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A Comprehensive Review on Smart Grid Ecosystem

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ABSTRACT

A smart grid is an intervention technology for the massive energy demand of the world today. It combines cyber-physical technologies, information communication technology, and electrical power networks from the generating company stations to the end-users while ensuring bidirectional communication among the actors. The smart grid is a complex growing technology that is yet to reach its maturity state. This paper seeks to examine the literature on the state of the art of smart grid technology both from the industry perspective and from academia. To this end, a literature review with a qualitative deductive approach built on the National Institute of Standards and Technology (NIST) guideline and the simplified International Telecommunication Union Telecommunication Standardization Sector (ITU-T) five-domain model were used as a guide to this research. Furthermore, the paper reviewed Smart Grid data centre topologies and identified prospects in spine-leaf architecture as a promising architecture that can be adapted in a smart grid ecosystem data centre design. The literature was searched from the databases: IEEE Xplore Digital Library, Springer Link Digital Library, and Google Scholar, IET Digital Library, Frontiers Library, ACM Digital Library repositories resulting in 151 papers after several exclusions. The work reviewed relevant literatures published from 2002 to 2021 and grouped the reviewed papers according to the key domains of the NIST/ITU-T model. Based on the evaluated literature, the need for more built-in predictive learning curves in smart grid systems and robust Smart grid architecture with enhanced data centre design for Smart grid systems is observed and recommended
Keywords: Smart Grid, Smart Metre, Data Centre Computing, Distributed Energy, Protocols

INTRODUCTION

A smart grid is a cyber-physical electrical network that supports duplex communications through the use of built-in information communication technologies [1,2,4,5]. This innovation is an intervention to the growing demand for energy in the world today. In more recent times, the traditional power grid has expanded to include wind, solar and hydro energy sources without much reference to intelligent grid construction that balances integration of different energy sources to the grid [2,6,7,8]. In the past, the power grid was designed to accommodate a distribution network (Example one to multiple distributions), where national or regional electricity is feed by the central generator (power stations), and the electricity is distributed to customers by a large network cable and sub-converters/transformers [9,10,11,12,13]. The challenge of balancing power demand by the power companies and the power demand of end users is common in the historical power grid [3]. According to the used load forecasting model, service providers tend to bring in excess demand over time (considered to be the highest loading conditions) [14,15,16,17,18]. Secondly, it is very costly and unfriendly for a power company to set up and operate peak power plants [19,20,21]. With the growing demand for electricity, it will also be difficult to match the supply of this high energy requirement, perhaps not possible over time, which is why the need to balance, control, track energy demand and supply the available energy resources in any effective technology/process [22,23,24,25,26].

The smart grid addresses the above-mentioned problem and also allows the customer to participate in power generation [4]. Therefore, the value of an intelligent grid and its proper research cannot be overemphasized.

