorption in Case 1 are bigger than those in Case 3. But there is more renewable energy curtailment in Case 1 as redundant renewable energy in period 15:00~16:00 cannot be absorbed which has been analyzed in Subsection 4.2.2.4.1. The operational cost of Case 1 is 5.06 RMB less than that of Case 3. The discomfort levels of the two cases are equal to zero, which indicate both of them can meet the heat demand.

The electricity power trading with external power grid of the two cases is obviously different as shown in Figure 4-25. As the renewable energy generation is less in Case 3, it will sell less and buy more electricity power to satisfy the heat demand and heat energy stored, which are verified in Table 4-15 and Figure 4-25. Especially in period 15:00 and 16:00, Case 3 sells much less electricity power than Case 1. Around 24:00, the redundant electricity power cannot support electric boiler to operate with a higher tap, so it is sold as income to reduce operational cost. However, as the renewable energy is smaller and the objective is to minimize operational cost, the total stored heat energy in Case 3 is less than that in Case 1 as shown in Figure 4-22. Also the difference between peak and valley is smaller in Case 3.

Table 4-14 Comparison results between the two optimization strategies

	Optimization strategy in Case 1	Optimization strategy in Case 3
Total renewable energy (kWh)	7323.41	7295.88
Absorption of renewable energy (kWh)	7310.57	7288.93
Renewable energy curtailment (kWh)	12.84	6.95
Operational cost (RMB)	-4413.50	-4408.44
Discomfort level	0	0

Table 4-15 Comparison results of electricity trading between the two strategies for one day

	Daytime (kWh)		Night (kWh)	
	Purchased from external power grid	Sold to external power grid	Purchased from external power grid	Sold to external power grid
Optimization strategy in Case 1	188.55	427.65	30.90	40.58
Optimization strategy in Case 3	201.87	416.54	14.54	46.99

From the above analysis, it can be seen that when renewable energy is low, microgrid will reduce the amount of electricity power sold to meet the heat demand. The larger the renewable power is, the less operational cost and the larger renewable energy absorption will be achieved.

4.4 Chapter summary

Several case studies are implemented to verify the efficiency of the proposed model. Compared to the existing operational strategy, the optimized strategy obtained in this section can absorb more renewable energy. The electric boiler operates at high taps to absorb more renewable energy in the night and releases thermal energy to meet thermal demand in the daytime. The microgrid will buy or sell electricity power in different period depending on the optimal strategy. The comparison results show that the optimization strategy has better performance than the actual strategy.

Chapter 5

Conclusions and further work

5.1 Conclusions

This thesis proposed an optimization model to control a microgrid optimally with a boiler, together with TES, and renewable generation so that the operational cost of the microgrid is minimized and at the same time the end users' thermal comfort is maintained. The model is also able to reduce the amount of curtailed renewable energy as shown in the case studies. The main conclusions are:

- The optimization model to control a microgrid, which is composed of a photovoltaic (PV), a wind turbine, an electric boiler, a thermal energy storage system and an external power grid, is obtained. The electric boiler works with high taps to absorb more renewable energy in the night and with low taps of being switched off in the day time. Thermal demand in the day time is supplied through the TES system.

- The mathematical models of the heating unit (electric boiler and TES) and power exchange of the external power grid are established. The redundant renewable energy can be absorbed by electric boiler and the external power grid. The electric boiler combined with the TES system is more effective to absorb surplus renewable generation than the external power grid due to the upper limit of power exchange.

- Customers' discomfort level and the operational cost of the microgrid are minimized along with several constraints. The proposed model can deal with renewable energy curtailment problem effectively with lower operational cost.

When renewable power changes, the different optimization strategy can be obtained by the proposed model.

- The proposed model is beneficial to the external power grid by reducing the difference between peak load and valley load.

5.2 Further work

This thesis focuses on operation of the microgrid to reduce the operational cost and reduce renewable curtailment. The data of model is based on an actual microgrid, especially the rated power and size of electric boiler is fixed. The number of microgrids will keep on increasing in the future, while only one microgrid is investigated in the thesis. So future work to improve the thesis includes:

- The rated power and the size of the electric boiler can affect the maximal renewable energy absorbed. The impact of the rated power of the electric boiler on the renewable energy and load demand will be investigated in the future. An optimal designing strategy of a microgrid can be obtained to increase penetration of renewable energy.

- Multi-microgrids will be investigated for further work. It becomes complicated with the increase of the number of microgrids. Control scheme and mathematic model among microgrids and between microgrids and external power grid should be established. The optimal control strategy coordinated multi-microgrids and external power grid will be investigated to deal with renewable energy curtailment problem with the lowest cost.

Appendix

Table A1 Optimization strategy and actual strategy of the microgrid for one month

				Optimization strategy				actual strategy			
Time	P_{eload} (kW)	P_{wm} (kW)	P_{pvm} (kW)	P_{w1} (kW)	P_{pv1} (kW)	P_{g1} (kW)	u_1	P_{w2} (kW)	P_{pv2} (kW)	P_{g2} (kW)	u_2
1	84.55	308.69	0.00	308.69	0.00	15.86	12	288.32	0.00	-103.77	5
2	82.08	289.18	0.00	289.18	0.00	12.90	11	289.18	0.00	12.90	11
3	83.62	303.26	0.00	303.26	0.00	-39.64	9	303.26	0.00	-59.64	8
4	88.51	286.12	0.00	286.12	0.00	2.39	10	286.12	0.00	-57.61	7
5	234.35	237.72	0.00	237.72	0.00	-3.38	0	237.72	0.00	56.62	3
6	267.72	267.10	0.00	267.10	0.00	0.62	0	267.10	0.00	60.62	3
7	273.04	216.01	0.00	216.01	0.00	57.02	0	216.01	0.00	57.02	0
8	291.82	202.07	0.00	202.07	0.00	89.75	0	202.07	0.00	89.75	0
9	260.26	287.30	0.58	287.30	0.58	-27.62	0	287.30	0.58	-7.62	1
10	248.77	283.93	4.58	283.93	4.58	-39.75	0	283.93	4.58	0.25	2
11	215.04	221.38	31.85	221.38	31.85	-38.19	0	221.38	31.85	1.81	2
12	235.37	172.31	41.14	172.31	41.14	21.92	0	172.31	41.14	21.92	0
13	205.98	177.47	45.09	177.47	45.09	-16.58	0	177.47	45.09	23.42	2
14	69.66	158.34	44.42	158.34	44.42	-93.10	2	158.34	44.42	-13.10	6
15	77.04	187.92	42.25	176.23	42.25	-101.44	2	187.92	42.25	-13.13	7
16	67.08	219.74	33.51	195.01	33.51	-101.44	3	135.01	33.51	-101.44	0
17	220.92	270.01	17.99	270.01	17.99	-7.08	3	270.01	17.99	-7.08	3
18	265.45	239.48	1.09	239.48	1.09	24.88	0	239.48	1.09	24.88	0
19	255.09	297.56	0.00	297.56	0.00	-2.47	2	297.56	0.00	57.53	5
20	250.24	453.22	0.00	453.22	0.00	-2.98	10	453.22	0.00	-22.98	9
21	219.29	468.71	0.00	468.71	0.00	-9.42	12	468.71	0.00	10.58	13
22	191.16	534.46	0.00	534.46	0.00	-3.30	17	534.46	0.00	16.70	18
23	93.42	479.05	0.00	479.05	0.00	14.37	20	414.86	0.00	-101.44	11
24	83.88	476.99	0.00	476.99	0.00	6.89	20	425.32	0.00	-101.44	12
1	87.12	318.07	0.00	318.07	0.00	9.05	12	318.07	0.00	-90.95	7
2	88.08	310.33	0.00	310.33	0.00	-2.25	11	310.33	0.00	-22.25	10
3	81.60	295.94	0.00	295.94	0.00	-14.34	10	283.04	0.00	-101.44	5
4	91.68	296.36	0.00	296.36	0.00	-4.68	10	296.36	0.00	-84.68	6
5	249.96	253.56	0.00	253.56	0.00	-3.60	0	253.56	0.00	-3.60	0
6	252.96	252.37	0.00	252.37	0.00	0.59	0	252.37	0.00	0.59	0
7	271.92	215.13	0.00	215.13	0.00	56.79	0	215.13	0.00	56.79	0
8	276.24	191.28	0.00	191.28	0.00	84.96	0	191.28	0.00	84.96	0
9	236.27	260.82	0.53	260.82	0.53	-25.07	0	260.82	0.53	34.93	3
10	225.21	257.05	4.15	257.05	4.15	-35.98	0	257.05	4.15	-35.98	0
11	212.86	219.13	31.53	219.13	31.53	-37.80	0	219.13	31.53	22.20	3

