A hierarchical System for Energy Consumption Monitoring and Information Management

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***Abstract*—In this paper, an energy consumption monitoring and information management system based on multi-level energy consumption model is developed. It is based on internet, wireless internet of things and communication technologies of the intelligent terminal such techniques. The system consists of energy usage equipment, monitoring and control layer, network and communication layer, intelligence management layer, analysis and decision-making layer and the end-users layer. Firstly, the swarm load characteristics are studied and multi-level energy consumption model has been built. Then based on the smart terminal measurement system, the whole network is established for measurement, collection, storage, analysis of the user information purpose. The communication between the intelligent terminals and control center can be achieved via the interface of the medium-connection system. So a multi-level energy monitoring and information management platform can be developed in order to master the production consumption dynamics and energy management decision for the management personnel. Based on the practical experiments, the results identified that the system data can be transmitted safely and reliably, and the energy consumption can be regulated scientifically with bright prospect.**

***Key Words*-Smart city, Energy consumption monitoring, Information management, Analysis and decision**

I. Introduction

With the development of digital revolution and continuous expansion of the city, the digitization [1], instrumentation [2], intelligence [3] become the necessary trend and internal demand of urban construction & development direction [4]. More importantly, energy is the lifeblood of urban life, reflecting all aspects of the city life [5].

Energy consumption monitoring is an important part in energy management, and many countries have already put a great effort in this area. Germany has developed a quantified index system and related organization, personnel and regime to ensure the success of energy consumption detection [6]. In 1996, Energy Plus software was issued by the United States and Energy was issued by UK at the same period, where these software can be used to simulate and compute the building energy consumption [8]. The Ambient-Intelligent Interactive Monitoring System for Energy System(AmI-MoSES) was developed in Europe, whose purpose is to provide methods for Medium and small manufactures in order to improve the energy usage effectiveness. The current energy management system (EMS) can be combined with the AmI-MoSES platform to provide hardware equipment for data collection, refinement and transmission [9]. B. Dong and his co-workers developed the building energy consumption model of tropical region with support vector mechanism, which can be used as a basis for energy-saving project [10].

In order to meet the requirement of energy consumption, a scheme of 'unit GDP energy consumption monitoring system implementation plan' was issued jointly by the National Development and Reform Commission, National Bureau of Statistics and the State Energy Office of China in 2007. The one thousand important energy-consuming enterprises are the main parts to be monitored, which would guarantee the realization of the smart city. As it is known, the smart city involves internet of things [11], smart grid and intelligent energy usage terminals multiple technologies. With the aid of advanced communication, sensor and measurement technologies, the reliable, economic and environmentally friendly purposes can be realized in smart grid. Besides, various renewable energy resources can be connected in the whole energy supply system as effective supplement to reduce the operational cost [12][13].

In order to promote the process of smart city and implement the urban energy consumption monitoring and energy management more effectively, an energy consumption monitoring and information management system is configured to adapt to the enterprises and cities, where a hierarchy analysis model is developed for data analysis and a multi-level energy consumption monitoring & information management platform is also developed to realize the real-time monitoring, online analysis, automatic diagnosis and intelligent control and decision-making such functions.

The remainder of the paper is organized as follows. Section II describes structure of the hierarchical energy consumption monitoring and management system. In Section III, the detailed function at each layer of the system is explained. A case study is provided in Section IV to discuss the operation of the energy management system. Conclusion is given in Section V.

II. The Hierarchical Energy Consumption Monitoring and Management System

To configure the hierarchical Energy Monitoring and Information Management System (HEMIMS), the city energy consumption states including water, electricity, gas, heating, cold such devices can be acquired and reliable data can be obtained simultaneously. The configuration of the HEMIMS is shown in Fig. 1, which is composed of energy usage devices, monitoring control layer, network communication layer, in-

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telligent management layer, analysis & decision-making layer and end-users layer.

