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Load Curve Modeling Based on Behavior Analysis of Distributed Power Customers

Xinyang HAN¹, Yu ZHANG¹, Yuqiao JIAO^{2,3}, Yue ZHANG¹, Yanjing QU⁴ and Min DING^{2,3,*}

¹ State Grid Energy Research Institute, Beijing 102200, P. R. China;

² School of Automation, China University of Geosciences, Wuhan 430074, P. R. China;

³ Hubei Key Laboratory of Advanced Control and Intelligent Automation for Complex System, Wuhan 430074, P. R. China;

⁴ State Grid Shanghai Municipal Electric Power Company, Shanghai 200122, P. R. China

*E-mail:dingmin@cug.edu.cn Tel: 027-8883018

Abstract. As renewable power generation directly affects the customers' traditional electricity behavior and then offsets the power load, this paper proposes a load curve modeling method for renewable power customers based on the behavior analysis. Firstly, customers' active behavior is represented by the quantity of active customer households. Based on the analysis of customer behaviors, a modeling method for the quantity of active customer households is proposed based on Markov Chain Monte Carlo method. Then, with the inputs as the quantity of active customer households and time of photovoltaic power generation, an inference model based on fuzzy logic is proposed to get the quantity of customer household starting electrical appliances. By combining the average usage time of electrical appliances, load characteristics are analyzed based on usage state of electrical appliance of distributed power customers. Finally, the simulation results verify the effectiveness of the proposed method.

1. Introduction

Distributed power is a new type of power generation different from traditional power grid and it is necessary to master the introduction of distributed power on power grid load. Load characteristics are the basis of power grid planning, power grid operation and demand-side. VZ.Zakaria[1] compares accuracy of fuzzy cluster analysis and K mean value statistics method in customer load cluster and discrimination of different customer types. Dumbrava[2] introduces application of load curve in electricity price compilation, cost analysis, power grid planning, load management, market settlement and other aspects. literature[3] studies load characteristics in Changde and analyzes influence of seasonal load on load characteristics; literature[4] analyzes power load indexes in Chongqing and studies related influence of load characteristics and climate factors. However, none of these research methods consider the impact of user behavior factors on load characteristics.

The development of distributed power makes it possible for power customers to participate in operation of power system. In the current phase, method for load characteristic modeling based on customer behavior is mainly divided into two types: from top to bottom and from bottom to top. The former regards the whole load system as modeling target and adopts linear regression for modeling



based on measurement data of system load. For example, Song et. al.[5] use fuzzy linear regression to predict power consumption of residential families in different days. The latter regards single domestic appliance as modeling target and establishes customer load model based on electrical characteristics of electric appliance. For example, Walker C F[6] puts forward residential behavior model and tendency model to explain influence of residential behavior on switch characteristics of electrical appliance.

Aiming at load complicity and randomness brought by adding distributed power, one load curve modeling method including distributed power customer is proposed in this paper.

The chapters in this paper are arranged as: Chapter 2 introduces the analysis idea of this paper based on load characteristic analysis framework of distributed customer behavior. Chapter 3 presents a modeling method for number of active customers based on the Markov Chain Monte Carlo method to determine the number of active customers. Chapter 4 presents an inference model based on fuzzy logic to get the number of customers with open electrical appliances. Chapter 5 is the simulation which verifies effectiveness of the method proposed in the paper. Chapter 6 gives the conclusion.

2. Load Characteristic Analysis Framework Based on Customer Behavior

Basic information of power customers is the main contents of customers, determining use of distributed power and electrical appliance. Customer load characteristic is related to activities done by customer in a day[7] so that it has randomness and diversity.

