Chapter 75
Application of Cloud Computing in the Development of Smart Power Grid

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Abstract With the construction and development of smart power grid, the power system is evolving into the system of accumulating mass of data and information calculation. The advanced analysis, the operation of security and economic and the system control are becoming difficult with the expanding scale and complicating structure of power system. The existing computing platform of centralized power system does not meet the above requirements, which has become one of the main bottlenecks in the achievement of smart power grid. Cloud computing just can integrate the existing calculating resources of power system and provide the powerful capacity of calculation and storage. This paper first simply introduced the characteristic of smart power grid and cloud computing. Then the smart power grid cloud is put forward, and a further analysis and research on its composition, system structure, technology construction and application in smart power grid is done.

Keywords Cloud computing • Smart power grid • Smart power grid cloud • Power system

Introduction

With the interconnection of the power system in the whole country and the development of the remote power transmission system, the super large-scale power systems that cover one or more countries come into being. The modern power system is evolving into the system of accumulating mass data and information calculation. The advanced analysis, the operation of security and economic and the system control are

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becoming difficult with the expanding scale and complicating structure of power system. Recently the intelligent trend of the power system turns into a great upsurge in the world, and this is a challenge to the analysis calculation and control of the existing power system. In accordance with the definition that the energy department of USA determines, the smart power grid has some important characteristics such as strong self-cure capability, resisting extrinsic offensive, sustaining validly large-scale interim renewable energy sources and the join of distributed power source, assuring the reliability of power supply and the quality of electric energy, promoting the justice and effective operation of power market, and boosting users' participation. For meeting the demands above, the future power system should have the strong calculating capacity and the functions of collecting information, integration and analysis. The existing calculating platform of centralized power system is difficult to meeting the demands above, and this has become one of major bottlenecks of achieving smart power grid.

Clouding computing that has developed rapidly in recent years is a new computing mode, the development of distributed processing, parallel processing and grid computing and the business achievement of the computer science concept (Jun-zhou et al. 2011; Vaquero et al. 2009a; Rittinghouse and Ransome 2010). Firstly clouding computing integrates all kinds of wide-area heterogeneous computing resource by using internet into an abstract, fictitious and dynamically expanding computing resource pool, and then it provide services such as computing capacity, storing capacity, software platform and utility software for users by using internet. Through the integration of smart power grid and clouding computing, clouding computing platform of smart power grid is established. This can integrate the existing computing resource in the power system effectively and supply all kinds of computing task, intelligent analysis and decision and intelligence interaction with the strong support such as computing and storing. In a word, the important challenges from computing and disposing information of smart power grid can be effectively solved by applying clouding computing technology to the development of smart power grid. In this paper, the problems that smart power grid, the definition and characteristics of clouding computing, the coming up, components and system structure of smart power grid cloud, and the technology and applicable prospect of the smart power grid cloud in the power system would be discussed in detail.

Smart Power Grid

The smart power grid (Chen Shu-yong et al. 2009; Yu Yixin and Luan Wenpeng 2009) that is based on physics power grid highly integrates advanced the technology of Sensing measurement, communication, information, computer and control with physical power grid into new power grid.

Compared with the traditional power grid, smart power grid should have the major characteristics below:

Self Healing

Self healing is real-time control of the power grid operation condition, discovering in time, diagnosing fast, eliminating hidden dangers, isolating bug quickly, self-recover, and preventing major blackouts happening in the less manual intervention as far as possible. The modernized power grid with self healing would discover and respond to grid stoppage, solving fast and reduce blackout time and economic losses.

Interaction

The interaction of smart power grid is embodied in the interaction of power grid and power generation and the interaction of power grid and users. In the modernized power grid, the energy consumers as the business, the industry and residents would know electricity prices and be capable of selecting the most appropriate power solutions and electrovalence. The character of interaction is one of the important performances in the power grid intellectualization.