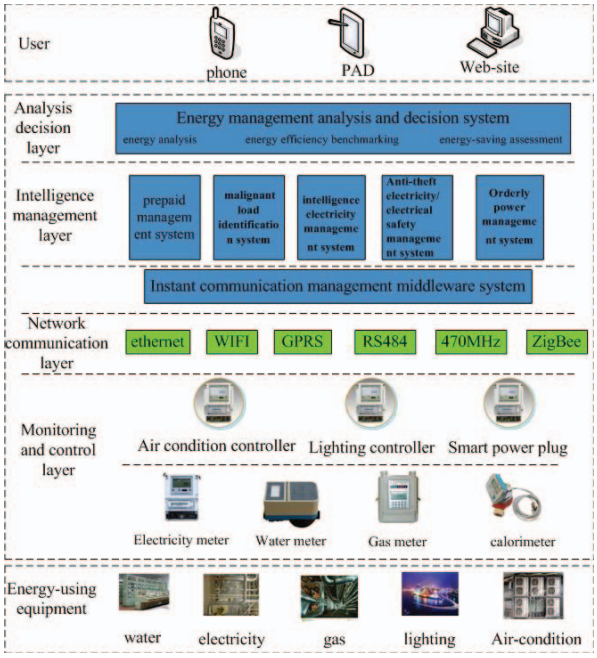

Fig. 1. The structure of the hierarchical energy consumption monitoring and management system

As for the energy usage devices layer, it can provide all kinds of load characteristics and develop the multi-level energy consumption model. The function of the monitoring control layer is to monitor and control various energy resources. The network communication layer is configured by communication terminal equipment, which is responsible for the information exchange between layers and terminals. The intelligent management layer is the execution layer to manage energy saving from administrative, technological and safety perspectives applied in enterprises and campuses. Besides, the function of the analysis and decision-making layer is to analyze, evaluate and make decisions for the energy usage globally. At the user terminal layer, end-users normally adopt mobile phones, PAD or Web for energy-saving examination.

III. The Hierarchical Analysis in HEMIMS

A. The energy usage devices

There are a variety of energy usage equipment in the cities. According to the end-users, load characteristics are discussed among the residential, industrial and commercial areas. The loads of the industrial and commercial users are relatively stable and follow obviously regular patterns. On the contrary, the residential loads vary a great difference due to individual different behaviors, which could result in increased peak-valley rate of the energy consumption. If electric devices with large power are used, i.e., electric vehicles, the usage time and spatial distribution of the energy consumption will become more uncertain, which could increase the complexity of the energy scheduling. At the same time, the smart metering technology will affect the behavior of energy consumers, resulting in more dynamic demand. Therefore, it is necessary to study the load characteristics with swarm intelligence, i.e., smart home [14], and establish the load model considering the impact factors to analyze the variation patterns so as to provide evidence for energy dispatching and control.

B. Monitoring control layer

The detection control layer contains all kinds of energy monitoring terminals and intelligent control terminals. The monitoring terminal includes electricity meter, water meter, gas meter, heat meter, fuel gauge and so on; the intelligent control terminal includes smart socket, air conditioning controller, lighting controller, reactive power compensation devices and frequency conversion devices.

Currently, most commercial lighting controllers can be used to control the device and only a few have realized the cable or wireless communication, but none of them possesses the energy metering function in lack of detection. In the designed system, a novel intelligent lighting controller was developed composing integrated energy metering module, the line control module and wireless communication module, where the central control module can realize the precise measurement with different electrical parameters acquirement via wireless communication and ad hoc network. Moreover, a new intelligent air-conditioning controller is developed which comprise an integrate fan coil control module, a temperature sensing module, a wireless communication module and a centralized control module as a whole. The designed controller can realize centralized management, time setting, temperature range setting, human body perception and other energy saving functions.

C. Network communication layer

The network communication layer contains telecommunications terminal equipment, including all kinds of collectors, concentrators, gateways and other equipment. In order to realize ad hoc network management, a wireless data concentrator is designed to be applied in large-scale engineering projects, where a wireless concentrator can manage up to 1024 meters. The wireless module of the designed concentrator is the pluggable downlink communication module, completing dynamic ad hoc network and data transmission. The whole wireless concentrator is divided into three components: a wireless control module, GPRS module and concentrator module, illustrated in Fig. 2.

