Cell-Like Fuzzy P System and Its Application of Coordination Control in Micro-grid

Ke Chen[1], Jun Wang[1](✉), Ming Li[1], Jun Ming[1], and Hong Peng[2]

[1] Sichuan Province Key Laboratory of Power Electronics Energy-saving Technologies and Equipment and School of Electrical Engineering and Electronic Information, Xihua University, Chengdu 610039, Sichuan, China
745257101@qq.com

[2] School of Mathematics and Computer Engineering, Xihua University, Chengdu 610039, Sichuan, China

Abstract. Based on the fuzzy knowledge, this paper presents a cell-like fuzzy P system (CFPS for short). The CFPS is mainly characterized by the introduction of the fuzzy concept and includes the fuzzy catalyst. Afterwards, the definition and the operation process of the CFPS are elaborated. Based on the CFPS, this paper realizes its application in the control of micro-grid. It takes micro-grid system frequency and current work status as inputs. The CFPS gives the decision-making to choice the reasonable working conditions which include the control of the distributed power and the switching of loads in the micro-grid. Firstly, detailed reasoning is presented to prove the rationality and feasibility of the proposed control thoughts. Then, MATLAB simulation verifies the decision made by the CFPS is correct and the application is rationality which is aimed to achieve a stable energy management and control micro-grid system steady. Experimental results show that CFPS can manage micro-grid effectively, and play a role in load shifting by energy management to stabilize the frequency of feeder.

Keywords: Membrane computing · Cell-like fuzzy P system · Micro-grid · Coordination control

1 Introduction

Membrane computing (also called P system) is a theoretical model that simulates the structure and function of the biological tissue and its powerful computing capability can solve many computational problems effectively [1]. There are three main types of membrane computing model currently: cell type, tissue type and neuronal membrane system. Cell type membrane system which was first proposed has been extensively studied [2]. At present, many foreign scholars have involved in the study of membrane systems and their applications. Reference [3] proposed a fuzzy P system, which introduce the fuzzy data and a fuzzy set multiple rewrite rules. In [4], a fuzzy reasoning SN P system (FRSN P systems)

M. Gong et al. (Eds.): BIC-TA 2015, CCIS 562, pp. 18–32, 2015.
DOI: 10.1007/978-3-662-49014-3_2

was applied in fault diagnosis. FRSN P systems were extended from SN P systems. Its main character is that FRSN P systems can handle fuzzy information and express fuzzy knowledge. A generalization of various communication models based on the P system paradigm where two objects synchronously move across components was considered in [5]. Nevertheless, the applied research of P systems is still very weak compared to the theoretical study. How to use P system to solve a variety of practical engineering problems has been an important issue in the field of membrane computing [14,15].

Micro-grid is a single control unit which composes of multiple distributed generation units [6], load, the storage devices, the corresponding control devices and other components. It can provide the appropriate quality and reliability of power supply according to user needs [7]. Many scholars have devoted to the research of micro-grid. For example, Ref. [8] proposed a distributed multi-micro-grid inverter cooperative control system for the energy management system of the micro-grid master layer. In [9], it described a micro-grid for energy management systems, and made a specific introduction to the economic operation which used the proposed method as a planning tool in the micro-grid. A fuzzy cognitive map and petri nets constructed applies to independent multi-generation micro-grid energy management system in [10]. An improved particle swarm algorithm was proposed and its application was realized in the economic operation optimization micro-grid in [11]. Reference [12] presented a micro-grid framework based on multi-agent system. It established micro-grid control agents, local control agents, distributed energy agency and workload agent which composed of multi-agent control system, and analyzed the specific functions of the various agents in detail. Thus, there are a lot of control thoughts of the micro-grid control has been proposed, such as the master-slave control, and peer-to-peer control and hierarchical control. Nevertheless, there are few advanced decision algorithms as micro-grid control strategies to be used effectively to manage a micro-grid. It demonstrates that it needs a lot of researches in the control of micro-grid.

In this paper, a cell-like fuzzy P system (CFPS) is proposed based on the fuzzy knowledge. The CFPS is mainly characterized by the introduction of a fuzzy concept and includes the fuzzy catalyst. Afterwards, the definition and the work process of the CFPS are elaborated. Based on the CFPS, this paper realizes the application in the control of micro-grid. It takes micro-grid system frequency and current work status as inputs, and the CFPS gives the decision-making to choice the reasonable working conditions which include the control of the distributed power and the switching of loads in the micro-grid. Firstly, detailed reasoning is presented to prove the rationality and feasibility of the proposed control thoughts. Then, the MATLAB simulation verifies the decision made by the CFPS is correct and the application is rationality which is aimed to achieve a stable energy management and control micro-grid system steady. Experimental results show that CFPS can manage micro-grid effectively, and play a role in load shifting by energy management to stabilize the frequency of AC feeder.

The structure of the paper is organized as follow. The definition and the work process of the CFPS are elaborated in Sect. 2. In Sect. 3, the application of the coordination control in micro-grid using the proposed is elaborated, and the reasoning of the method is developed detailed. In Sect. 4, simulation and analysis are given. Finally, a summary of our approach and future work are given in Sect. 5.

2 Cell-Like P System Fuzzy Logic System

2.1 CFPS for Language Fuzzy Model

The structure of cell-like P system is shown in Fig. 1(a). The tree is shown in Fig. 1(b). Based on the above preparation knowledge, and combined with membrane computing, we define cell-like fuzzy P system for language fuzzy model (referred to as CFPS) as follow.