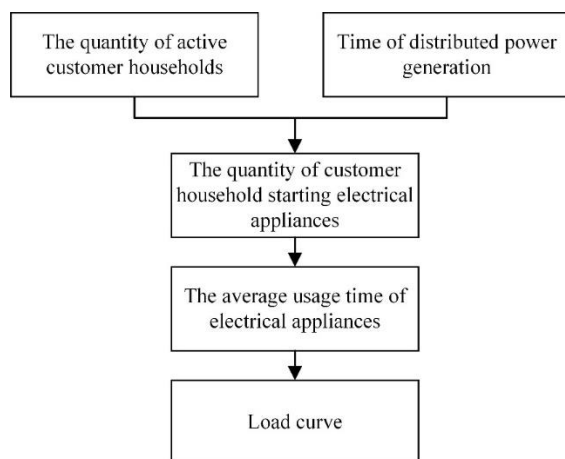


Figure 1. Load Characteristic Analysis Framework

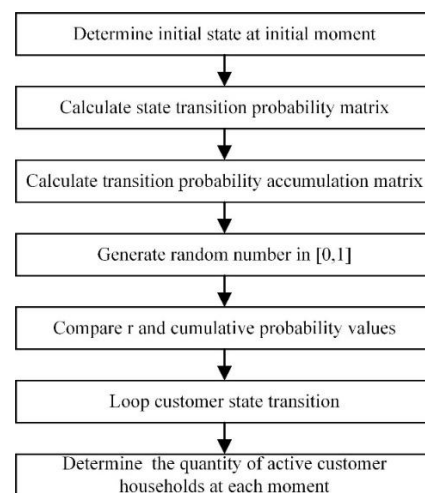


Figure 2. MCMC Simulation

Load curve modeling framework based on distributed power customer is: correspond customer activity with active customer state and adopt Markov Chain Monte Carlo to conduct dynamic simulation on transference of active state of power use of customers within designated time interval; establish fuzzy rule of the quantity of active customer households and time of photovoltaic power generation to determine the quantity of customer household starting electrical appliances; determine the average usage time of electrical appliances based on statistical data; finally, the quantity of active customer households, time of photovoltaic power generation, the quantity of customer household starting electrical appliances and the average usage time of electrical appliances commonly decide power use load curve of distributed power customer. Figure 1 shows the Load Characteristic Analysis Framework.

3. Active Customer Household Quantity Based on MCMC

Adopt Markov Chain Monte Carlo (MCMC) method to conduct dynamic simulation on transfer of active customer state in using power so as to get active state of N customers in certain area in various time intervals within 1 day.

3.1. MCMC Method

MCMC is the method of random simulation through computer in Bayes theory frame. The method introduces Markov process into Monte Carlo simulation[8] and uses dynamic simulation that sampling distribution is changed with simulation to make up for defects of traditional Monte Carlo integral which can only conduct static simulation. The statistical calculation method is widely applied in recent years.

3.2. Active customer state

Active customer state refers to the driving factor of energy use which can be divided into active state (there are people in the home and they are not sleeping) or non-active state (no one is at home or all of them are sleeping)[9]. Introduce random Markov process into Monte Carlo simulation, Correspond customer household n in active state with each state of Markov Chain.

Calculate the state probability transfer matrix of active customer state from various unit time intervals to next time interval based on activity statistical data with 15min as time interval in M days. Transition probability matrix of active customer state is consisted of residential state transition probability[10] $p_{ij}(n)$. It is specifically shown as follows:

$$p_{ij}(n) = \frac{a_{ij}(n)}{a_i(n)} \quad (1)$$

$p_{ij}(n)$ is the probability of transition of active customer from i household to j household in the n unit time interval; $a_{ij}(n)$ is the total quantity of transition of active customer from i household to j household in the n unit time interval; $a_i(n)$ is total quantity of state transition of active customers within the n unit time step: $a_i(n) = \sum_{j=0}^N a_{ij}(n)$.

The generated transition probability matrix of active customer state is as below:

$$P = \begin{bmatrix} p_{0,0} & p_{0,1} & \cdots & p_{0,N} \\ p_{1,0} & p_{1,1} & \cdots & p_{1,N} \\ \vdots & \vdots & \vdots & \vdots \\ p_{N,0} & p_{N,1} & \cdots & p_{N,N} \end{bmatrix} \quad (2)$$

It is assumed that the initial state is n_i , generate one random number r obeying balanced distribution $[0,1]$ and compare the value between r and various accumulated probability values; in the next step, the state shall be transited to corresponding active customer household state. Refer to Figure 2 for simulation chart.

4. Determination of Customer Electrical Appliance State Based on Fuzzy Logic Reasoning

Use state of electrical appliance includes starting time and the average usage time of electrical appliance (take flexible load washing appliance as example for the electrical appliance).