The instant messaging management middleware system is an independent service program to manage smart terminal resources and network communication, which is located on top of communication terminals and intelligent terminals. The middleware connects many stand-alone systems and a variety of smart terminals (even with different interfaces and communication protocols) to exchange information.

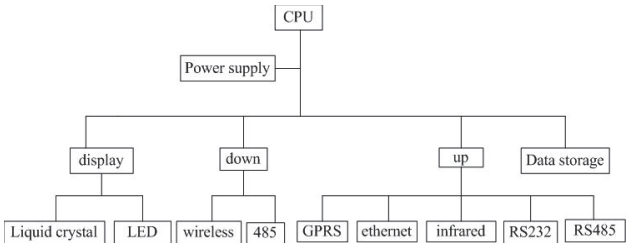

Fig. 2. The diagram of the wireless data concentrator

D. Intelligence management layer

The intelligence management layer is the execution layer of enterprise and campus for energy saving and safety issues via deploying specific systems. The whole layer is composed of five subsystems: the prepaid management system, malignant load identification system, intelligent power management system, anti-theft electricity/electrical safety management system and orderly power management system.

1) The prepaid management system: The current popular prepaid management solutions on the market include card prepaid, system pre-paid, prepaid cabinet, etc. However, they all have certain problems. For instance, electricity cabinet does not overly depend on network but adopt centralized installation with anti-thunder problems. Therefore, a network prepaid management system based on pre-paid smart electric meter was designed to solve billing, tripping control, equipment lightning protection and other issues, which can be installed in centralized or decentralized pattern. Besides, the system has achieved room energy usage closed-loop self-management, which can monitor the energy consumption status and financial statistical report with different payment modes, i.e., manual sale, recharging card or network third-party payment. The developed system supports the ad hoc network, and the application is shown in Fig. 3.

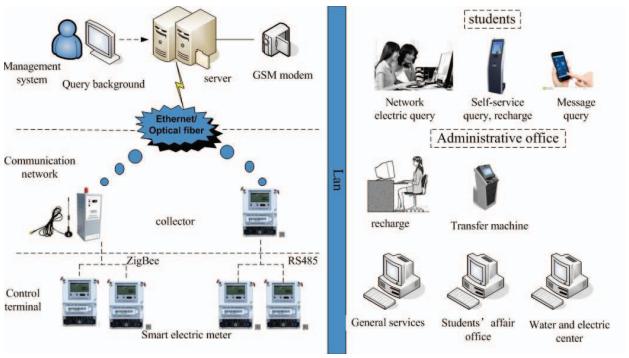

Fig. 3. The diagram of the prepaid management system

2) The malignant load identification system: The malignant load identification system is used to control the electric appliances which could easily cause fire or electrical accidents. The characteristics of different types of electric appliances are studied and the malignant loads can be identified via mathematical modelling to realize energy control in multiple malignant loads recognition.

3) The intelligent electricity management system: The intelligent electricity management system mainly includes three parts: video image recognition & crowd behavior analysis, intelligent lighting management and intelligent air-conditioning management. The energy consumption of air conditioning system and lighting system account for 60% -80% of the total building electricity consumption [15]. Thus it is important to study these two types energy consumption loads related energy saving techniques.

The principle of the video-based image recognition and group analysis is as follows. First, the range of each camera is determined and the background of each region is modelled. When there is someone stops for a while (threshold setting) in the images, group lump is labeled to analyze the density for single mode matching or multi mode matching. Then image features are extracted for number counting.

Based on the intelligent lighting controller and management system, the group distribution, lighting illumination and images can be input by internet transmission to the system for online analysis to realize indoor illumination adjusting, switching control, interval and sensing control etc. Besides, the intelligent air-conditioning system can also achieve the temperature control, human body sensing switches and other intelligent management capabilities.

