Computer Networks xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Cloud Computing for Smart Grid applications

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ARTICLE INFO

Article history:
Received 6 August 2013
Received in revised form 29 November 2013
Accepted 12 June 2014
Available online xxxx

Keywords:
Smart Grid
Cloud Computing
Smart Grid and Cloud Computing architecture
Cloud Computing based Smart Grid applications and projects

ABSTRACT

A reliable and efficient communications system is required for the robust, affordable and secure supply of power through Smart Grids (SG). Computational requirements for Smart Grid applications can be met by utilizing the Cloud Computing (CC) model. Flexible resources and services shared in network, parallel processing and omnipresent access are some features of Cloud Computing that are desirable for Smart Grid applications. Eventhough the Cloud Computing model is considered efficient for Smart Grids, it has some constraints such as security and reliability. In this paper, the Smart Grid architecture and its applications are focused on first. The Cloud Computing architecture is explained thoroughly. Then, Cloud Computing for Smart Grid applications are also introduced in terms of efficiency, security and usability. Cloud platforms' technical and security issues are analyzed. Finally, cloud service based existing Smart Grid projects and open research issues are presented.

1. Introduction

The Smart Grid (SG) is used by electric power utilities to track and control power usage of consumers. In SGs, the governance of energy usage is done in real time with the ability of smart meters' bidirectional communication [1]. A more reliable and secure communication is guaranteed with the SG's distributed energy management feature which is called as load balancing. Electric power utilities achieve preferable operation and management of their electric power systems by monitoring their energy usage. When consumed energy reaches peak levels, signals are sent to consumers to reduce energy consumption. In this way, the SG balances its energy load [2]. Entire power supply system and protection devices are monitored by control centers for providing security of SG's load balancing system during communication. Cloud Computing (CC) is used to perform this communication process between substations and power supply companies' power plants. Built-in redundancy is utilized to increase the reliability, security and robustness of this communication [3]. In this context, scalable platforms are needed to run many SG applications when data intensity is high. Over the time of the day, the resource requirement varies as the utilization differentiates between day (peak operation) and night (lower level operation). CC platforms can be utilized for obtaining scalable, elastic, secure, robust and sharable resources in order to build and operate a functional SG architecture [3].

Utilities and consumers take the security and privacy of their data very seriously. This affects the acceptance of SGs provided by cloud platforms, i.e. the privacy issues for the users should be addressed by the utilities [4,5]. CC platforms chosen for SG applications should realize high assurance in their communication systems. There are some performance issues related to the use of cloud platforms for

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http://dx.doi.org/10.1016/j.comnet.2014.06.007
1389-1286/© 2014 Published by Elsevier B.V.

SG applications as well, e.g. the requirement for supporting real time services to give rapid response to consumers. Internet congestion and server failure are the main constraints in this respect [6]. Consistency and fault tolerance services are necessary for cloud systems. In order to ensure these features, some consistency models such as database guarantees, replication behavior of state machine and virtual synchrony must be applied to cloud platforms. An important advantage of cloud systems for SG applications is their highly qualified Internet routing capability that is supplied by providing multi-path Internet routes between access points and cloud services. In this manner, connection losses are prevented and communication is reliably achieved between the SG and cloud hosted services.

The next generation computing paradigm, provided by CC, satisfies the requirements of SG applications [7]. Cloud providers facilitate CC and offer services with their huge servers for computations and with their big data centers for storage. Many resources shared in the network, such as software and information, are provided to the power grid utility's devices through CC. Therefore, it is preferable for many SG applications to use CC for information management and distributed energy management.

