

An Overview of Cloud Computing Uses in Intelligent Distribution Systems

Dr. Ranjan Kumar Mondal

Assistant Professor, Department of CSE, Swami
Vivekananda University, Kolkata, WB

ranjankm@svu.ac.in

Abstract:

In light of the Smart Grid idea, distribution networks will see a significant metamorphosis over the following years to facilitate the development of a more durable, dependable, sustainable, affordable, and efficient system. Modernization can only be accomplished via the widespread application of information and communications technologies to integrate and control this system. In this sense, distributed data storage and parallel processing are two features envisaged as being made practical by cloud computing. This article presents an overview of the key connected works in the field and highlights the possible uses of cloud computing in innovative distribution systems. Along with the basics of cloud computing, it also describes the fundamental advances and technologies underpinning intelligent distribution systems.

1. Overview

The electric power system is the apparatus that produces, transmits, and distributes electricity to final users. Throughout the majority of the 20th century, there has been a steady growth in global energy consumption, necessitating deliberate planning to meet demand. In addition, utilities are attempting to address several issues, such as demand response, energy conservation, more efficient use of renewable energy, and decreased carbon emissions [1-4].

The notion of Smart Grid (SG) emerged to tackle these issues. With further integration of renewable energy sources, the

Smart Grid aims to be a more dependable, secure, affordable, efficient, and sustainable power infrastructure that enables end users to take a more active role in the energy market [5, 6]. Control, automation, and high use of facilities derived from Information and Communications Technologies (ICT) are required to accomplish these aims. In light of these technical advancements, strategic planning

Thus, the efficiency of the distribution system may be enhanced. Comparing the measuring devices—mostly electromechanical and eventually becoming digital—it is easy to see these advancements. These days, many of these gadgets have communication interfaces in addition to being digital. The data exchanged via these communication channels will be saved and examined to enable intelligent decision-making [7, 8].

It's crucial to note, nevertheless, that distribution networks serve as a "bottleneck" for SG, necessitating improvements to customer monitoring devices (which are now primarily electro-mechanical/standalone digital meters in poor nations). The fact that each feeder has many users raises severe concerns since the communication networks will have to send enormous amounts of data, which would result in heavy traffic. It will thus be necessary to store and analyze this massive quantity of data to make historical and decision-making decisions. Therefore, it will be crucial to have a scalable platform that can operate dependably with terabytes of data daily [9]. In this regard, cloud computing has emerged as a promising technology with solid performance [8,10].

Research has been done to identify potential uses cloud computing with the intelligent grid idea [11–16]. Furthermore, several studies aim to anticipate the difficulties associated with managing massive amounts of data, which might potentially be created during the installation of an intelligent grid [17, 18].

Accordingly, this study addresses specific trends and issues by providing an overview of the most essential publications correlating cloud computing with innovative distribution systems.

The purpose of Section 2 is to provide the reader with a better understanding of the Smart Grid idea. The influence of SGs on power distribution systems will be discussed in Section 3, along with the key elements that need to be implemented. An overview of cloud computing is given in Section 4. The main advancements and uses of cloud computing in intelligent distribution systems are covered in Section 5. Lastly, some debates and conclusions about this survey are included in Section 6.

2. GRID FOUNDATIONS SMART

The idea behind the so-called “smart grid” originated from the need to update the electricity system by combining the newest innovations in information technology, instrumentation, control, and communication.

The goal of global energy sector players to modernize electricity networks gave rise to the phrase “smart grid.” With cutting-edge computer and communication resources, this new system should be able to track the growth in energy demand, enhance power quality, decrease losses, and boost operational safety across the system via monitoring, automation, and control [5].

The concept of a “smart grid” is highly inclusive and immediately relates to national interests. As a result, no one definition has been accepted worldwide. For instance, the primary goals in the United States are to revitalize the country’s aging electricity systems, enhance customer satisfaction, provide employment opportunities, support business growth, and boost user involvement. In contrast, the primary goal in Europe is to increase the use of renewable energy sources and lessen reliance on fossil fuels to improve energy security.

“The Smart Grid is a grid system that integrates many varieties of digital computing and communication technologies and services into the power system infrastructure, enabling bidirectional flows of energy and two-way communication and control capabilities,” according to the National Institute of Standards and Technology (NIST) [19].

