Design of cloud computing architecture for power system analysis

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Abstract— **cloud computing is a novel solution to deal with the problems of power system analysis raised by the expansion of power system and the interconnection among power grids. Introducing it to power system analysis, considering the development needs of computing resources and distributed applications, the possible applications of cloud computing in power system analysis are discussed, and the structure of power system analysis cloud platform is put forward. To validate the design, the Eucalyptus private cloud platform is established and the power system reliability assessment is deployed to the platform. Simulation results prove the feasibility and superiority of cloud computing in power system analysis.**

Key words— Eucalyptus ; private cloud platform ; power system analysis ; cloud computing

I. Introduction

With the scale of the power system expanding and its structure growing more and more complex, it becomes increasingly difficult to achieve security assessment, stability control as well as economic operation in the grid. Meanwhile, the explosive growth of network data brought about by increasing grid interconnection, and coordination of the network information conducted by distributed renewable energy, have created a greater challenge to the traditional power system analysis platform. Currently the power system analysis is based on the local fixed cluster or grid of computers, which has limited computing power, poor scalability, high upgrade costs, and low network resource utilization. These drawbacks are yet not very prominent, as the existing SCADA system of the grid is restrained in the substation level when collecting data, where the data sampling frequency is low, and the requirements of the system data is still not high enough [1]. But with the data explosion brought about by the trend of intelligence, the above-mentioned drawbacks would seriously affect the development of the grid.

Cloud computing has emerged as a new paradigm for providing programmatic access to scalable Internet service venues [2]. It brings new opportunities to solve the problems of insufficient processing power and low resource utilization of power system analysis. In this paper, combined with the advantages and core technology of cloud computing, the possible applications in power system analysis are explored, the architecture of power system analysis cloud platform is put forward, and a local private cloud platform Eucalyptus has been built, combined with the power system reliability evaluation on this platform, the advantages of which is verified.

II. Cloud Computing

Cloud computing is the latest development of parallel computing, grid computing and distributed computing. It is able to implement these calculations, but also has its unique value to be promoted. Adoption of cloud computing for scientific computing is much cheaper than the purchase of a supercomputer with a dedicated high-performance cluster, and is more flexible than the use of grid computing, more scalable than commercial PC cluster.

One of the key technologies of cloud computing is the virtualization technology, By using multiple virtualization technologies, such as network virtualization, server virtualization, application virtualization, storage virtualization and desktop virtualization, cloud computing abstracts various resources into the form of services, screens out the difference between different infrastructures, operating systems and application software. In the form of providing different services, it provides users with tailored resources services.

Another key technology of cloud computing is the distributed technology. Distributed technology is mainly used in achieving distributed parallel usage of various types of IT resources, including: (1) Parallel technology, which is used to achieve usage of various computing resources at the same time; (2) Distributed programming framework, which is the overall framework to achieve distributed parallel computing development model; (3) Distributed information database, which is a large database connecting distributed wide-area information resources through the network;(4)Distributed file system, achieving distributed file management。

III. Cloud Architecture of Power System Analysis

A. *Requirement for Power System Analysis*

With the continuous progress of the smart grid, the development of UHV synchronous grid and the formation of northwest, northeast sending end grid in China, the traditional electric power system analysis is now faced with challenges such as much larger systems, more complex structures, more massive data and stronger network dependence, etc. These all raise a higher requirement for the hardware of analysis platform. Reflected on the IT level, these requirements can be summed up as: the urgent need of more powerful mass data processing and

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Tab.1 Possible Usability of Cloud Computing in Power System Analysis

Core Technology	Application Analysis	
Virtualization Technology	Network Virtualization	The demand is not urgent, but there are some prospects
	Server Virtualization	Build a strong virtual pool of power system analysis, improve power system resource utilization and simplify management system
	Application Virtualization	Can effectively solve the problems as version compatibility for all kinds of power system analysis apps, improve the versatility of different analysis software, and reduce the threshold for the user
	Storage Virtualization	Achieve storage and management analysis of the actual various types of massive distributed heterogeneous resources in power system, improve the availability of power system analysis
	Desktop Virtualization	Can be used in large-scale software development of power system analysis applications, office automation, etc
Distributed Technology	Parallel Technology	Can be put into important applications in Power System Analysis for fast and accurate implementation, including the two parts of the algorithm calling and task management, mainly used in all aspects of system analysis and calculation, such as formula calculation, system evaluation, and system security online analysis
	Distributed Information Database	Form a logical unified and physically distributed large database by interconnect all kinds of wide-area information through network, to improve the information accuracy of power system analysis, and can be used for wide-area analysis and control
	Distributed Programming Framework	Provide a better solution to deal with the mass of information of the future power system
	Distributed File Management	Applied to the integration of hierarchy level control center data, the online / offline data within the regional power grid, static data and dynamic data, to provide a solution for the integration and management of the vast amounts of information