12	258.42	189.19	45.17	189.19	45.17	24.06	0	189.19	45.17	24.06	0
13	222.97	192.11	48.81	192.11	48.81	-17.95	0	192.11	48.81	82.05	5
14	66.57	151.32	42.45	151.32	42.45	-87.20	2	151.32	42.45	-7.20	6
15	72.89	177.80	39.97	176.63	39.97	-103.71	2	177.80	39.97	55.12	10
16	70.62	231.34	35.28	199.05	35.28	-103.71	3	179.05	35.28	-103.71	2
17	210.64	257.45	17.15	257.45	17.15	16.04	4	257.45	17.15	-3.96	3
18	275.22	248.29	1.13	248.29	1.13	25.80	0	248.29	1.13	25.80	0
19	238.42	278.12	0.00	278.12	0.00	-19.70	1	278.12	0.00	60.30	5
20	229.39	415.46	0.00	415.46	0.00	13.93	10	415.46	0.00	33.93	11
21	231.26	494.29	0.00	494.29	0.00	-3.03	13	494.29	0.00	16.97	14
22	180.01	503.28	0.00	503.28	0.00	36.73	18	503.28	0.00	76.73	20
23	86.22	442.13	0.00	442.13	0.00	44.09	20	389.93	0.00	-103.71	10
24	81.35	462.62	0.00	462.62	0.00	18.73	20	462.62	0.00	-101.27	14
1	83.20	303.75	0.00	303.75	0.00	39.44	13	303.75	0.00	-20.56	10
2	83.17	293.02	0.00	293.02	0.00	-9.85	10	293.02	0.00	-29.85	9
3	85.65	310.64	0.00	310.64	0.00	-24.98	10	289.37	0.00	-103.71	5
4	98.65	318.89	0.00	318.89	0.00	-40.24	9	318.89	0.00	-60.24	8
5	249.07	252.66	0.00	252.66	0.00	-3.59	0	252.66	0.00	16.41	1
6	271.17	270.53	0.00	270.53	0.00	0.63	0	270.53	0.00	60.63	3
7	274.22	216.95	0.00	216.95	0.00	57.27	0	216.95	0.00	57.27	0
8	291.42	201.79	0.00	201.79	0.00	89.63	0	201.79	0.00	89.63	0
9	243.48	268.78	0.54	268.78	0.54	-25.84	0	268.78	0.54	-5.84	1
10	254.67	290.67	4.69	290.67	4.69	-40.69	0	290.67	4.69	-40.69	0
11	201.14	207.07	29.79	207.07	29.79	-35.72	0	207.07	29.79	-15.72	1
12	246.78	180.67	43.14	180.67	43.14	22.98	0	180.67	43.14	22.98	0
13	214.38	184.71	46.93	184.71	46.93	-17.26	0	184.71	46.93	22.74	2
14	72.80	165.48	46.42	165.48	46.42	-79.10	3	165.48	46.42	0.90	7
15	80.60	196.62	44.21	156.93	44.21	-100.53	1	196.62	44.21	-40.22	6
16	64.87	212.51	32.41	192.99	32.41	-100.53	3	132.99	32.41	-100.53	0
17	222.87	272.39	18.15	272.39	18.15	-27.67	2	272.39	18.15	52.33	6
18	242.33	218.62	1.00	218.62	1.00	22.71	0	218.62	1.00	62.71	2
19	255.93	298.54	0.00	298.54	0.00	-2.61	2	298.54	0.00	17.39	3
20	255.45	462.66	0.00	462.66	0.00	-27.21	9	462.66	0.00	-67.21	7
21	200.18	427.85	0.00	427.85	0.00	-7.67	11	427.85	0.00	52.33	14
22	182.19	509.39	0.00	509.39	0.00	32.80	18	509.39	0.00	72.80	20
23	85.17	436.75	0.00	436.75	0.00	48.42	20	385.70	0.00	-100.53	10
24	84.11	478.30	0.00	478.30	0.00	5.81	20	404.64	0.00	-100.53	11
1	94.60	345.39	0.00	345.39	0.00	9.21	13	315.13	0.00	-100.53	6
2	84.30	297.00	0.00	297.00	0.00	7.29	11	297.00	0.00	27.29	12
3	75.27	272.98	0.00	272.98	0.00	22.29	11	255.79	0.00	-100.53	4
4	83.39	269.57	0.00	269.57	0.00	-6.18	9	269.57	0.00	-46.18	7
5	266.36	270.20	0.00	270.20	0.00	-3.84	0	270.20	0.00	-3.84	0
6	236.91	236.35	0.00	236.35	0.00	0.55	0	236.35	0.00	0.55	0

7	268.33	212.29	0.00	212.29	0.00	56.04	0	212.29	0.00	76.04	1
8	270.17	187.08	0.00	187.08	0.00	83.09	0	187.08	0.00	83.09	0
9	267.43	295.22	0.60	295.22	0.60	-28.38	0	295.22	0.60	51.62	4
10	236.30	269.70	4.35	269.70	4.35	-37.75	0	269.70	4.35	-17.75	1
11	214.19	220.51	31.72	220.51	31.72	-38.04	0	220.51	31.72	1.96	2
12	225.28	164.93	39.38	164.93	39.38	20.98	0	164.93	39.38	20.98	0
13	185.43	159.77	40.59	159.77	40.59	-14.93	0	159.77	40.59	-14.93	0
14	73.76	167.66	47.04	167.66	47.04	-100.94	2	167.66	47.04	39.06	9
15	75.59	184.39	41.46	157.83	41.46	-103.69	1	184.39	41.46	-10.25	7
16	69.77	228.55	34.85	198.61	34.85	-103.69	3	158.61	34.85	-103.69	1
17	224.26	274.09	18.26	274.09	18.26	-28.09	2	274.09	18.26	31.91	5
18	290.34	261.93	1.19	261.93	1.19	27.21	0	261.93	1.19	27.21	0
19	272.15	317.46	0.00	317.46	0.00	-25.31	1	317.46	0.00	34.69	4
20	256.00	463.67	0.00	463.67	0.00	-7.66	10	463.67	0.00	32.34	12
21	221.61	473.67	0.00	473.67	0.00	7.94	13	473.67	0.00	-32.06	11
22	204.44	571.60	0.00	571.60	0.00	-27.15	17	571.60	0.00	-47.15	16
23	94.77	485.99	0.00	485.99	0.00	8.78	20	378.47	0.00	-103.69	9
24	82.72	470.40	0.00	470.40	0.00	12.32	20	446.41	0.00	-103.69	13
1	87.12	318.08	0.00	318.08	0.00	9.04	12	290.82	0.00	-103.69	5
2	94.51	332.98	0.00	332.98	0.00	1.53	12	332.98	0.00	-58.47	9
3	86.73	314.53	0.00	314.53	0.00	-7.81	11	290.42	0.00	-103.69	5
4	86.88	280.84	0.00	280.84	0.00	26.04	11	280.84	0.00	-13.96	9
5	266.35	270.18	0.00	270.18	0.00	-3.84	0	270.18	0.00	36.16	2
6	263.64	263.03	0.00	263.03	0.00	0.61	0	263.03	0.00	0.61	0
7	283.92	224.63	0.00	224.63	0.00	59.30	0	224.63	0.00	59.30	0
8	291.29	201.70	0.00	201.70	0.00	89.59	0	201.70	0.00	89.59	0
9	269.64	297.66	0.60	297.66	0.60	-28.62	0	297.66	0.60	-28.62	0
10	225.80	257.72	4.16	257.72	4.16	-36.08	0	257.72	4.16	23.92	3
11	194.86	200.60	28.86	200.60	28.86	-34.61	0	200.60	28.86	65.39	5
12	235.43	172.36	41.15	172.36	41.15	21.92	0	172.36	41.15	81.92	3
13	226.50	195.15	49.58	195.15	49.58	-18.23	0	195.15	49.58	61.77	4
14	69.67	158.37	44.43	158.37	44.43	-93.13	2	158.37	44.43	-13.13	6
15	82.08	200.22	45.02	198.86	45.02	-101.79	3	200.22	45.02	-43.15	6
16	64.26	210.49	32.10	210.49	32.10	-98.33	4	133.95	32.10	-101.79	0
17	229.49	280.48	18.69	280.48	18.69	-29.68	2	280.48	18.69	-49.68	1
18	254.91	229.97	1.05	229.97	1.05	23.89	0	229.97	1.05	23.89	0
19	274.13	319.77	0.00	319.77	0.00	-25.64	1	319.77	0.00	14.36	3
20	252.36	457.07	0.00	457.07	0.00	-4.71	10	457.07	0.00	-64.71	7
21	228.62	488.64	0.00	488.64	0.00	-20.02	12	488.64	0.00	-40.02	11
22	180.79	505.47	0.00	505.47	0.00	-4.68	16	505.47	0.00	75.32	20
23	93.20	477.93	0.00	477.93	0.00	15.27	20	415.00	0.00	-101.79	11
24	83.43	474.44	0.00	474.44	0.00	8.99	20	425.23	0.00	-101.79	12
1	79.67	290.88	0.00	290.88	0.00	28.79	12	281.47	0.00	-101.79	5

