Regional Energy Management System Considering Demand Response

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Abstract: In order to support the development of the smart grid and the demand side management, this paper designs and implements a regional energy management system (R-EMS) considering demand response (DR). The R-EMS can realize the information linkage between the regional energy management and single-point energy management. Firstly, the design requirements and architecture of the system are proposed. And then three core functions and the realization method are described. Finally, a summary about the whole work is made. The system proposed supports multi-dimensional analysis and knowledge mining about mass electricity data, and has excellent features of standard access, information sharing and high reliability which will play an important role in the development of smart grid

Key Words: Regional energy management system; Demand response; Load control; Energy efficiency evaluation

1. INTRODUCTION

Electricity, as a major form of terminal energy consumption, plays an important role in the energy efficiency improvement. At present, the low power utilization efficiency of user-side leads to a severe electricity waste. On the other hand, the high electricity difference ratio between peak and valley and the low utilization efficiency of the power equipment mean a huge potential for energy-saving [1-4]. It is a new task of the intelligent electricity service to change the model which unilaterally rely on expanding power plants or power grid construction to meet the electricity growth, and strengthen the power grid and the user-side flexible interaction by economic and technological means.

In recent years, demand-side energy efficiency management was researched by many well-known companies. Microsoft and Google Company, launched the "Microsoft Hohm" and "Power Meter" home energy management service system in 2009, respectively[5,6]. The two systems gave energy saving suggestions to the user and power grid companies by real-time monitoring of users' energy consumption and analyzing the related data. In 2010, the State Grid Corporation of China (SGCC) showed numerous research results of unified strong and smart grid through the construction of Shanghai World Expo smart grid comprehensive demonstration project. This project implemented collection and analysis of the electricity information, home appliance monitoring and management, electricity reasonable utilization advising. And it also adjusted the grid peak valley load, and achieved intelligent use of electricity between grid and users [7]. All researches mentioned above were focused on the electricity management of single equipment or the single-electrical user. Single point of electricity management system can play an effective role in improving the energy efficiency of a single link. However, the regional energy efficiency is not just the sum of single-point. It is necessary to design a Regional Energy Management System(R-EMS) to improve the energy efficiency by coordinating the user of single-point.

In this paper, we design and implement an R-EMS considering demand response (DR) for grid companies or regional energy managers. This system can not only realize the regional and the single user's electricity consumption monitoring and analysis, but also achieve the region peak demand management through multiple single-point energy management information, which can effectively enhance DR analysis and control intelligence. As an improvement of the existing power distribution and utilization management system, information management system and energy telemetering system, the R-EMS realizes the information interaction and functions complementary. It also provides a new idea for the regional load coordinated control and integrated energy efficiency management.

2. THE SYSTEM OVERALL DESIGN

2.1 Design Requirements

R-EMS can effectively achieve real-time interaction among the energy flow, information flow, and business flow of grid and users relying on advanced meter, efficient control, high-speed communications and other smart grid technologies. The system design must meet the following technical requirements:

(1) Distributed power source's "Plug and Play": The system should implement distributed power source flexible access, real-time monitoring, and flexible control.

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(2) "Grid-load" information intelligent interactive: Through interactive information efficiency between regional side and demand side, the user can choose the best response interaction model according to the electricity utilization suggestions pushed by R-EMS, the electricity information released by grid and its own electricity demand situation. And then users adopt load-shedding or load-shifting to reduce grid peak load, save electricity costs and improve operational efficiency of transmission equipment.

(3) Personalized, differentiated electricity services: The system can provide users with flexible customization, variety selection, convenient and efficient electricity services, to meet diverse needs and enhance customer satisfaction.

(4) Improvement of the terminal energy efficiency: R-EMS should guide the user greenly using energy by a reasonable allocation of user-side resources, and also give full play to the role of distributed power and energy storage devices, to improve the energy efficiency of terminals.

2.2 System architecture

The overall architecture of R-EMS is shown in Fig.1. This system is composed of five layers and two support modules. The five layers are data source layer, data integration layer, data storage layer, supporting layer and business application layer. The two support modules are safety protection sub-system and standard specification sub-system.

(1) Data Source Layer: The system is region-oriented, whose managed objects obtain all types of users, such as buildings, residential communities, industrial enterprises and distributed powers. This layer gets the power consumption data from single user, critical equipment or distributed power through terminal acquisition equipment such as smart meters, interactive terminals, etc. It provides basic analysis data for the system.

(2) Data Integration Layer: This layer processes data accessed from data source layer through extraction, transformation, loading, connect, share, and series of processing loaded into the data storage layer by ETL [8-9] or DBLINK [10] technologies. For different data source, the system provides corresponding data processing technology to integrate the data.