Security

The thorough security is considered in the construction of the modernized power grid. The requirements of the smart power grid are that the outage in the large area would not happen and the valuable cost of recovery would not be expended when the smart power grid experiences the physical and network attacks. The smart power grid is less likely to suffer from the influence of natural disasters.

Cloud Computing

Cloud computing is a super calculation model that based on the internet. Thousands of computers and servers are linked into a computer cloud. The users connect to the data center through the computer, laptop and cell phone, and then operate according to their own needs. The shared software and hardware resource and information is offered to computers and other equipments on demand by the compute mode.

Compared with the traditional computing model, cloud computing should have the major characteristics below (Chen Kang and Zheng Wei-Min 2009; Vaquero et al. 2009b; Zhao Junhua et al. 2010):

Integrating Large-Scale Heterogeneous Computing Resources

The traditional distributed computation generally only applies to a small range of computing network such as LAN. There are high requirements to the isomorphism of the computing resource. The computing resources those are different in the computing and storage capacity, the operating system and the development platform are difficult to be disposed. The computing resources those distribute in a vast territory and belong to several organizations could be integrated though cloud computing, and form a computing and storage platform that has very strong functions.

Easy to Dynamic Expansion

The expandability is one of the biggest advantages of cloud computing. The cloud computing could integrate all kinds of computing devices such as the hardware kinds, the network type, the operating system and the software platform, so the computing and storage capacity of the cloud computing platform could be expanded fast when it is needed. The time that the traditional computing platform upgrades is some days or weeks while the time that the cloud computing platform upgrades is generally only a few minutes. It occurs dynamically when the whole running of the system could not be influenced.

Virtualization and Service

The virtualization is also one of the important characteristics of the cloud computing. No matter how many computing devices that the cloud computing platform actually integrates, it is a single entity and the only interface that offers the computing service from users' view. Because of the adoption of virtualization technology, many computing tasks operate in the same powerful equipment of the cloud computing platform, and one computing task could be divided into some parts those operate in multiple devices. In this way, the idle computing resource of the system could be used furthest. Besides, the cloud computing platform distributes computing resource dynamically and structures system platform according to the demands of customers though using the virtualization technology.

The cloud computing abstracts all kinds of different types of computing resources to the service form that is offered to users though using the virtualization technology. The service is generally divided into three different levels those are respectively called infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS), and they are collectively referred to as XaaS (Wang Dewen et al. 2010).

The best advantage that XaaS brings is that most of users' computational tasks are accomplished in the cloud computing platform. So the strong computing and storage capacity in the user terminals is not needed. Users could expediently make use of all kinds of software in the cloud computing platform whenever the network is connected. Specific to the electric power system, basing on the XaaS function of the cloud computing platform, researchers or system operation personnel could accomplish all kinds of analysis tasks of power system and monitor the running state of the whole power system in any place though taking advantage of many different kinds of terminals such as the desk computer, the portable computer and even the mobile phone.

Strong Economies of Scale Benefit

The economic benefit would provide study and application of cloud computing in the power system with a big boost. There are a lot of unused computing and storage resources in the modern power system. Cloud computing could integrate the idle resources and reduce the investment in the information equipment. In the need to upgrade, generally the investment in the cloud computing platform also greatly lower than that in the traditional computing platform.

Smart Power Grid Cloud Computing

Smart Power Grid Cloud Comes Up

The operational characteristic of the existing power system in China is that the provincial power grid as an independent unit on the structure interconnects by the tie-lines, the whole power grid harmoniously operates, and each provincial power dispatch center possesses and maintains the detailed parameters of the power grid (Zhang Wei et al. 2004). At present the provincial power companies have their respective independent computing platforms whose functions are exactly similar. This gives rise to the repeated construction and the resources waste of the power information system. Besides, the computing capability that is required to on-line dynamic analysis and control in the power system will greatly exceed the current actual configuration with the construction of smart power grid, the expansion of power grid and the appearance of collecting device that possesses the faster sampling rate. If the calculation processing resources are just increased, the investment is excessive.

In order to solve the problem above, we may consider integrating each independent computing platform into regional and even national private cloud computing platform of the power system.