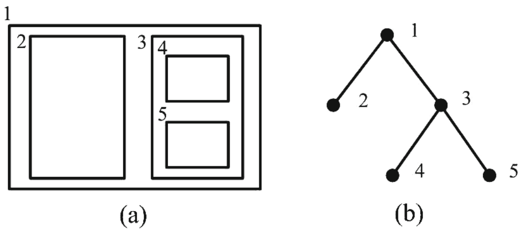

Fig. 1. (a) CFPS, (b) The tree of CFPS.

$$\Pi = (O, \mu, n, \omega_1, \cdots, \omega_m, C_1(u_1), \cdots, C_m(u_m), R_1, \cdots, R_m, i_0) \quad (1)$$

Where:

(1) $O = \{d_j\}$. O is a fuzzy multi-set [13]. d_j is a object to be used as the input. Operation starts from the compartments which don't contain cells in the next level.
(2) μ indicates that membrane structure is composed by m membranes.
(3) n indicates the levels of the P system. Level contains the input stage, intermediate stage and output stage. Among them, the highest level pattern is output, and the level excluding the lowest level pattern can be used as input. The level which is attached to the next level and the upper level is namely the middle level to do the operation. Intermediate stage can be multiple levels, but the input and output stages is only one. In Fig. 2, for example, the level of the system is 3. There is no next level but the upper level in 2, 4, and 5. They can be used as the input stage. There are the next levels but no upper level in 1, so it used as an output. Membrane 3 includes upper and lower levels, so we can see it as an intermediate layer, not as an input or output.

(4) ω_i, $i = m$. It indicates the fuzzy multi-set exists in the areas $1, 2, \cdots, m$ in the initial state. Here, we define ω_i only exists in the basic structure of the input stage membranes, and other membrane is empty.

(5) $C_m(u_m)$ is catalyst contained in each membrane. The place of the catalyst is unaltered, so that the value of it can be restored, and it let that calculation can be made without having to redefine each catalyst. The values in C_m is between $[0, 1]$. m is the degree of the membrane system. u_m is the reliability of the use of the catalyst, and indicates the intensity of the reliability for the associated rules related to catalyst. The value of u_m is between $[0, 1]$. Where, the catalyst in basic membrane and the membrane which don't include basic membrane is $C[c_1, c_2, \ldots, c_j]$ to act on the j objects, and the value of u_m is 1. The catalyst in the membrane n that in the middle level is $C[c_{n-(n+1)}, c_{n-(n+1)-(n+2)}, \ldots, c_{n-(n+1)-\ldots(k-1)-k}]$, $1 \leq n \leq k$, $1 \leq k \leq m$, $U[u_{n-(n+1)}, u_{n-(n+1)-(n+2)}, \ldots, u_{n-(n+1)-\ldots(k-1)-k}] \notin [0, 1]$. $c_{n-(n+1)}, c_{n-(n+1)-(n+2)}, \cdots, c_{n-(n+1)-\ldots(k-1)-k}$ is generated accompanying the cell movement between membrane n and the input level membrane. C is a set of catalysts from membrane n to membrane k through the membranes $n+1, \cdots, k-1$. When the membrane a in the input level meets the excitation conditions, and the relative catalyst exists and meet the conditions, then the objects will be changed by rule R_i from membrane a to membrane b. With this movement, the catalyst $c_{a-b}(u_{a-b})$ is generated. Foot marks a and b express the two membrane that engender related movement.

(6) R_i $(1 \leq i \leq m)$ is the set of the evolution rules. Rules indicate the form of the movements between the cells, such as transport, exchange and other forms. Here, we have defined the following three categories of fuzzy language model for the evolution rules, in which the input stage and the intermediate stage of the membrane were represented by n, the output stage was represented by m:

- **(a)** In the input level of basic membrane n, a class rule R_A can be used: $d_j c_j \rightarrow (d_j c_j, in_{(n+1)})$; $d_j > c_j(u_j)$. j represents the number of objects and their corresponding catalysts and rules. The rule indicates that when the membrane presence of the catalyst c_j and the object d_j meet excitation conditions $d_j > c_j$, R_A will be activated, and the object d_j will be transported from basic membrane n to the next level membrane $n+1$.
- **(b)** In the intermediate stage membrane n, a class rule R_B can be used: $d_j c_{n-(n+1)-\ldots(k-1)-k} \rightarrow (p_k c_{n-(n+1)-\ldots(k-1)-k}, in_n)$; $d_j > c_{n-(n+1)-\ldots(k-1)-k}$. j represents the number of objects and their corresponding catalysts and rules. The rule indicates that when the membrane presence of the catalyst $c_{n-(n+1)-\ldots(k-1)-k}$ and the object d_j meet excitation conditions $d_j > c_{n-(n+1)-\ldots(k-1)-k}$, R_B will be activated, and the object d_j will be transformed into p_k and transported from basic membrane m to the next level membrane k through membrane $n+1$ to $k-1$.
- **(c)** In the output level membrane n, a class rule R_C can be used: $p_k c_{n-(n+1)-\ldots(k-1)-k} \rightarrow (p_k c_{n-(n+1)-\ldots(k-1)-k}, out)$;

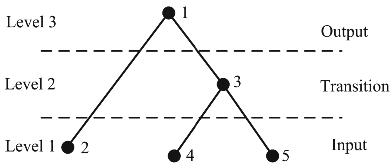

Fig. 2. The levels presentation of cell-like P system.

$p_k > c_{n-(n+1)-\ldots(k-1)-k}$. k represents the number of objects and their corresponding catalysts and rules. The rule indicates that when the membrane presence of the catalyst $c_{n-(n+1)-\ldots(k-1)-k}$ and the object p_k meet excitation conditions $p_k > c_{n-(n+1)-\ldots(k-1)-\ k}$, R_C will be activated, and the object p_k which is the output of the system will be transported to the environment.