(3) Data Storage Layer: This layer provides real-time database and non-real-time database. Real-time database storages primary data like power, voltage and electric current, and corresponding processed data. Non-real-time database storages file data, business data and statistic data.

(4) Supporting Layer: This layer provides support services and tools for R-EMS to facilitate the system's design and build, including process designer, data mining tools, graphical presentation tools. The collected national, foreign, local and industry energy consumption standards provide basis for the function of the energy efficiency evaluation. Core engine of this layer includes metadata engine and knowledge base engine.

(5) Business Application Layer: This layer mainly provides core and support functions of regional energy management. The functions include visual monitoring, load control management considering DR and electrical energy efficiency assessment. The support functions include permissions management, log management, information management, and user management.

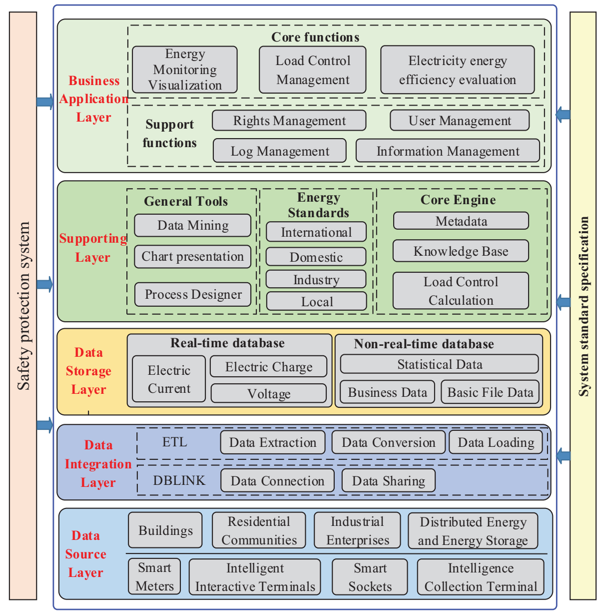

Fig.1.System Overall Framework

3. System function design

R-EMS is designed based on struts/MVC three layers model architecture, using Java and JSP scripting language and SQL Server 2005 database. In the process of R-EMS design, the reuse principle is followed to improve the system scalability, maintainability and efficiency. And the basic operation of database and results are unified. The function structure diagram is shown in Fig.2.

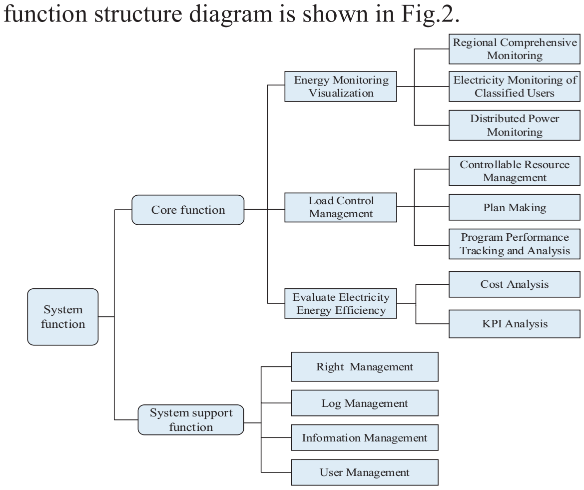

Fig.2. Function structure

3.1 Energy Monitoring Visualization

Energy monitoring visualization is an important part of the R-EMS. It monitors and alarms key parameters of all measuring point in the region. The monitoring range is the whole region, including industrial enterprises, public buildings and residential communities. Furthermore, it can monitor distributed powers, analyze electricity utilization trend and warn the faults. Specific functional modules are shown as Fig.3.

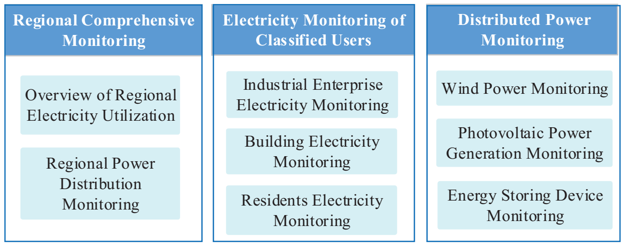

Fig.3. Energy monitoring visualization function

(1) Regional Comprehensive Monitoring: This function can realize comprehensive monitoring and visually display of regional electricity utilization, assisting regional energy managers to grasp the running states of regional distribution network, important distribution equipment and line, and electricity use information in an even better fashion.

(2) Electricity Monitoring of Classified Users: According to the whole real-time show, it can display electricity utilization difference among three classification users and corresponding contribution degree to grid.

(3) Distributed Power Monitoring: It provides functions such as real-time monitoring of charge and discharge conditions of wind, solar, and energy storage devices, trend analysis and alarm fault. It also provides distributed power data to property owner side and combines it with power grid state data to make distributed power operation strategy and to realize schedule and control for distributed power.

