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Cloud computing for energy management in smart grid – an application survey

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Abstract. The smart grid is the emerging energy system wherein the application of information technology, tools and techniques that make the grid run more efficiently. It possesses demand response capacity to help balance electrical consumption with supply. The challenges and opportunities of emerging and future smart grids can be addressed by cloud computing. To focus on these requirements, we provide an in-depth survey on different cloud computing applications for energy management in the smart grid architecture. In this survey, we present an outline of the current state of research on smart grid development. We also propose a model of cloud based economic power dispatch for smart grid.

1. Introduction

Electrical power has become an indispensable part of modern day life. Hebra [1] and NIST [2] styled today's electric power system as a multifaceted system of power generation, transmission, and distribution. With the global economy more reliant on sustainable development of energy, a series of problems, such as energy shortage, electricity blackout and global warming are gaining attention. ABB [3] pointed out that there are tenacious economic as well as environmental urgings for the refurbishment of the conventional power systems, and its replacement with a Smart Electrical Power Grid or simply Smart Grid. A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users [4].

Energy demand from the users changes dynamically in different time-periods. The existing power grids need optimal balancing of electricity demand and supply between the customers and the utility providers. To address these requirements in smart grid, the energy management systems (EMS) such as building energy management (BEMS), demand side management (DSM) and home energy management (HEM) are integrated. A smart grid allows various renewable energy sources to have an efficient management of supply and demand. The special characteristic of a smart grid is its heterogeneous architecture, which includes Demand Response (DR), distributed generation, resource scheduling, and real-time pricing model.

In a smart grid environment, multiple devices are implemented such as smart meters, substations, micro-grids, home appliances, sensor nodes, and communication network devices. Smart meters, deployed in the distribution sites, generate massive data for real-time communication with the utilities. To handle such massive data efficiently and effectively, smart grid relies on the utilization and integration of advanced information technologies [5]. One of the important trends in today's information management is outsourcing tasks to cloud computing, which has been regarded as the next-generation computing and storage paradigm [6].

1.1. Contribution
In this paper, we provide a methodical summary of assimilating cloud computing applications for energy management in smart grids. Communication network plays an important role for reliable energy management as smart grid is the combination of electrical and communication network. Cloud computing techniques proposed in the existing literature for energy management in smart grid are discussed briefly. A model of power dispatching in smart grid with cloud is described. In short, our objective in this paper is to offer the following:

- A comprehensive overview of smart grid and cloud computing in terms of energy management.
- A clear concept of cloud computing applications in smart grid.
- A highlight on cost effective cloud based power dispatching in smart grid.

The rest of the paper is organized as follows. In Section 2 and Section 3, we give a comprehensive overview of smart grid and cloud computing. We briefly describe the cloud computing applications in the context of energy management in smart grid in Section 4. Cost effective cloud based power dispatching in smart grid is presented in Section 5. Finally, a conclusion is provided in Section 6.

2. Smart Grid
Smart Grid monitors power use, adapts consumption to match power costs and system load, and integrates new kinds of renewable energy sources with conventional power generating systems. It associates every distributed electricity producer (independent power producer) in the energy market from conventional thermal, hydroelectric and atomic power plants to new kinds of renewable energy systems with each electricity consumer, from industries to residences, and to every load plugged into the electric network. The digitally controlled, self-monitoring and self-healing Smart Grid provides two-way communication for energy production, transmission and distribution, control and monitoring, supply and demand balancing, etc. with more customer choices. According to NIST [2] "a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications". The NIST Smart Grid Framework is shown in figure 1, which shows the involved domains, the actors in a particular domain and interaction between the actors from other domains. Each domain encompasses Smart Grid actors and applications. Actors make decisions and information exchange that are required for performing applications. Actors include devices (e.g. smart meters, solar energy generators, and control systems), programs, systems, and stakeholders. Tasks performed by one or more actors within a domain are called applications (home automation, and energy management).An important characteristic of a smart grid is controlling electricity consumption at the customers' ends [7]. To achieve this metering and monitoring, a few components are incorporated in the smart grid architecture. These key components of smart grid are discussed as under:

2.1. Advanced Metering Infrastructure
Advanced metering infrastructure (AMI) is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers [8]. Smart meters at the customer site are the electrical meters that record real-time readings i.e. consumption of electrical energy, and voltage quality that are anticipated to be read

periodically in shorter intervals (range from minutes to milliseconds). In general, AMI support data communication architecture by including software and electronic/digital hardware.