2.2 Operation Process of CFPS

$$\Pi = (O, \mu, n, \omega_1, \cdots, \omega_5, C_1(u_1), \cdots, C_5(u_5), R_1, \cdots, R_5, i_0)$$

Where:

(1) $O = \{d_1, d_2, d_3, d_4, d_5, d_6\}$. $n = 3$. $i_0 = 4, 5$.
(2) $\omega_1 = \omega_3 = \lambda$, $\omega_2 = \{(d_5, 0.3), (d_6, 0.8)\}$, $\omega_4 = \{(d_1, 0.4), (d_2, 0.6)\}$, $\omega_5 = \{(d_3, 0.7), (d_4, 0.3)\}$.
(3) $C_1[c_{4-3-1} = 0.1(0.8), c_{5-3-1} = 0.5(0.7), c_{2-1} = 0.9(0.4)]$, $C_2[c_5 = 0.4(1), c_6 = 0.7(1)]$, $C_3[c_{4-3} = 0.3(0.6), c_{5-3} = 0.8(0.4)]$, $C_4[c_1 = 0.7(1), c_2 = 0.3(1)]$, $C_5[c_3 = 0.1(1), c_4 = 0.8(1)]$.
(4) $R_1 = R_C$, $R_2 = R_3 = R_B$, $R_4 = R_5 = R_A$.

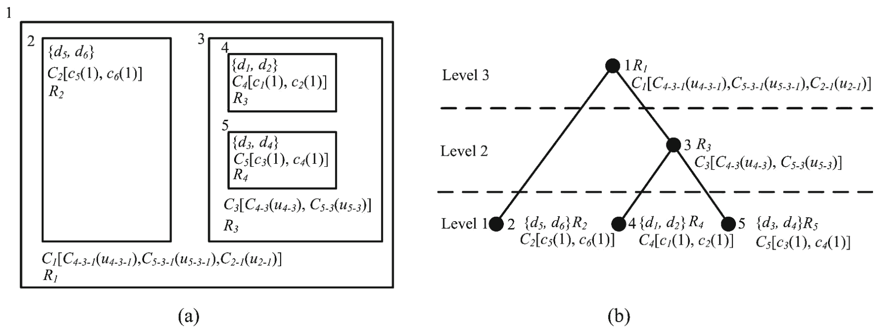

Fig. 3. (a) A CFPS as an example, (b) The tree of CFPS as an example.

The structure of CFPS as an example is shown in Fig. 3(a). The tree of it is shown in Fig. 3(b). Operation process is as follows:

Step1. Objects are included in membrane $4, 5, 2$, so the parallel operations start in $4, 5, 2$. In membrane 4, there are $d_1 = 0.4$, $c_1 = 0.7(1)$ and $d_1 < c_1$. Rule R_4 doesn't meet the excitation conditions. There are $d_2 = 0.6$, $c_2 = 0.3(1)$ and $d_2 < c_2$. R_4 meets the excitation conditions, hence d_2 moves into membrane 3. In membrane 5, $d_3 = 0.7$, $c_3 = 0.1(1)$, $d_3 > c_3$. R_5 meets the excitation conditions, hence d_5 moves into membrane 3. $d_4 = 0.3$, $c_4 = 0.8(1)$, $d_4 < c_4$, R_5 doesn't meet the excitation conditions. In membrane 2, $d_5 = 0.3$, $c_5 = 0.4(1)$, $d_5 < c_5$. R_2 doesn't meet the excitation conditions. $d_6 = 0.8$, $c_6 = 0.7(1)$, $d_5 > c_5$. R_2 meets the excitation conditions, hence d_6 moves into membrane 1.

Step2. Membrane 3 gets the objects d_2 and d_3 from membrane 4 and 5. Then, $d_{4\text{–}3} = d_2u_2 = 0.6$, $d_{5\text{–}3} = d_3u_3 = 0.7$. $C_3[c_{4\text{–}3} = 0.3(0.6)$, $c_{5\text{–}3} = 0.8(0.4)]$. Similarly, $d_{4\text{–}3} = d_2 = 0.6$ move into membrane 1.

Step3. Membrane 1 gets the objects d_6 and $d_{4\text{–}3}$ from membrane 2 and 3. Thus, $d_{4\text{–}3\text{–}1} = d_{4\text{–}3}u_{4\text{–}3} = 0.6 * 0.3 = 0.18$, $d_{2\text{–}1} = d_6u_6 = 0.8$. $C_1[c_{4\text{–}3\text{–}1} = 0.1(0.8)$, $c_{5\text{–}3\text{–}1} = 0.5(0.7)$,$c_{2\text{–}1} = 0.9(0.4)]$, $d_{4\text{–}3\text{–}1} > c_{4\text{–}3\text{–}1}$, R_1 meet the excitation conditions, $d_{out} = d_{4\text{–}3\text{–}1}u_{4\text{–}3\text{–}1} = 0.18 * 0.8 = 0.144$. d_{out} which is the output of the system will be transported to the environment. This is the end of operation.

The input objects can be given the appropriate physical sense. When the condition is satisfied, according to the evolution rules, the object will be evolved. Objects generated by the evolution rules also have its corresponding physical sense. The final output of the complete evolution of object called an output target. It is applied to fuzzy probabilistic reasoning and so on.

3 The Application of CFPS in Control of Micro-grid

Here, we use the CPFS with containing intermediate layer of fuzzy P System which also called language fuzzy model (basic model) to achieve its application in micro-grid. In grid-connect mode, system voltage and frequency are supported by the distribution network. In this paper, DGs only run under the islanded mode.