3.2 Load Control Management

The main role of this function is to achieve optimal management of diversity load for demand-side. According to the control process, the function is divided into three functional modules, namely controllable load resource management module, plan making module and effect-tracking analysis module. The principle of each functional module and the relationship among the modules are shown in Fig.4.

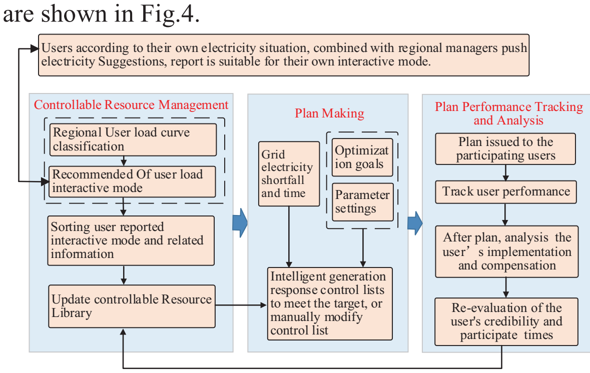

Fig.4. Load control management function

(1) Controllable Resource Management Module: it mainly maintains three kinds of controllable load resources include demand bidding, interruptible load and direct load control. It also displays typical load curve classification results of diverse users real-time and "Grid-load" interactive advice information for various types of user groups. Interactive information includes load interaction, load control amount, load control time, load compensation price, number of participate, credibility, etc.

(2) Plan Making Module: According to grid electricity short fall and time requirements, regional manager sets the following information: load control target, priority control mode, optimization goal weight, implementation date, control time, advance notice of the date. Then, a user control list will be generated by intelligent algorithm which satisfies the target. In addition, it allows manually modification and confirmation. The scheme formulation processes is shown in Fig.5.

The multi-objective optimization model [11] of energy efficiency is based on the interests of both the grid and the user. The formulas of the optimization goals are (1)-(3), and the constraint conditions are composed of gap of grid electricity information, regulation time and power grid safe operation range.

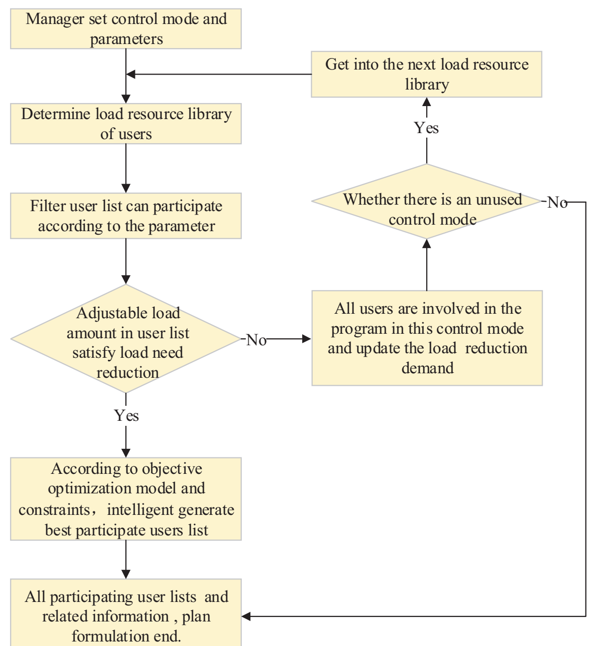

Fig.5. The flow chart of plan formulation

The calculation formulation for grid smallest loss:

$$\min \quad LosProfit = \sum_{i=1}^{n}\sum_{t=1}^{48} x^i \cdot P^i(t) \cdot Price^i(t) \cdot 0.5 + \sum_{i=1}^{n} x^i \cdot ComPrice^i \tag{1}$$

The calculation formulation for smallest affected power use number:

$$\min \quad Num = \sum_{i=1}^{n} x^i \tag{2}$$

The calculation formulation for the highest degree of program implementation reliability:

$$\min \quad Relia = -\sum_{i=1}^{n} x^i \cdot Cred^i \tag{3}$$

In the formulation, n represents users' number of participating in plan in controllable resource list; t represents time period. In this system, it divides 24 hours into 48 time periods, each time period is half an hour. x^i represents whether the user I participates in this project, by value of 0 or 1, where 0 represents not participation and 1 represents participation. $P^i(t)$ is control volume of the user i in time t. Where, positive number and negative number represent start and stop respectively. $Price^i(t)$ represents time-of-use power price of user i. The value can be reference to local electricity price charge standard. $Comprice^i$ is amount of compensation that user received for take part in this program. $Cred^i$ represents credibility of user i. It ranges from 0 to 1. The higher, the better. Initial credibility is 1.