2	82.36	290.18	0.00	290.18	0.00	32.18	12	290.18	0.00	12.18	11
3	80.68	292.61	0.00	292.61	0.00	8.07	11	242.48	0.00	-101.79	3
4	91.52	295.83	0.00	295.83	0.00	15.68	11	295.83	0.00	-44.32	8
5	267.07	270.92	0.00	270.92	0.00	-3.85	0	270.92	0.00	-3.85	0
6	230.84	230.30	0.00	230.30	0.00	0.54	0	230.30	0.00	40.54	2
7	278.63	220.43	0.00	220.43	0.00	58.19	0	236.83	0.00	101.79	3
8	272.07	188.39	0.00	188.39	0.00	83.68	0	188.39	0.00	83.68	0
9	270.25	298.32	0.60	298.32	0.60	-28.68	0	298.32	0.60	11.32	2
10	247.22	282.17	4.55	282.17	4.55	-39.50	0	282.17	4.55	-19.50	1
11	195.14	200.89	28.90	200.89	28.90	-34.66	0	200.89	28.90	25.34	3
12	238.76	174.80	41.73	174.80	41.73	22.23	0	174.80	41.73	82.23	3
13	207.74	178.98	45.47	178.98	45.47	-16.72	0	178.98	45.47	43.28	3
14	71.24	161.94	45.43	149.31	45.43	-103.49	1	161.94	45.43	-36.12	5
15	75.04	183.05	41.16	183.05	41.16	-89.16	3	183.05	41.16	50.84	10
16	61.82	202.52	30.88	202.52	30.88	-91.58	4	134.43	30.88	-103.49	0
17	214.76	262.48	17.49	262.48	17.49	-5.21	3	262.48	17.49	34.79	5
18	276.94	249.84	1.14	249.84	1.14	25.96	0	249.84	1.14	85.96	3
19	245.46	286.33	0.00	286.33	0.00	-20.87	1	301.97	0.00	103.49	8
20	229.06	414.86	0.00	414.86	0.00	-5.80	9	414.86	0.00	14.20	10
21	207.47	443.44	0.00	443.44	0.00	-15.97	11	443.44	0.00	24.03	13
22	185.98	519.98	0.00	519.98	0.00	26.00	18	519.98	0.00	-14.00	16
23	92.90	476.38	0.00	476.38	0.00	16.52	20	396.39	0.00	-103.49	10
24	91.24	518.85	0.00	518.85	0.00	-27.61	20	434.73	0.00	-103.49	12
1	88.16	321.87	0.00	321.87	0.00	6.29	12	321.87	0.00	-93.71	7
2	80.11	282.26	0.00	282.26	0.00	-2.14	10	282.26	0.00	-22.14	9
3	74.83	271.37	0.00	271.37	0.00	23.45	11	258.32	0.00	-103.49	4
4	86.01	278.02	0.00	278.02	0.00	-12.01	9	269.50	0.00	-103.49	4
5	229.41	232.72	0.00	232.72	0.00	-3.30	0	232.72	0.00	-3.30	0
6	232.12	231.58	0.00	231.58	0.00	0.54	0	231.58	0.00	0.54	0
7	255.77	202.35	0.00	202.35	0.00	53.42	0	202.35	0.00	53.42	0
8	289.96	200.78	0.00	200.78	0.00	89.18	0	200.78	0.00	89.18	0
9	250.85	276.91	0.56	276.91	0.56	-26.62	0	276.91	0.56	-26.62	0
10	228.17	260.42	4.20	260.42	4.20	-36.45	0	260.42	4.20	-36.45	0
11	228.55	235.28	33.85	235.28	33.85	-40.59	0	235.28	33.85	-20.59	1
12	239.15	175.08	41.80	175.08	41.80	22.27	0	175.08	41.80	22.27	0
13	188.84	162.70	41.34	162.70	41.34	-15.20	0	162.70	41.34	-15.20	0
14	76.10	172.97	48.52	151.10	48.52	-103.53	1	172.97	48.52	-45.40	5
15	69.98	170.71	38.38	170.71	38.38	-99.11	2	170.71	38.38	60.89	10
16	63.23	207.14	31.59	195.18	31.59	-103.53	3	195.18	31.59	-103.53	3
17	241.71	295.41	19.68	295.41	19.68	-33.39	2	295.41	19.68	-33.39	2
18	290.21	261.82	1.19	261.82	1.19	27.20	0	261.82	1.19	27.20	0
19	247.68	288.92	0.00	288.92	0.00	-1.24	2	288.92	0.00	58.76	5
20	244.70	443.19	0.00	443.19	0.00	-18.49	9	443.19	0.00	21.51	11

21	238.60	509.98	0.00	509.98	0.00	-51.38	11	509.98	0.00	28.62	15
22	208.24	582.22	0.00	582.22	0.00	-53.97	16	582.22	0.00	26.03	20
23	87.27	447.52	0.00	447.52	0.00	39.75	20	430.80	0.00	-103.53	12
24	80.30	456.61	0.00	456.61	0.00	23.69	20	456.61	0.00	-96.31	14
1	84.81	309.63	0.00	309.63	0.00	15.18	12	309.63	0.00	-44.82	9
2	86.34	304.21	0.00	304.21	0.00	2.13	11	304.21	0.00	22.13	12
3	77.80	282.16	0.00	282.16	0.00	-4.36	10	261.33	0.00	-103.53	4
4	92.43	298.79	0.00	298.79	0.00	-26.36	9	298.79	0.00	-86.36	6
5	258.10	261.82	0.00	261.82	0.00	-3.72	0	261.82	0.00	-3.72	0
6	231.63	231.09	0.00	231.09	0.00	0.54	0	231.09	0.00	0.54	0
7	267.33	211.50	0.00	211.50	0.00	55.83	0	211.50	0.00	75.83	1
8	254.77	176.41	0.00	176.41	0.00	78.36	0	211.23	0.00	103.53	3
9	264.64	292.13	0.59	292.13	0.59	-28.08	0	292.13	0.59	-8.08	1
10	239.86	273.76	4.42	273.76	4.42	-38.32	0	273.76	4.42	1.68	2
11	223.34	229.93	33.08	229.93	33.08	-39.66	0	229.93	33.08	60.34	5
12	238.48	174.59	41.68	174.59	41.68	22.20	0	174.59	41.68	22.20	0
13	201.79	173.86	44.17	173.86	44.17	-16.24	0	173.86	44.17	63.76	4
14	64.77	147.22	41.30	147.22	41.30	-63.75	3	147.22	41.30	56.25	9
15	71.93	175.45	39.45	173.16	39.45	-100.68	2	175.45	39.45	-42.97	5
16	60.71	198.87	30.33	198.87	30.33	-88.49	4	131.06	30.33	-100.68	0
17	225.24	275.28	18.34	275.28	18.34	-28.39	2	275.28	18.34	-8.39	3
18	251.56	226.95	1.03	226.95	1.03	23.58	0	226.95	1.03	43.58	1
19	240.62	280.68	0.00	280.68	0.00	19.94	3	299.94	0.00	100.68	8
20	245.54	444.72	0.00	444.72	0.00	20.82	11	444.72	0.00	-39.18	8
21	201.13	429.90	0.00	429.90	0.00	-8.76	11	429.90	0.00	91.24	16
22	194.83	544.72	0.00	544.72	0.00	-9.89	17	544.72	0.00	10.11	18
23	90.53	464.21	0.00	464.21	0.00	26.32	20	411.20	0.00	-100.68	11
24	89.50	508.95	0.00	508.95	0.00	-19.45	20	430.18	0.00	-100.68	12
1	79.99	292.05	0.00	292.05	0.00	47.94	13	280.67	0.00	-100.68	5
2	81.74	288.00	0.00	288.00	0.00	33.74	12	288.00	0.00	53.74	13
3	75.95	275.46	0.00	275.46	0.00	-19.51	9	275.46	0.00	-39.51	8
4	87.75	283.67	0.00	283.67	0.00	4.08	10	283.67	0.00	-75.92	6
5	245.10	248.63	0.00	248.63	0.00	-3.53	0	248.63	0.00	-3.53	0
6	245.32	244.75	0.00	244.75	0.00	0.57	0	244.75	0.00	40.57	2
7	246.31	194.87	0.00	194.87	0.00	51.44	0	205.64	0.00	100.68	3
8	271.20	187.79	0.00	187.79	0.00	83.41	0	187.79	0.00	83.41	0
9	275.67	304.31	0.61	304.31	0.61	-29.26	0	304.31	0.61	-29.26	0
10	252.09	287.72	4.64	287.72	4.64	-40.28	0	287.72	4.64	-20.28	1
11	198.86	204.72	29.45	204.72	29.45	-35.32	0	204.72	29.45	64.68	5
12	252.43	184.80	44.12	184.80	44.12	23.50	0	184.80	44.12	23.50	0
13	213.17	183.66	46.66	183.66	46.66	-17.16	0	183.66	46.66	22.84	2
14	74.20	168.66	47.32	168.66	47.32	-81.78	3	168.66	47.32	38.22	9
15	73.31	178.82	40.21	175.97	40.21	-102.86	2	178.82	40.21	-5.72	7