2.2. Advanced Metering Infrastructure

Health and performance monitoring of transformers, feeders, capacitors, circuit breakers, condition monitoring of lines (e.g. PLCs), fault detection and replacement of assets can be performed effectively and efficiently by the analysis of data sensed at regular intervals by the intelligent monitoring system. With the development of sensors that utilize low-cost, ultra-low-power processors and communication links to transmit data, a new regime of sensors known as the smart sensors have recently come into existence [9]. Extensive research in the wireless technology reducing the signal noise, power requirement and enhancing the range has made the wireless technology a potential for integration with smart sensors to carry communication with utilities. Development of effective network topologies such as multi-hop link networks and efficient wireless signal routing algorithms have further improved the range and reduced power consumption; hence made the advent of protocols like ZigBee Pro [10]. Some examples of sensors present in the commercial domain are Tollgrade's Lighthouse MV sensors, USi's Power Donut, ABBs Grid Sync, Grid Sense's Line IQ, Sentient monitor, and Grid Sentry's Line sentry. The size, cost and weight restrictions of the sensors mentioned above have posed the hindrance to their wide acceptance.

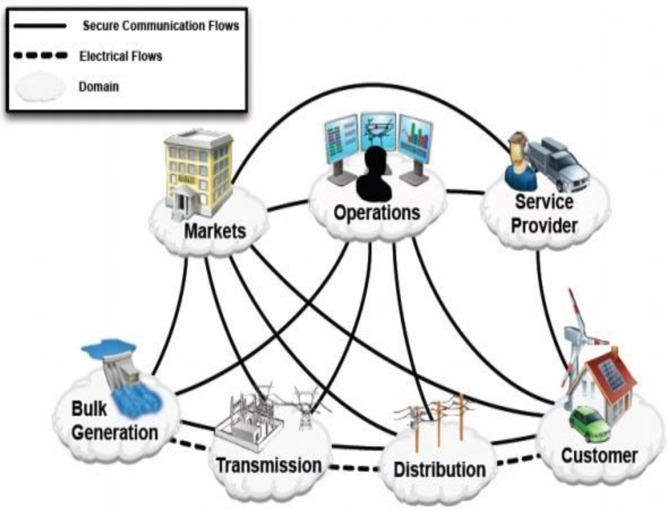

Figure 1. NIST Smart Grid Framework**.**

3. Cloud Computing

Cloud computing - a model that enables convenient, ubiquitous, on-demand access to a pool of computing resources (e.g. servers, networks, applications, storage, and services) that are configurable. With minimal management effort, resources can be provisioned and released seamlessly [11]. NIST’s visual model of cloud computing definition is shown in figure 2. It delivers infrastructure, platform, and software to customers as subscription-based services in a pay-as-you-go model. The advantages, essential characteristics, of using a cloud computing model are as follows [12-14]

- On-demand self-service: A consumer can individually provision computing capabilities as needed automatically without requiring human interaction with each service provider.
- Broad network access: Capabilities are available over the network. It can be accessed through standard mechanisms, to be used by heterogeneous thin or thick client platforms.

- Resource pooling: A multi-tenant model is used to serve multiple consumers from a pool of computing resources. The customer has no control over the exact location of the provided resources.
- Rapid elasticity: Cloud computing supports elastic nature of storage and memory devices. It can expand and reduce itself according to the demand from the users, as needed.
- Measured service: Cloud computing offers metering infrastructure to customers. Cost optimization mechanisms are offered to users, enabling them to provision and pay for their consumed resources only.

