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Application of Cloud Computing for Power Systems

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Abstract
In the past power system is evolved through different restructuring and policy changes at different periods. From the early stage of state owned monopoly energy providing service to smart grid driven customer and third party aggregators' participation in order to cope up to the ever growing energy demand in terms of capacity as well as the dynamics of end user consumption, demand side management, different energy generation systems and demand response. In this process information communication and computation systems are playing a major role in monitoring, controlling and improving the energy delivery system. In smart grid a vast amount of data is collected from every corner of the energy delivery network, from customer energy meters, energy generation units in the customer premises and third party players. This bi-directional information flow needs appropriate communication ways and the collected vast amount of data has to be processed in a reliable, distributed, parallel and scalable computing resources. On the other hand the power system is lacking such computing capacity to address this requirement. Researchers suggest that cloud computing may be used to address this problem. In this paper the application of cloud computing for power system application is analysed. The feasibility study of the available cloud computing tools for smart grid is conducted.

Keywords
Smart Grid, Power System, Cloud Computing

I. INTRODUCTION

To increase the utilization of green energy, considering carbon emission and energy mix several changes has been taking place in power system. In order to satisfy these requirements, additional energy generation resources are placed in the power system in addition to the traditional energy generation systems. These energy generations can be owned either by utilities or customers. In this case energy and information are exchanged in both ways to enable smooth operation and reliable energy delivery system. The electric network that can support these additions which are improved in a reliable, sustainable and low cost method. Smart grid will provide a solution to this effort in increasing reliability, quality of power supplies and energy efficiency.

Different players such as utilities, network operators, demand response providers and customers are involved in smart grid to ensure the efficient delivery of energy where it is needed most. Huge amount of online and offline information need to be exchanged among them and enormous data are collected by these players for different uses. Processing and computing these data in time enables efficient monitoring and controlling of resources, directing energy to where it is most needed to make technical or administrative decisions and smooth operation of the energy delivery network. The coordinated information exchange and active participation of all the players who have roles in the power system operation is vital in minimizing down time and satisfy the customers need in terms of energy consumption management, predictions and quality energy delivery.

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The question is, does the conventional power system provides elastic, distributed, scalable and cost effective computation system to handle the overwhelming data processing requirement of the future smart grid. Many researchers have doubt about the answer. Instead they suggest cloud computing for future power system computation needs. According to [1] cloud computing is defined as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources”.

Several researches have been taking place all over the globe suggesting different solutions to the high requirements of storage and computational resources by power system. Among them, the implementation of cloud based demand-side management applications [2], Grid computing, a distributed and parallel computing techniques for future power system [3], analysis of the benefits and opportunities from the perspective of both smart grid and cloud computing domain, methods connecting these domains [4] and a Lab demonstrator in South Westphalia University [5], implementing the monitoring and controlling of distributed energy generation to show the possibility of integrating the cloud computing in smart grid applications.

In this paper the feasibility study based on a short literature review and the application of cloud computing for power system applications with an lab demonstrator is analysed.

II. Cloud Computing

According to National institute of standards and technology (NIST) [1] cloud computing is defined as “a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction.” The computing resources can be networks, servers, storage, applications, and services. Cloud based systems are a sharing of an enormous amount of Information Technology (IT) infrastructures, such as computational and database resources in the form of service, which focus on maximization the efficiency of operation, scalability, maintainability and reliability by decreasing cost. These resources are provided in three service models: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). According to [9] a single cloud computing data center might have storage and computing capabilities tens or hundreds of times greater than all of the world’s supercomputing facilities combined.

Cloud providers own a large number of networked servers with low expenses. This infrastructure consists of massive pooled systems that are linked together and works with virtualization techniques to provide a high performance of data storages and runs along-side with a local network connection that can runs from a few to trillions of computations per second depending on the demand.

III. Existing Researches and Projects on Applications of Cloud Computing for Smart Grid

Recently several researches and projects are conducted and plenty of them are under way to bring a solution for future smart grid computing and data storage requirements using cloud computing platforms.

A. *Running smart grid control software on cloud computing architectures*

Running smart grid control software on cloud computing architectures [9] by Cornell University department of computer science identifies the computing requirements of the smart grid and evaluates the current power industry computing infrastructure if they meet these demands. According to the authors argument the future smart grids computational needs are grouped into:-

- The smart home which may be filled with energy meters and monitoring devices adapting behavior to match cost of power, load on the grid, and activities of the residents
- Ultra-responsive SCADA which incorporates micro-power generation into the grid and coping up with the variable production and demand
- Wide area grid state estimation

These computing requirements need high decentralization, scalability, data security consistency and reliability. They need a scalability of a kind that only cloud computing can offer and the authors also assess the benefit of using cloud computing. It is a remarkably efficient and green way to achieve the green energy considerations, quite inexpensive, robust, can be managed cheaply and in highly automated ways, offers astonishing capacity and elasticity.