16	68.11	223.13	34.03	216.95	34.03	-102.86	4	136.95	34.03	-102.86	0
17	229.95	281.04	18.72	281.04	18.72	-9.82	3	281.04	18.72	30.18	5
18	285.73	257.78	1.17	257.78	1.17	26.78	0	257.78	1.17	86.78	3
19	232.77	271.53	0.00	271.53	0.00	1.25	2	271.53	0.00	61.25	5
20	233.25	422.46	0.00	422.46	0.00	10.79	10	422.46	0.00	30.79	11
21	235.14	502.57	0.00	502.57	0.00	-7.43	13	502.57	0.00	-7.43	13
22	198.04	553.70	0.00	553.70	0.00	-15.66	17	553.70	0.00	-35.66	16
23	85.01	435.91	0.00	435.91	0.00	49.10	20	367.87	0.00	-102.86	9
24	90.82	516.45	0.00	516.45	0.00	-25.63	20	393.68	0.00	-102.86	10
1	79.25	289.34	0.00	289.34	0.00	49.91	13	289.34	0.00	-90.09	6
2	79.66	280.65	0.00	280.65	0.00	39.01	12	280.65	0.00	59.01	13
3	84.79	307.50	0.00	307.50	0.00	-22.71	10	267.65	0.00	-102.86	4
4	92.63	299.42	0.00	299.42	0.00	-26.80	9	299.42	0.00	-26.80	9
5	244.30	247.82	0.00	247.82	0.00	-3.52	0	247.82	0.00	56.48	3
6	238.08	237.52	0.00	237.52	0.00	0.56	0	237.52	0.00	20.56	1
7	245.59	194.30	0.00	194.30	0.00	51.29	0	194.30	0.00	51.29	0
8	275.63	190.86	0.00	190.86	0.00	84.77	0	190.86	0.00	84.77	0
9	278.45	307.38	0.62	307.38	0.62	-29.55	0	307.38	0.62	-29.55	0
10	255.69	291.84	4.71	291.84	4.71	-40.85	0	291.84	4.71	-40.85	0
11	228.32	235.05	33.82	235.05	33.82	-40.55	0	235.05	33.82	39.45	4
12	258.47	189.22	45.18	189.22	45.18	24.07	0	189.22	45.18	64.07	2
13	185.74	160.03	40.66	160.03	40.66	-14.95	0	160.03	40.66	85.05	5
14	67.87	154.27	43.28	146.68	43.28	-102.09	1	154.27	43.28	-29.68	5
15	80.94	197.43	44.39	178.64	44.39	-102.09	2	197.43	44.39	-40.88	6
16	68.33	223.84	34.14	216.29	34.14	-102.09	4	136.29	34.14	-102.09	0
17	201.04	245.72	16.37	245.72	16.37	-21.04	2	245.72	16.37	38.96	5
18	257.38	232.20	1.06	232.20	1.06	24.12	0	232.20	1.06	24.12	0
19	244.60	285.32	0.00	285.32	0.00	19.28	3	285.32	0.00	39.28	4
20	255.74	463.19	0.00	463.19	0.00	-27.45	9	463.19	0.00	32.55	12
21	207.46	443.43	0.00	443.43	0.00	-15.96	11	443.43	0.00	84.04	16
22	206.11	576.25	0.00	576.25	0.00	-10.14	18	576.25	0.00	-30.14	17
23	84.63	433.97	0.00	433.97	0.00	50.66	20	433.97	0.00	-89.34	13
24	83.05	472.28	0.00	472.28	0.00	10.77	20	405.14	0.00	-102.09	11
1	79.95	291.90	0.00	291.90	0.00	28.05	12	282.04	0.00	-102.09	5
2	93.78	330.40	0.00	330.40	0.00	3.38	12	330.40	0.00	-36.62	10
3	78.11	283.27	0.00	283.27	0.00	-25.16	9	283.27	0.00	-65.16	7
4	99.56	321.85	0.00	321.85	0.00	-22.28	10	301.66	0.00	-102.09	5
5	271.94	275.85	0.00	275.85	0.00	-3.92	0	275.85	0.00	56.08	3
6	262.14	261.53	0.00	261.53	0.00	0.61	0	261.53	0.00	0.61	0
7	280.62	222.01	0.00	222.01	0.00	58.61	0	222.01	0.00	78.61	1
8	262.39	181.69	0.00	181.69	0.00	80.70	0	220.30	0.00	102.09	3
9	275.37	303.98	0.61	303.98	0.61	-29.22	0	303.98	0.61	-9.22	1
10	251.72	287.30	4.63	287.30	4.63	-40.22	0	287.30	4.63	-0.22	2

11	213.69	219.99	31.65	219.99	31.65	-37.95	0	219.99	31.65	62.05	5
12	237.50	173.87	41.51	173.87	41.51	22.11	0	173.87	41.51	82.11	3
13	217.01	186.97	47.50	186.97	47.50	-17.47	0	186.97	47.50	82.53	5
14	70.25	159.67	44.79	159.67	44.79	-94.22	2	159.67	44.79	-14.22	6
15	70.72	172.50	38.78	153.98	38.78	-102.05	1	172.50	38.78	39.43	9
16	66.76	218.69	33.35	175.46	33.35	-102.05	2	135.46	33.35	-102.05	0
17	200.87	245.50	16.36	245.50	16.36	-0.99	3	245.50	16.36	-40.99	1
18	254.10	229.24	1.04	229.24	1.04	23.82	0	229.24	1.04	23.82	0
19	243.83	284.42	0.00	284.42	0.00	-20.59	1	284.42	0.00	79.41	6
20	231.34	418.99	0.00	418.99	0.00	12.35	10	418.99	0.00	-7.65	9
21	209.43	447.63	0.00	447.63	0.00	-18.20	11	447.63	0.00	21.80	13
22	179.18	500.96	0.00	500.96	0.00	38.22	18	500.96	0.00	58.22	19
23	92.40	473.84	0.00	473.84	0.00	18.57	20	414.45	0.00	-102.05	11
24	87.64	498.36	0.00	498.36	0.00	-10.73	20	449.69	0.00	-102.05	13
1	78.50	286.61	0.00	286.61	0.00	51.89	13	286.61	0.00	-8.11	10
2	95.96	338.09	0.00	338.09	0.00	-42.13	10	338.09	0.00	-82.13	8
3	77.26	280.20	0.00	280.20	0.00	-2.94	10	280.20	0.00	-62.94	7
4	82.85	267.81	0.00	267.81	0.00	35.03	11	267.81	0.00	-84.97	5
5	227.23	230.50	0.00	230.50	0.00	-3.27	0	230.50	0.00	-3.27	0
6	244.32	243.75	0.00	243.75	0.00	0.57	0	243.75	0.00	20.57	1
7	269.82	213.47	0.00	213.47	0.00	56.35	0	213.47	0.00	76.35	1
8	280.31	194.10	0.00	194.10	0.00	86.21	0	194.10	0.00	86.21	0
9	235.30	259.75	0.52	259.75	0.52	-24.97	0	259.75	0.52	-24.97	0
10	238.44	272.14	4.39	272.14	4.39	-38.10	0	272.14	4.39	-38.10	0
11	217.69	224.11	32.24	224.11	32.24	-38.66	0	224.11	32.24	41.34	4
12	233.15	170.69	40.75	170.69	40.75	21.71	0	170.69	40.75	21.71	0
13	209.84	180.80	45.94	180.80	45.94	-16.89	0	180.80	45.94	23.11	2
14	69.96	159.01	44.61	159.01	44.61	-73.67	3	159.01	44.61	-53.67	4
15	74.68	182.16	40.96	178.14	40.96	-104.42	2	182.16	40.96	-48.44	5
16	63.96	209.51	31.95	196.42	31.95	-104.42	3	196.42	31.95	-104.42	3
17	241.86	295.61	19.70	295.61	19.70	6.56	4	295.61	19.70	46.56	6
18	288.16	259.97	1.18	259.97	1.18	27.01	0	259.97	1.18	67.01	2
19	277.35	323.52	0.00	323.52	0.00	-26.18	1	323.52	0.00	73.82	6
20	245.08	443.88	0.00	443.88	0.00	21.20	11	443.88	0.00	41.20	12
21	206.42	441.20	0.00	441.20	0.00	5.22	12	441.20	0.00	25.22	13
22	203.53	569.03	0.00	569.03	0.00	-5.51	18	569.03	0.00	14.49	19
23	101.55	520.74	0.00	520.74	0.00	-19.19	20	485.97	0.00	-104.42	14
24	78.17	444.52	0.00	444.52	0.00	33.65	20	444.52	0.00	-86.35	14
1	83.59	305.18	0.00	305.18	0.00	-1.59	11	305.18	0.00	-41.59	9
2	96.10	338.58	0.00	338.58	0.00	-22.48	11	338.58	0.00	-42.48	10
3	78.33	284.07	0.00	284.07	0.00	-25.74	9	242.74	0.00	-104.42	3
4	93.28	301.53	0.00	301.53	0.00	-28.25	9	301.53	0.00	-28.25	9
5	253.99	257.65	0.00	257.65	0.00	-3.66	0	257.65	0.00	-3.66	0