3.1 CFPS of the Control System for Micro-grid

The application object of this paper is a general micro-grid system and its topology structure is shown in Fig. 4. It consists of the photovoltaic generator system (PV), wind turbine generator system (WT), gas turbine generator system (GT), storage systems (Storage1, Storage2), important load (Load1) and general load (Load2). Reasonable control objective is to achieve coordinated control and energy management, maintain the frequency on the bus stability, meet the demands of important load Load1, and extend the service life of the energy storage device. Main control thought is as follow. PV and WT as an important distributed power supply has been accessed the micro-grid to ensure the full use of new energy. Storage1 as main power source responses the instantaneous fluctuation of load in micro-grid to guarantee basic power supply stability and its quality. Load1 is an important load. So the grid shall guarantee basic power supply stability and its quality. Our control objects choose GT, Storage2 and Load2. Their removal and access are not cause energy waste, and control reasonably. Reasons are as follows. The GT can be regarded as constant power source, and its power fluctuation is small. Its power is more smoothly than PV and WT. It is necessary to control fuel gas bubbled into or blocking to control its access or disconnect which reduces the waste of energy, achieves the rational use of fuel gas, and saves energy.

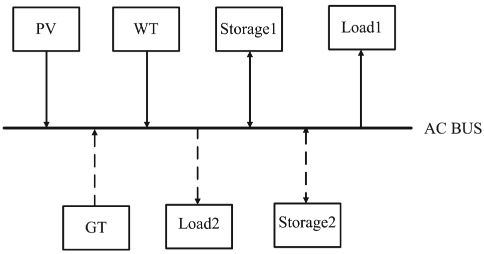

Fig. 4. Topology structure.

Control block diagram is shown in Fig. 5. We use CFPS to control the controllable GT, Storage2 and Load2. CFPS controller has four inputs that are the frequency on AC bus, current operating state of GT, Storage2 and Load2, the charge state of Storage2, and SOC respectively. Using three CFPS control unit to determine the correct state of GT, Storage2 and Load2 in the next moment.

3.2 Fuzzification of the Inputs in CFPS

Here, the values of inputs are in $[0, 1]$ to represent the degree. When f is in $[49, 51]$, micro-grid is working normally and all devices keep the original state. When f is in $[51, +\infty]$, it expresses the frequency is high. Corresponding measure is needed to be taken to regulate f to recover to the normal region. When f is in $[-\infty, 49]$, it expresses the frequency is low. Corresponding measure is needed, too. We will take 50 as the origin of coordinates to converted to zero, the value of f is mapped to $[0, 1]$. The size of the value is said the departure degree to the standard frequency. Polarity is expressed in plus or minus. "+" means the value is larger than standard value and "−" means the value is smaller than standard value. It is not mathematical in the sense of positive and negative. Here, we define "+" can be omitted, and "−" cannot be omitted. Catalyst also has a polarity. The corresponding catalyst also be with "+" or "−". The state of charge (SOC for short) is on behalf of the charge state of battery. SOC$= Q_c/Q_0$. Q_c is the remaining power. Q_0 is the capacity that battery discharges at a constant current I. SOC $= 1$ represents the full charged state. Here, we define when SOC

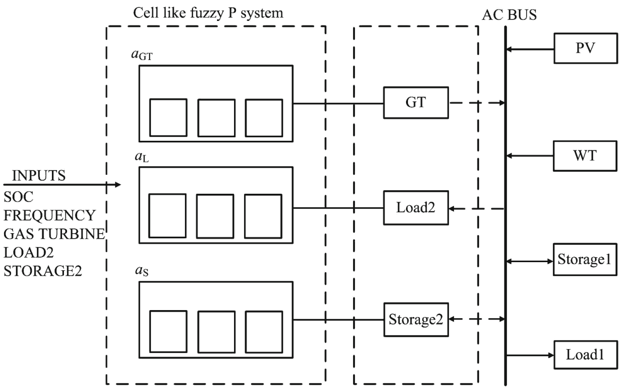

Fig. 5. Micro-grid control structure modeled by CFPS.

is greater than 0.8, storage should be disconnected to prevent the overcharge. When SOC is less than 0.2, it should be timely disconnected to prevent the excessive discharge which is damage to the battery life. There are three states of GT, Load, and Storage: on state, off state and maintaining state. Polarity "−" means disconnect and "+" means access. "±0" means maintain. More than or less than 0 indicates that access or disconnect the length of time $t = X * t$. Revising t to achieve precise control by continuous calculation. Deviation degree of the input f and each DG's control state will affect the switch state of the control objects. For example, GT= −0.6 means GT is in an off state, and the judge the turn-off time is $t = 0.6 * t$.

3.3 CFPS Model

Below we set input $f = +0.8$, $soc = 0.8$, $s = -0.4$, $gt = 0.8$ and $l = 0.8$ as an example to reason in detail as follow. Here, we only introduce CFPS model for GT. Using same method, CFPS model for Load2 and CFPS model for Storage2 CFPS model a_{GT} for GT can be expressed using (1). The structure of CFPS for GT is shown in Fig. 6(a). The tree is shown in Fig. 6(b). The operation process of a_{GT} is as follows. Object f exists in a_{GT4}, a_{GT7} and a_{GT10} respectively. $f = +0.8$ meets the excitation condition $f > +0.5$ of rule R_{GT4} in a_{GT4}. Thus, f accesses a_{GT1}. There is no f in a_{GT7} and a_{GT10} so that rules can't be used. a_{GT0} get effective objects from a_{GT1}. The work statement in a_{GT2} and a_{GT3} is needless to be discussed. In a_{GT5}, $soc = 0.8$, $s = 0.4$, $c_{5s} = 0$, $soc = 0.8$. It meets the excitation condition $s < c_{5s}\&soc = c_{5soc}$ of rule R_{GT5}. Then soc accesses a_{GT1}. In a_{GT6}, $gt = 0.8$, $l = 0.8$, $c_{6gt} = 0$, $c_{6l} = 0$. It meets the excitation condition $gt > c_{6gt}\&l > c_{6l}$ of rule R_{GT6}. Then gt and l access a_{GT1}. There are f, s, l and gt in a_{GT1} so that rule R_{GT1} can be used. Therefore, $Output = 0.8 * 0.25 + 0.8 * 0.25 + 0.8 * 0.25 + 0.8 * 0.25 = -0.8$. Similarly, CFPS model for Load2 expressed as a_L and model for Storage2 expressed a_s as can be built using Eq. 1.