4) Anti-theft electricity/safety management system: Anti-theft is a long-standing problem for energy supply enterprises. For example, there are over one million electricity black hole for a 20,000 people community. The electricity theft will bring huge economic losses but also significant safety problems. Here, we developed a new type of anti-theft electricity/safety management system for online data analysis so as to achieve the electricity theft identification. In the system, electricity circuit identification, power line loss estimation and electricity balance analysis techniques are adopted to achieve single circuit virtual connection, short connection, empty connection and series connection of multi-loop circuits to prevent theft from various trunk line connection and eliminate safety risks.

5) Orderly power management system: The orderly power management system is originally designed to guarantee quality and quantity of the power supply. Considering the management requirement from internal enterprises, the system will design a new orderly energy usage management system and promote the technique in campuses and enterprises so that the energy consumption from construction, production line and main equipment can be regulated, automatically tracked and alarmed from abnormal status capture in real-time.

E. The Decision-making and analysis layer

The decision-making and analysis layer conducts energy monitoring, analysis, evaluation and decision-making globally, on the basis of data collection and analyzation and a series of energy management strategy, which can achieve the following functions:

1) Energy monitoring. Through the internet and wireless internet of things, the measurement data from the terminal can be read instantly so as to monitor the dynamics of all kinds of energy resources, i.e, electricity, water, gas, heat.

2) Energy analysis. Through the energy consumption data collected at each monitoring point, the consumption curves such as building and production line, can be drawn accordingly. Combined with the product quantity, personnel, area, temperature, runtime and other factors, the energy costs can be decomposed and computed. Besides, it can be used to evaluate the effectiveness of the energy saving project and management strategies.

3) Energy efficiency benchmarking. According to production, personnel, area, the whole energy efficiency index can be calculated, and the banchmarking of the main equipment will be computed and compared independently to master the energy efficiency status.

4) Energy-saving assessment. Through energy-saving diagnosis, the energy usage problems in daily lives of the enterprises and campuses can be revealed so it could assist to reorganize energy resources structure and production plan with economic benefits.

F. The end-users

A multi-level energy monitoring and information management platform is developed so that the end-users can monitor, analyze and evaluate the energy consumption behaviour via phone, PAD, web and other modern communication tools.

The platform is responsible for collecting and analyzing energy consumption, where the energy decision analysis system can conduct consumption structure analysis and energy distribution so as to provide useful information to the related personnel for timely mastering dynamic consumption state. In the mean time, it can calculate the consumption level of the manufacturing procedure to seek energy saving opportunities and follow the evaluation of the energy saving measure and strategies. Moreover, it can enhance the stability of the energy resources and usage efficiency and lower the cost, where the information management platform is demonstrated in Fig. 4.

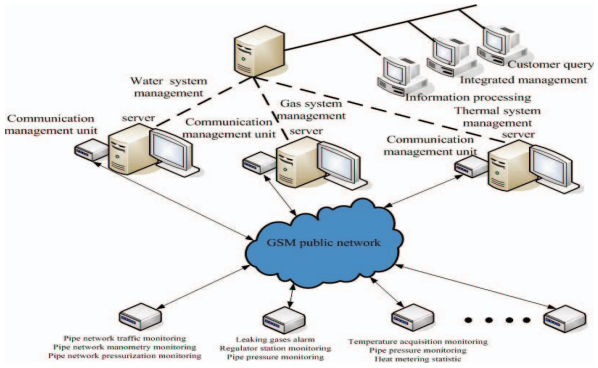

Fig. 4. The illustration of the information management platform

IV. Case Study

A. The developed malignant load identification system

Through mathematical modeling and intelligent recognition algorithms, the malignant load can be recognized fast online under multiple loads circumstances, which can solve regulation issues of enterprises, business, campus and secure the life and property safety of the human beings.