parallel computing power; need of further development in the direction of on-line analysis, identification and controlling; the ability of wide-area panoramic distributed coordination analysis needs to be improved; fast and flexible coordination of existing software resources to achieve different analysis functions, such as security analysis, state assessment, risk assessment, and meet with requirements from different types of users of different levels; ensuring access of large-scale intermittent energy and distributed grid; achieving integration, standardization, and meticulous management of grid information, to achieve a high degree of resource integration and sharing, and unifying analysis system platforms and models; with the investment increasing, at the mean time of ensuring the redundancy, resources need to be more fully utilized.

B. Feasibility of the Application of Cloud Computing Model

Combined with the core of cloud computing technology and analysis requirements of the power system, the cloud computing model can be applied in power system analysis as shown in the following Tab.1.

C. Architecture of Power System Analysis Cloud Platform

As is shown in Fig.1, the designed entire power analysis cloud system consists of three parts: the physical infrastructure part, the power system analysis cloud service part and the operation management part. Among them, the physical infrastructure part includes the data center infrastructure, such as

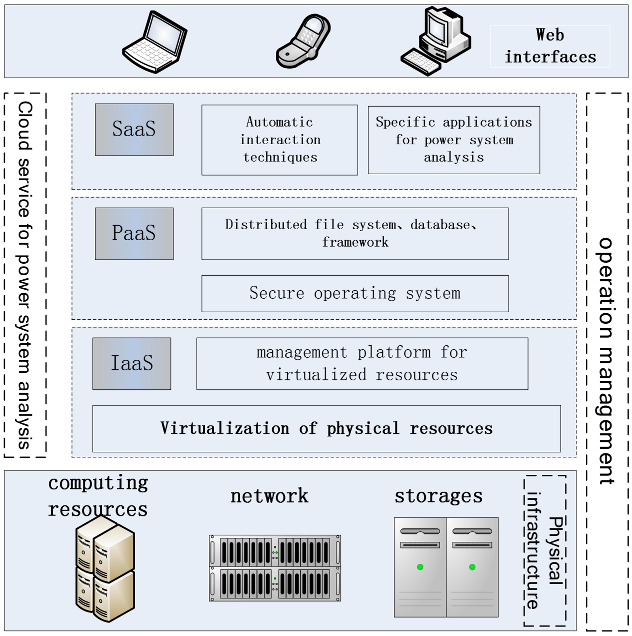

Fig.1 Structure of Power System Analysis Cloud Platform

storage facility, power supply, server, distributed computing resources, servers and network equipment. The part of power system analysis cloud services provides different levels of power system analysis computing services. The operation management part relates to the safe and stable operation of the power analysis cloud, ensuring service quality and system security, such as access authentication, monitoring, statistics and analysis of the power cloud, control of cloud computing system, user data, ensuring application security services and cloud services quality, etc.

1) Cloud Services for Power System Analysis

The power analysis cloud services are the core business, mainly including three levels of service: Infrastructure as a service (IaaS), Platform as a service (PaaS), and Software as a service (SaaS) [3].

The IaaS layer provides the power system analysis with a unified IT infrastructure through virtualization technology, including CPU, RAM, I/O virtualization, network virtualization. It uses virtualization technology to effectively achieve rapid deployment of virtual machines and quick connection with the network. The same business can be stored, deployed and removed through the way of virtual image [3], and the entire virtual resource system can be set to be managed by resource monitoring part.

The PaaS services involve the operating system, distributed database file system and the development and test environment. In order to ensure the security of the private cloud platform, the state security operating system is selected. Distributed database and parallel platforms provide a convenient and unified development interface for users to conduct distributed mass data processing and large-scale computing. Achieve distributed storage management and document management with open source Hadoop technology, so as to ensure the efficiency of the power system mass data processing. Deploy distributed programming framework on this basis, combined with the MapReduce framework of Hadoop and the MPI parallel programming model commonly used in parallel computing, to build parallel programming framework needed in scientific computing. Add middleware part to meet with the existing habits in power grid application development, and deploy the software development kit and shared components according to the actual need, such as C, PHP, Python and other commonly used programming languages, and shared components such as SKD [1]. Finally the PaaS layer also needs to provide distributed web-development interface.