4.1. Starting time of electrical appliance

The starting time of electrical appliance of users can be gotten through fuzzy logic reasoning. It is assumed that there are 10 distributed power households in one area and the time for photovoltaic power generation is from 6 a.m. to 18 p.m.; regard active customer household n_i and photovoltaic power generation time t_i as input variable and electrical appliance starting household A_i as output variable. The step is designed as below:

Step 1: Fuzzification. Select fuzzy field of n_i , t_i and A_i as $n_i = \{0,1,2,3,4,5,6,7,8,9,10\}$, $t_i = [6,18]$,

$A_i = \{0,1,2,3,4,5,6,7,8,9,10\}$.

Curve shown in Figure 3 is adopted for membership function of the quantity of active customer households and the quantity of customer household starting electrical appliances; curve shown in Figure 4 is adopted for time of photovoltaic power generation time.

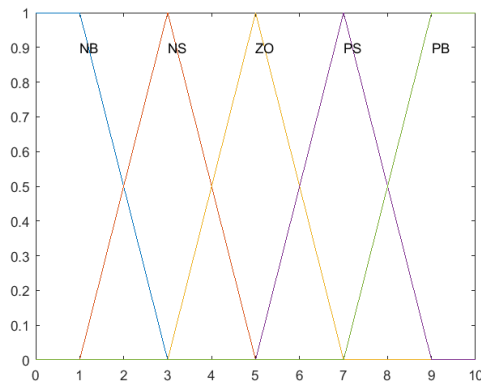


Figure 3. Membership Function of n_i

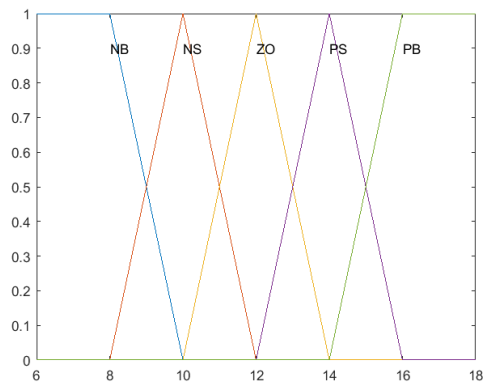


Figure 4. Membership Function of t_i

Step 2: Fuzzy reasoning. Fuzzy rule is shown in Table 1.

Step 3: Clarity. Adopt method of weighted mean to clarify and get the final output value.

Table 1 Fuzzy Rule of A_i

	n_i	t_i				
		NB	NS	ZO	PS	PB
Fuzzy set	NB	NB	NB	NS	NS	ZO
	NS	NB	NS	NS	ZO	PS
	ZO	NS	NS	ZO	PS	PS
	PS	NS	ZO	PS	PS	PB
	PB	ZO	PS	PS	PB	PB

4.2. Average usage time of electrical appliance

Count operation duration after the electrical appliance is started each time in M days and calculate average value of use duration so as to get the average usage time of electrical appliance. The calculation formula is as follows:

$$\overline{T_{av}} = \frac{\sum_{t=0}^{M*N} T_d}{M * N} \quad (3)$$

where, T_d is the use time of electrical appliance of one customer in one day.

4.3. Customer load curve

The calculation formula of electrical appliance load is:

$$P_a = A_i \times P_{PER} \quad (4)$$

where, P_{PER} is the power consumed by the washing appliance within one average duration.

The calculation formula of total load of distributed power customer within a day is:

$$P_{day} = \sum_{t=1}^{24} P_{PV} + \sum_{t=1}^{24} P_a + \sum_{t=1}^{24} P_r \quad (5)$$

where, P_{pv} is photovoltaic power generation load; P_a is electrical appliance load; P_r is additional load.

5. Model Simulation

Adopt method described in this paper to model and predict power load of N households of one area in one day, Compare the model data with the measured data and analyse the error and verify the validity of the model.

5.1. Active customer household quantity

Correspond active/inactive state of N households with two states of Markov Chain and there is no specific and clear value to describe two states; therefore, active time sequence of customer belongs to classified binary type, namely 0 or 1 state. Conduct dynamic simulation through MCMC for N households of one area to get active customer households in various periods.