In the report of the European Smart Grids Task Force Expert Group 1 [20], a smart grid is defined as “an electricity network that can cost-efficiently integrate the behavior and actions of all users connected to it—generators, consumers, and those that do both—to ensure an environmentally efficient, sustainable power system with low losses and high levels of quality, security of supply, and safety.”

The Electric Power Research Institute (EPRI) website provides a shorter definition of an intelligent grid [21]: “A smart grid integrates information and communications technology into all aspects of electricity generation, delivery, and consumption to minimize environmental impact, enhancing markets, improving reliability and service, lowering costs, and increasing efficiency.”

A power grid that integrates ICT and is capable of intelligently connecting all parties involved—generators, customers, markets, service providers, utilities, appliances, etc.—is generally understood to be a “smart grid,” even though the phrase has no one definition [13].

A power grid must have specific characteristics to qualify as intelligent, including [22] allowing for consumer active participation, accommodating all generation and storage equipment, enabling new markets, products, and services, providing power quality, optimizing asset utilization, operating efficiently, anticipating and responding to system

Disruptions (self-healing), withstand the assault and natural calamities with resilience. These qualities will make it possible to reap several advantages, including [19]:

Enhances the quality and dependability of electricity;

Maximizes the use of facilities and prevents the need to build back up (peak load) power plants;

- Expands the capability and effectiveness of current electrical grids

Enhances resistance against assaults and natural catastrophes;

Facilitates anticipatory upkeep and “self-healing.” reactions to disruptions in the system;

- Promotes the increased use of renewable energy sources;
- Supports a variety of energy sources;
- Automates upkeep and functionality;
- Lowers greenhouse gas emissions by making new energy sources and electric/hybrid cars possible; lessens the need for wasteful generating during times of peak use, thereby lowering oil consumption; offers chances to strengthen grid security; Facilitates the shift to plug-in electric cars and introduces novel possibilities for energy storage.
- Gives customers timely and valuable information details on their energy use;
- Expands customer options and makes new goods, services, and markets possible.

To ensure interoperability of Smart Grid devices and systems, the National Institute of Standards and Technology (NIST) in the United States is in charge of coordinating the creation of a framework that comprises protocols and standards for information management. NIST has identified nine priority areas, including network communications, cybersecurity, and seven essential functions, to direct the development of this new power grid architecture [19]. These features, which include the goals suggested by the Federal Energy Regulatory Commission in its policy statement, are essential to developing Smart Grid technologies and services [23]. They are listed in the following order:

Demand Reaction and Energy Efficiency of Consumers;

Broad Area Situational Intelligence;

Resources for Distributed Energy (DER);

- Energy Reserve;
- Electronic Mobility;

AMI stands for Advanced Metering Infrastructure.

- Distribution Grid Administration

Cybersecurity, as well as

- Network correspondence.

These modifications will most impact the distribution system [1], which will be the focus of these services and functions, which will be applied to the power system as a whole.

The distribution system, which serves most users and handles billing, is very complicated by its very nature. It comprises a vast network of substations, cables, poles, and meters, among other things. This system must be completely redesigned to comply with Smart Grid standards. The intelligent distribution system will be able to control the entire grid in real time through automated equipment and smart meters. This will include load balancing, preventing power outages by identifying and isolating faults, reconfiguring and restoring the supply automatically, and managing voltage levels and power flow [24]. A few essential innovative distribution system technologies are covered in the following section.

3. Systems for innovative distribution

Although it makes up most of the power system, the distribution system is presently the least automated. Furthermore, it often contains data from the sub-station feeder and has no discernible intelligence [5].

Many improvements and features are being created to enable the implementation of Smart Grids and improve the system's safety, efficiency, and proactiveness. The following are some of the more notable new technologies: distributed energy resources and peak-shaving, which will allow production to be balanced with demand and improve system reliability; advanced tools and information management, which will enable network situational awareness through system monitoring and control and support planning and optimization tasks through forecasting and simulation procedures; and advanced metering infrastructure and distribution automation, which will enable extensive system monitoring, control, and automated reconfiguration.

3.1. Sophisticated infrastructure for metering

Smart meters, energy management programs, and communication infrastructure are just a few technologies that

make up an advanced metering infrastructure. These systems allow for bidirectional communication between customers and utilities, allowing for real-time power use monitoring [25].