(3) Plan Performance Tracking and Analysis Module: Users carry out received program within the stipulated time. The coordinated optimization system of energy efficiency tracks and analyzes implementation effect of this program. Then it re-evaluates credibility of participating users, updates the user participating number and collects compensation information.

3.3 Electricity Energy Efficiency Evaluation

Electricity energy efficiency evaluation deeply analyzes and visually displays information such as power consumption, the using of energy characteristics. Electricity energy efficiency evaluation includes three function modules, namely cost analysis, load analysis, KPI (Key Performance Indicators) analysis. Specific function is shown in Fig.6.

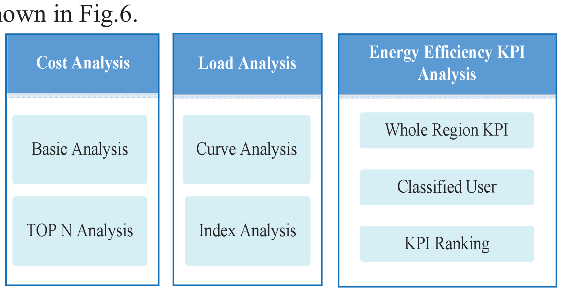

Fig.6. Electricity energy efficiency evaluate function

(1) Cost Analysis: Statistical analysis, compare and top N rank of electric charge, average price, peak-flat-valley fees, and peak-flat-valley fees rate are implemented for users. The analysis time is multiple dimensions, which can be divided into time point and time period according to time span, or divided into year, month and day based on time granularity. This function is the basis of sending power optimization proposals to users.

(2) Load Analysis: It analyzes users' load curve and the related indicators (including average load, load rate, D-value of peak-valley, D-value of peak-valley rate, occurrence time of the peak load and valley load) within the scope of the regional management, to provide support data for peak demand management strategy.

(3) Energy Efficiency KPI Analysis: The function sets up the statistical evaluation model for typical KPI indexes that describe the energy efficiency circumstance of the whole region and classified users firstly. And then compares them with the basic values of energy efficiency to realize energy efficiency diagnosis for the whole region or classified users. All of those can let users understand its energy consumption level in a certain period of time and space. Energy efficiency KPI evaluation process is shown in Fig.7.

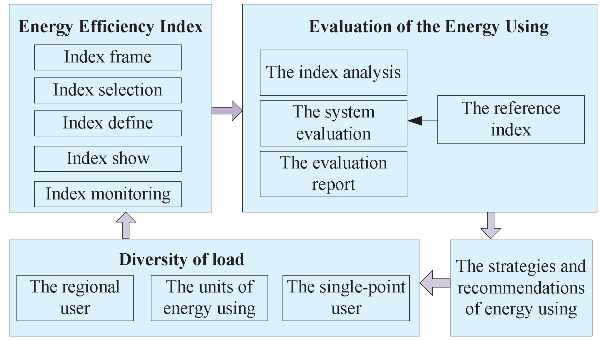

Fig.7. Efficiency KPI assessment process

During the assessment of energy efficiency KPI, the system defines an energy efficiency index (EEI) to measure and assess users' energy efficiency level. The calculation for EEI is shown in formula (4). Where, expected KPI (eKPI) is energy efficiency reference value based on assess requirements. It can be level of energy efficiency that expected to achieve in the coming N years and also can be advanced energy efficiency level in similar area.

$$\mathrm{EEI}=\begin{cases}1-\dfrac{\mathrm{KPI}-\mathrm{eKPI}}{\mathrm{eKPI}} & \mathrm{KPI}>\mathrm{eKPI}\\ 0.5 & \mathrm{KPI}=\mathrm{eKPI}\\ 0.5-\dfrac{\mathrm{KPI}-\mathrm{eKPI}}{\mathrm{eKPI}} & \mathrm{KPI}<\mathrm{eKPI}\end{cases} \tag{4}$$

The manager gets the energy consumption level information of single user in the same area or industry by the energy efficiency assessment report. Energy-saving warning and advice are send to low energy efficiency users by this module.

4. CONCLUSIONS

It has been unable to meet the smart grid and demand-side management in-depth development that confined to manage the energy usage of the each single-point user separately, without considering about the facility frame design concept among the single-point user or between users and grid. Therefore, it is necessary to design an energy management system which emphasizes coordinated interaction among diversity loads and enhances the overall energy efficiency. In this paper, we first designed the implementation framework of the R-EMS considering DR, and made a detailed description to data source layer, data integration layer, data storage layer, supporting layer and the business application layer. We also explained the main action and the implementation mechanism of three core functions namely energy visualization system monitoring, load control management, energy efficiency evaluation. R-EMS considering DR designed by using the modular design and data mining technology has a strong scalability and suitability and offers a powerful guarantee to improve regional energy efficiency level. Along with the increase of interaction users and the mature of the related technologies, this system will be developed to energy management platform and provide the information support for the wisdom city in future.

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