B. *Gridcontrol*

Gridcontrol [10] a cloud computing based software platform to support the smart grid developed by a joint research group of Cornell University and Washington State University. It provides the power industry monitoring, management and control of power system. Enabling grid state quickly with a large numbers of sensors deployed in the network, control of power systems through internet with a high scalability and simulation of smart grid behavior.

C. *Cloud Computing and Smart Grids*

Another application is the implementation of electricity management of smart homes in the cloud [6]. In this application customers follow electricity consumption in real time as well as tariff plan recommendations, dynamic analysis of electricity consumption through graphs, calculation and application of penalties, issue invoices each month and also a display of financial statement review and notification through desktop alert and emails.

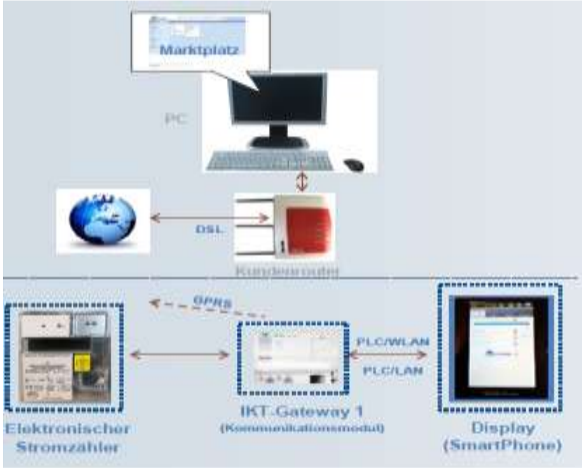

Fig 1 E-DEMA Cloud-based Monitoring application structure

D. "E-DEMA" Cloud-based Energy Monitoring application

"E-DEMA" Cloud-based Energy Monitoring application [12][13] A joint project between RWE, Siemens, Miele, public utility Krefeld(SWK), ProSyst, Technical University of Dortmund, University of Bochum, University of Duisburg-Essen and Dortmund University of Applied Sciences. It is a modern ICT application for "Energy-Marketplace of the future". In this pilot project the SWK use the extended-Grid-Platform from Digi to monitor the real-time price data of electricity, gas and water in a user friendly manner. As shown in Fig 1, the consumption data of the customer from energy meters (Elektronischer Stromzähler) are collected using wireless technology (Kommunikationsmodul), transmitted via the Digi Device Cloud and then visualized using apps graphically (Display Smartphone), so they can be viewed by the customer in real time on a tablet computer, smart phone or any thin client device. Based on these data, the customers can then actively monitor and manage their consumption.

D. The application of cloud computing in smart grid status monitoring

The application of cloud computing in smart grid status monitoring [11]is helpful for the following demonstrator on cloud computing: - According to these authors the amount of state data such as the status of primary and secondary equipment, real-time online data, basic information, inspection records, test data and operation data will be increasing greatly in the environment of smart grid. This is beyond the reach of the traditional condition monitoring application. Here is the architecture of cloud computing platform of the status data proposed to meet the needs of smart grid condition monitoring. For this purpose a software package Hadoop cluster technology, suitable for condition monitoring of smart grid is used. In this project a lab demonstration is realized which shows the use of cloud computing for accessing the insulator condition of the power system network.

E. Cloud computing for Load forecasting application

The electrical load forecasting application is conducted by South Westphalia University, Department of Automation Technology [7]. In this work an Electrical Power Load forecasting application is implemented in Amazon Cloud computing platform. The Matlab based load forecasting application using artificial neural network is deployed in the cloud and on the local computers having similar computing capacities with the corresponding cloud computing instances. The computational performance of local computer hardware is compared to the equivalent EC2 instances and the result shows that the high performances of cloud computing over the local computers.

F. Numetris, Cloud Metering system

Numetris is a "Metering-as-a-Service" model software system offered by Numetris AG [14]. This system provides a complete metering management service through cloud. So that the utilities reduce the massive IT infrastructure cost in addition to focusing on their own core business. As shown in Fig 2, data from the smart meters (Zähler) are collected and the data are processed in central system (numetris Cloud Metering). The processed data are communicated to customers, network operators and suppliers (Kunde, Netzbetreiber and Lieferant) depending on their demands.

The implementation of cloud based demand-side management applications [2] and the analysis of the benefits and opportunities from the perspective of both cloud computing and smart grid, methods of interfacing these two domains [4] are some of the researches and projects around the world working on finding the way cloud computing can be used for future smart grid application to serve its overwhelmingly growing computational and data storage demands.