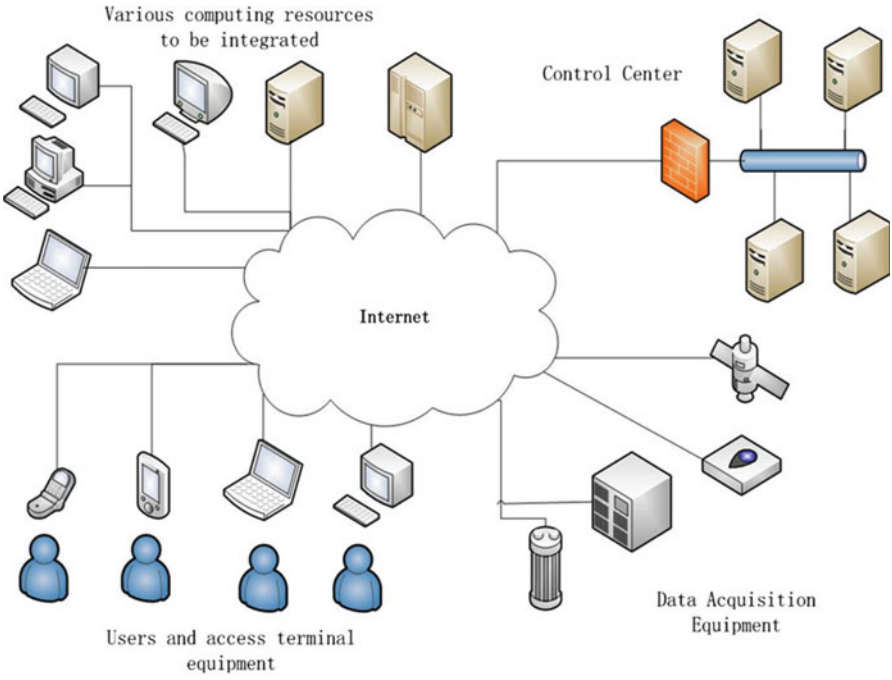

Fig. 75.1 Composition of smart power grid cloud

Composition of Smart Power Grid Cloud

The smart power grid cloud is a complicated entity composed of multiple devices and users interconnected by network as shown in Fig. 75.1. Generally speaking, the smart power grid cloud consists of two major parts: the control centre and computing resources integrated. The main functions of the control centre are providing services for customers, dividing the computing task into several subtasks, and then dynamically assigning each subtask to computing devices integrated by the cloud computing platform though the internet. After the subtasks are finished, the computing results are summarized in the control centre again and sent back to the customers at last. In addition, the control centre is also in charge of distributing the data needed to store into data storage devices, and reading the data from storage devices again when there is a need.

The smart power grid cloud is connected with data acquisition network composed of sensors and data acquisition equipments. To the smart power grid, the future data acquisition network includes both the sensors of traditional SCADA system, and PUM and smart meters set in the homes of terminal users, even the embedded systems of smart consumer electronics. These devices offer the comprehensive information systems in order to support the analysis and decision making of smart power grid. Moreover, the smart power grid cloud connect with other data

