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Multi-Agent-Based Cloud Architecture of Smart Grid

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Abstract

Power system is a huge hierarchical controlled network. Large volumes of data are within the system and the requirement of real-time analysis and processing is high. With the smart grid construction, these requirements will be further improved. The emergence of cloud computing provides an effective way to solve these problems low-costly, high efficiently and reliably. This paper analyzes the feasibility of cloud computing for the construction of smart grid, extends cloud computing to cloud-client computing. Through "Energy Hub", Microgrid is separated into a network of three storeys that match with the conception of cloud-client computing. This paper introduces multi-agent technology to control each node in the system. On these bases, cloud architecture of smart grid is proposed. Finally, an example is given to explain the application of cloud computing in power grid CPS structure.

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Keywords: Cloud/cloud-client computing, smart grid, Microgrid, Energy Hub, Multi-agent

1. Introduction

Strong smart grid is the development trend of the future power grid. According to the definition of the U.S. Department of Energy [1], smart grid should have a number of important features: have a strong self-healing ability and able to withstand external attacks; can support large-scale intermittent renewable energy and distributed power access; can ensure power supply reliability and power quality; can promote fair electricity market, effective operation and user participation. In order to meet these requirements, there will be huge increase in the amount of data in Smart Grid environment. Phase Measurement Unit (PMU), smart meters, smart appliances embedded in system may provide a lot of real-time system information. Meanwhile, with the gradual access of solar, wind, hydro and other renewable energy and the development of distributed energy technologies, power system will be larger, more complex, distributed more widely. Faced with these massive, distributed, heterogeneous multi-source information, future power system control center should have strong computing power and information collection,

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integration and analysis capability.

Because of the characteristics of electricity itself, electrical energy cannot be large-scale storage, generation, transmission, distribution and use must be carried through at the same time. Hence the production and management of electricity is a system of hierarchical management and control, distributed processing [2]. This hierarchical network matches with the level of cloud computing. Therefore, the wide area network within power system can be used to establish private cloud in order to provide the system with the ability of super computer, maximize the integration of existing data and processor resources, through cluster applications, distributed computing and other functions. Cloud resources does not rely on public cloud computing service providers, the storage and access to them can be completely controlled by the power system itself in order to insure data security.

2. Cloud/Cloud-Client Computing

Cloud computing is an emerging computing model. In 2006, Amazon launched Elastic Compute Cloud (EC2) service to small and medium enterprises to buy data centre according their own needs [3], since then, the cloud computing era begins. The current understanding of cloud computing continues to develop and improve. According to Wikipedia[4], cloud computing refers to the provision of computational resources on demand via a computer network, the user's computer may contain almost no software or data (perhaps a minimal operating system and web browser only), serving as little more than a display terminal for processes occurring on a network of computers far away. Users no longer need to understand the infrastructure of the "cloud" in details, do not possess necessary professional knowledge and need no direct control.

Google and IBM's cloud computing concept [5,6] emphasized that almost all software can be moved online, software can be replaced by service. Application of different users are not required to run on their personal computers, mobile phones and other terminal equipment, but running on the Internet in the cluster mass. Data to be processed is not stored locally, but stored in a data centre on the Internet. However, this cloud computing applications defined the terminal nodes (users) just as consumer, the consideration of the contained computing, storage even resource is not sufficient. “Cloud-client computing” proposed by Microsoft [7] considers the cloud and terminal have strong computing power, emphasizes the balance of cloud and terminal. As the terminal node itself has the resources, when the terminal joins the cloud computing environment, it may also contribute its idle resources to service. However, this behavior is clearly not reliable, of course, difficult to ensure the quality of service. Even so, the terminal is often a huge number of nodes (even millions), so the redundancy to improve performance is possible. Based on Multi-Agent technology, paper [8] divided the cloud-client model into three levels: core (consists of high performance servers), inlayer (including cluster servers) and out layer (terminal nodes). Agent, representative of the node action and resource, can help maximize resource utilization.