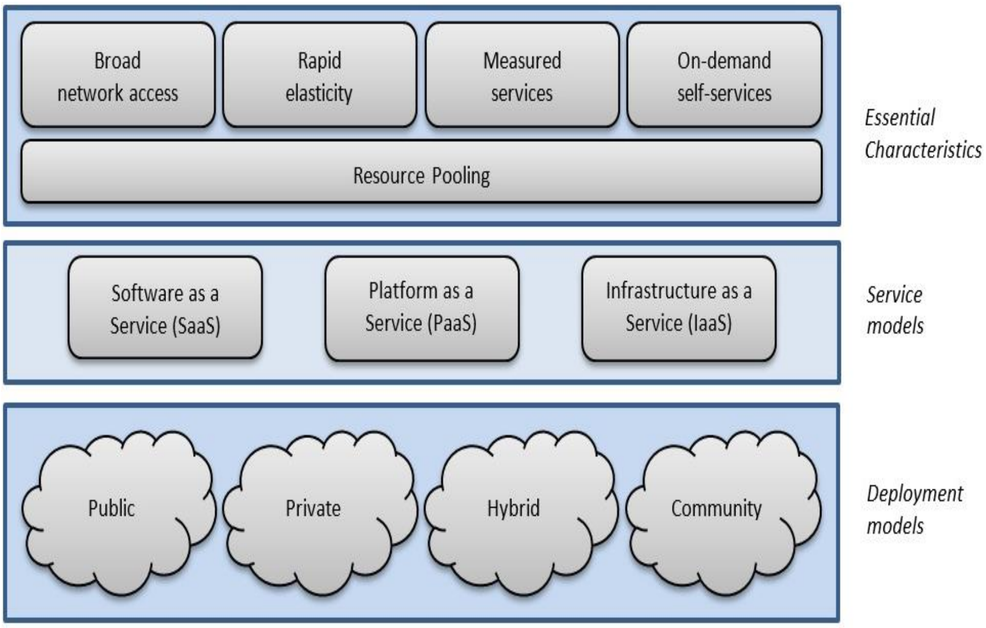

Figure 2. NIST Visual model of cloud computing definition.

Virtualization technology can be used in cloud computing that can take a variety of different types of computing resources as abstracted services to users. These cloud services are divided into Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS).

- Infrastructure-as-a-Service: IaaS provides scalable infrastructure e.g. servers, network devices, and storage disks to consumers as services on demand. The access to the cloud is provided through various user interfaces, such as web service application programming interface (API), command-line interfaces (CLI) and graphical user interfaces (GUI) which provide different level of abstraction. The consumer has control over operating systems, storage, and deployed applications but they are not required to manage or control the cloud infrastructure.
- Platform-as-a-Service: PaaS provides a platform where users or customers can create and run their applications or programs. The users can build and deliver Web-applications without downloading and installing required software, as PaaS service completes the requirements. It is responsible for the runtime execution of users' given task. The most important customers for this layer are the developers.
- Software-as-a-Service: SaaS is responsible for delivering various kinds of applications plus the interfaces for the end users. This feature of cloud computing is accessible through Web-browsers. The SaaS provides the modeling of software deployment where users can run their

applications without installing software on his/her own computer. However, this service is limited to the users, i.e., only existing set of services is available to the customers.

According to the deployment model, a cloud can be classified as public cloud, private cloud, community cloud, and hybrid cloud[11].

- Private cloud: The Private cloud is a virtual environment deployed within an organization that is restricted to users within the company and usually resides behind the corporate firewall. It is suited for secured confidential information and core systems. It may exist on or off premises.
- Community cloud: The Community cloud is similar to a Private cloud. It is provisioned to a group of organizations who have similar type of requirements with additional features. It may exist on or off premises.
- Public cloud: The Public cloud is a virtual environment that is publically available for any consumer to purchase computing resources, usually on a pay per use basis, via an easy to use web portal. It exists on the premises of the cloud provider.
- Hybrid cloud: The combination of the Public and Private cloud whereby specific resources are used in Public Cloud while others are used in Private Cloud.

4. Cloud Applications for Energy Management

Energy management is the process of monitoring, controlling, and conserving energy [15]. In smart grid, energy management is a major concern [16]. It is needed for resource conservation, climate protection and cost saving without compromising work processes by optimally coordinating several energy sources. BEMS (Building Energy Management System) and HEMS (Home Energy Management System), dynamic pricing, and load shifting are different applications that are implemented by researchers in the past to address energy management.

4.1. Problems with Existing Approaches without cloud

Demand Response (DR) refers to “changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity overtime, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized” [17, 18]. DR is achieved through the application of a variety of DR resource types, including distributed generation, dispatchable load, storage and other resources that may contribute to modify the power supplied by the main grid [19]. In the conventional smart grid architecture (without cloud), several problems, as detailed below, are addressed by researchers [12, 13, 20, 21].

- Master-Slave architected (without clouds) could cause Cyber-attacks (Distributed Denial of-Service (DDoS)).
- Any failure in Master-Slave architecture could lead to a system failure, which does not exist in cloud computing.
- Can serve for limited number of users (customers) due to limited server capacity.
- Serving of such large number of the customer will be challenging because of limited memory and storage.
- Management, as well as stability issues, will be required.