6	255.83	255.24	0.00	255.24	0.00	0.60	0	255.24	0.00	0.60	0
7	264.10	208.94	0.00	208.94	0.00	55.16	0	208.94	0.00	55.16	0
8	296.11	205.04	0.00	205.04	0.00	91.07	0	205.04	0.00	91.07	0
9	240.67	265.67	0.54	265.67	0.54	-25.54	0	265.67	0.54	-25.54	0
10	259.27	295.92	4.77	295.92	4.77	-41.42	0	295.92	4.77	38.58	4
11	213.90	220.21	31.68	220.21	31.68	-37.99	0	220.21	31.68	22.01	3
12	222.13	162.62	38.83	162.62	38.83	20.68	0	162.62	38.83	20.68	0
13	214.08	184.45	46.86	184.45	46.86	-17.23	0	184.45	46.86	22.77	2
14	71.91	163.44	45.85	163.44	45.85	-77.39	3	163.44	45.85	42.61	9
15	83.74	204.27	45.93	161.27	45.93	-103.45	1	204.27	45.93	33.54	10
16	67.84	222.23	33.89	217.40	33.89	-103.45	4	177.40	33.89	-103.45	2
17	210.20	256.90	17.12	256.90	17.12	-3.82	3	256.90	17.12	-43.82	1
18	254.63	229.72	1.05	229.72	1.05	23.87	0	229.72	1.05	43.87	1
19	260.50	303.87	0.00	303.87	0.00	16.63	3	317.04	0.00	103.45	8
20	237.22	429.65	0.00	429.65	0.00	7.57	10	429.65	0.00	-52.43	7
21	218.49	467.00	0.00	467.00	0.00	11.50	13	467.00	0.00	31.50	14
22	204.64	572.15	0.00	572.15	0.00	-47.51	16	572.15	0.00	32.49	20
23	102.08	523.45	0.00	523.45	0.00	-21.37	20	485.53	0.00	-103.45	14
24	77.09	438.38	0.00	438.38	0.00	38.71	20	380.54	0.00	-103.45	10
1	78.66	287.18	0.00	287.18	0.00	31.48	12	287.18	0.00	-28.52	9
2	90.38	318.45	0.00	318.45	0.00	-28.07	10	318.45	0.00	-48.07	9
3	81.15	294.30	0.00	294.30	0.00	-33.15	9	294.30	0.00	-73.15	7
4	86.72	280.32	0.00	280.32	0.00	26.39	11	280.32	0.00	-93.61	5
5	226.48	229.74	0.00	229.74	0.00	-3.26	0	229.74	0.00	-3.26	0
6	255.61	255.01	0.00	255.01	0.00	0.60	0	255.01	0.00	0.60	0
7	289.68	229.18	0.00	229.18	0.00	60.50	0	229.18	0.00	80.50	1
8	274.45	190.04	0.00	190.04	0.00	84.41	0	190.04	0.00	84.41	0
9	269.51	297.51	0.60	297.51	0.60	-28.60	0	297.51	0.60	-28.60	0
10	226.47	258.48	4.17	258.48	4.17	-36.18	0	258.48	4.17	63.82	5
11	211.13	217.36	31.27	217.36	31.27	-37.50	0	217.36	31.27	22.50	3
12	253.62	185.67	44.33	185.67	44.33	23.61	0	185.67	44.33	63.61	2
13	190.77	164.37	41.76	164.37	41.76	-15.36	0	164.37	41.76	24.64	2
14	64.41	146.40	41.07	146.40	41.07	-103.06	1	146.40	41.07	16.94	7
15	72.81	177.60	39.93	156.64	39.93	-103.77	1	177.60	39.93	-4.72	7
16	72.52	237.56	36.23	220.06	36.23	-103.77	4	200.06	36.23	-103.77	3
17	215.74	263.68	17.57	263.68	17.57	-5.51	3	263.68	17.57	-25.51	2
18	238.92	215.54	0.98	215.54	0.98	22.39	0	215.54	0.98	22.39	0
19	265.67	309.91	0.00	309.91	0.00	-24.23	1	321.91	0.00	103.77	8
20	238.40	431.78	0.00	431.78	0.00	-13.38	9	431.78	0.00	-33.38	8
21	208.71	446.08	0.00	446.08	0.00	22.62	13	446.08	0.00	82.62	16
22	174.58	488.10	0.00	488.10	0.00	46.48	18	488.10	0.00	86.48	20
23	102.66	526.41	0.00	526.41	0.00	-23.75	20	466.42	0.00	-103.77	13
24	77.42	440.24	0.00	440.24	0.00	37.18	20	440.24	0.00	-102.82	13

1	78.50	286.60	0.00	286.60	0.00	31.90	12	286.60	0.00	-48.10	8
2	89.36	314.83	0.00	314.83	0.00	14.52	12	314.83	0.00	14.52	12
3	82.47	299.09	0.00	299.09	0.00	-16.62	10	286.23	0.00	-103.77	5
4	91.56	295.97	0.00	295.97	0.00	15.59	11	295.97	0.00	-84.41	6
5	225.00	228.24	0.00	228.24	0.00	-3.24	0	228.24	0.00	56.76	3
6	259.12	258.51	0.00	258.51	0.00	0.60	0	258.51	0.00	60.60	3
7	291.77	230.83	0.00	230.83	0.00	60.94	0	248.00	0.00	103.77	3
8	281.52	194.93	0.00	194.93	0.00	86.58	0	194.93	0.00	86.58	0
9	273.72	302.16	0.61	302.16	0.61	-29.05	0	302.16	0.61	10.95	2
10	267.83	305.69	4.93	305.69	4.93	-42.79	0	305.69	4.93	-42.79	0
11	205.33	211.38	30.41	211.38	30.41	-36.46	0	211.38	30.41	-16.46	1
12	218.14	159.70	38.13	159.70	38.13	20.31	0	159.70	38.13	20.31	0
13	214.92	185.17	47.05	185.17	47.05	-17.30	0	185.17	47.05	42.70	3
14	73.63	167.36	46.95	149.04	46.95	-102.36	1	167.36	46.95	-40.69	5
15	81.18	198.01	44.52	159.02	44.52	-102.36	1	198.01	44.52	18.65	9
16	61.48	201.40	30.71	193.13	30.71	-102.36	3	153.13	30.71	-102.36	1
17	238.71	291.75	19.44	291.75	19.44	-32.48	2	291.75	19.44	-52.48	1
18	270.28	243.83	1.11	243.83	1.11	25.33	0	243.83	1.11	45.33	1
19	239.52	279.40	0.00	279.40	0.00	20.12	3	279.40	0.00	80.12	6
20	234.15	424.09	0.00	424.09	0.00	30.06	11	424.09	0.00	-29.94	8
21	220.27	470.79	0.00	470.79	0.00	9.48	13	470.79	0.00	69.48	16
22	183.90	514.16	0.00	514.16	0.00	29.74	18	514.16	0.00	49.74	19
23	98.24	503.79	0.00	503.79	0.00	-5.55	20	400.61	0.00	-102.36	10
24	91.62	521.02	0.00	521.02	0.00	-29.39	20	393.99	0.00	-102.36	10
1	80.59	294.22	0.00	294.22	0.00	26.37	12	294.22	0.00	-93.63	6
2	91.87	323.69	0.00	323.69	0.00	8.19	12	323.69	0.00	-51.81	9
3	77.23	280.10	0.00	280.10	0.00	17.13	11	259.60	0.00	-102.36	4
4	100.41	324.57	0.00	324.57	0.00	-24.16	10	302.77	0.00	-102.36	5
5	256.64	260.33	0.00	260.33	0.00	-3.70	0	260.33	0.00	-3.70	0
6	269.14	268.51	0.00	268.51	0.00	0.63	0	268.51	0.00	0.63	0
7	264.48	209.25	0.00	209.25	0.00	55.24	0	209.25	0.00	55.24	0
8	282.42	195.56	0.00	195.56	0.00	86.86	0	195.56	0.00	86.86	0
9	243.61	268.92	0.54	268.92	0.54	-25.85	0	268.92	0.54	-25.85	0
10	243.56	277.99	4.48	277.99	4.48	-38.91	0	277.99	4.48	21.09	3
11	230.63	237.43	34.16	237.43	34.16	-40.96	0	237.43	34.16	-0.96	2
12	258.63	189.34	45.21	189.34	45.21	24.08	0	189.34	45.21	44.08	1
13	201.34	173.47	44.07	173.47	44.07	-16.21	0	173.47	44.07	83.79	5
14	76.60	174.12	48.85	169.38	48.85	-101.63	2	174.12	48.85	-66.36	4
15	80.79	197.08	44.31	197.08	44.31	-100.59	3	197.08	44.31	-40.59	6
16	63.86	209.18	31.90	173.58	31.90	-101.63	2	133.58	31.90	-101.63	0
17	241.39	295.03	19.66	295.03	19.66	-33.30	2	295.03	19.66	-53.30	1
18	262.90	237.18	1.08	237.18	1.08	24.64	0	237.18	1.08	44.64	1
19	257.52	300.40	0.00	300.40	0.00	-22.88	1	315.90	0.00	101.63	8

20	255.32	462.42	0.00	462.42	0.00	-7.10	10	462.42	0.00	32.90	12
21	199.71	426.85	0.00	426.85	0.00	12.86	12	426.85	0.00	-7.14	11
22	194.88	544.86	0.00	544.86	0.00	-29.98	16	544.86	0.00	50.02	20
23	87.26	447.49	0.00	447.49	0.00	39.78	20	447.49	0.00	-80.22	14
24	79.05	449.54	0.00	449.54	0.00	29.51	20	400.68	0.00	-101.63	11
1	83.95	306.49	0.00	306.49	0.00	17.46	12	306.49	0.00	-22.54	10
2	90.75	319.72	0.00	319.72	0.00	11.03	12	319.72	0.00	11.03	12
3	76.20	276.35	0.00	276.35	0.00	-0.15	10	276.35	0.00	-80.15	6
4	92.44	298.80	0.00	298.80	0.00	-26.37	9	298.80	0.00	-46.37	8
5	261.99	265.76	0.00	265.76	0.00	-3.77	0	265.76	0.00	-3.77	0
6	235.86	235.31	0.00	235.31	0.00	0.55	0	235.31	0.00	0.55	0
7	277.51	219.55	0.00	219.55	0.00	57.96	0	219.55	0.00	57.96	0
8	250.64	173.55	0.00	173.55	0.00	77.09	0	209.01	0.00	101.63	3
9	247.45	273.16	0.55	273.16	0.55	-26.26	0	273.16	0.55	-6.26	1
10	259.00	295.61	4.77	295.61	4.77	-41.38	0	295.61	4.77	38.62	4
11	196.59	202.38	29.12	202.38	29.12	-34.91	0	202.38	29.12	-34.91	0
12	251.99	184.48	44.05	184.48	44.05	23.46	0	184.48	44.05	23.46	0
13	225.18	194.01	49.29	194.01	49.29	-18.13	0	194.01	49.29	21.87	2
14	64.81	147.32	41.33	145.87	41.33	-102.38	1	147.32	41.33	-43.84	4
15	72.56	176.99	39.79	175.15	39.79	-102.38	2	176.99	39.79	-4.23	7
16	66.03	216.29	32.98	195.43	32.98	-102.38	3	155.43	32.98	-102.38	1
17	240.15	293.51	19.56	293.51	19.56	7.08	4	293.51	19.56	7.08	4
18	258.16	232.90	1.06	232.90	1.06	24.20	0	232.90	1.06	24.20	0
19	250.53	292.24	0.00	292.24	0.00	-21.71	1	308.15	0.00	102.38	8
20	226.29	409.84	0.00	409.84	0.00	16.44	10	409.84	0.00	-3.56	9
21	223.46	477.62	0.00	477.62	0.00	-34.16	11	477.62	0.00	45.84	15
22	199.15	556.80	0.00	556.80	0.00	2.35	18	556.80	0.00	-17.65	17
23	86.63	444.21	0.00	444.21	0.00	42.42	20	429.01	0.00	-102.38	12
24	80.58	458.20	0.00	458.20	0.00	22.38	20	458.20	0.00	-97.62	14
1	88.38	322.66	0.00	322.66	0.00	-14.28	11	322.66	0.00	-94.28	7
2	81.63	287.60	0.00	287.60	0.00	14.03	11	287.60	0.00	-5.97	10
3	74.15	268.92	0.00	268.92	0.00	-14.77	9	268.92	0.00	-34.77	8
4	94.43	305.24	0.00	305.24	0.00	-30.81	9	305.24	0.00	-50.81	8
5	238.08	241.51	0.00	241.51	0.00	-3.43	0	241.51	0.00	-3.43	0
6	241.44	240.87	0.00	240.87	0.00	0.56	0	240.87	0.00	0.56	0
7	282.56	223.54	0.00	223.54	0.00	59.01	0	223.54	0.00	59.01	0
8	269.89	186.88	0.00	186.88	0.00	83.01	0	187.50	0.00	102.38	1
9	267.74	295.56	0.60	295.56	0.60	-28.41	0	295.56	0.60	11.59	2
10	262.27	299.35	4.83	299.35	4.83	-41.90	0	299.35	4.83	38.10	4
11	212.21	218.47	31.43	218.47	31.43	-37.69	0	218.47	31.43	2.31	2
12	249.52	182.67	43.61	182.67	43.61	23.23	0	182.67	43.61	83.23	3
13	209.72	180.70	45.91	180.70	45.91	-16.88	0	180.70	45.91	23.12	2
14	66.65	151.51	42.50	151.51	42.50	-67.36	3	151.51	42.50	-47.36	4