Services by cloud/cloud-client computing have such features: arrange resource or get service based on virtualization technology; can achieve dynamic, scalable expansion; provide resources on demand, pay according to usage amount; through the Internet, orient mass information processing; users can easily participate; form flexible; reduce the processing burden of user terminals and dependence on IT expertise[9]. The advantages of cloud/cloud-client computing present by distributed computing and storage, huge scale, virtualization, high reliability, nice management and expansibility, extremely low cost.

3. Cloud Architecture of Smart Grid

Microgrid is a controlled small-scale network to solve the problem of the accessing of distributed

generations to the power grid [10]. It's also the important part of smart grid. The characteristic of small-scale is conducive to the adoption of new technologies and their development. Based on Energy Hub, layered-controlled system in Microgrid is established. Meanwhile, cloud architecture of smart grid is proposed based Multi-Agent technology. The framework is shown in Fig.1.

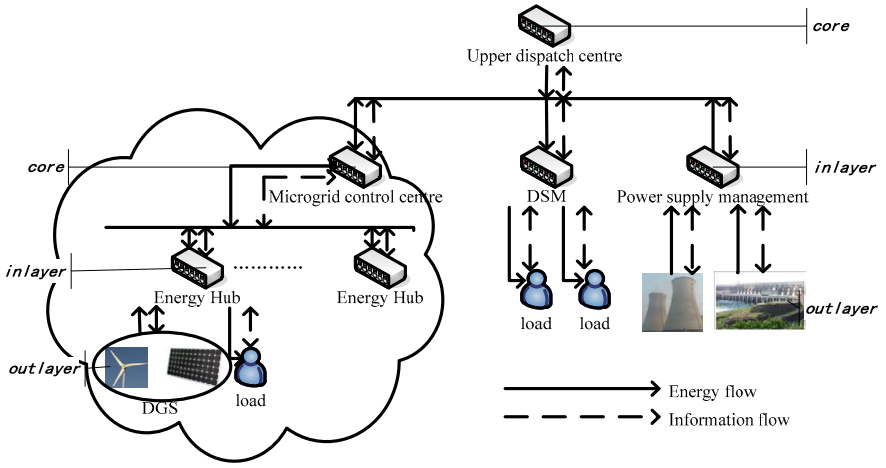

Fig. 1. Cloud Architecture of Smart Grid.

This architecture includes two embedded clouds. A small cloud consisting of the elements in Microgrid, which can operates independently, is a sub-cloud of the great network cloud. As terminal nodes in out-layer, the distributed generations and loads are controlled by the nearest Hub. The information of loads, power flow, power quality and power market can exchanges among each Hub and upload to the control centre of Microgrid. The optimal generation assignment plan is made by the control centre, through the analysis of the information inside and outside, and then sent to the Hub to carry out. With regard to the great system, the upper dispatch centre acting as the cloud core, plans as a whole of various information uploaded by the inlayer nodes including control centre of Microgrid, local demand side management (DSM) and power supply management, coordinates the exchange of information, sends control instruction.

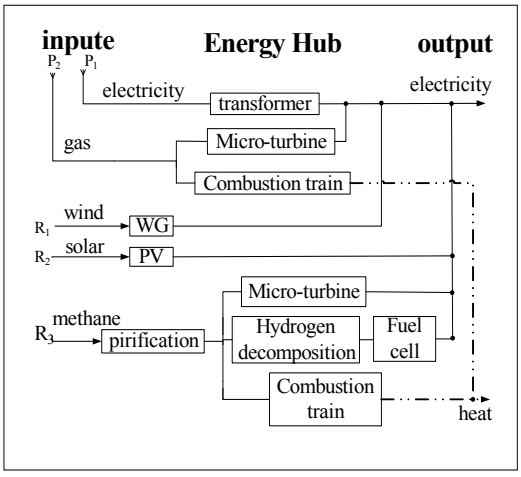

Fig. 2. Internal structure of a Hub of Microgrid.