4.2. Solution Concept with Cloud Applications

For many years, researchers proposed several solution concepts for demand response and micro-grid management [12-14, 20, 22-39].

Kim et al. [12] proposed the concept of Cloud-Based Demand Response (CDR) for fast response times in large scale deployment. In the concept of CDR, the Energy Management System (EMS) and smart meters will be the slaves while master will be the utility. The data-centric communication, publisher/subscriber will be used by the CDR, whereby two cloud-based demand models are suggested (a) data-centric communication and (b) topic-based group communication rather than typical IP-centric communication. Overhead problems, such as implementation cost, and the selection of appropriate strategy, exists in the demand response model [12] that occurs in the private cloud when the size of the network is small [7].

Ming Chen et al. [22] analyzed the necessity and feasibility of cloud computing technology in power dispatching and presented the Deployment Method of power dispatching automation system based on cloud computing. Easy standardization of power dispatching technique; rapid delivery of advanced functions; and significant improvement reliability of IT infrastructures can be achieved by means of cloud computing technology. It reduces administrative costs, and it solves the contradiction between hierarchical management and "integrated construction" in energy sector [22].

ZHANG Liang [23] proposed the concept of cloud dispatching, a kind of cloud computing-based overall framework of intelligent dispatching center. The cloud computing-based layered architecture includes Physical Resource Layer- physical hardware, platform resources and application systems such as SCADA, EMS, TMR, WARMS, Virtual Resource Layer - map physical resources in various types into virtual resources, Cloud Service layer - packages virtual resources into services, that are posted to the clouds, Cloud Management Layer - provides integrated management of cloud services for users, and Cloud Access Layer - the way user access cloud dispatching. It integrates the existing resources demands among various dispatching centers, reduces the system construction and expansion cost and improves overall dispatching business ability.

The smart grid infrastructure needs to be deployed globally. In order to balance the real-time demand and supply curves, rapid integration and analyzation of information that streams from multiple smart meters simultaneously is required that necessitates the scalable software platform. Yang et al. [13] proposed that cloud platforms are well suited to support huge data and computationally-intensive, always-on applications. To build a software infrastructure to support such dynamic and always-on applications, scalable requirements of resources are offered by the cloud applications. In these environments, cloud platforms serve as essential components due to the various benefits they offer, as mentioned below:

- Cloud acts elastically to avoid costly capital investment by the utility during the peak hours.
- Customers can be benefited from the real-time information by sharing the real-time energy usage and pricing information.
- Some data can be shared with a third party by using cloud services, after meeting the data privacy policies for developing intelligent applications to customize consumer needs.

In order to take decisions at different instances, implementation of specialized data abstraction for data streams generated from the different components is required for real-time monitoring. On the other hand, third-party vendors are allowed to participate in such real-time monitoring system that necessitates defining an effective privacy policy as a security mechanism.

Virtualization is one of the most efficient techniques for cost reduction, resource optimization, and server management [20]. Cloud computing can be implemented in the form of different strategies of the micro-grids. Rajeev and Ashok [20] proposed a framework for integrating cloud computing applications for micro-grid management in the form of different modules such as infrastructure, power management, and service. The infrastructure and power management modules are used for task scheduling and micro-grid power management respectively. The different operators publish their service description using the service module. With the implementation of cloud computing, the external computing devices can be integrated with the internal ones. Thus, the number of supported customers increases as suggested by Rajeev and Ashok [20]. In such a manner, integrating virtual energy sources with the existing energy storage devices and the energy exchange mechanism can be achieved among the micro-grids to meet the energy requirements from consumers.

Dynamic pricing implementation can be used to address energy management. Xuan Li and Lo [14] proposed two smart grid related issues: (a) peak demand and (b) dynamic pricing. Requests from customers, which are to be executed, based on the priority, available resources, and other applicable constraints, are scheduled with the integration of cloud. During peak hours, the messages from smart meters are more than those in the nonpeak hours [14]. In such a scenario, incoming jobs from users are scheduled according to their priority, available resources, and applicable constraints. With the integration of dynamic bandwidth allotment mechanism using cloud application, these issues can be addressed conveniently. During the peak-hour, the allotted bandwidth is higher than that in the non-peak hour, in order to serve all the incoming jobs simultaneously.