These systems include data management, consumer-associated systems, controllers, software, hardware, and communications [26, 27]. This way, the data-collecting feature of smart meters may be enabled to provide

Some details for service providers and customers [19]. These smart meters will offer real-time power pricing, monitor voltage and current, record waveforms, and remotely connect and disengage customers. However, to provide helpful information, these activities will produce much data that must be handled and analyzed. The data above will be accessible for planning and operation purposes, potentially enhancing asset management and dependability [28]. Furthermore, demand response systems made possible by these meters will allow customers to lower their power energy prices. However, utilities can run their systems, reducing the demand at its peak. The distribution system may be utilized more effectively if peak demand per customer is decreased [29].

3.2. Automation of distribution

The initial stage in the evolution of a distribution grid is distribution automation, which opens up new application possibilities via widespread control and monitoring. The distribution automation idea, for this purpose, refers to a collection of systems that allow the utility to remotely monitor, coordinate, and control the distribution grid components in real-time [30]. Improve effectiveness, dependability, and service quality entails the integration of sensors, bidirectional communication systems, Intelligent Electronic Devices (IEDs), and Supervisory Control and Data Acquisition (SCADA) systems. This system remotely controls circuit breakers, switches, reclosers, capacitor banks, and other equipment to allow Smart Grid functions. It also monitors the voltage and current levels, power demand (active and reactive power flow), equipment, and operational conditions [22].

The system can self-heal based on these monitoring and regulating capabilities, primarily in fault circumstances. As a result, during system restoration, this activity helps the repair teams and control center operators [5]. Thus, distribution automation technologies would enable, among other things, automated reconfiguration, integration of DER, and minimization of both technical and non-technical losses in conjunction with distribution management systems and improved metering infrastructures.

3.3. DER and shaving during peak

Small power sources known as distributed energy resources include microgrids, distributed production from conventional and renewable energy sources,

Energy storage technologies and electric cars [7]. Integrating distributed energy resources (DER) based on renewable energy sources reduces carbon emissions and lessens issues associated with rising consumer demand. Peak-shaving [31] is another advantage of distributed energy resources (DER). This may be accomplished by demand response rules (through load control and intelligent appliances) or by utilizing the energy produced or stored.

As noted, reducing peak demand and improving the demand profile improve system dependability, which lowers capital expenditures. Reducing distribution system losses and using variable power sources more effectively may enhance the grid.

3.3.1. Virtual power plants and distributed generation. Small-scale generation is known as distributed generation. An extensive collection of dispersed generators under the supervision of the system operator, whose aggregate capacity is equivalent to that of a traditional power plant, is referred to as a virtual power plant [8]. The combined output of a virtual power plant may replace a conventional power plant while offering more efficiency and flexibility. Its technical and commercial characteristics are comparable to a central generating unit [32]. However, a massive quantity of data would need to be collected, analyzed, and stored to make this idea feasible.

3.3.2. Tiny grid. A microgrid is a collection of loads and distributed energy resources (DERs) that may provide electricity to a single major consumer or nearby region. As a result, about the grid, a microgrid functions as a single controlled unit. It can also function in grid-connected and island mode by connecting and disengaging from the grid [33].

Different control and power management systems are available for microgrids, which may be configured to operate in a decentralized or centralized way [34, 35]. A microgrid is often not grid-independent [36]. The distributed generators continue to provide electricity to their customers even while the microgrid runs in island mode, negating the utility grid's power requirement. In addition to offering several benefits, the ability to island provides the possibility for superior local dependability than the power system as a whole. For instance, a microgrid may keep going during a power grid interruption. This process may be done by disconnecting the microgrid to execute a load shedding or going into island mode.



Fig. 1. Mental map of the information management system conceptually.

It is crucial to remember that, even while operating in island mode, the microgrid must communicate with the utility to determine the grid's state and whether to rejoin [8].

3.3.3. Electric cars with energy storage. By reducing the peak demand, electricity storage, including electric vehicles, has

several advantages for the distribution system. Energy storage devices may be utilized to make energy accessible when demand grows for variable renewable energy sources (like wind and solar) and sometimes for conventional generating (like thermal, nuclear, and hydroelectric) [7]. Electric cars may function as a stand-alone energy source and support the electrical system. In this manner, energy from electric vehicles' batteries might be transferred to the grid, mostly while parked and linked to it, via vehicle-to-grid technology [37].