The “Energy Hub” in Fig.1 derived from the conception of “Hub” in the field of computer science, it can also be called “energy control centre”. In power system, it is a broad multi-port network node. The input is electricity power and other forms of energy, such as wind and solar energy. The output is different forms of energy supplying all kinds of loads (electricity/heat/cold). Fig.2 shows the internal structure of a Hub of Microgrid including wind, solar, gas and biomass. This Hub provide electricity and heat to local loads, redundant power can be re-transmitted to the distributed network through transformers and the supplied to loads in other regions. This Hub has higher reliability and energy utilization.

This cloud architecture is a dynamic and distributed system. The different characteristics of each component determine that they have to be controlled in specific ways; the system cannot use a unified control strategy. Distributed generations and load may cut out or access at any time which causes some difficulties to unified management. Microgrid and the traditional network constitute a layered topology; the variety of subsystem creates layered information. Taking into account the above characteristics, Multi-Agent technology is introduced, which aims to build a platform that can reflect capacity and status of each node as well as coordinate the control of each node.

Each component has its own agent and exclusive control strategy. Multi-Agent-based distributed control allows information among nodes to interact and share, so as to achieve coordinated control of the whole system. With application of Multi-Agent technology, management unit control power operation on its level. At the same level, different subsystems are both independent and interconnected. Compared with centralized control, it will not produce a delay on processing time so that the dispatch of power system can run more specific and flexible.

4. Agent in the Cloud-Client Model of Power System

Deriving from distributed artificial intelligence technology, Multi-Agent technology rising recent years is a fusion of distributed computing, artificial intelligence, information theory, systems theory and other disciplines of programming ideas and methods. Each agent in Multi-Agent system has the characteristics as follows[11]: (1) Autonomy: in the absence of external intervention, through their knowledge or perception of the external environment, they can independently control their own behavior to accomplish certain tasks;(2) Collaborative: different agents can collaborate together to complete the task or the other complex problems, provide information to other agent when needed, this feature is especially suitable for distributed problem;(3) Study: they take the initiative to learn and get information from external environment in order to constantly revise their own database, which makes them more reasoning and planning.

According to the different levels of each node belongs to, the node functions are different. Dispatch centre agent, including data management agent and performance evaluate agent, has been equipped with a scheduling strategy with a more complete knowledge base and database in the initialization. Data management agent accepts information from the next-level agent or the Hub; continuously learns and updates according to their own environment. Performance evaluate agent evaluates some indicators, such as reliability, power quality, environmental impact and so on, gives a reasonable and economical output policy coordinating with data management agent.

Hub agent should have processing capacity of local data, such as electrical parameters of power supply and load, while communicate with other Hub, accept commands on the up-level agent and assign the task to the next-level agent.

Power generator agent has the ability of prediction, communication with superiors and enforcement command from them. Because of the different characteristics of each generator, different agents have specific function, for example, PV agent has the function of maximum power point tracking (MPPT), battery monitoring and inversion; fuel cell agent has the function of water treating, fuel processing, air

supply, hydrogen and oxygen content monitoring, fuel injection control, heat treatment, power conditioning and grid connection; storage battery can monitor its own voltage, current and stored energy, start, stop or limit charge-discharge; wind agent can predict and control wind speed, monitor electrical parameters.

Load agent can cut off some non-critical load when all of the power output cannot balance the demand.

According to the functions of each agent analyzed above, agent in cloud-client model of power system can be defined as following expression:

$$Agent =< ID, position, role, resource, state, police >$$

where:

ID is the identity of agent. Since the same physical device may have more than one agent, ID should contain two parts: serial number of the node and the agent, expressed as $ID = NodeIdentity \bigcup SerialNo.$.

Position marks the layer of an agent: core, inlayer or out layer. As the architecture in this paper includes embedded clouds, the position should identify the number of the cloud layer the agent belongs to, expressed as $position = layer \bigcup CloudNo.$.