15	78.21	190.77	42.89	158.33	42.89	-103.02	1	190.77	42.89	-35.45	6
16	63.97	209.56	31.96	195.03	31.96	-103.02	3	175.03	31.96	-103.02	2
17	241.06	294.62	19.63	294.62	19.63	-33.19	2	294.62	19.63	-53.19	1
18	286.78	258.72	1.18	258.72	1.18	26.88	0	258.72	1.18	26.88	0
19	270.93	316.03	0.00	316.03	0.00	-5.11	2	316.03	0.00	74.89	6
20	260.31	471.47	0.00	471.47	0.00	-11.16	10	471.47	0.00	-11.16	10
21	207.25	442.97	0.00	442.97	0.00	-15.72	11	442.97	0.00	24.28	13
22	191.06	534.18	0.00	534.18	0.00	-23.12	16	534.18	0.00	-3.12	17
23	99.99	512.74	0.00	512.74	0.00	-12.75	20	463.01	0.00	-103.02	13
24	88.71	504.44	0.00	504.44	0.00	-15.73	20	431.72	0.00	-103.02	12
1	89.85	328.05	0.00	328.05	0.00	21.80	13	328.05	0.00	-78.20	8
2	79.60	280.44	0.00	280.44	0.00	19.16	11	280.44	0.00	-40.84	8
3	76.30	276.72	0.00	276.72	0.00	19.58	11	239.32	0.00	-103.02	3
4	88.49	286.06	0.00	286.06	0.00	2.43	10	286.06	0.00	-17.57	9
5	247.88	251.45	0.00	251.45	0.00	-3.57	0	251.45	0.00	-3.57	0
6	238.23	237.67	0.00	237.67	0.00	0.56	0	237.67	0.00	0.56	0
7	251.05	198.62	0.00	198.62	0.00	52.43	0	198.62	0.00	52.43	0
8	273.37	189.30	0.00	189.30	0.00	84.08	0	189.30	0.00	84.08	0
9	244.66	270.08	0.55	270.08	0.55	-25.96	0	270.08	0.55	34.04	3
10	254.47	290.44	4.69	290.44	4.69	-40.66	0	290.44	4.69	39.34	4
11	197.67	203.50	29.28	203.50	29.28	-35.11	0	203.50	29.28	24.89	3
12	215.51	157.77	37.67	157.77	37.67	20.07	0	157.77	37.67	80.07	3
13	216.09	186.18	47.30	186.18	47.30	-17.39	0	186.18	47.30	82.61	5
14	65.27	148.37	41.62	148.37	41.62	-64.72	3	148.37	41.62	-4.72	6
15	82.29	200.74	45.13	180.86	45.13	-103.70	2	200.74	45.13	16.43	9
16	64.01	209.68	31.98	195.73	31.98	-103.70	3	135.73	31.98	-103.70	0
17	212.75	260.03	17.32	260.03	17.32	-24.60	2	260.03	17.32	35.40	5
18	277.53	250.37	1.14	250.37	1.14	26.01	0	250.37	1.14	66.01	2
19	268.99	313.78	0.00	313.78	0.00	15.22	3	313.78	0.00	55.22	5
20	247.43	448.14	0.00	448.14	0.00	19.29	11	448.14	0.00	-0.71	10
21	229.19	489.86	0.00	489.86	0.00	-0.67	13	489.86	0.00	-0.67	13
22	190.86	533.62	0.00	533.62	0.00	17.24	18	533.62	0.00	-2.76	17
23	91.84	470.95	0.00	470.95	0.00	20.89	20	415.54	0.00	-103.70	11
24	90.66	515.52	0.00	515.52	0.00	-24.87	20	454.36	0.00	-103.70	13
1	89.30	326.04	0.00	326.04	0.00	23.26	13	326.04	0.00	-56.74	9
2	83.18	293.06	0.00	293.06	0.00	10.12	11	293.06	0.00	10.12	11
3	88.54	321.09	0.00	321.09	0.00	-52.56	9	321.09	0.00	-72.56	8
4	97.70	315.82	0.00	315.82	0.00	-38.12	9	281.40	0.00	-103.70	4
5	248.78	252.37	0.00	252.37	0.00	-3.58	0	252.37	0.00	56.42	3
6	258.13	257.53	0.00	257.53	0.00	0.60	0	257.53	0.00	40.60	2
7	286.33	226.53	0.00	226.53	0.00	59.80	0	226.53	0.00	59.80	0
8	291.34	201.74	0.00	201.74	0.00	89.60	0	201.74	0.00	89.60	0
9	276.25	304.96	0.62	304.96	0.62	-29.32	0	304.96	0.62	50.68	4

10	224.07	255.74	4.13	255.74	4.13	-35.80	0	255.74	4.13	-35.80	0
11	218.01	224.44	32.29	224.44	32.29	-38.72	0	224.44	32.29	61.28	5
12	256.21	187.57	44.78	187.57	44.78	23.86	0	187.57	44.78	23.86	0
13	220.70	190.15	48.31	190.15	48.31	-17.76	0	190.15	48.31	82.24	5
14	65.76	149.48	41.93	149.48	41.93	-65.65	3	149.48	41.93	-25.65	5
15	78.89	192.43	43.26	192.43	43.26	-96.81	3	192.43	43.26	23.19	9
16	72.61	237.87	36.28	217.78	36.28	-101.44	4	157.78	36.28	-101.44	1
17	231.90	283.44	18.88	283.44	18.88	-10.42	3	283.44	18.88	9.58	4
18	248.96	224.60	1.02	224.60	1.02	23.33	0	224.60	1.02	23.33	0
19	237.73	277.31	0.00	277.31	0.00	0.42	2	277.31	0.00	40.42	4
20	258.42	468.04	0.00	468.04	0.00	-29.62	9	468.04	0.00	10.38	11
21	197.68	422.51	0.00	422.51	0.00	15.17	12	422.51	0.00	95.17	16
22	176.99	494.84	0.00	494.84	0.00	42.15	18	494.84	0.00	22.15	17
23	86.93	445.78	0.00	445.78	0.00	41.15	20	368.37	0.00	-101.44	9
24	90.40	514.09	0.00	514.09	0.00	-23.69	20	491.84	0.00	-101.44	15
1	88.12	321.72	0.00	321.72	0.00	6.40	12	321.72	0.00	-53.60	9
2	84.39	297.34	0.00	297.34	0.00	7.05	11	297.34	0.00	-52.95	8
3	80.19	290.84	0.00	290.84	0.00	-30.65	9	290.84	0.00	-70.65	7
4	84.77	274.03	0.00	274.03	0.00	30.74	11	274.03	0.00	-9.26	9
5	243.71	247.22	0.00	247.22	0.00	-3.51	0	247.22	0.00	-3.51	0
6	261.44	260.83	0.00	260.83	0.00	0.61	0	260.83	0.00	60.61	3
7	255.16	201.87	0.00	201.87	0.00	53.29	0	201.87	0.00	53.29	0
8	257.45	178.27	0.00	178.27	0.00	79.18	0	178.27	0.00	99.18	1
9	264.15	291.59	0.59	291.59	0.59	-28.03	0	291.59	0.59	11.97	2
10	237.20	270.73	4.37	270.73	4.37	-37.90	0	270.73	4.37	2.10	2
11	205.36	211.41	30.42	211.41	30.42	-36.47	0	211.41	30.42	3.53	2
12	239.96	175.68	41.94	175.68	41.94	22.34	0	175.68	41.94	42.34	1
13	195.65	168.57	42.83	168.57	42.83	-15.75	0	168.57	42.83	84.25	5
14	76.13	173.04	48.54	173.04	48.54	-85.46	3	173.04	48.54	-25.46	6
15	81.81	199.55	44.87	199.55	44.87	-102.61	3	199.55	44.87	-22.61	7
16	67.65	221.60	33.79	198.44	33.79	-104.59	3	138.44	33.79	-104.59	0
17	219.62	268.42	17.88	268.42	17.88	13.31	4	268.42	17.88	-26.69	2
18	284.07	256.28	1.17	256.28	1.17	26.63	0	256.28	1.17	26.63	0
19	240.03	279.99	0.00	279.99	0.00	20.04	3	279.99	0.00	20.04	3
20	252.89	458.03	0.00	458.03	0.00	14.86	11	458.03	0.00	-65.14	7
21	227.87	487.04	0.00	487.04	0.00	-19.17	12	487.04	0.00	60.83	16
22	203.66	569.41	0.00	569.41	0.00	-5.75	18	569.41	0.00	-5.75	18
23	84.68	434.24	0.00	434.24	0.00	50.44	20	434.24	0.00	-89.56	13
24	80.77	459.30	0.00	459.30	0.00	21.47	20	405.35	0.00	-104.59	11
1	80.85	295.19	0.00	295.19	0.00	25.66	12	295.19	0.00	-74.34	7
2	88.28	311.03	0.00	311.03	0.00	-2.75	11	311.03	0.00	-2.75	11
3	81.61	295.99	0.00	295.99	0.00	5.62	11	295.99	0.00	-74.38	7
4	86.13	278.43	0.00	278.43	0.00	7.70	10	278.43	0.00	-12.30	9