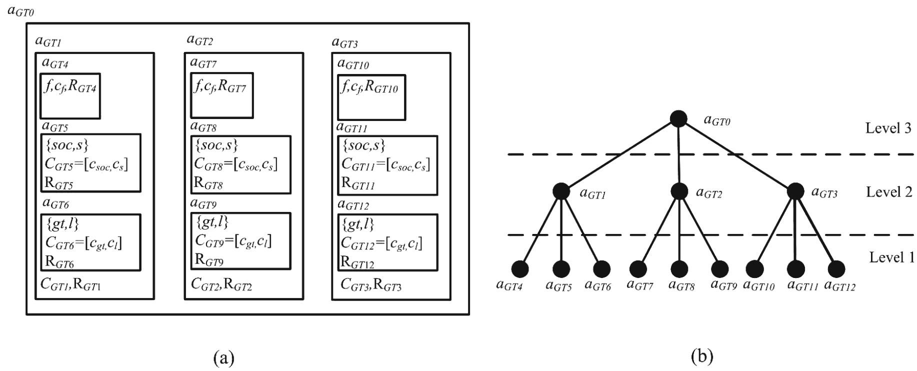

Fig. 6. (a) CFPS model for GT, (b) The tree of CFPS model for GT.

3.4 Result Analysis of Reasoning

Using multiple sets of data reasoning, the computation situation is as follows in Tables 1, 2 and 3. Where, t_{0n} represents the present state. t_{1n} shows the state the next time. $n = 1, 2, 3, 4$. The data in Tables 1, 2 and 3 shows that it obtains a more accurate result by using a cell-type fuzzy inference P system. When micro-grid is under different operating conditions, the change of the operating status of GT, Load2 and Storage2 are more reasonable to achieve effective energy management, maintain a frequency stability of the AC bus, and meet the energy demands of important load Load1. What's more, it extends the device life of the energy storage.

Table 1. f is larger than standard value.

T	t_{01}	t_{11}	t_{02}	t_{12}	t_{03}	t_{13}	t_{04}	t_{14}
f	0.8		0.6		0.7		0.8	
GT	0.8	–0.8	0.8	0.8	0.6	0.6	0.5	0.5
LOAD2	0.8	0.79	–0.2	–0.2	–0.2	0.46	–0.2	–0.2
STORAGE2	–0.4	–0.4	–0.4	0.5	0.5	0.5	–0.4	0.6
SOC	0.8		0.4		0.6		0.1	

4 Simulation

Based on the micro-grid systems given above and CFPS of it, we use MATLAB to verify the feasibility of the ideas. The parameters of DGs and loads are shown in the following Table 4.

Table 2. f is moderation.

T	t_{01}	t_{11}	t_{02}	t_{12}	t_{03}	t_{13}	t_{04}	t_{14}
f	0.3		0.4		–0.3		0.4	
GT	0.4	0.35	–0.4	–0.4	–0.4	–0.4	0.4	0.4
LOAD2	0.5	0.4	–0.5	–0.5	–0.5	–0.5	0.6	0.6
STORAGE2	0.6	0.45	–0.2	–0.2	0.2	–0.25	–0.6	0.5
SOC	0.3		0.8		0.8		0.2	

Table 3. f is smaller than standard value.

T	t_{01}	t_{11}	t_{02}	t_{12}	t_{03}	t_{13}	t_{04}	t_{14}
f	–0.6		–0.7		–0.8		–0.9	
GT	0.8	0.8	–0.2	0.45	0.6	0.6	–0.6	0.5
LOAD2	0.8	0.8	–0.2	0.45	0.6	0.6	–0.6	0.5
STORAGE2	–0.4	0.5	–0.2	0.45	–0.5	–0.65	0.4	0.6
SOC	0.5		0.7		0.2		0.6	

The changes of active power lead to the changes of frequency in Micro-grid. Therefore, we simulate the change of frequency by observing the change of active power. Two cases that are before or after control were compared. Data in 24 h are as example to simulate. The normal output power and power consumption of PV, WT and important load are shown in Fig. 7. The Fig. 8 shows that, when there were only the photovoltaic systems and wind power generation system as important load power supplied in micro-grid system, the system operated in an abnormal state most of the time. Output power appeared excessive in 0–18.2 h and shortage in 18.2–22.4 h, it made a serious impact on quality of power supply and causes AC feeder frequency fluctuations. It was not conducive to the normal operation of important loads. Consequently, accessing part of DGs to mitigate the serious distortion of power quality is essential.