The SaaS layer services relate to the specific power system analysis business, mainly used by the program users, rather than developers. The callable images of related power system analysis business are stored in the storage systems of the cloud platform by the developers. For convenience of the users, introduce the virtual machine automatic deployment technology, the sandbox technology, the application interactive technology and the web presentation technology, guaranteeing user experience with the safety access management part.

2) Security, Real Time Considerations and QoS of Power System Analysis Cloud Platform

In order to ensure the data security of the system, the private cloud platform has become the focus of the study. Within the power system of China, there has formed a relatively complete WAN, which can be made full use to build a private cloud of power system. Since access to cloud storage and computing resources can be fully controlled by the power system itself, which creates a complete physical isolation, so the data security is ensured. And in cloud computing, each user is provided with a totally isolated visual environment, which blocks all the access from other visual environment.

In the IaaS service layer, for the security risk brought by the virtualization technology, a privileged virtual machine is set on the server to manage other virtual machines, thus full monitoring and management of the privileged virtual machine is also very important; in PaaS / SaaS layer, access control mechanism is built, using AAA authentication to access the platform file system, database and application system, to control authority of data management and access permission of different levels and different types [1]. Meanwhile, the management part of the cloud platform needs to be introduced with the system security audit section, so as to keep track of the movements of the system, and protect the overall security of the whole system.

In the cloud system, the same operation is stored, deployed and removed by means of the virtual image; the virtual machine image (namely the template) is pre-installed with operating system and simulation environment, and even the application software; virtual machine template technology can effectively reduce the deployment time of the virtual machine. At the same time, the applications of disk fault-tolerant technology, application recovery technology and online reconfiguration can ensure the system's real-time usage well.

And for the QoS of cloud platform, As there are different service requirements for different levels of cloud services, the assessment parameters for the IaaS layer services are divided into two categories: one is the minimum quality of service provided by the cloud services, such as server availability; the other one is the service response time [3]. The corresponding SLA is decided through consultation according to assessment parameters for different requirements depending on different application requirement levels. The deterministic SLA 100% guarantees service needs, the probabilistic SLA is usually expressed with the percentage of availability, and guarantees the user needs at a certain probability. For PaaS / SaaS layer services, design load forecasting model based on queuing theory, and by comparing the hardware facilities workloads, the load of user requests and quality of service (QoS) metrics, adjust the number of virtual machines used in the service, and confirm the division of the service granularity.

IV. The Simulation Based on Eucalyptus

A. Overview and Establishment of Private Cloud Platform Eucalyptus

Eucalyptus[2,4]（Elastic Utility Computing Architecture for Linking Your Programs To Useful System）is an open source software platform for the realization of cloud computing. Based on the idea of IaaS, and compatible with the business EC2 interface, the platform is considered as an open source implementation of Amazon EC2. It achieves flexible, practical cloud computing via computing clusters or workstation group.

Based on virtualization, Eucalyptus uses open source web services technology to achieve the control and management of the platform. Eucalyptus consists of five main components, each of which is composed of several web services with well-defined interfaces described by WSDL, and secure communications are supported by WS-security policy. The underlying architecture of Eucalyptus is supported by industry-standard software packages, such as Axis2, Apache and Rampart. Users can have access through the web browser or SOAP-based and REST-based tools (the commonly used euca2ools is a SOAP-based tool).

UEC (Ubuntu Enterprise Cloud) is an open source project put forward by Linux operating system Ubuntu, which contains Eucalyptus and a series of open source software, so cloud system can be more easily installed and configured. In this paper, Ubuntu Server of 10.04LTS-i386 version is adopted to build a single cluster, multi-node private cloud.