5	228.50	231.79	0.00	231.79	0.00	-3.29	0	231.79	0.00	-3.29	0
6	275.39	274.75	0.00	274.75	0.00	0.64	0	274.75	0.00	0.64	0
7	275.01	217.57	0.00	217.57	0.00	57.44	0	217.57	0.00	57.44	0
8	297.24	205.82	0.00	205.82	0.00	91.42	0	232.65	0.00	104.59	2
9	255.82	282.40	0.57	282.40	0.57	-27.15	0	282.40	0.57	-7.15	1
10	228.24	260.50	4.20	260.50	4.20	-36.47	0	260.50	4.20	43.53	4
11	205.91	211.98	30.50	211.98	30.50	-36.57	0	211.98	30.50	23.43	3
12	239.41	175.27	41.85	175.27	41.85	22.29	0	175.27	41.85	22.29	0
13	205.62	177.16	45.01	177.16	45.01	-16.55	0	177.16	45.01	3.45	1
14	69.94	158.98	44.60	158.98	44.60	-73.64	3	158.98	44.60	46.36	9
15	71.40	174.15	39.15	157.61	39.15	-105.36	1	174.15	39.15	38.09	9
16	67.46	220.97	33.70	219.12	33.70	-105.36	4	199.12	33.70	-105.36	3
17	201.86	246.71	16.44	246.71	16.44	18.71	4	246.71	16.44	18.71	4
18	274.60	247.74	1.13	247.74	1.13	25.74	0	247.74	1.13	85.74	3
19	250.56	292.28	0.00	292.28	0.00	-21.72	1	292.28	0.00	58.28	5
20	230.42	417.34	0.00	417.34	0.00	-6.91	9	417.34	0.00	-46.91	7
21	217.18	464.19	0.00	464.19	0.00	-27.01	11	464.19	0.00	-27.01	11
22	201.10	562.25	0.00	562.25	0.00	-41.15	16	562.25	0.00	38.85	20
23	85.73	439.62	0.00	439.62	0.00	46.11	20	431.09	0.00	-105.36	12
24	89.11	506.75	0.00	506.75	0.00	-17.64	20	494.48	0.00	-105.36	15
1	84.85	309.78	0.00	309.78	0.00	35.07	13	309.78	0.00	-104.93	6
2	93.34	328.86	0.00	328.86	0.00	-35.52	10	328.86	0.00	24.48	13
3	80.28	291.16	0.00	291.16	0.00	-10.88	10	265.65	0.00	-105.36	4
4	84.66	273.68	0.00	273.68	0.00	-9.01	9	273.68	0.00	-29.01	8
5	230.51	233.83	0.00	233.83	0.00	-3.32	0	233.83	0.00	-3.32	0
6	241.84	241.28	0.00	241.28	0.00	0.56	0	241.28	0.00	0.56	0
7	263.04	208.11	0.00	208.11	0.00	54.94	0	208.11	0.00	94.94	2
8	302.43	209.41	0.00	209.41	0.00	93.01	0	209.41	0.00	93.01	0
9	276.01	304.68	0.62	304.68	0.62	-29.29	0	304.68	0.62	50.71	4
10	259.97	296.72	4.79	296.72	4.79	-41.53	0	296.72	4.79	38.47	4
11	203.39	209.39	30.13	209.39	30.13	-36.12	0	209.39	30.13	3.88	2
12	249.24	182.46	43.56	182.46	43.56	23.21	0	182.46	43.56	23.21	0
13	186.55	160.73	40.84	160.73	40.84	-15.02	0	160.73	40.84	84.98	5
14	71.40	162.29	45.53	162.29	45.53	-96.42	2	162.29	45.53	23.58	8
15	80.54	196.45	44.17	196.45	44.17	-100.08	3	196.45	44.17	-60.08	5
16	66.17	216.76	33.06	195.09	33.06	-101.98	3	155.09	33.06	-101.98	1
17	238.66	291.69	19.43	291.69	19.43	-12.47	3	291.69	19.43	27.53	5
18	240.88	217.31	0.99	217.31	0.99	22.58	0	217.31	0.99	42.58	1
19	239.88	279.81	0.00	279.81	0.00	-19.94	1	279.81	0.00	20.06	3
20	248.79	450.60	0.00	450.60	0.00	18.19	11	450.60	0.00	-21.81	9
21	213.26	455.80	0.00	455.80	0.00	-22.55	11	455.80	0.00	-22.55	11
22	175.32	490.16	0.00	490.16	0.00	5.16	16	490.16	0.00	85.16	20
23	87.69	449.65	0.00	449.65	0.00	38.03	20	449.65	0.00	-101.97	13

24	81.65	464.29	0.00	464.29	0.00	17.36	20	383.63	0.00	-101.98	10
1	88.88	324.51	0.00	324.51	0.00	24.37	13	310.86	0.00	-101.98	6
2	88.31	311.13	0.00	311.13	0.00	-22.82	10	311.13	0.00	-62.82	8
3	79.43	288.06	0.00	288.06	0.00	11.37	11	288.06	0.00	-88.63	6
4	89.98	290.87	0.00	290.87	0.00	19.11	11	290.87	0.00	-20.89	9
5	252.40	256.04	0.00	256.04	0.00	-3.64	0	256.04	0.00	-3.64	0
6	276.13	275.49	0.00	275.49	0.00	0.64	0	275.49	0.00	40.64	2
7	279.86	221.41	0.00	221.41	0.00	58.45	0	237.88	0.00	101.98	3
8	252.73	175.00	0.00	175.00	0.00	77.73	0	175.00	0.00	77.73	0
9	264.77	292.28	0.59	292.28	0.59	-28.10	0	292.28	0.59	-28.10	0
10	253.00	288.76	4.66	288.76	4.66	-40.42	0	288.76	4.66	39.58	4
11	208.42	214.56	30.87	214.56	30.87	-37.01	0	214.56	30.87	-37.01	0
12	219.25	160.51	38.32	160.51	38.32	20.41	0	160.51	38.32	60.41	2
13	186.08	160.32	40.73	160.32	40.73	-14.98	0	160.32	40.73	5.02	1
14	71.49	162.50	45.59	162.50	45.59	-96.60	2	162.50	45.59	-16.60	6
15	75.31	183.71	41.30	176.07	41.30	-102.06	2	183.71	41.30	30.30	9
16	67.75	221.95	33.85	215.96	33.85	-102.06	4	195.96	33.85	-102.06	3
17	226.64	277.00	18.46	277.00	18.46	11.18	4	277.00	18.46	31.18	5
18	249.00	224.64	1.02	224.64	1.02	23.34	0	224.64	1.02	23.34	0
19	237.94	277.55	0.00	277.55	0.00	20.39	3	277.55	0.00	100.39	7
20	225.22	407.91	0.00	407.91	0.00	-2.69	9	407.91	0.00	-2.69	9
21	219.11	468.32	0.00	468.32	0.00	10.79	13	468.32	0.00	-9.21	12
22	188.68	527.52	0.00	527.52	0.00	1.16	17	527.52	0.00	-18.84	16
23	86.14	441.70	0.00	441.70	0.00	44.44	20	368.19	0.00	-102.06	9
24	85.71	487.41	0.00	487.41	0.00	-1.70	20	487.41	0.00	-101.70	15
1	90.43	330.17	0.00	330.17	0.00	20.26	13	312.49	0.00	-102.06	6
2	81.70	287.87	0.00	287.87	0.00	-6.16	10	287.87	0.00	33.84	12
3	87.17	316.13	0.00	316.13	0.00	-48.96	9	269.22	0.00	-102.06	4
4	98.18	317.38	0.00	317.38	0.00	0.80	11	317.38	0.00	-99.20	6
5	256.93	260.63	0.00	260.63	0.00	-3.70	0	260.63	0.00	56.30	3
6	264.50	263.88	0.00	263.88	0.00	0.62	0	263.88	0.00	20.62	1
7	260.00	205.70	0.00	205.70	0.00	54.30	0	205.70	0.00	54.30	0
8	280.38	194.14	0.00	194.14	0.00	86.23	0	238.32	0.00	102.06	3
9	268.95	296.89	0.60	296.89	0.60	-28.54	0	296.89	0.60	11.46	2
10	256.52	292.78	4.72	292.78	4.72	-40.98	0	292.78	4.72	-40.98	0
11	233.24	240.12	34.55	240.12	34.55	-41.42	0	240.12	34.55	-1.42	2
12	246.67	180.59	43.12	180.59	43.12	22.97	0	180.59	43.12	42.97	1
13	206.67	178.06	45.24	178.06	45.24	-16.64	0	178.06	45.24	-16.64	0
14	73.09	166.13	46.61	150.10	46.61	-103.62	1	166.13	46.61	-19.65	6
15	72.98	178.02	40.03	176.58	40.03	-103.62	2	178.02	40.03	-5.07	7
16	69.26	226.87	34.60	178.28	34.60	-103.62	2	138.28	34.60	-103.62	0
17	234.40	286.49	19.09	286.49	19.09	-11.17	3	286.49	19.09	-11.17	3
18	251.19	226.62	1.03	226.62	1.03	23.54	0	226.62	1.03	43.54	1