Cloud-based services are used for communication and management schemes in the smart grid by Ji et al. [24], while providing the facility of power monitoring and early-warning system as well. In such a scenario, the real-time support is provided by using enterprise service bus (ESB) and service-oriented architecture (SOA). On-demand, efficient, flexible, and scalable smart grid power monitoring system can be built by this approach. Standard Web services, service finding, service registry, interfaces, and service access are implemented into a single cloud application using SOA, as the SOA relies on publishing applications as a service. Smart grid energy management can be performed using the ESB architecture, which includes activities such as security management, task management, and resource management, with the implementation of cloud applications [24].

The Energy Service Interface (ESI) interconnects internal customer energy resources and external systems. Eun-Kyu Lee et al. [25] built an ESI test-bed which includes ESI, a demand response service server, and customer energy resources. A demand response client module is implemented by ESI. The customer energy data are represented by XML format and web service interfaces are implemented for inter-domain communications. An additional test-bed, in which the ESI is deployed on a public cloud. The two test-beds are deployed to verify that the ESI plays the service "prosumer" in a practical manner for a couple of energy service scenarios. The Energy Service Interface (ESI) interconnects internal customer energy resources and external systems.

The trend of the power grid to shift to the Smart Grid leads to the enormous pool of computing and massive data storage requirements. To overcome these demands of cloud computing, highly distributed and scalable computing resources, to host the smart grid applications was proposed. Bitzer and Gebretsadik [26] discussed the feasibility of handling the monitoring of renewable energy in smart grid on cloud computing framework by a Lab-demonstrator. The Lab-demonstration set up considers the power system and the cloud computing domains. The distributed energy resources and the local SCADA control are considered as the power system domain whereas the cloud computing domain contains a specific cloud computing provider [27]. Generation plants can be monitored and controlled by the local SCADA software running on the local computer. Through web-based SCADA monitoring and controlling of the plants can be done from anywhere.

Jinsung Byun et al. [28] proposed intelligent cloud home energy management system (iCHEMS) to address inefficient home energy management systems due to intermittent energy generation by renewable energy. In iCHEMS, a household appliance is assigned with dynamic priority according to its type and current status. The use of household appliances is scheduled based on the assigned priority and renewable energy capability. To enhance utilization of computing and renewable energy system resources, iCHEMS exploits cloud computing. Energy distribution, situation-based energy management, and user-centric energy management are services provided by cloud resources. With the help of cloud computing, the proposed system reduces the high cost, required to implement smart green home and average total power consumption.

Aras Sheikhi et al. [29] proposed a model for utilizing the cloud computing technology in the smart grid domain and explores how cloud computing plays an effective role in DSM (Demand Side Management) game among a group of Smart Energy Hubs (S.E.). Interaction between the utility company and demand response realizing functions, the amount of loads per customer are to be reduced and at which incentive price, are performed on the cloud. In this model, to reach an optimal DSM, based on the game theoretic approach, load profiles of S.E. Hubs are communicated to the CC (Cloud

Computing) where each S.E. Hub attempts to minimize its own energy cost in response to the aggregated information on the actions of the other users [30]. The result of the game, Nash Equilibrium (NE), leads to a proper strategy for each S.E. Hub to minimize their energy bill [29]. The DSM game reduces the PAR (Peak to average ratio) in the electricity grid and the daily energy charges of each S.E. Hub can be significantly reduced.

Rajeev and Ashok [31] proposed a dynamic load-shifting program, makes use of real-time data, in a cloud computing framework to address the forecasting and operational challenges issues, which are to be met when implementing effective renewable energy program. A new dynamic renewable factor, a reference parameter (captures and represents the dynamics in the pricing and shifting strategy) in the algorithm, is proposed to facilitate on-time incentive based load shifting program. With the help of cloud-based infrastructure, the widely distributed renewable energy sources operations are coordinated by the utility at a minimal cost. In addition improved utilization renewable sources, reduction in the peak demand at domestic level, additional household annual bill savings are the benefits of dynamic shifting program.

Smart grids with the usage of information technologies enable efficient power grid. To cope with the huge amount of data and daily fluctuations by the smart meters the underlying infrastructure must be (i) massively scalable and (ii) elastic. Cloud computing is a cost-efficient alternative to dedicated data centers. Martin et al. [32] explored the combination of an elastic Event Stream Processing (ESP) system named Stream Mine3G and cloud technologies in the context of energy forecasting. ESP aim at processing high volume streams of data by processing data on-the-fly instead of storing it first. StreamMine3G, scalable and elastic ESP, is equipped with a resource manager, acquires and releases virtual machines, enables load shifting from overloaded nodes to less loaded ones through migration of stateful and stateless operators. The elasticity properties of ESP system was showcased by performing several experiments on deployed StreamMine3G at Amazon EC2.