PNN is one kind of artificial neural networks with simple structure, concise training procedure and widely application, which possesses the advantages that it can use the linear learning algorithms to complete the tasks realized by the nonlinear learning algorithms, while maintaining high precision of the characteristics of the nonlinear algorithms. The weight of the network is the distribution of the pattern samples, where the network does not require training but it can meet the real-time training requirements. Generally, PNN is a 4-layer hierarchical model, including input layer, pattern layer, summation layer and output layer, where the diagram of the network structure is illustrated in Fig. 5. The input layer

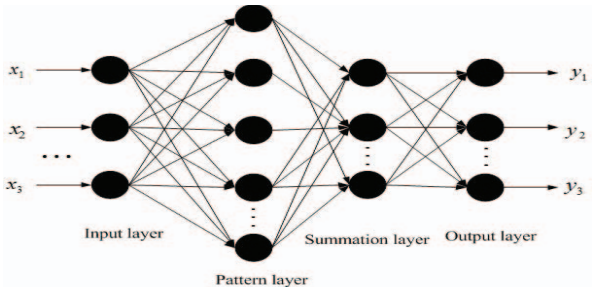

Fig. 5. The network structure of the PNN

receives the values from the training samples, and transfers the feature vector to the network, where the number of neurons is equal to the dimension of the sample vectors. The pattern layer computes the relationship among the input feature vectors and the various modes of the training sets, where the number of model neurons of the pattern layer is equal to the total number of the training samples of each categories. The output of each pattern unit is expressed as,

$$f(X, W_i) = \exp\left[-\frac{(X - W_i)^{\mathrm{T}}(X - W_i)}{2\sigma^2}\right] \tag{1}$$

where X is the input mode vector; W_i is the weight from the input layer to the pattern layer; σ is the smoothing factor, which plays a vital role in the classification.

The malignant load recognition used in campus apartment is used as a case study, where the probabilistic neural network (PNN) is adopted as the intelligent recognition algorithm to develop the nonlinear mapping relationship between the load type and parameters. Several typical electrical loads are selected from the market for the experiments, such as heater, electric blankets, hair dryer and other resistive load, to simulate the load usage in the apartment of universities. The general 4 layer structure of PNN is adopted here, and the error function of the PNN is defined as the fitness function, $J_m = \sum_{k=1}^{q}\sum_{t=1}^{s}[\hat{y}(k) - y_t(k)]^2$, where $\hat{y}(k)$ and $y_t(k)$ are the expected and actual output from the training model and optimized PNN, respectively. Detailed can be referred [16].

First, all electric loads in the apartment are labeled to establish a database, where the data (i.e.,voltage, current, power, power factor, harmonics and other performance parameters) are collected at each 15s sampling interval and used as the input feature vector of PNN network to establish a non-linear mapping relationship between the performance parameters and the load type. Here, the data from 22 different types of load combination are collected, and five groups of electric parameters of each type are collected so that 110 groups of training dataset are obtained. 70 data samples are chosen randomly from the 110 groups dataset used as training data of PNN network and the rest 40 groups are used as the test data. The recognition results of malignant loads based on PNN are shown in Fig. 6 and Fig. 7.