3.3.4. Reaction to demand. Demand response refers to a shift in the amount of electricity used (by demand-side resources) in response to price fluctuations (real-time, interval, time-of-use, and critical peak pricing) or to monetary incentives designed to lower peak energy consumption [7, 38]. Customers may take an active role in grid operations by using demand response programs, which enable them to alter their behavior, modify equipment or processes, employ consumer-owned generation (DER distribution), or provide direct control over demand-side appliances and equipment (load management) [33].

3.4. The primary differentiator of intelligent grids is integrated information management systems and enhanced technologies. It is their duty to amalgamate and improve oversight, evaluation, and

Optimization systems facilitate the efficient operation of innovative distribution systems. Therefore, information collection, information processing, and information storage are the three fundamental activities these systems typically include [8,39].

Information collecting involves acquiring data from sensors, smart meters, and IEDs over an adequate communication infrastructure [39–44].

Data modeling, information analysis, integration, and optimization are all connected to information processing. Semantic data representation is the focus of data modeling, which facilitates information sharing across many devices. For device integration, this data must adhere to specific

interoperability standards [19,45,46]. To support new capabilities based on large-scale information management, real-time data analysis, and closed-loop systems, information analysis is used to extract valuable information from the massive amounts of data generated by the widely deployed metering and monitoring systems in Smart Grids [47–50]. Integrating information from several sources with disparate conceptual, contextual, and typographical representations is the goal of information integration [8,45,46]. Information optimization increases information efficiency, lessens communication load, and stores only relevant data [51, 52].

Lastly, information storage is the primary storage for all relevant data collected from various devices via various wired and wireless channels and transit modes. This storage may include additional pertinent processing data [17]. Utilizing cutting-edge methods, the saved data are used for distribution system analysis, planning, and simulation.

Figure 1 shows the conceptual mind map of the information management system described above and its sub-visions and associated problems.

Large-scale information management makes new capabilities based on real-time data analysis and closed-loop systems possible for managing, monitoring, and regulating the intelligent distribution grid [53]. Integrating applications such as electricity management, state estimate, power flow analysis, demand forecasting, outage management, and asset management may achieve a complete distribution management system with high situational awareness [16,54].

The deployment of an information management system necessitates high processing and ample storage space due to the volume of data from the metering infrastructure, which has proven difficult [55]. This premise has led to the concept of cloud computing as a promising technology that may overcome these obstacles and improve information integration while facilitating extension and interoperability [12,56,57]. The features highlighted as benefits of cloud computing in the Smart Grid sector include processing power, storage capacity, scalability, flexibility, cost-effectiveness, real-time response, and interconnection, as mentioned by [58].

The following section will cover the essential terms and ideas of cloud computing technology.

4. COMPUTING IN THE CLOUD

4.1. Definitions

A new computing paradigm known as “cloud computing” allows for the dynamic allocation and scalability of computer resources as services delivered via the Internet. The term “cloud” refers to a metaphor for the Internet, formerly shown in network diagrams as a cloud to abstract the intricacy of its infrastructure [59]. A broad phrase for distant computer resources that are usually accessible via the Internet has emerged: cloud computing. These computer resources are often dispersed throughout the internet and have no fixed physical location. They are typically virtual.

Clouds are vast repositories of readily available and useable virtualized resources, including development platforms, hardware, and services. These resources may be optimally used by dynamically reconfiguring them to suit varying task demands. Cloud computing uses a pay-per-use payment model, where the cloud provider provides service assurances to the customer via personalized Service Level Agreements (SLA) [60].

Even though cloud computing is relatively new, the concept of remotely supplying computer resources on demand goes back to John McCarthy’s early 1960s suggestion that shared computing resources may eventually lead to a world where computing power and

Specific applications, like phone and power services, where each user pays for the utilization capacity, might even be sold as utilities [61].

One of the primary benefits of cloud computing is its capacity to provide on-demand services to customers, relieving them of the expense of purchasing, maintaining, and operating hardware. Because of this, these customers will only pay for what they need and when they need it, saving IT expenses while also providing flexibility and scalability. Cloud computing may dynamically adjust resource utilization

based on demands and available resources without affecting service. The number of allocable resources seems limitless to users. The capacity to provide online services over the Internet or another network resource, enabling service consumption from any location with network access, is another advantage of cloud computing. Because most of the data processing has to be done on the cloud server, cloud computing permits the use of smaller hardware terminals, allowing access to a broader range of hardware platforms.