Neeraj Kumar et al. [33] proposed a context-aware layered architecture for demand side management using vehicular cyber–physical system (VCPS) with cloud support. With the integration of vehicles with cloud computing, storage, sensing, software, platform, and Network-as-a-Service (NaaS) are offered to the clients. Bayesian coalition game concept and learning automata, an intelligent context-aware data collection and processing, are used. In this scheme, players are the mobile vehicles, which can sense the SG environment and collect information from it. Alert generation and information dissemination are the actions performed by the players in the game. The player's action probability vector is updated based on the feedback from the environment to the players. Reduction in the energy shortage and information processing delay, the increase in energy sold back to the grid are achieved in the proposed scheme.

The importance of BEMS (Building Information Management System) is increasing as Smart Grid spreads. BEMS of each entity is improved to provide high-quality services. The number of the entity increases according to the coverage area of a building. Insung Hong et al. [34] proposed the Cloud computing-based BEMS to lessen the burden of each entity by a System Manager, a centralized server. To monitor power consumption and environmental information, sensor entities with 8-bit microcontroller and ZigBee and Low-cost power are used. The BEMS consists of three the Power Monitoring Entity (PME) - monitor and control device's power consumption, Environmental Information Entity (EIE) - collect environmental information, and System Manager - collect and manage data and provide services to users. This system reduces each entity's cost and hardware specification.

Effective DEM depends on load and renewable production forecasting that leads to large volumes of data generated by a vast number of smart meters. In order to optimize the smart grid operations, DEM requires high performance computing, efficient data network management, robust data analytics, and cloud computing techniques [35]; the cloud computing model meets these requirements [36]. In Literature, approaches have been developed to increase the energy efficiency of High Performance Computing (HPC) data centers, such as the cooperation with the SG in [37], energy conscious scheduling in [38]. Most of smart grid applications, such as advanced metering infrastructure, SCADA, and energy management can be facilitated by the available cloud service models, namely software as a service, platform as a service, and infrastructure as a service [39].

5. Cloud Based Economic Power Dispatching

Smart grids needs to be equipped with an integrated solution to the problem of modern energy delivery network that enables two-way energy and communication with the customers. To manage large amounts of data, cloud computing is the best way for smart grids due to its scalable, economical, and flexible characteristics. We propose a cloud based dispatching model in the smart grid domain. The prime responsibility of the Electric Utilities is to meet the customers' requirements at all times with quality and quantity as agreed. It matches the power generation by the utilities against the customers' power demand at all times. As the consumers' demand changes at every instant, the power generation by the Utilities should match with the consumers' demand. In reality, the power generation can't be adjusted at every instance; hence the generation is adjusted normally at 20 minutes interval. The matching of power generation against the consumers' demand is known as Power Dispatching (Hongseok Kim et al. [12], and Palanichamy et al. [40]). In cloud based economic power dispatching model, the utility and customers interact through the cloud, and the functions for cost optimization are performed in the cloud. From utility's perspective, cloud appears to be an information system, which takes an input from utility (e.g., Power demand, weather data, fuel cost etc.), processes the information, and gives an output to utility and customers (e.g., generations of the individual plants, total production cost etc.). It is worth pointing out that the Cloud network performs the power dispatching job as per the instruction of the Electric Utilities since the decision authority is the Utility. For its services, the Cloud gets it service charges from the Utilities. This arrangement is economical for the Utilities since they need not invest on communication and computing facilities.

6. Conclusion

In this survey, we provided an overview of existing works integrating cloud computing in the existing smart grid architecture, in order to have a reliable and efficient energy distribution. Different aspects of energy management in the smart grid were discussed. We identified some important technical issues and proposed several future research directions on cloud-based smart grid. Using cloud computing applications, energy management techniques in smart grid can be evaluated within the cloud, instead of between the end user's devices. This architecture gives more memory and storage to evaluate computing mechanism for energy management, and cost-optimization. We proposed a new highlight on cost-effective cloud based power dispatching for smart grid applications. From this surveyed work, we can see the integration of cloud computing in smart grid is envisioned to be useful for evolving the smart grid architecture further in terms of considerations such as monitoring cost, computing, and power management.

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