4.1 Original Micro-grid System

In order to ease energy fluctuation, the GT, general load and two storage systems are connected to the above system. Photovoltaic power generation systems and wind power generation system access micro-grid with maximum power tracking control mode to improve the energy utilization. Two storage systems use droop

Table 4. The parameters of DGs and loads

PV/kW	WT/kW	GT/kW	Storage 1/kW	Storage 2/kW	Load 1/kVA	Load 2/kVA
20	15	5	20	10	20	5

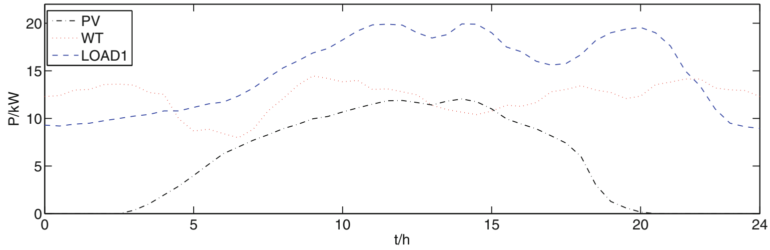

Fig. 7. Power of PV, WT and Load1.

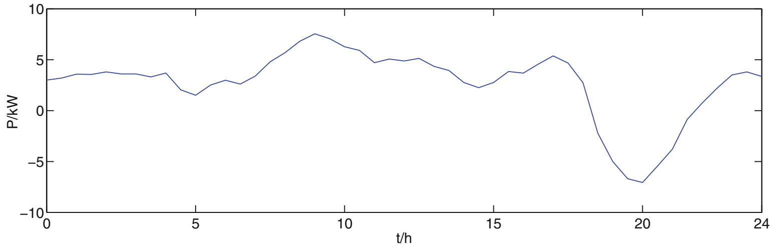

Fig. 8. Power difference curve.

control method. The initial states of charge are SOC1=0.23 and SOC2=0.4. GT operates with rated power shown in Table 1. Two storage systems can absorb the excess power or supplement insufficient power to bring down the energy fluctuation and guarantee the frequency stability in a period of time. The charge states of two storage systems in 24 h are shown in Fig. 9(a). PV, WT, Load1, Storage1 and Storage2 power changes are shown in Fig. 9(b). Figure 9(a)–(c) show that there was excess power at 0–12. Under the consumptive role of storage system Storage1 and Storage2, it achieved the balance of power. Storage1 had reached maximum storage charged state until 12, and cannot continue to absorb the extra power. In 14, Storage2 has reached the maximum charged state and unable to absorb excess power. So in the output power in 13.5 to 18.5 was high. It increased the feeder frequency of the system directly. The discharge of the storage systems in 18–21.3 and the charging of the storage system in 21.3–24 balanced the energy and power stably. The power curve of the whole system is shown in Fig. 9(c). Feeder frequency is shown in Fig. 9(d).

4.2 Micro-grid Using CFPS

We use ON/OFF control to GT, Load2 and Storage2 in the original system. CFPS is used to reasoning the control thought. Experimental results are as follows. The charge states of Storage1 and Storage2 are shown in Fig. 10(a). PV, WT, Load1, Storage1 and Storage2 power changes are shown in Fig. 10(b). The power of GT and Load2 changes are shown in Fig. 10(c) and Fig. 10(d). The figure shows that

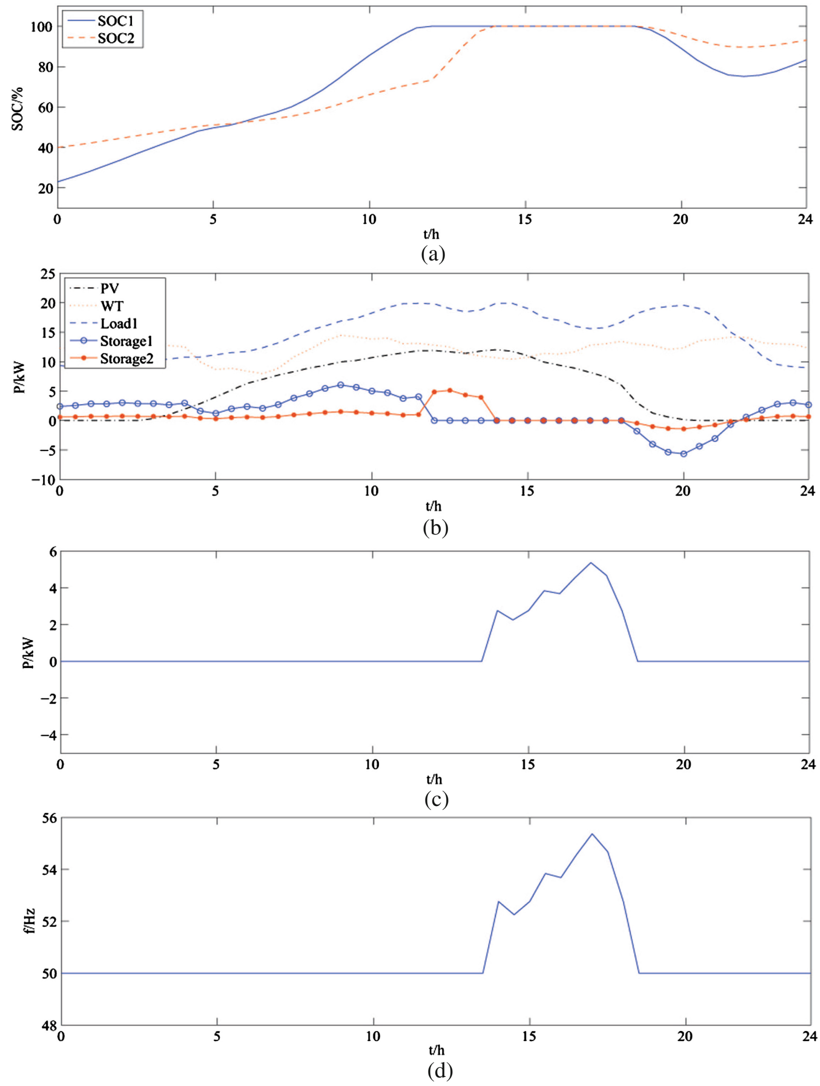

Fig. 9. (a) SOC of the original system, (b) DGs' power distribution of the original system, (c) The power difference curve of the original system, (d) AC frequency curve of the original system.