Another benefit of cloud computing is improved operational security since data and processes are duplicated across numerous servers. Physical cloud servers are often located in several geographical areas. As a result, additional servers may take over if participating servers fail due to natural catastrophes or technical issues, lowering the likelihood of data loss and service outages.

NIST has been defining standards relating to cloud computing since 2010 [62, 63]. The NIST cloud computing definition [64], utilized as a foundational model for the services provided, is generally acknowledged as having significantly contributed to a clear understanding of cloud computing technology and services. Cloud computing, according to NIST, is a model that allows for ubiquitous, easy, and instantaneous network access to a shared pool of reconfigurable computing resources (such as networks, servers, storage, apps, and services), which can be rapidly provisioned and released with little involvement from service providers or management work [65]. This cloud architecture comprises three service models, four deployment methods, and five key features (measured services, resource pooling, broad network access, on-demand self-service, and quick elasticity) [64].

These are the three service models that may be used as a basis for further models:

SaaS, or software as a service, is the highest hierarchical

Layer via which the user may access apps

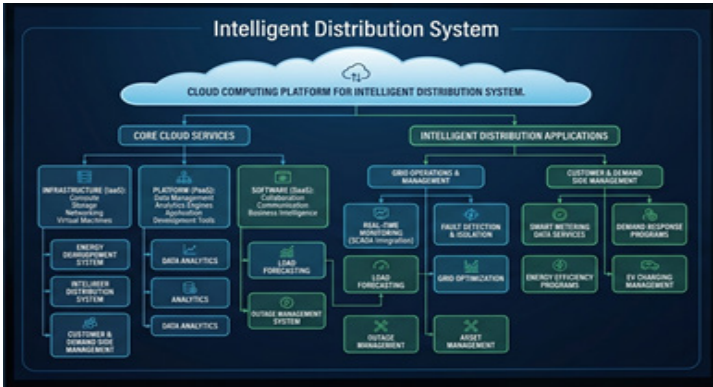


Fig 2. Services Organization Chart

Operating on a cloud infrastructure via a client device (thin client, web browser, program interface, etc.) connected to a network, usually the Internet, the service provider manages and controls the software updates, patches, and underlying infrastructure; the customer is not responsible for these things. PaaS (Platform as a Service): this gives the user the capacity to install, test, and oversee apps that users have obtained or developed on a cloud infrastructure. While the development platform and solution stack are hosted in a cloud environment, the PaaS streamlines the software development process. Although they do not influence the underlying cloud infrastructure (network, servers, operating systems, storage, etc.), users are in charge of the deployed apps and may even be able to modify the application-hosting environment's configuration settings;

● Access to Infrastructure as a Service (IaaS)

Virtual machines, storage accessible via a network, network infrastructure elements, and other essential computing resources allow users to install and execute any software, including operating systems and apps. Disaster recovery and infrastructure upkeep and repair are within the purview of the service provider.

Figure 2 shows these service models may be grouped hierarchically according to the hardware abstraction level. The higher the abstraction level, the less customer engagement with the hardware is required or permitted.

Deployment methods are classified as private, public, communal, or hybrid depending on how exclusive the computing resources are made to a cloud customer. Because of the scale economy, a cloud's services will be more affordable for the more consumers it serves.

A single organization has exclusive usage of the infrastructure in a private cloud. It is usually owned, run, and managed by the company, a different company, or a mix of these parties. In contrast, the infrastructure in a public cloud is made available for anybody to utilize at any time. An operator, manager, and owner might be a service provider. Like a private cloud, a community cloud is used by a collection of organizations with everyday needs and concerns. It may be owned, managed, and run by any of the community's companies, a third party, or a mix. Ultimately, a hybrid cloud comprises two or more separate clouds (private, communal, or public) that continue to exist as separate entities but are connected by proprietary or standardized technology that permits data transfer and applications.

4.2. Framework for cloud computing for intelligent grids
Smart grid data are continuously created and sent as a data stream to the utilities. A stream of data, or a time series, may be seen as an endless series of time-stamped documents. These records must be handled promptly and kept for historical purposes.