There have been several studies on how SG applications can exploit CC to increase their reliability and performance. In the study by Simmhan et al. [8], a SG's demand response is optimized by using CC. This is achieved by CC with a flexible and scalable model of Cloud virtual machines. These Cloud virtual machines perform computations to determine the availability of resources to be used on demand and to be discharged when not in use. Also, redundancy is achieved for critical SG applications by these Cloud virtual machines by adding extra virtual machines to duplicate computations and replicate the data. In the work by Rusitschka et al. [9], a different CC model is proposed for real time data retrieval and parallel processing for SG applications. In another research, conducted by Bai et al. [10], CC provides efficient and secure storage management for a Smart Grid condition monitoring application. CC also offers many other advantages to a SG in terms of affordability and scalability. Kim et al. offered a CC based demand response architecture which aims at giving fast response to customers by providing direct communication between consumers and utilities [11]. Grid aware CC routing algorithms, which solve service request routing problems, are implemented by Mohsenian-Rad et al. [12], Fayyaz et al. [13] and Alcaraz and Lopez In [14], the authors focused on addressing the security and reliability issues in combining SG applications with CC. In addition to research conducted on the application of CC for SGs, there are also some products, already in the market, implementing SG applications utilizing CC. Hohm, Microsoft's energy management tool, is hosted on a cloud platform proposed to be used by special residential buildings [15]. Proprietary power saving suggestions are procured by Hohm [15]. Google's PowerMeter is another tool utilizing CC for SG applications and was ended in September 26, 2011 [16]. It is a scalable platform and facilitates monitoring the energy usage of consumers. There are also many other applications for testing and observing the performance of CC on SG applications [17–19]. Some of these applications are already in use and some are still being researched. All these studies are summarized in Table 1.

The remainder of this paper is organized as follows. In Sections 2 and 3, the SG and CC architectures are presented, respectively. In Section 4, opportunities and challenges to apply CC in SG is discussed. In Section 5, the use of CC for SG applications is analyzed in technical and security perspectives. In Section 6, an overview of CC based SG applications and projects are given. Open research issues in CC for SGs are presented in Section 7. Finally, this paper is concluded in Section 8.

2. The Smart Grid (SG) architecture

An electric grid with the information and communications technology (ICT) is called a Smart Grid. In SG, information about consumers' electricity consumption behavior is collected automatically with the use of the ICT [1]. This helps increase the efficiency, reliability and performance of the electric grid. The European Technology Platform is preparing a SG policy to overcome many challenges in current electricity supply, in terms of reliability, flexibility, efficiency, load adjustment, peak power cut, permanency, market supply and demand response support [20]. Reliability is provided by a SG with its features such as the ability for fault detection and self-healing. In SG applications, bidirectional energy flow allows for flexible network topology with distributed generation. The demand side management feature of the SG ensures efficiency in energy consumption. The load adjustment feature helps balance loads in spite of their variations. If a user's load exceeds an average threshold, power can be cut for this user to control electricity usage in high-cost/peak-usage periods.

The SG conceptual model, identified by the National Institute of Standards and Technology (NIST) [21], gives the characteristics, requirements, operations and services that should be provided by a SG. It also specifies communication ways from top level to lower levels for SG applications. The conceptual model includes seven domains such as bulk generation, transmission, distribution, customer, service provider, operations and markets [21] as given in Fig. 1. The conceptual model begins with bulk generation. In this domain, electricity generation and protection procedures are realized. The second domain is the markets which perform load balancing by analysing and optimizing energy pricing to help control energy consumption of customers. Business processes of energy producers, customers and transmission companies are performed by a service provider, which is the third domain of the SG conceptual model [21]. Operations in the network such as monitoring of network operation, network control, fault detection and reporting are realized with the fourth operations domain. Transportation of electricity from sources to distribution are achieved by using the transmission domain. Service providers optimize flows by the agency of the transmission domain and connect with customers via the distribution domain which achieves real time monitoring of electricity consumption. The last SG domain is the customers who let their energy usage be managed. All of these domains make up the SG architecture and result in many benefits

Q1 Please cite this article in press as: M. Yigit et al., Cloud Computing for Smart Grid applications, Comput. Netw. (2014), http://dx.doi.org/10.1016/j.comnet.2014.06.007