the surplus energy which can result a high frequency makes Storage1 and Storage2 charged in 0–8.5 h. In 8.5 h, the GT was disconnected and Load2 kept accessing. In 11, Load2 was disconnected and Storage1 and Storage2 stopped charging. Storage1 and Storage2 began to discharge in 12.5–14. In 15, Load2 accessed, Storage1 and Storage2 discharged, and GT kept disconnected. In 16, load2 was disconnected, Storage1 and Storage2 discharged, and GT was disconnected. In 17–18,

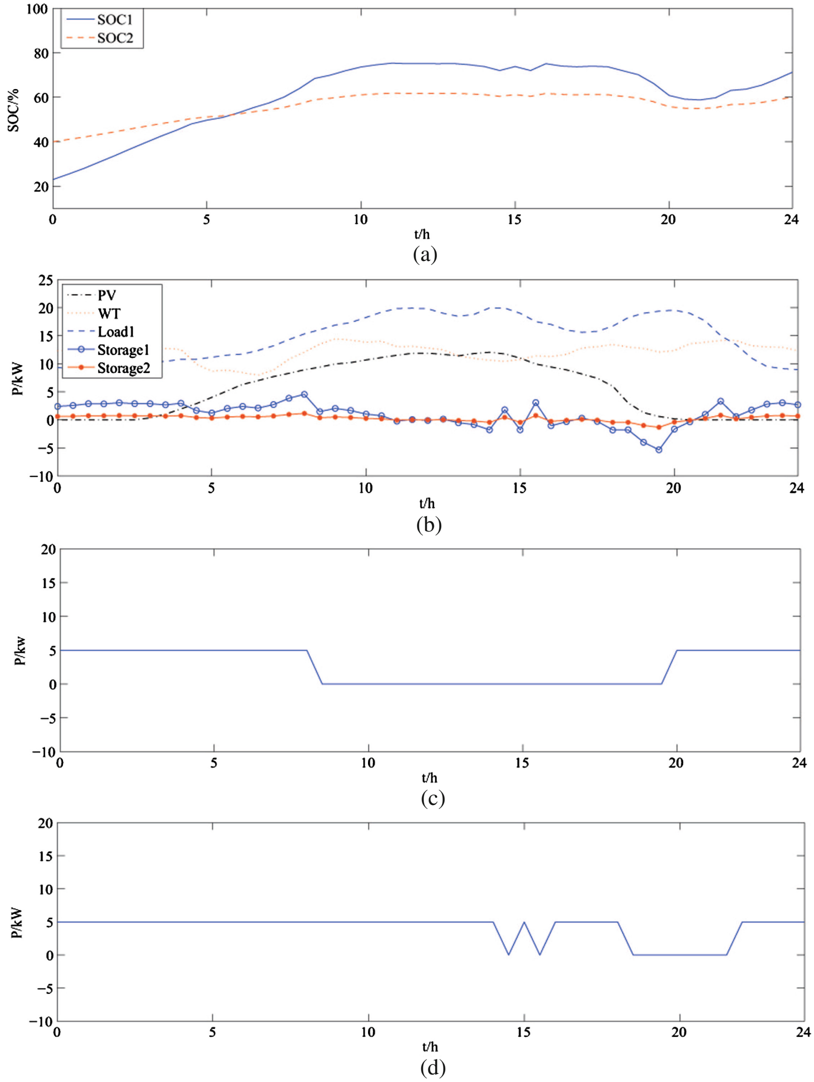

Fig. 10. (a) SOC, (b) Power distribution of DGs, (c) Power of GT, (d) Power of Load2.

Load2 kept accessing, Storage1 and Storage2 discharged, and GT kept being disconnected. Load2 kept disconnecting, Storage1 and Storage2 discharged, and GT was disconnected in 18 to 20. In 20.5–20.5, Load2 was disconnected, GT accessed, Storage1 and Storage2 charged. In 21.5–24, Load2 accessed GT accessed, Storage1 and Storage2 charged to regulate the energy balance and maintain frequency. Power curve after adjusted is shown in Fig. 11(a). It is known that its value is close to 0. It maintains the communication frequency stability of the feeder. The frequency of the AC feeder is shown in Fig. 11(b).

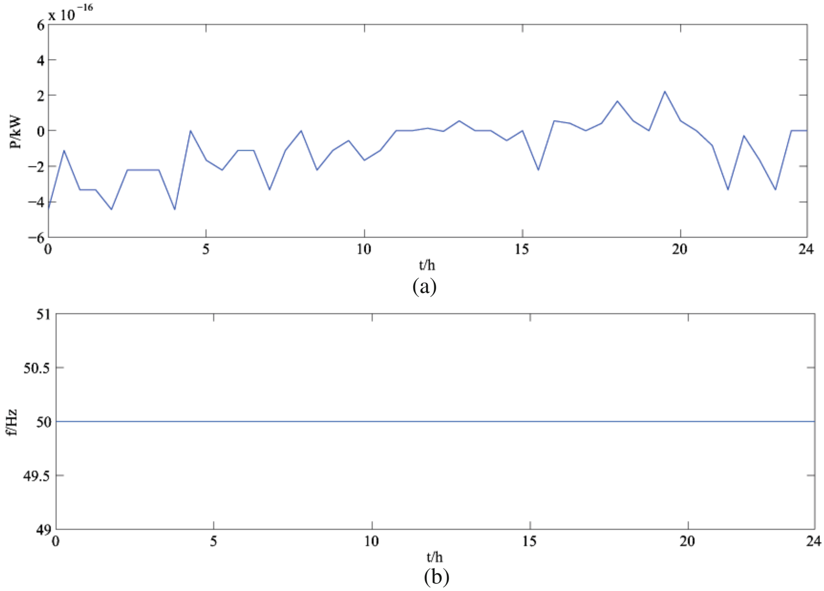

Fig. 11. (a) Power difference curve, (b) AC frequency curve.