Related Works

Over the years, several works have attempted to review the trend and state of research and development on smart grids.This section considers some notable studies on smart grid reviews in [3] analysed current improvements in energy data management in smart grids, pricing modalities in a modern power grid, and the core elements of the smart grid in depth and detail. The report outlined recent developments in the field of network reliability. The reliance of smart cities on improved communication infrastructure, on the other hand, raises issues about data integrity [41,42,43,44,45,46,47,48].The study also discussed the problems and current state of security on smart grids [49,50]. In [4], the author provided a quick review of real cyber-attack instances in traditional energy grid networks as well as those aimed at the smart metering network. The research proposed a threat taxonomy that included: 1) vulnerabilities to system-level security; 2) vulnerabilities to services and/or theft; and 3) challenges to privacy. The paper developed a set of security and privacy standards for SG metering networks based on the dangers presented [51,52,53]. Also, the article reviewed various strategies that have been proposed to manage these concerns, weighing the benefits and drawbacks of each, and finally investigated outstanding research challenges in SG metering networks to shed new light on future studies prospects. The paper in [5] presented a thorough examination of several cloud computing applications for smart grid design in three areas: energy management, data management, and security [54,55]. The efficacy of cloud computing applications is examined in these domains, as well as future potential for the smart grid's development. The research also identified many obstacles that can be resolved using the cloud in a traditional power grid (without cloud service) [56,57,58]. The authors provided a synthesized summary of the current status of research on smart grid development in this survey. In addition, the paper identified the current research concerns in the fields of cloud-based energy management, data management, and smart grid security vulnerabilities. The work in [6] is a comprehensive assessment of the Smart Grid communication (SGC) technology based on Software Defined Networks (SDN). The authors of this [6] research examined the taxonomy of benefits of an SDN-based SG communication (SGC) system. SDN-based SGC designs were also covered in the work, as well as case examples. This paper goes through routing methods for SDN-based SGC in great detail [59,60]. The work also presented a comprehensive overview of security and privacy schemes for SDN-based SGC and discussed SDN-based SGC's problems, open topics, and future research prospects. The authors [7] provided a detailed review of current research on cognitive radio (CR) Smart grid communications, highlighting what has been studied and what still needs to be addressed, notably in terms of standardization and security. The survey works in [8] and [9] presented solutions to the problem of consumer privacy protection and smart grid security challenges. The review in [10] addresses the most key researches on electric energy demand forecasting during the previous 40 years, as well as the various models utilized, and future developments. It also examined the most recent studies on demand forecasting in future environments resulting from the use of smart grids. In [11], the authors offered a structured descriptive analysis of several data centre network topologies, as well as a comparison of these structures to data centre network performance matrices. The study was concluded with a discussion on the potential future improvements of the DCN architectures and operations. In [60,61,63,64,65], the authors, in summary reviewed, discussed detailly the optimization and fabrication techniques of solar photovoltaic systems. The author further comprehensively reviewed the advantages and disadvantages of renewable energy (solar) enhancement and its integrations in Electric vehicles. The papers showed the types of grids and the distributions methods to adopt more especially when dealing with solar electric vehicle charging stations [65,66,67,68,69]. The rest of the sections of the paper is organized as follows: Section 2.0 presents the research methodology of the work. Section 3.0 addressed the distribution of the research articles from 2002 to 2021. Section 4.0 presents a review on the theoretical perspective of the smart grid ecosystem from NIST standpoint. Section 5.0 presents Organizations, and researchers active in Smart grid technologies researches. Sections 6.0 presents Active Conferences and Journals on Smart grid technologies [70,72,73,74,75,76].Section7.0 discussed research works on Distributed energy systems, Smart meters, Demand Side Management, and Demand Response. Section 8.0 presents regularization activities for Smart Grid Connectivity. Section 9.0 presents Smart Grid Distributed Data Centre Networks. Section 10 addressed Problems of absence of Predictive learning Curve in a Smart grid Systems. Section 11 presents The authors of [1,77,78,79.80,81,82,83] focused on challenges affecting the security of the Smart Grid and the Smart Home as a component of the Smart Grid. The report described some of the most prominent risks to the Smart Home / Smart Grid environment based on numerous scenarios [27,28,29,30]. The risks discovered are classified according to the Smart Home/Smart Grid environment's specific security goals, and their influence on overall system security is assessed [84,85,86,87,88]. Following that, a review of recent literature is carried out by the authors Threats to validity/Constrains. Section 12 recommends the future research work on smart grid ecosystem [89,90,91,92,93,94]. Section 13 is the conclusion of the review findings. characteristics of advanced metering infrastructures, smart grid deployment scenarios, and the interaction between smart grid and AMI. The report looked at the major characteristics of AMI as well as security risks and challenges [39,40,95,96,97]. The research also included a discussion of key management's function in AMI, as well as distinctions between standard electrical systems and smart grids. The authors of [2] categorized and reviewed the available papers in the literature that deal with AMI's secure key management system. Finally, a summary of potential future open research concerns and obstacles for KMS in AMI was provided in the report. The publication in [3] provided a categorical evaluation of the smart grid paradigm's recent accomplishments and earlier research developments over the last two decades. The study's major goal is to produce an application-focused survey in which each category and sub-category is extensively and independently examined. The paper with the goal of presenting promising security countermeasures in relation to the defined unique security objective for each case. According to the authors in [2,98,99,100,101], this is the first study to emphasize the importance of key management systems (KMS) for advanced metering infrastructure (AMI) security in smart grids. The survey focuses on how the key management strategies can be used to protect sophisticated metering infrastructures by highlighting critical security risks.

RESEARCH METHODOLOGY

The quality draw method [6] was implemented using the NIST/ICTU-T model to comprehend the Smart grid state of the art and possible distributed communication network architecture that can support a robust smart grid system. A literature survey of the journal articles published between 2002 to 2021 from IEEE Xplore Digital Library, Springer Link Digital Library, and Google Scholar, IET Digital Library, Frontiers Library, ACM Digital Library repositories was carried out.

Research questions

This review makes it possible to know the extent of research done on the smart grid within the past 18 years (2002 to 2021). The paper helps to identify research and the results will assist researchers in investigating smart grid technology to get an overview of the art and trend at a glimpse.

This work extensively reviewed and compiled selected research works on the basis of their research contribution to each of the sub domains of NIST [5]. In particular, this report seeks to answer the following fundamental research questions (RQs) below. Each RQ addresses a specific area of smart grid technologies and data SG data center computing schemes.