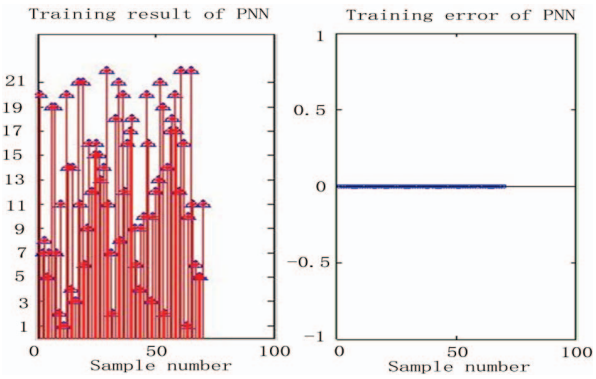

Fig. 6. The classification with the PNN training data

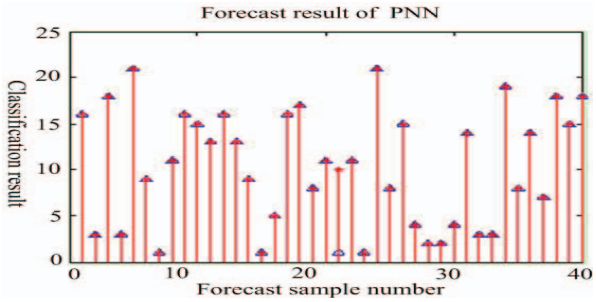

Fig. 7. The classification with the PNN prediction model

From the figures it can be shown that the trained PNN network has certain adaptive learning capability. The accuracy recognition rate is 97.5% when the trained PNN network is used to verify the malignant loads. Besides, it takes less time for PNN training and strong deduction ability which can tolerant small wrong samples. During the test, off-line matching is used to verify the PNN performance, however, online test has also been performed as well.

B. The city energy consumption monitoring and information management platform

If only the equipment of the energy consumption system is upgraded without the improvement of energy-saving operation and management level, it will fail to bring long-term energy-saving benefits. Then a city energy consumption monitoring and information management platform is developed to carry out energy monitoring, analysis, evaluation and decision-making globally. On the one hand, it can realize the 24hour uninterrupted state monitoring for the equipment and reduce the fault rate greatly to guarantee the stable and safety system operation. Besides it can provide accurate metering data for the enterprises for refined management to achieve high-efficient operation and higher energy-saving benefits.

The energy consumption monitoring platform was applied in Shenzhen Nortel Instrument Co. and other campuses in China, where it has achieved good performance in energy control. The user login page and system operation interface are shown in Fig. 8.

The system allows the access of electricity, water, gas, heat and cold full energy resources, which can collect distributed precise energy consumption data in real-time. The collected data is used for data analysis and consumption cost. Let take an electricity consumption of one enterprise as an example. The system supports the power-line monitoring, power analysis, public electricity inquiry, electricity alarms, curve of electricity load illustration, where the different analysis can be provided including electricity usage comparison, electricity loss analysis and so on. Fig. 9 displays the electricity analysis graph per day of one company.

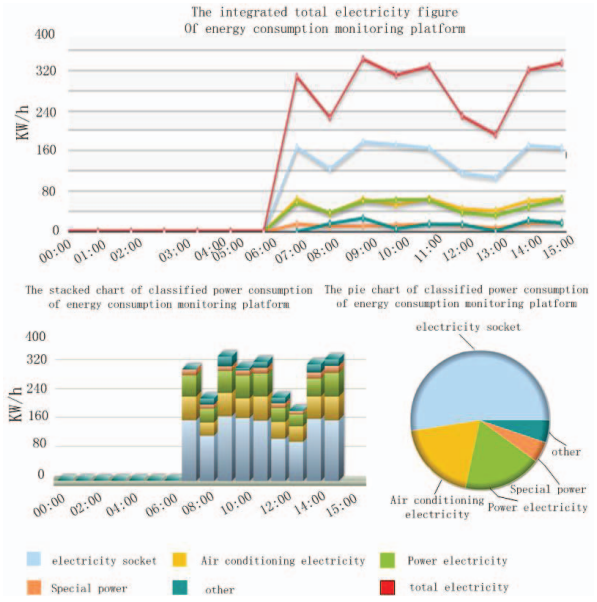

Fig. 9. The energy usage analysis of a certain period intervals

The variation and tendency of the electricity index and energy usage ratio is shown clearly in Fig. 9. The monitoring platform can provide precise energy usage load monitoring for the users so as to make reasonable energy saving strategy.

Fig. 10 demonstrates the average energy consumption of one company, which can be used to master the individual energy

Fig. 8. User login page and system operation interface

usage behaviour so the energy saving strategies can be made.