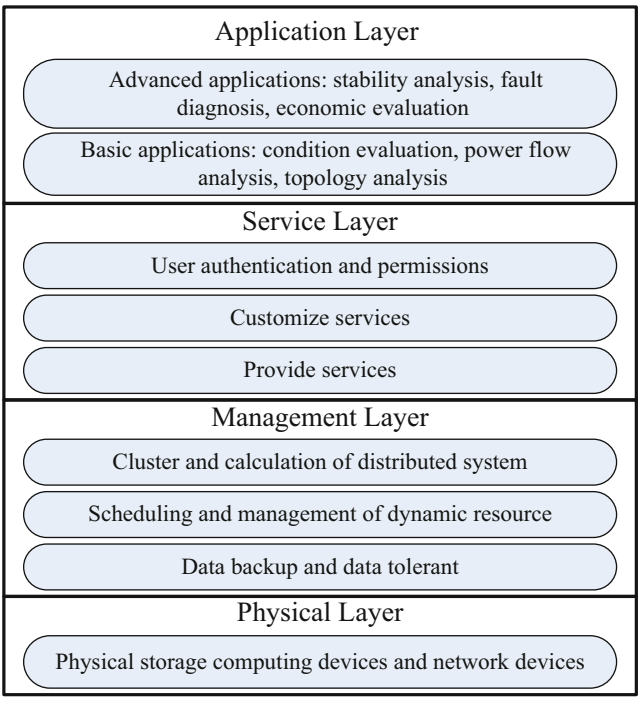

Fig. 75.2 System structure of smart power grid cloud

sources as the regional meteorological database in order to obtain the data of temperature, humidity, wind speed and sunshine. The data volume collected by such a large-scale network will be striking. No other than the powerful computation ability of the smart power grid cloud store and analyze.

System Structure of Smart Power Grid Cloud

The system structure of smart power grid cloud is shown in Fig. 75.2.

- Physical Layer: the physical layer includes the physical storage computing devices and network devices of smart power grid cloud which distribute in different geographical position and connected by WAN or power line in the power system, and it is the physical basis.
- Management Layer: the cluster and distributed system are adopted to realize the cooperative works of all the storage devices in the smart power grid cloud. The cooperative works include the scheduling and management of dynamic resource, the data backup and the data tolerant, and so on.

- Service Layer: the service layer is the most flexible part of the smart power grid. The power operation management institutions at different levels provide different services in accordance with requirements and permissions. The power grid at different levels could log in, customize and obtain the corresponding services by the common interfaces of smart power grid cloud.
- Application Layer: the application Layer provides the powerful software platform which includes advanced applications and basic applications for the operation of the power system. Besides, it could be customizing and developing freely as needed on the basis of the platform.

Technology Construction of Smart Power Grid Cloud Computing

Data Base Model

The current networks of every province generally only consider power grid data models within the scope of home network and not other networks province in the information construction. The own data model library is constructed respectively. The information sharing, data exchange and application integration are difficult to achieve with each other.

IEC61970 provides the technical standard for solving the data exchange and application integration. The two pillars of IEC61970 are the common information model (CIM) and the component interface specification (CIS). CIM defines the semantic of information exchange contents, and CIS stipulates the grammar of information exchange. CIM is the basis of the whole framework of IEC61970 agreement. For the power system, CIM is the model of the power system metadata, and provides the logic description of the unified power system independent of the platform. In the basis of the power system data model taking CIM as a standard, the data exchange among different power databases is realized by CIS. The problem that privatized interfaces inside the systems of various manufacturers hamper the data access of systems is solved by using CIS.

Power Line Communication

One of the construction goals of smart power grid is to structure the hyper-scale power system covering the whole country. The application of cloud computing in the smart power grid needs to integrate all kinds of resources in the power grid. The first problem needing to be solved is that how to structure so large physical transmission network for transferring data.

The power line communication (PLC) is the communication technology of transmitting signals by the power lines. The Chinese transmission and distribution network is the largest cable network in the world. The construction of PLC

networks covering the whole country by using the existing power networks and the high speed wireless communication technology as WIFI both saves much manpower and material investment in the network construction and getting rid of the dependent to the telecom operators.

Service Oriented Architecture

The interactivity of smart power grid will be increased in the process of development and construction. Both the interaction between power grid and power generation and the interaction between power grid and users cannot do without the software support. There are higher requirements for the expandability and the upgrade ability of the software. One important characteristic of cloud computing is easy to expand and upgrade. The service oriented architecture (SOA) is an architecture model could distributed deploy, combine and use the application components of loose coupling and coarse granularity as needed by the networks. In the design method of traditional software, the function or class acts the basic function module and the application programming interface (API) acts the communication mean among programs. Unlike the traditional method, the service acts the basic function module in SOA. Each kind of main function is wrapped the service of mutual independence. It is communicating by the extensive makeup language (XML) in SOA, and don't relate to the bottom programming interface and communication model.