Role is the agent role and conditions the agent should have in this role. It includes dispatch/control centre, Hub, power supply and load.

Resource mainly refers to the resource that a node had and can be shared, including CPU, memory and other computing resources; hard drives and other storage resources; programs, files, data and other software resources.

State describes the agent current working status, such as “busy”, “idle” and so on.

Policy is the strategy setting according to the node condition (state and resource). It determines the decision made for the node when facing with current or temporary task.

5. Application of cloud computing in power grid CPS structure

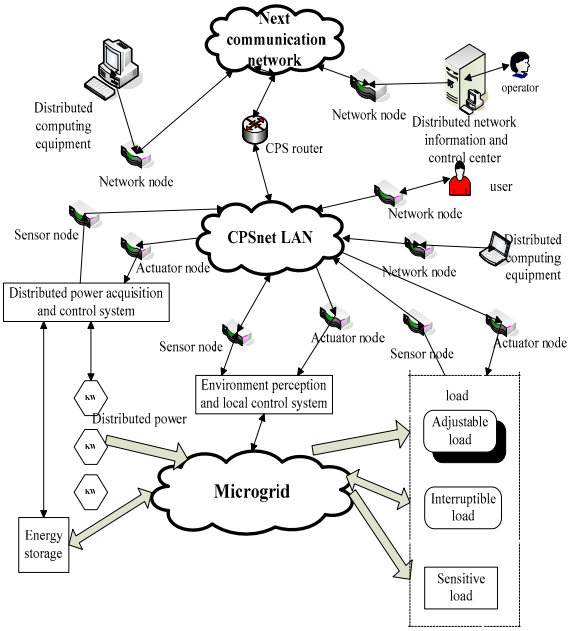

Fig. 3. The architecture of CPS in Microgrid

CPS (cyber physical system) depth integrates usually computing power, communication ability, and autonomous control ability and makes this three compatible. It's an interaction of information system and physics system. The essence of CPS is a control network with the function of calculation, communication and control fully based on the perception of environment. On the basis of the Internet, emphasizing on the environmental awareness, CPS realizes real-time information control and information service, can test or control the physical entity in a safe, reliable, efficient and real-time way [12]. Advanced information technology is the necessary security of Smart Grid. Microgrid is the important component of Smart Grid. According to the model of CPS proposed in paper [13], combined with the characteristics of Microgrid, an overall framework of the Microgrid CPS is established as shown in figure 3 above.

In figure 3, thick arrow lines say power flow, fine arrow lines stand for information. Microgrid CPS framework including two parts: power network and information network. Physical equipment is mainly power equipment, such as distributed power supply, electronics device, energy storage, load, etc. Information equipments include sensors, distributed computing equipment, server, CPS real-time network, etc, connected by communication network. Through transmission lines, electric power equipment joined together to form a controllable small system, connected into power system, can be in an emergency independent operation by disconnecting static switch.

Microgrid CPS can be a local area network of future Smart Grid, connected great power grid CPS with the CPS router. CPS router should be able to easily realize IP address addressing and the transformation of the heterogeneous data format. Local information and control center is set in the distribution network, can integrate all of the data near the CPS to analysis, and simulate, real-time process collection of data, check the legitimacy of user identity, according to local users demand of the data analysis, request to the actuator control node.

6. Conclusion

This paper introduces cloud/cloud-client computing into power system. According to its own characteristics of power system, the system and Microgrid in it is divided into three levels network that matched with the conception of cloud-client computing. Multi-Agent technology is introduced; the composition of agent in cloud-client model of power system is analyzed. The cloud architecture proposed can maximum integrate the computing and storage resources without change of the internal structure and existing equipments of power system. It provides to the system "super computing power" for fast simulation and modeling, full range of real-time analysis and calculation, which can increase the overall performance of the current system, reduce the investment, and provide strong technical support to the establishment and implementation of smart grid.

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