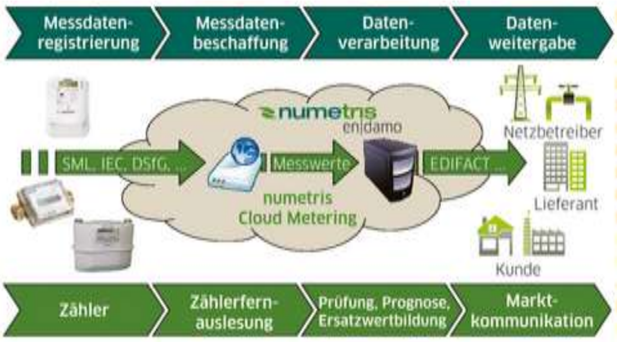

Fig 2 Structure of Numetris /14/, translation und explanation in the text

IV. MONITORING AND CONTROL APPLICATION

To alleviate the energy demand and the dynamic

Energy consumption profile the future smart grid is expected to accommodate different renewable energy generation units capable of bidirectional energy and information flow, e.g. the future electric vehicles, smart and active loads. The dispersed nature of small distributed energy generations throughout the power delivery network including the customer premises increase the nodes where energy and information is gathered and exchanged. This frequent information exchange between the field devices and the control center enables efficient, reliable and effective monitor and control of the components in smart grid. However this huge amount of information is collected across the network and furthermore demands for processing can be provided like a distributed, ubiquitous, elastic, enormous pool of computing resources and storage capacity as only cloud computing can do it. The intention of the authors here is to try to assess the possible options to integrate the cloud computing in smart grid applications. "Cloud computing for monitoring and controlling of distributed energy generation",is a study which describes the topic in a master thesis [5], In South Westphalia University a Lab demonstrator for monitoring and controlling is realized as application of distributed energy resources using cloud computing framework.

In this work, the architecture to implement smart grid application into cloud computing is shown as in Fig 3. It has multiple layers which consider and describe both the cloud computing and the smart grid domain. This configuration can be modified for different application depending on the algorithm, type of data or information required to access, computation needs, whether it is a real-time or an offline application. The type of additional software tools used to realize the specific application may also define the needs.

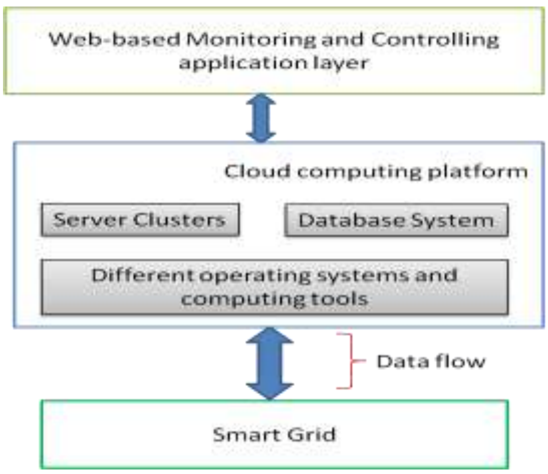

Fig 3 Cloud-based SCADA configuration

As shown in Fig 3, the above layer, web-based monitoring and controlling application layer is an application layer to visualize, monitor and control the readings of different sensors installed across the network and send control signal to the actuators when it is necessary. The middle layer is a cloud computing platform which provides server, database system, different operating systems and computing tools. The virtual servers and operating systems used as a local computer to provide unlimited storage to accommodate the vast amount of data collected from the smart grid, it is also possible to run applications in different instances in parallel to increase the speed of the computation and decrease execution time. The lower layer is the smart grid where the actual grid data is collected. The data can be, the reading of current sensor, network voltage, phase angle, frequency, energy meter readings, the status of a relay or circuit breaker or insulator, and so on.

V. Lab demonstration

The Lab-demonstration is intended to show the integration of cloud computing in controlling and management of smart grid applications. So that the power industry benefit from efficient, clean, scalable and flexible computing and data storage capabilities of cloud computing. Here the power system and the cloud computing domains are considered. The setup contains different distributed renewable energy resources to be monitored and controlled and local control from the smart grid side. The cloud computing domain is a specific service provider used in this lab demonstration.

A. Smart grid

As shown in Fig 4 the smart grid domain consists of solar panel, battery and load. They are electrically connected one to the other. A current sensor is installed across each component to measure the current through them. These components also monitored and controlled locally.