Cloud computing is likely the most straightforward and effective method to satisfy large-scale Smart Grid needs because of its scalable and flexible features, cheap cost, redundant design, quick reaction time, and capacity to handle massive volumes of data [12,14,56]. A wide range of technologies may be used when creating a cloud architecture. The fundamental problem is deciding which is best for a given application. As a result, much research [9,49,56,66-78] has been done to create a cloud computing framework that

can handle the enormous data storage, transportation, and communication required by smart grids by offering large-scale real-time computing capabilities.

Dealing with Smart Grids immediately raises the issue of what to store and how to store the data provided by the many available sensors and meters. These data are often gathered across various intervals, from days to microseconds. Different technology and storage techniques are required for such data granularity. For instance, the standard data storage solution based on Relational Database Management System (RDBMS) is not ideal when dealing with a large quantity of data (in the order of terabytes), as it lacks performance in both storage space and speed. Employing NoSQL databases or other

A hybrid approach might help solve this issue [17]. The storage strategy should also consider whether the data will be disseminated across the network or kept locally. While some distributed databases employ third-party Distributed File Systems (DFS), others provide inbuilt DFS. Many ideas have been proposed to complete this storage [66–70, 75, 76, 78, 79].

There are many NoSQL databases with various storage strategies, including time series databases (OpenTSDB), document-oriented databases (Mongo DB, Couch DB, etc.), key-value databases (Riak, Redis, etc.), and column-oriented databases (Cassandra, H base, etc.) [80]. A few well-known time-series databases are compared in [79].

When working with large volumes of data, computing power is necessary to complete calculations and analyses in a reasonable amount of time. Some writers have suggested various approaches to address these high-performance computing needs [50, 72, 75–77]. Many writers have implemented parallel processing and distributed storage using the MapReduce programming paradigm and the Apache Hadoop environment.

The Apache Organization's open-source Hadoop platform makes scalable distributed computing possible. HBase is an open-source distributed NoSQL database that is part of Hadoop. It operates on top of the Hadoop Distributed Filesystem (HDFS) and can handle large datasets with

billions of rows and millions of columns. The MapReduce programming model is supported by the Hadoop framework, which is used by several big websites like Amazon, Facebook, Yahoo, and others to construct and run applications [81]. Google developed the MapReduce programming approach to handle massive amounts of data across computer clusters [82]. When data processing is highly parallelizable—when one process runs independently of the others—Hadoop and MapReduce are meant to be used. In other cases, a more thorough analysis of this solution's suitability would be required. Stream processing, for instance, is preferable when data has to be processed quickly and constantly since it allows data to be examined as it enters the data workflow. However, a hybrid approach could be more appropriate in other circumstances. [71] presents a comparative analysis of several stream processing solutions.

While cloud computing may seem to be a remedy for

Despite the storage and processing difficulties encountered by intelligent grids, not all intelligent grid applications need much processing power or storage. It can still benefit from cloud computing features, however, including on-

Demand measured services, quick elasticity, resource pooling, broad network access, and self-service.

A further worry with cloud computing is assured data delivery and communication time delays, which might be necessary for mission-critical applications. Since most communication occurs online, sending data in real-time with a high delivery probability might be challenging.

A few security and privacy problems must be considered when using cloud computing in intelligent distribution system applications to maintain data integrity and information privacy while transferring data over public networks. To improve data security, network assaults may be prevented by using intrusion detection, trust management, encryption, and authentication security techniques. Many people have spoken about this subject [8,9,13,15,56,83,84].

The cloud deployment methodology is one of the elements that influences security and privacy concerns. When comparing private clouds to public clouds, there are situations where security and compatibility must be traded off against complexity and cost-effectiveness [15,85]. In contrast to public clouds, private clouds are more secure against cyberattacks but lack some benefits, such as non-upfront investment, cheaper operational costs, high scalability, quick access, and fewer business risks and maintenance costs. The actual hardware is often on the utility's property [58]. However, dispersing data among many off-premise cloud providers globally may enhance this data's resilience to disasters.

Therefore, it is improbable that an electric company would use a public cloud for all its information management needs. Implementing a hybrid approach to benefit from the economies of scale provided by public clouds and maintain the security of sensitive data stored in private clouds may be more advantageous.