4.3 Result Analysis

Simulation results show that it appears power imbalance (13.5-18.5 h) in the process of automatic control system for the micro-grid. The storage system achieves full state. Feeder frequency is higher than the standard. It reduces the utilization rate of DGs. Nevertheless, CFPS is adopted to improve the decision-making control system can better complete the decision making reasoning process in Tables 1, 2 and 3 in Sect. 4. Compared two kinds of control modes, CFPS control mode can maintain 24 h power balance in micro-grid, maintains the system frequency stability, realizes stable control effect and improves the utilization efficiency of DGs to verify the rationality of mind control.

5 Conclusion

This paper presents a cell-like fuzzy P system (CFPS for short) which based on the fuzzy knowledge. Based on the CFPS, this paper realizes the application in the control of micro-grid. Detailed reasoning is presented to prove the rationality and feasibility of the proposed control thoughts. The MATLAB simulation verifies the decision made by the CFPS is correct and the application is rationality which is aimed to achieve a stable energy management and control micro-grid system steady. Experimental results show that CFPS can manage micro-grid effectively, and play a role in load shifting by energy management to stabilize the frequency of AC feeder. Nonetheless, the hardware features of the system in the process of simulation are not considered so that the control results are ideal. This problem needs further consummate in future work to make the results more close to actual situation.

Acknowledgments. This work was supported by the National Natural Science Foundation of China (Grant No. 61170030, 61472328), Fund of Sichuan Provincial Department of Science and Technology (No. 2013GZ0130) and a grant from the key equipment project of Sichuan Provincial Economic and Information Committee (No. [2014]128).

References

1. Păun, G.: Introduction to membrane computing. Appl. Membr. Comput. 1–42. Springer, Heidelberg (2006)
2. Păun, G.: Computing with membranes. J. Comput. Syst. Sci. **61**(1), 108–143 (2000)
3. Syropoulos, A.: Fuzzifying P systems. Comput. J. **49**(5), 619–628 (2006)
4. Peng, H., Wang, J., Mario, J., Pérez-Jiménez, M.J., Wang, H., Shao, J., Wang, T.: Fuzzy reasoning spiking neural P system for fault diagnosis. Inf. Sci. **235**, 106–116 (2012)
5. Verlan, S., Bernardini, F., Gheorghe, M.: Generalized communicating P systems. Theor. Comput. Sci. **404**(1), 170–184 (2008)
6. Lasseter, R.H.: Microgrids. In: 2002 Power Engineering Society Winter Meeting, pp. 305–308 (2002)
7. Lu, X.Z., Wang, C.X., Min, Y.: Overview on micro-grid research. Autom. Electr. Power Syst. **31**(19), 100–107 (2007)
8. Prodanovic, M., Green, T.C.: High-quality power generation through distributed control of a power park microgrid. IEEE Trans. Ind. Electron. **53**(5), 1471–1482 (2006)
9. Muller, H., Rudolf, A., Aumayr, G.: Studies of distributed energy supply systems using an innovance energy management system. In: 2001 IEEE Power Engineering Society Meeting: Institute of Electrical and Electronics Engineers, CPP, pp. 87–90 (2001)
10. Kyriakarakos, G., Dounis, A.I., Arvanitis, K.G.: A fuzzy cognitive maps-petri nets energy management system for autonomous polygeneration microgrids. Appl. Soft Comput. **12**(12), 3785–3797 (2012)
11. Liu, T., Wang, J., Sun, Z.: An improved particle swarm optimization and its application for micro-grid economic operation optimization. In: Pan, L., Păun, G., Pérez-Jiménez, M.J., Song, T. (eds.) Bio-Inspired Computing-Theories and Applications, pp. 276–280. Springer, Heidelberg (2014)
12. Wu, Z., Gu, W.: Active power and frequency control of islanded micro-grid based on multi-agent technology. Electr. Power Autom. Equip. **29**(11), 57–61 (2009)
13. Miyamoto, S.: Multisets and fuzzy multisets. Soft Comput. Human-Centered Mach. 9–33. Springer, Japan (2000)
14. Song, T., Pan, L.: Spiking neural P systems with rules on synapses working in maximum spikes consumption strategy. IEEE Trans. NanoBiosci. **14**(1), 38–44 (2015)
15. Song, T., Pan, L.: Spiking neural P systems with rules on synapses working in maximum spiking strateg. IEEE Trans. NanoBiosci. **14**(4), 465–477 (2015)

http://www.springer.com/978-3-662-49013-6

Bio-Inspired Computing -- Theories and Applications
10th International Conference, BIC-TA 2015 Hefei,
China, September 25-28, 2015, Proceedings
Gong, M.; Pan, L.; Song, T.; Tang, K.; Zhang, X. (Eds.)
2015, XVIII, 727 p. 303 illus. in color., Softcover
ISBN: 978-3-662-49013-6