B. Cloud Platform Simulation for Power System Reliability Analysis

Power system reliability evaluation analysis is an important part of the power system security analysis. Mostly, power system uses the Monte-Carlo method as the tool for large-scale complex grid reliability study[5,6], and decomposition via Monte-Carlo sampling algorithm makes it possible to build Monte-Carlo parallel task allocation. This paper describes the system reliability assessment application based on the heuristic nearest load reduction model of DC power flow. During assessment, firstly we use the depth-first algorithm from graph theory to determine the disconnection of the system and each subsystem formed after the disconnection, followed by the use of optimal power flow model based on the DC flow, then use the heuristic nearest load reduction model to conduct load reduction calculation [5,7], and finally calculate the reliability index of LOLP, EDNS and EENS.

Assume that the power system cloud integrates resources of 4 ordinary computers (in fact, the cloud can integrate resources far more than this number). Cloud computing platform can flexibly split a computing task into multiple small tasks for parallel computing. In this paper, Monte Carlo sampling is split into three parts, along with the evaluation process afterwards, which are allocated to three virtual machines, and another virtual machine serves as a parallel computing control node.

Users visit the system via a web interface, and after security certification, one can select their desired power system analysis task (In this article, which is the reliability assessment), and choose the needed virtual machine resources. After receiving the task and the required data, the selected primary VM(virtual machine)will split the task and evenly distribute them to the parallel virtual machines. The virtual machines will accept the scheduling and then perform parallel computing. The calculated results are returned to the main virtual machine, and then the primary VM will finally integrate the results to obtain the composite indicator, and display it to the user.

C. Result analysis

Conduct test using the RTS79 system. Computing on centralized computing platform, the sampling frequency is set to 300000. The simulation costs the time of 119.37s. Changing the sampling frequency, the statistical results of centralized computing platform operating are shown in Table 2:

Tab.2 results of the program on local one machine(Intel E6300 total indicators)

Sampling Frequency	*LOLP (MW)*	*EDNS (MW)*	*EENS (MW)*	*TIME(s)*	*Variance*
	0.07233	0.13016	114016.159	1.10	0.08554
90000	0.08627	0.14851	130094.313	35.79	0.01463
300000	0.08585	0.14955	131009.550	119.73	0.00798
900000	0.08573	0.14885	130396.534	358.67	0.00463
3000000	0.08581	0.14859	130161.525	1196.23	0.00253

Deploy the program to the cloud platform, the statistical results are shown in Table 3：

Tab.3 results of the program on cloud computing(m1.large total indicators)

Sampling Frequency	*LOLP (MW)*	*EDNS (MW)*	*EENS (MW)*	*TIME (s)*	*Variance*
3000	0.06700	0.11919	104407.202	0.89	0.08751
90000	0.08457	0.14619	128066.074	12.56	0.01489
300000	0.08612	0.14883	130372.275	40.84	0.00802
900000	0.08585	0.14955	131009.550	122.01	0.00461
3000000	0.08567	0.14858	130158.422	404.76	0.00253

Comparing Table 2 and Table 3, it can be seen that, the precision of reliability evaluation increases as the sampling frequency increases, while the assessment error gets smaller and smaller, and the results obtained by both methods tend to be consistent. However, in regards of the operation time, expect for the initialization-related operation, from the beginning of the program to the in-between communication, till the final result is obtained, the cloud platform execution spends about 1/3 time of the local execution (except for the sample of 3000), which is approximately the theoretical best acceleration effect (with 3 virtual machines, the accelerate ratio is 3). As communication is not frequent in the program, the communication bit is small, thus the acceleration effect is obvious.

After reliability assessment analysis has been completed, release four virtual machines, and these physical resources can be re-applied for other applications. If one needs to add other analysis and calculation functions into the cloud computing platform, all one needs is to upload the locally produced virtual image to the cloud database, thus making it possible for calling at any time and autonomous control, showing great advantages in program development and batch processing.

In conclusion, the cloud computing platform not only can achieve better power system analysis and calculation, but also has high scalability, high portability and low cost, thus it has a more prominent advantage in large-scale analysis and calculation.

V. CONCLUSIONS

After discussing the possibility and advantages of cloud computing in power system analysis, this paper set up the cloud platform architecture of power system analysis, locally built the Eucalyptus private cloud platform, deployed the paralleled power system reliability analysis on it and achieved satisfying acceleration effect, which shows the feasibility of cloud platform in power system analysis.

Put forward by this paper, the cloud computing architecture provides a new way of thinking for the power system analysis application implementation. Still, there is need for further improve in future work, such as the cloud-matched parallel algorithm、dynamic allocation of load、and distributed data process of the cloud.

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