Notably, the SLA between the utility and the provider considers these three primary risks when outsourcing computing and storage to an external service provider: dependability, performance, and safety. Furthermore, it is relatively uncommon for SLAs to exclude some provisions, such as confidentiality and integrity [84]. The following risks are taken into account while evaluating performance and dependability [13]:

What impact would a fluctuation in performance have?

The business?

What impact will latency and fluctuation have on customers' experiences?

- **What is the acceptable latency?**

Will crucial data be lost in the event of a system failure?

These inquiries would help plan what to outsource and when. Sometimes, when there is a significant demand for computer resources—a phenomenon known as “cloud bursting”—the utility may decide to employ a public cloud.

The proper cloud computing framework can develop many innovative distribution system applications, including demand-side management, demand response, power system monitoring and control, power system analysis, system simulation, state estimation, demand forecast, energy profile analysis, etc. As a result, the primary cloud computing research effort applied to intelligent distribution systems will be presented in the next part.

5. Cloud computing applications in intelligent distribution systems

By combining all utility systems in a cloud environment, cloud computing can increase the degree of information integration in a smart grid, simplifying information system design and lowering operating costs [12, 14].

Most research on cloud computing in intelligent grids involves computing power for data processing and storage in information management [11]. These computer capabilities have been used in other conventional fields, such as power system analysis, reliability analysis, and management systems, in addition to enabling the creation of new fields.

This section provides an overview of the work done in the field to serve as a springboard for future scholars. Table 1 summarizes the critical intelligence.

Applications for distribution systems that use cloud computing technology in their development or implementation, which may be found in the literature up to 2016, are categorized as information management tasks (Section 3.4). These applications vary significantly from one another and have unique needs that call for particular architectures. As is evident, many apps have been created, but there is still room for more. A wide range of research subjects and advancements are possible in the young and rapidly developing field of cloud computing applied to intelligent distribution systems.

Innovative distribution systems mostly use cloud computing for Energy Management System (EMS) applications. In this context, EMS refers to the software package that monitors, manages, and enhances power system performance. The

Supervisory Control and Data Acquisition (SCADA) monitoring and control functions, as well as the “advanced tools” analysis and optimization tools, are a few examples of the software suite that may be included [114]. As mentioned in the ensuing subsections, these programs may include demand response, system modeling and simulation, real-time metering, and several administrative tasks.

5.1. Applications for management and control

Power system monitoring and control [10, 54, 68, 70, 96–99], demand-side management [18, 75, 76, 86–93], micro grid management [18, 94, 95], and other DER management apps [100–103] are the primary energy management applications created in the cloud environment.

The two most crucial roles of the EMS are power distribution system monitoring and control.

They are in charge of gathering, processing, analyzing, and visualizing the data from the smart grid and carrying out certain grid management operations. In this fashion, cloud computing-based system designs were presented by [68] and [70] to analyze and store monitoring data. Their solutions use Apache Hadoop for parallel processing based on the MapReduce programming style and HBase and HDFS for data storage. The creation of a SCADA system using cloud computing was suggested by Alcaraz et al. [96,97] and Goose et al. [10], who also described the specifications for this new architecture and some potential security measures for data sharing. Strategies for controlling and offering service-sensing resources in the cloud were covered by Fazio and Puliafito [98]. To eliminate the equipment from the substations and lower the investment, Bo et al. [54] proposed designing and developing a cloud computing platform to replace the calculating functions of secondary equipment dispersed among several grid substations. Another use case presented by [99] is the creation of Web Services for the cloud computing-based processing of power quality data captured by smart meters or other comparable devices in smart grids.

Demand-side management pertains to adjusting peak loads to accommodate generating capacity by changing customer

demands in response to utility-mandated programs [88, 90], such as demand response initiatives or other tactics that encourage load shifting.

Simmh An et al. [18, 87], Sheikh et al. [88], Lohrmann and Kao [92], and Kim et al. [86] suggested several kinds of cloud-based demand response applications. Mohsenian-Rad et al. [93], Li et al. [91], and Wang et al.

[89] they suggested a few strategies for altering cloud data center energy use to encourage load balancing within the distribution grid. A dynamic load-shifting method based on real-time data was indicated by Rajeev and Ashok [90] to facilitate the integration of renewable energy sources. An energy management system capable of using service-oriented architecture to communicate with appliances and regulate their operation was presented by Yang et al. [75,76].