Scheduling and Management of Dynamic Resource

The central issue of power cloud platform is the scheduling and management of resources. Firstly it is how to describe resources of users. Each computing device will be integrated before entering the cloud, and the device information is recorded as references for the follow-up process. The data structure describing the status of computer resources is shown as: the million floating point operations per second (MFLOPS) got by the actual measurement is the major index to the property of computer resources, RAM ranks only second to the predecessor in the influence of the computing performance, and the cache direct influence the speed of data communication. Secondly it is how to schedule and manage resources. The load balancing algorithm is the core of cloud computing. The dynamic load balancing has proved a more effective algorithm of distributing computing tasks (Fan Tao et al. 2011; Cui Chunlei and Fang Yanjun 2011; Attiya and Hamam 2004). The fundamental is that the tasks are distributed dynamically in accordance with the computing speed of computing devices in order to ensure computing devices returning results at the same time basically. In the actual visit, the load balancing algorithm is adopted to manage the cloud resources.

Technology Application Prospect of Smart Power Grid Cloud Computing

Intelligent Warning of Smart Power Grid Cloud

The present power system warnings include the local control proceeding in the automatic equipment of substation and the evaluation plan got after offline computing to system typical operation mode in the control center, which is not comprehensive and non-real time. For the real-time simulation of entire network, the real-time computation of large amount of calculation is needed (Yang Weidong et al. 2000). The intelligent warning based on the smart power grid cloud could establish the integration simulation of power system with the characteristics of wide-area distribution of data resources and computing resources, large amount of calculation and high requirements for computing ability. The supercomputing ability of power cloud is sufficient to satisfy requirements of real-time mass data processing. The intelligent warning based on the smart power grid cloud includes (Hu Jun-yi and Fang Xin-yan 2006):

(a) *Voltage warning*: It can monitor in real-time whether the voltage keeps in the prescribed range, whether the node voltage is out of limit and the rationality of distributing reactive power, forecast the margin of the system voltage collapse, confirm weak points of system voltage and prevent the system from the voltage collapse accident.
(b) *Power-angle and tide warning*: It can monitor in real-time the system trend, analyse and judge the normal operation and whether the stability of power-angle will be lost in the condition of prescribed disturbance, forecast the trend data of system when the generator power changes, the structure of power grid changes and the loads are transferred or cut off and prevent the system from the unstability of power-angle and oscillation accident.
(c) *Frequency warning*: It can monitor in real-time system frequency, analysis and compute the influence of system frequency when the generator power changes and the structure of power grid changes, keep the power of tie lines in the desired value and prevent the system frequency from the instability accident.
(d) *Equipment warning*: It can monitor in real-time the condition of system devices, analysis and compute the influence of devices when the generator power, the structure of power grid and the system trend change in normal mode and N-1 mode and prevent the system devices from the dynamic and thermal stability accident.

User Interaction Based on Smart Power Grid Cloud

The electricity is necessity of every household. So the smart ammeters that transformed and set up in users' home by the smart power grid act the interactive

terminals between power grid and users and the tentacles of the smart power grid cloud extending to users' home. The strong computing power of cloud computing could achieve the following goals: the remote connections and disconnections, the detection and notice of outage. The smart power grid cloud collect electricity information of users in real-time, analyze the data in a period of time and at last feed back to users in order that users could know electricity prices and according to their actual needs select the power solutions and electricity prices that suit themselves.

Conclusion

In recent years cloud computing has been a new computing model that develops rapidly, integrates the heterogeneous computing resources and possesses the strong ability of computing and storage. The appearance of smart power grid cloud has a major influence on the information exchange, computing ability and storage space in the development of smart power grid.

The cloud computing platform not only provides the ability of computing and storage for the analysis of power system, but also has the advantages of strong expandability, less hardware investment, easy to the development and upgrading of software and so on. So cloud computing will replace the existing centralized computing and become the core computing technology of smart power grid.

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