RQ1. What is the distribution of smart grid researches published between 2002 and 2021?

RQ2. What is the NIST functional perspective on the smart grid?

RQ3 Which researchers, organizations, and countries are active in Smart grid technology?

RQ4. What are the techniques/ management methods in the Smart grid Ecosystem?

RQ5. What are the research gaps for RQ4?

RQ6. What are the standardization activities/ unifying standards for smart grid communication networks?

RQ7. What are the research gaps for RQ6?

RQ8. What are the promising techniques on Data Centre Network computing for smart grid enterprises?

RQ9. What are the research gaps for RQ8?

RQ10 What are the problems of the absence of a Predictive Learning Curve in a Smart Grid System?

Literature sources

A literature survey of the journal articles published between 2002 to 2021 from IEEE Xplore Digital Library, Springer Link Digital Library, and Google Scholar, IET Digital Library, Frontiers Library, ACM Digital Library repositories was carried out in this study.

Search Criteria

Certain keywords and criteria (Acceptance and Rejection criteria) were used to identify relevant works. The search keywords include Smart Grid technology, Smart Grid Functionality Architecture, Smart Grid domain, smart grid communication, SG DER Architecture - Energy Distribution, management, Control & Monitoring, Smart Grid predictive analysis, Distributed Data Center Networks, smart meters, Distributed Energy Resources (DER), demand response, consumer energy efficiency, SG Energy Management, Next Generation Network Architecture Database. Searches were repeated until new articles were found and duplicate results were removed. All the papers gotten from different repositories were imported and sorted using the Zotero reference management software. The papers were reduced from 281 to 151 after being sorted based on their relevance to smart grid technologies.

Acceptance criteria

The fetch criteria were as follows: Publications written in the English language, published between the years 2002 and 2021, review papers (narrative, rating, systematic, etc.), position papers not reporting on novel research or systematically reviewing existing research, Doctoral theses, or dissertations.

Rejection criteria

Publications irrelevant to smart grid communication architecture were rejected. The criteria used for exclusion of a research paper in the search process include unpublished papers, date of publication, publications not written in the English language, textbooks, non-peer-reviewed papers. Figure 1 shows the results of the distribution of paper from 2002 to 2021. The article sorting process and some of the search criteria were implemented using Zotero software as shown in Figure 1.

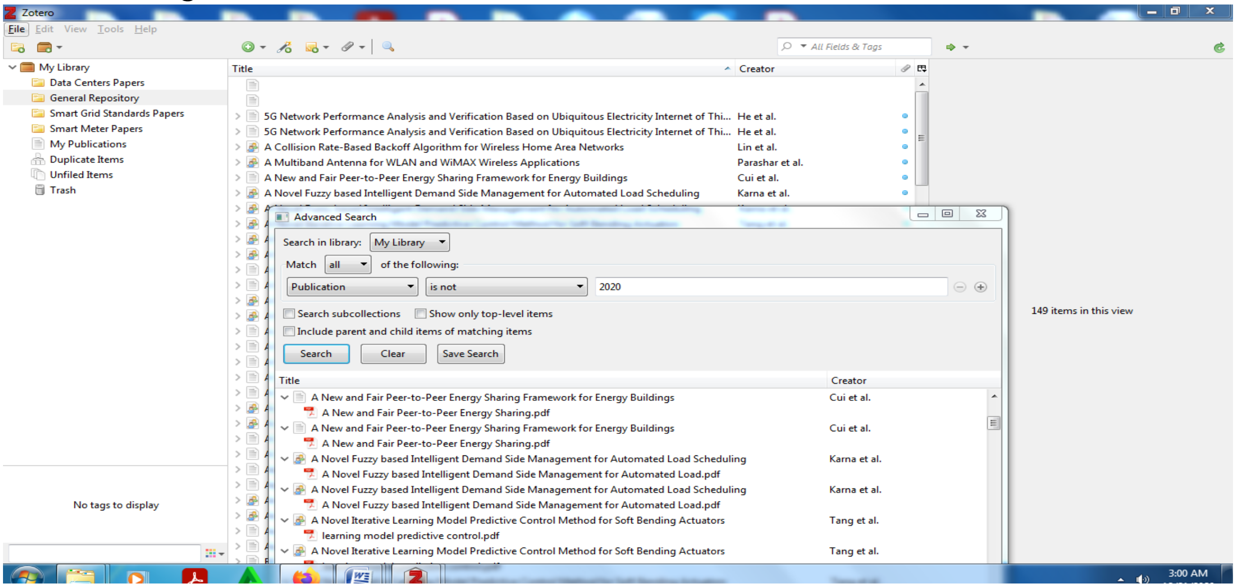

Figure 1:Articles sorting process in Zotero reference management software.