B. Cloud computing

Amazon Web Service (AWS) is used as a cloud computing service provider in this lab demonstration. Amazon Elastic Compute Cloud (Amazon EC2) instance is a virtual computing platform provided by AWS which offers a resizable computing capacity in the cloud. It is accessible in a broad variety of computing configurations and capacity of CPU, memory, storage and networking access. The instances can be launched in different operating systems either in MS windows, windows server and Linux. Temporary and persistent data volumes also provided as a service. This resources are a shared services in a pool of resources. Users can also create an isolated virtual private network which are logically isolated from the rest of AWS cloud for more privacy and secure operation.

Depending on the requirements, which are based on the project at hand, the appropriate type of services either on-demand or as a reserved instance for a specific period of time have to be chosen. The choice of instance family is also depend on the computational and storage requirement the user is looking for. The following are the different families of instances available in AWS:-

General purpose instance: instances providing a balance of compute, memory and network resources. They are suitable for small and mid-size databases.

Compute-Optimized instance: instance types providing high compute power. They have a higher ration of CPUs to memory than other families and fit to high performance web-servers, video encoding and distributed analytics applications.

Memory-optimized instances: instances optimized for memory-intensive applications.

Storage-optimized instances: these instances are for very high storage density applications

VI. EXPECTED OUTCOMES FROM THE MONITORING APPLICATION

In smart grid both power provider and customers want to monitor, control or forecast consumption data and plant status. In local smart grid system this information can only be accessed using specific local computer. However the implementation of smart grid applications in cloud computing environment helps users to access electric grid status through internet connection with their own device from anywhere in the world. So, smart grid cloud enable consumers to experience the sharing of large volume of data and a better access to large number of users. In addition, the cloud based backup system provides easy recovery during system failure [5]. In this work the designed web-based monitoring and controlling application using cloud computing is realized. In this application the user can monitor the load, the battery or the panel current. The selected current value with the corresponding time stamp is visualized. The lab demonstration in this work shows that the implementation of cloud computing for smart grid monitoring application and it is also expected to benefit for high computational and storage demanding smart grid application as well.

VII. PRIVACY AND SECURITY

The traditional power system operation is known for its privacy and regulatory matters. Which is a contradictory culture to the resource pooling and sharing of cloud computing. However the growth of smart grid application for consumers forces the electric utilities to share electricity usage and operational information with external services [8]. The third party service providers are another entities involved in data and information exchange in today's smart grid systems. While planning to deploy smart grid application to the cloud computing a proper definition of the level and the type of information to be exchanged must be outlined. The question, which type of data has to be shared, what level of access is provided for each party, has to be clearly answered. As

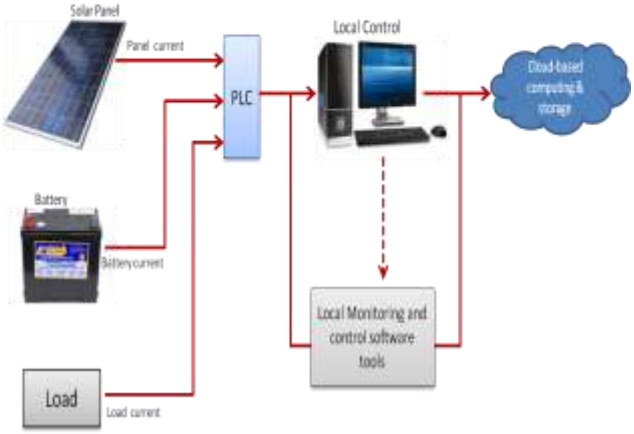

Fig 4 Lab-Demonstration Setup

the communication between the cloud computing and smart grid domain is mainly through internet protocols, they can be easily exposed to cyber-attacks. These attacks may not only cause the power disruption but also power theft and altering energy usage data. So the privacy and security issues of the implementation of smart grid application in cloud computing platforms need further study and investigation.

VIII. CONCLUSION

To meet the increasing restructuring requirement, to cope up the dynamic energy user profile and regulatory issues in power system several measures are taking place. Broadening the energy generation mix, which are owned by both utilities and consumers, will restructure and optimize the overall energy delivery network. This further leads the active involvement of different players such as utilities, network operators, demand response providers and customers in the power systems. In this case energy and information are exchanged in both ways to enable smooth operation and reliable energy delivery system. Huge amount of online and offline information need to be exchanged among them and enormous data are collected by these players for different uses.

To help the power system industry in processing and computing of such big data, researchers are looking for different solutions. Cloud computing is one of the proposed solution which is expected to provide a platform for future smart grid applications. In this paper several conducted and ongoing research works around the globe have been surveyed. It is indicated that cloud computing can provide a clean, highly reliable, elastic, distributed and scalable computing resources to host smart grid applications. Most of the efforts that have been done prove that it is not too far before the cloud computing and the smart grid domain integrated and shift the future smart grid to a new era. The smart grid monitoring lab-demonstrator in South Westphalia University also supports the realization of cloud computing for power system applications.

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