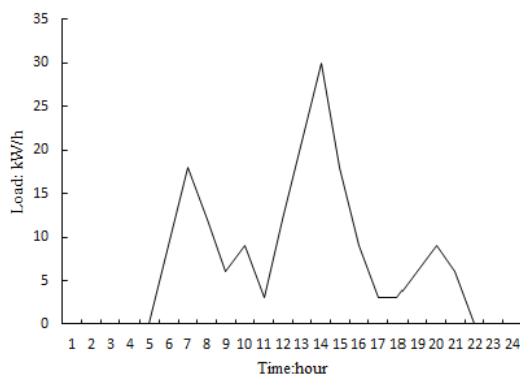


Figure 5. Appliance Load Curve

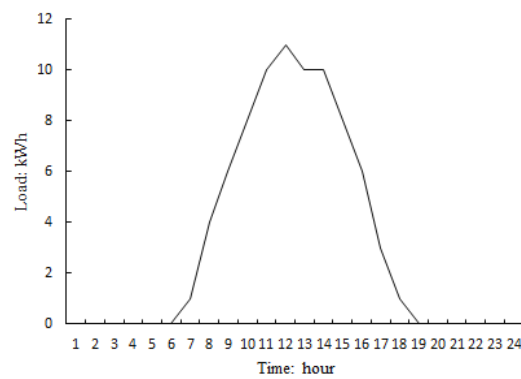


Figure 6. PV Output Curve

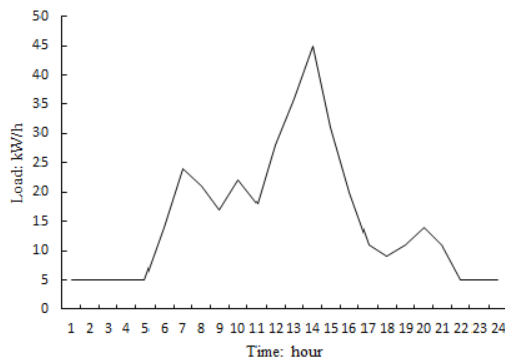


Figure 7. Total Load Curve

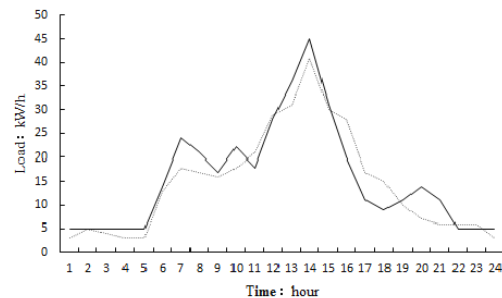


Figure 8. Comparison of Simulation and Actual Data

5.2. Household quantity starting electrical appliance

Conduct fuzzy reasoning based on fuzzy rule and current input state to get household quantity of electrical appliance at various moments. IF...THEN... is adopted in this paper to show the relation between input and output. If the active customer household quantity is 6 and use time of photovoltaic is 13 pm, the main steps are:

- (1) Calculate membership of two input quantities.
- (2) The activation rule can be obtained by checking the entered membership value table. Calculate fuzzy degree of four rule conclusions respectively based on max-min principle.

Get the max of all rules to get the result of fuzzy reasoning. Convert fuzzy degree of output variable gotten from fuzzy reasoning into precise value and method of weighted mean is adopted.

5.3. Customer load curve

Load curve can be obtained by model simulation. Get the power use load in various periods based on calculation formula of electrical appliance load, as shown in Figure 5. Photovoltaic output curve within a day can be gotten from photovoltaic power generation data, as shown in Figure 6. Overlap various loads to predict daily customer load curve of distributed power of N households, as shown in Figure 7.

It also can be gotten from Figure 8 and error calculation formula $e = \frac{1}{t} \sum_{i=1}^t \left(\frac{P_a - P_s}{P_a} \right)$ that the error between load simulation and actual value is 20%. P_a is actual value and P_s is simulation value. The actual value is taken from the data in one day, so it has pretty strong randomness; the general trend of load is the same, showing the model is pretty effective.

6. Conclusion

The paper proposes a load curve modeling method based on customer behavior of distributed power aiming at the problem that distributed power generation influences power use action of customers' so as to further change load curve. The validity of the model is discussed through simulation analysis. In general, the paper provides reference for power grid planning and operation strategy.

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