Distribution of publications (RQ1)

The study literature was all examined to identify their frequency and evolution. The findings on the distributions of the papers are shown in Figure 2. According to the findings, the year 2020 witnessed the highest number of smart grid automated technologies. Part of the reason is the advent of cov19 that necessities the need for automated systems. Over the last two years, smart grid computing has gotten a lot of attention. For a variety of reasons in the industry, academics, and developers have given this boost ever since 2019. The ambitious move by the European Union and several governments of different countries to move from fossil fuel to renewable energy usage has added to more researchers on scalable smart grids since the last 2 years. Furthermore, the current energy demand of the teaming population added to the research bang in this area.

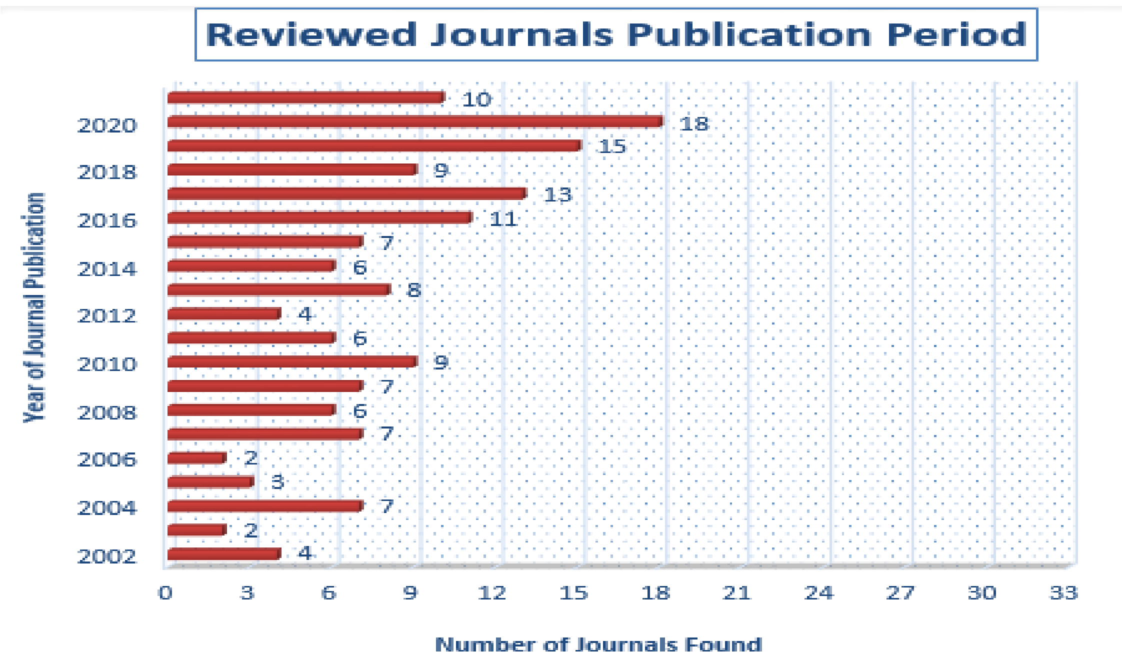

Figure 2: Distribution of Reviewed Papers with their year of Publication.

Review on Smart Grid Ecosystems - Theoretical Perspective (RQ2)

This section presents the doctrinal understanding of the Smart grid ecosystem using the NIST conceptual framework as a basic reference [6]. In [7], the Smart grid represents the novel concept in power generation, transmission, distribution, and management with associated benefits. It is an electrical grid that uses information and communication technology (ICT) to collect and process information, such as information about supplier and consumer behavior, in a way that automatically improves efficiency, reliability, economic, and product stability and distribution [8],. The concept of SG depicts a model for changing the electrical grid systems leveraging complex automated control ICTs. This is a complex system of systems that integrates new tools and technologies from generation, transmission, and distribution to consumer equipment and equipment. It sets the energy infrastructure, processes, devices, information, and markets into a cohesive and collaborative process that allows energy to be produced, distributed, and used efficiently and effectively [10]. The IEEE vision and road map until 2050 are still available but Africa is yet to key into this massive grid ecosystem.

From Figure 3, the NIST SG conceptual reference model enumerated seven key areas viz [11]: bulk generation, transmission, distribution, markets, operations, service provider, and customer.