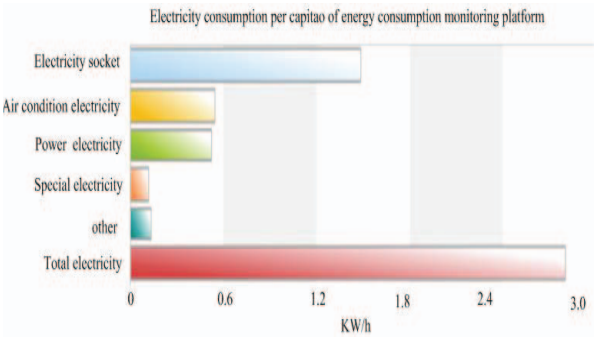

Fig. 10. Electricity consumption per capita of energy consumption monitoring platform

At the same time, it can provide electricity benchmarking service for the companies, where their energy consumption problems could be discovered via comparative analysis. Furthermore, it would assist the users to conduct market analysis or management strategies.

V. Conclusion

In this paper, a hierarchical energy consumption monitoring and information system was developed with the consideration of system structure and performance index, to satisfy the requirement of urban energy consumption. The developed system can realize the real-time energy monitoring, online analysis, automatic diagnosis and intelligent control such functions.

Currently, the developed system/platform has been put into practice in several campuses and some companies with satisfied performance. Through the implementation of the energy management and energy-saving technologies, the total energy consumption can be reduced between 10%-30% depending on the applied objects, which will bring bright prospect for the promotion of intelligent energy management in the future.

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References

[1] H. Yang. Institutional analysis on digital urban management. Urban Studies, 2009, 16(1):109-113.
[2] X. Huang, J. Wei, et al. Internet of materials helping the development of urban information: Exploring a new mode for urban management. Bulletin of Chinese Academy of Sciences, 2010, 25(1):64-70.
[3] T. Yang, Y. Wang, et al. Human-centric urban transportation multimedia surveillance method. Compute Science, 2013, 40(11A):366-368.
[4] J. Wang, C. Li, et al. Survey of data-centric smart city. Journal of Computer Research and Development, 2014, 51(2): 239-259.
[5] S. Gu, J. Yang and J. Liu. Problem in the development of smart city in china and their solution. China Soft Science, 2013, 1:6-12.
[6] H. Dai, S. Su, et al. Method study on energy performance management of micro-grid under smart energy grid. Smart Grid, 2015, 3(10): 895-900.
[7] X. Zhou. Energy consumption monitoring and control theories and practices in China and other countries. Sino-global Energy, 2013,18(8):1-7.
[8] D. Liu and Q. Chen, et al. Data-based analysis and modeling of building electricity energy consumption. Journal of TONGJI university (natural science), 2010, 38(12): 1841-1845.
[9] AmI-Moses Concept. AmI-Moses Project. Ambient-Intelligent interactive monitoring system for energy use optimization in manufacturing SMEs[EB/OL]. http://www.ami-moses.eu/fileadmin/templates/amimoses/files/AmI-MoSES-D7.4-Concept-Public-v.1.0.pdf.
[10] B. Dong, C. Cao and SE Lee. Applying support vector machines to predict building energy consumption in tropical region. Energy and Buildings, 2005, 37(5): 545-553.
[11] G. Kuang and Z. Sun. The Application of Management Information System in Internet of Things based on RFID Technology. Sensors & Transducers, 2013, 154(7): 103-112.
[12] F. Resende and J. Lopes. Management and Control System for Large Scale Integration of Renewable Energy Sources into the Electrical Networks. IEEE International Conference on Computer as a Tool, 2011, Zagreb, Croatia, pp.1-6.
[13] J. Revuelta, J.C. Fernandez and J.L. Fernandez. Large Scale Integration of renewable energy sources in the Spanish power system Curtailment and market issues. European Energy, 2011, Zagreb, Croatia, pp.25-27.
[14] B. Zhou, W. Li, et al. Smart home energy management systems: Concept, configurations, and scheduling strategies. Renewable and Sustainable Energy Reviews, 2016, 61:30-40.
[15] Y. Li, H. Zhang and C. Chen. Comparison of features in electricity consumption by different type of large-scale public buildings, Building Electricity, 2010, 1:32-38.
[16] Q. Wu, T. Yan and Y. Zhou. Malignant load identification of university dormitory based on probabilistic neural network, IEEE International Conference on Robotics and Biomimetics, Qingdao, 2016, pp.1727-1731.