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The contributions of cloud technologies to smart grid

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ABSTRACT

Electric power systems (EPS) are regarded as the largest artificial systems that cover the most area. However, EPS are relatively weak among all infrastructures because they could collapse easily in the case of great disturbance, disasters, and so on. The resulting blackouts may cause serious social problems and safety damage. Here, we show that cloud technologies, including cloud machine, cloud storage, cloud computing and cloud security, play an important role in improving the disaster preparedness level and the resilience of power systems to disasters. In addition, by using cloud technologies, the level of power system optimization and the accuracy of power system simulation can be increased. By improving resilience, the level of optimization, and the accuracy of simulation, cloud technologies can promote the access of renewable and sustainable energy to smart grid (SG).

Contents

1. Introduction

Since the computer was invented in 1946, the information technology (IT) industry has experienced several significant revolutions [1,2]. Cloud computing has evolved from conventional computing and is a data-intensive and compute-intensive model. The National Institute of Standards and Technology defined cloud computing and technology in 2011 [3]. Cloud computing is a model for enabling ubiquitous, convenient and on-demand network access to a shared pool of configurable computing resources. This cloud model consists of five essential characteristics, including on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service; and is composed of Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). Other cloud technologies such as cloud storage have also been derived and developed. This technology is based on highly virtualized infrastructure and has the same characteristics as cloud computing in terms of agility, scalability, elasticity and multi-tenancy [4]. As cloud technologies develop, it is applied more widely and deeply, e.g., in smart grid.

Power Systems are considered as the largest artificial systems with the most extensive coverage, and are also the most important

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infrastructure in modern society. To face global challenges such as climate change, energy shortage and environment pollution, SG technologies are a key solution and have thus become an important part of the national energy strategy of many countries. In power systems, the generation and load is balanced instantaneously and the time constants of electromagnetic process are extremely short. Oscillation, voltage deviation and other effects caused by imbalance can spread throughout the whole power grid easily. Thus, power systems infrastructures are relatively weak. If a power system experiences a great disturbance, disaster, or terrorist attack, it could collapse easily, resulting in serious social problems and safety concerns. Examples of system collapses include the blackout in USA and Canada on August 14, 2003, the blackout in Europe on November 4, 2006, and the blackout in India in December 23–25, 2012. New energy development and utilization is a critical strategy but a serious challenge for power systems. Renewable energy generation (such as wind power, solar generation) is intermittent and uncontrolled, thus does harm to the balance of a power system. Therefore, new technologies should be applied to improve the ability to access intermittent power sources.

SG technology is an integration of approaches to improve the level of optimization of planning, construction and dispatching. Generally speaking, there are three major objectives of SG: (i) to improve the ability to accept renewable generation greatly [5]; (ii) to strengthen the self-healing capability of power system [6,7]; (iii) to enhance the economy and reduce costs [8], energy consumption, and pollution [9]. Cloud technology is an important tool to realize these goals [10]. On January 25, 2009, the President of the USA, Barrack Obama, detailed a new recovery plan [11], which marks the start of a new era for SG in America. As early as in 2006, the Council of the European Union announced an initiative on sustainable energy, which includes plans to develop smart grids in Europe [12]. At the 2009 International Conference of UHV Transmission Technology on May 21th, 2009, China proposed a national development strategy of the strong and smart grid [13]. With the growth in solar power and other fluctuant renewable energy, integrating cloud technologies into SG could ensure the stability and reliability of power system [14].

Cloud computing are the supportive technologies for the next generation of SG. The term cloud computing refers to converged infrastructure and shared services over a network. Hardware and network resources, such as CPUs, memories, storage, network devices and bandwidths, are integrated via virtualization to abstract the hardware and reallocate and dispatch the resources. For instance, the cloud platform of Amazon EC2 integrates millions of servers around the world. There are potential applications of cloud-based technology in many areas of SG, including system monitoring and control, information security and storage, power system simulation, and dispatching and planning. Building a new SG platform based on cloud architecture not only will provide high-performance computing and theoretically unlimited storage capacity (Cloud storage is theoretically infinite, which means, what is actually used can be neglected compared to the overall capacity. Cloud storage can be extended limitlessly as you need, as Amazon puts it, "unlimited everything" [15].), but also stronger extension, richer application, faster update and lower cost [16–23]. Research has shown that cloud computing offers features that are well suited to SG software platforms including computation, storage, combining of information, analysis, and applications such as flexible resources and shared services [10,24–26]. Through the establishment of an intelligent cloud, the whole performance of the current power system can be improved over the Internet under immense workload conditions [27–29]. Software architectures can also be deployed to analyze massive data from millions of smart meters, power users and demand responses from them [30,31]. A cloud-technology-based demand response system, including data-centric communication, publisher/subscriber and topic-base group communication, provides a faster and more reliable demand response [32,33]. On the other hand, with the application of cloud technology into SG, there are also growing concerns on security and privacy issues due to the sharing of data [34]. Thus, private cloud computing or hybrid cloud computing may be more preferred in the development of SG as opposed to public cloud computing [35,36].

In this paper, we review the contributions of cloud technologies to SG, including cloud machine, cloud storage, cloud computing and cloud security.

2. The application of cloud storage in power systems

One of the characteristics of SG is the exponential growth of data from smart meters and sensors, and the demand for rapid information retrieval from massive amounts of data [37]. The application of cloud storage allows for the necessary data storage, access and analysis. First, SG could take advantage of the feature of cloud storage. Cloud storage can provide high fault-tolerance through redundancy and rollback-recovery through versioned copies [38]. Second, cloud storage can provide a smart, automated, and distributed network storage. The storage of distributed energy data can be ideally fulfilled using distributed network storage. On the platform constructed via distributed network storage, the data produced during distributed generation are gathered and analyzed. The results can be beneficial to supervision and dispatch of distributed energy. Third, with more monitoring objects, such as real-time monitoring of user electricity usage and consumption behavior in demand response, and shorter monitoring interval, such as the transition from the second-precision supervisory control and data acquisition (SCADA) system to millisecond-precision wide-area measurement system (WAMS), far more data are generated and collected in these processes [39]. Consequently, data storage needs to be of a higher volume, more dependable, secure, and have the capability to obtain and integrate data from anywhere [29]. Finally, a huge amount of historical and real-time data on weather, load, and generation is also needed in the analysis and decision-making involved in SG [40,41]. Data centers [33,42] and warehouse [43] for SG can improve the capacity not only for large-scale data research [44], but also for massive-scale data mining and analysis [45].

Cloud storage is also suitable to improve power system security through unified management and multi-location data backup [46]. As shown in Fig. 1, power dispatching centers at all levels can share data and back up data at multiple points. If a dispatching center experiences a terrorist attack, others can operate in its place through the sharing of dispatch data in cloud storage [47]. This feature represents a significant improvement over the traditional "one master and one standby strategy" for disaster preparation that requires one simplified backup dispatching center near the master dispatching center.

3. The application of cloud machine in power systems

Cloud machine based on virtualization is a way to reallocate integrated resources. It can bring advantages of cloud computing to SG. Through the management platform of cloud computing, various applications can be installed on different virtual machines, such as the SCADA system used to analyze real-time data [28,48] and energy management system (EMS) used to monitor, control, and optimize power systems [49]. These applications will inherit the abilities of distributed and load balance from cloud platform. Cloud machine can also dynamically dispatch computing and