Applications for microgrid management are in charge of keeping an eye on and controlling the intelligent microgrid's functioning and consumption and handling its related responsibilities. On a smaller scale, microgrid management may also benefit from some intelligent distribution systems management applications, such as those suggested by [18]. Jin et al. [94] and Marchi et al. [95] have put out several methods to leverage multi-

Smart microgrids using agent systems as a distributed control architecture.

Apart from the applications above, additional management applications concerning distributed energy resources (DERs) exist. These applications facilitate utility interface with electric vehicle supply equipment [103] and cloud computing-based monitoring and control of distributed renewable energy resources [100–102].

5.2. Sophisticated instruments

The “advanced tools” are a unique component of the EMS for distribution system analysis and optimization. Using cloud computing, applications for power system analysis [104], cost optimization [105,106], system modeling [107–109], and state estimate [110] have been created.

Using Google App Engine, Huang et al. [104] created a cloud computing-based power system analysis platform offering three primary services: load flow, contingency analysis, and data transformation.

Devie and Kalyani [105], as well as Fang et al. [106], proposed several cloud-based information management models for Smart Grids and provided optimization frameworks for lowering cloud processing and storage costs while using public clouds.

A scalable open-source simulation system that integrates MATPOWER and Grid lab-D as simulation tools was presented by Anderson et al. [107]. The best dispatch schedules for flexible loads and placement optimization for distributed generation have been designed using these technologies. A cloud computing application architecture for power system transition simulation was presented by Lei Jiao et al. [108]. Cloud computing was used by Maheshwari et al. [109] to parallelize and enhance the functionality of a program that helps the utility planner determine if a power system can sufficiently meet the demands of the consumer load.

In their description of a monitoring framework and characterization of a PMU-based state estimation application, Maheshwari et al. [110] explained how the intended system might be integrated into a suggested cloud architecture.

5.3. Data mining and analytics

The science of analyzing unprocessed data to derive conclusions about it is known as data analytics. It is centered on inference, concluding only from the researcher's prior knowledge. In contrast to data analytics, the field of data mining is noted where

Some tools are used to find patterns that haven't been seen before and uncover connections that haven't been seen. Consequently, data mining methods aim to identify trends and information from massive amounts of data [115].

Specific applications in data analytics suggested by Simmhan et al. [18,87], Mayilvaganan and Sabitha [111], and Martin et al. [112] need to be emphasized. They used several demand

forecasting techniques and a cloud-based platform to keep supply and demand in balance.

Nikolopoulos et al. [113] conducted an energy profile study using data mining methods on a cloud computing platform to assist and direct utilities in understanding their customers' consumption habits. Thanks to this study, utilities can provide customized customer plans and services.

As shown, an intelligent distribution system may be used with various cloud computing applications. However, most of the journals and publications in this sector were released less than three years ago, indicating that the discipline is still developing.

6. RESULTS

This essay has discussed smart grids in light of the need to update electrical power infrastructure. By considering associated technologies, applications, and problems, the study focuses on cloud computing applications in innovative distribution systems. Essential definitions and ideas related to cloud computing were presented. The cloud computing infrastructure for intelligent grids was examined regarding storage, processing, security, and dangers to identify the primary research activities, difficulties, and trends.

The study has shown how cloud computing, which offers distributed network storage and parallel processing with large-scale processing capabilities, can handle the enormous amount of data generated by meters and sensors that must be evaluated and saved. It has been determined that NoSQL databases are more suited for storing massive volumes of data than conventional RDBMS. Utilizing MapReduce for parallel processing and the Hadoop environment for distributed storage is the most popular method for handling this data. However, when data has to be handled quickly and constantly, other intriguing alternative methods should not be disregarded. It was said that crucial applications may be impacted by Internet-related communication latency and data supply dependability.

In terms of cybersecurity, intelligent distribution system apps must have security procedures to lower the risks associated with data security to a manageable level. Data outsourcing to a public cloud and its potential effects on the user are significant concerns about cloud use covered in the article.

Lastly, a summary of the primary intelligent distribution system applications that use cloud computing technology in their development and implementation was provided. These applications may be found in the literature. Innovative distribution systems can leverage the processing and storage capabilities of cloud computing to enhance the accuracy and optimization level of power system simulations, power system optimal dispatching, power system optimal planning, real-time monitoring and forecasting systems, and distributed renewable resource management.