19	242.98	283.43	0.00	283.43	0.00	-0.45	2	283.43	0.00	39.55	4
20	261.89	474.33	0.00	474.33	0.00	-32.44	9	474.33	0.00	27.56	12
21	240.31	513.62	0.00	513.62	0.00	-53.32	11	513.62	0.00	26.68	15
22	197.11	551.11	0.00	551.11	0.00	-13.99	17	551.11	0.00	46.01	20
23	102.41	525.15	0.00	525.15	0.00	-22.74	20	426.03	0.00	-103.62	11
24	88.35	502.42	0.00	502.42	0.00	-14.07	20	411.97	0.00	-103.62	11
1	82.08	299.66	0.00	299.66	0.00	22.41	12	299.66	0.00	-97.59	6
2	84.22	296.72	0.00	296.72	0.00	-12.50	10	296.72	0.00	-32.50	9
3	80.17	290.74	0.00	290.74	0.00	-30.57	9	290.74	0.00	-90.57	6
4	96.67	312.48	0.00	312.48	0.00	-15.81	10	312.48	0.00	-35.81	9
5	266.30	270.14	0.00	270.14	0.00	-3.84	0	270.14	0.00	16.16	1
6	242.00	241.44	0.00	241.44	0.00	0.56	0	241.44	0.00	20.56	1
7	250.93	198.52	0.00	198.52	0.00	52.41	0	198.52	0.00	72.41	1
8	290.80	201.36	0.00	201.36	0.00	89.44	0	201.36	0.00	89.44	0
9	239.80	264.71	0.53	264.71	0.53	-25.45	0	264.71	0.53	-5.45	1
10	234.36	267.48	4.31	267.48	4.31	-37.44	0	267.48	4.31	-17.44	1
11	224.41	231.03	33.24	231.03	33.24	-39.85	0	231.03	33.24	-19.85	1
12	222.35	162.78	38.86	162.78	38.86	20.70	0	162.78	38.86	20.70	0
13	207.26	178.57	45.37	178.57	45.37	-16.68	0	178.57	45.37	43.32	3
14	73.65	167.41	46.96	167.41	46.96	-80.73	3	167.41	46.96	-40.73	5
15	70.87	172.86	38.86	172.86	38.86	-100.86	2	172.86	38.86	39.14	9
16	64.52	211.36	32.23	196.68	32.23	-104.39	3	156.68	32.23	-104.39	1
17	216.42	264.51	17.62	264.51	17.62	14.29	4	264.51	17.62	-5.71	3
18	279.44	252.10	1.15	252.10	1.15	26.19	0	252.10	1.15	46.19	1
19	261.84	305.43	0.00	305.43	0.00	-3.59	2	305.43	0.00	36.41	4
20	226.95	411.04	0.00	411.04	0.00	15.91	10	411.04	0.00	15.91	10
21	241.14	515.40	0.00	515.40	0.00	-54.26	11	515.40	0.00	5.74	14
22	181.91	508.59	0.00	508.59	0.00	13.32	17	508.59	0.00	-6.68	16
23	97.89	501.96	0.00	501.96	0.00	-4.07	20	382.28	0.00	-104.39	9
24	78.15	444.41	0.00	444.41	0.00	33.74	20	382.54	0.00	-104.39	10
1	85.90	313.61	0.00	313.61	0.00	32.29	13	313.61	0.00	-27.71	10
2	89.95	316.91	0.00	316.91	0.00	-6.96	11	316.91	0.00	-66.96	8
3	86.77	314.68	0.00	314.68	0.00	-27.92	10	314.68	0.00	-87.92	7
4	86.91	280.96	0.00	280.96	0.00	5.96	10	280.96	0.00	-14.04	9
5	267.03	270.87	0.00	270.87	0.00	-3.85	0	270.87	0.00	36.15	2
6	256.62	256.02	0.00	256.02	0.00	0.60	0	256.02	0.00	20.60	1
7	259.53	205.32	0.00	205.32	0.00	54.20	0	215.14	0.00	104.39	3
8	295.94	204.92	0.00	204.92	0.00	91.02	0	251.55	0.00	104.39	3
9	241.91	267.04	0.54	267.04	0.54	-25.67	0	267.04	0.54	-25.67	0
10	251.08	286.57	4.62	286.57	4.62	-40.11	0	286.57	4.62	59.89	5
11	213.60	219.90	31.64	219.90	31.64	-37.93	0	219.90	31.64	22.07	3
12	234.34	171.56	40.96	171.56	40.96	21.82	0	171.56	40.96	21.82	0
13	205.88	177.38	45.07	177.38	45.07	-16.57	0	177.38	45.07	83.43	5

14	75.68	172.01	48.26	172.01	48.26	-84.59	3	172.01	48.26	-24.59	6
15	70.50	171.97	38.66	171.97	38.66	-100.13	2	171.97	38.66	39.87	9
16	65.75	215.37	32.84	198.43	32.84	-105.53	3	198.43	32.84	-105.53	3
17	212.73	260.00	17.32	260.00	17.32	-24.59	2	260.00	17.32	-4.59	3
18	254.66	229.75	1.05	229.75	1.05	23.87	0	229.75	1.05	43.87	1
19	277.06	323.19	0.00	323.19	0.00	13.87	3	323.19	0.00	13.87	3
20	247.72	448.66	0.00	448.66	0.00	-0.94	10	448.66	0.00	-40.94	8
21	207.15	442.76	0.00	442.76	0.00	4.39	12	442.76	0.00	64.39	15
22	191.63	535.79	0.00	535.79	0.00	-4.15	17	535.79	0.00	55.85	20
23	96.91	496.96	0.00	496.96	0.00	-0.04	20	382.44	0.00	-105.53	9
24	75.55	429.62	0.00	429.62	0.00	45.93	20	429.62	0.00	-94.07	13
1	78.61	287.02	0.00	287.02	0.00	31.60	12	287.02	0.00	-28.40	9
2	84.82	298.84	0.00	298.84	0.00	5.98	11	298.84	0.00	-34.02	9
3	77.48	281.00	0.00	281.00	0.00	16.48	11	281.00	0.00	-83.52	6
4	93.95	303.69	0.00	303.69	0.00	10.26	11	303.69	0.00	-49.74	8
5	231.78	235.12	0.00	235.12	0.00	-3.34	0	235.12	0.00	-3.34	0
6	266.83	266.21	0.00	266.21	0.00	0.62	0	266.21	0.00	0.62	0
7	292.47	231.38	0.00	231.38	0.00	61.08	0	231.38	0.00	81.08	1
8	303.53	210.18	0.00	210.18	0.00	93.35	0	238.00	0.00	105.53	2
9	238.24	262.99	0.53	262.99	0.53	-25.28	0	262.99	0.53	54.72	4
10	261.46	298.41	4.81	298.41	4.81	-41.77	0	298.41	4.81	18.23	3
11	216.79	223.18	32.11	223.18	32.11	-38.50	0	223.18	32.11	21.50	3
12	230.71	168.91	40.33	168.91	40.33	21.48	0	168.91	40.33	41.48	1
13	206.09	177.57	45.11	177.57	45.11	-16.59	0	177.57	45.11	23.41	2
14	63.87	145.17	40.73	145.17	40.73	-82.03	2	145.17	40.73	-42.03	4
15	82.28	200.69	45.12	160.93	45.12	-103.77	1	200.69	45.12	-43.54	6
16	62.91	206.08	31.43	206.08	31.43	-94.60	4	135.26	31.43	-103.77	0
17	222.51	271.95	18.12	271.95	18.12	-7.56	3	271.95	18.12	32.44	5
18	271.76	245.17	1.12	245.17	1.12	25.47	0	245.17	1.12	65.47	2
19	275.07	320.86	0.00	320.86	0.00	-25.80	1	331.29	0.00	103.77	8
20	229.29	415.29	0.00	415.29	0.00	34.00	11	415.29	0.00	-26.00	8
21	237.15	506.87	0.00	506.87	0.00	-29.72	12	506.87	0.00	10.28	14
22	202.76	566.89	0.00	566.89	0.00	-4.13	18	566.89	0.00	35.87	20
23	99.70	511.26	0.00	511.26	0.00	-11.56	20	403.47	0.00	-103.77	10
24	84.47	480.33	0.00	480.33	0.00	4.13	20	408.24	0.00	-103.77	11

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