Within each domain are the main players and applications, it also shows the interaction within the domains of the main players and applications through the interactive information sharing that takes place. The interoperability standards are needed. The conceptual framework of the NIST SG/reference model is under review by the Smart Grid architecture Committee, established as a sub-committee of the Smart Grid Interoperability Panel [11]. In [12], the authors provided various ideas and techniques in the SG system considering the use of technology, configuration, and performance. In this regard, the reference model of the DG concept includes the interoperability model, information interoperability, and information network mode.

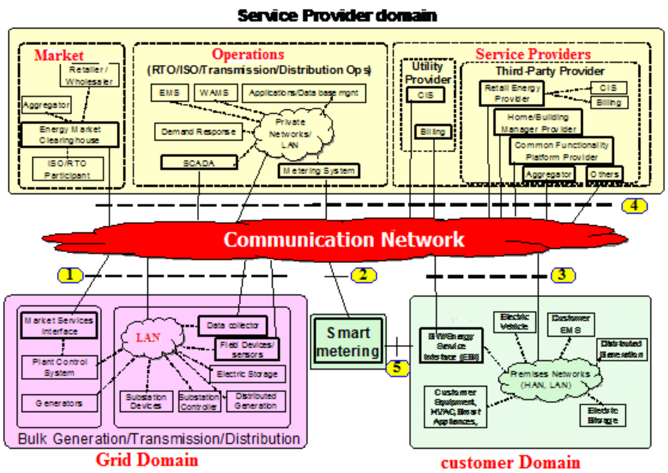

Figure 3: Conceptual Reference Architecture of Smart Grid [6].

In more recent times, the energy grid has expanded to include wind, solar and hydro energy sources without reference to intelligent grid construction in Figure 3. In the US, Europe, Asia, SG architecture has become increasingly adopted extensively [13]. In 2019, a report showing countries with the highest levels of electricity supply did not have an African country included [14]. As countries begin to use SG, this will reduce pollution, improve grid efficiency, increase DER consumption, increase end-user control (power management), etc.

Smart Grid Domain Organization

As explained previously, the identified related fields of SG highlighted but the simplified ICT ITU-T perspectives highlighted the five-domain model as shown in Figure 4. The five domains are categorized into three broad categories, namely Smart Grid Service / Applications, Communication, and Physical Equipment [6]. This category includes the following five domains namely: Grid Domain (production, distribution, and transfer); Smart metering (AMI); Customer domain (smart devices, electric vehicles, geographic networks (Home / Building / Industrial Area Network)); Communication network;

and Service provider domain (markets, operators, service providers).

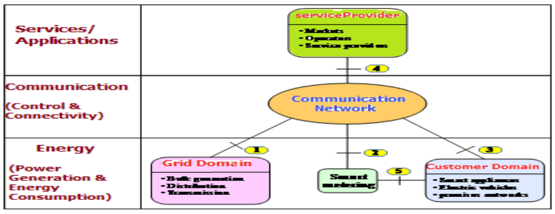

Figure 4: Smart Grid Domain

Classification framework

The domain interfaces are shown in circles depicting where ICT exchange between the core Communication link network and the other four sub-domains. Also, the communication layer links the Smart metering domain with the end-user interface. These constitute the reference points in SG ecosystems. Let's discuss the various subsystems of the reference points in Figure 3.0.

i. SG Interface Reference 1 (Network Communication & Grid Cluster).

This interface supports the bidirectional massive exchange of data and control data streams from the cluster and the Cloud provider housing applications like Supervisory Control and Data Acquisition (SCADA) [15]. Other elements and operational components included in Reference 1 are:

- Transmission Remote Terminal Unit (TRTU) for SCADA activation.
- The transmission drives Intelligent Electronic Devices (TIED) for SCADA duplexing with the provide Cloud [16].
- SG Plant Coordinating Control Module (SPCCM) linking the SCADA and energy management module within the Cloud [17].
- SPCCM Partnership with Broker (i.e., Regional Transmission Organizations (RTO) /Independent Systems Operators (ISO) for greater market performance (e.g. [18].
- ICT & Signal information and Generation information between Grid layer (e.g., mass production) and service provider cover (e.g., control and performance).
- Grid domain on the SG edge (e.g., transmission sensors and measurement devices) delivering data from the transmission line to the Cloud Service vendor (e.g., transfer functionality, protection, and control). The reason is for transmission line preventive maintenance specification, reporting, monitoring, and SCADA.
- Extensive data distribution/collaborative of data between Grid domain (e.g., source power generator) &Cloud Service provider layer (i.e., energy transmission operation & Cloud control).

- SG Distributed Edge sensors and Device measurement nodes which offers distribution system data to DER systems.

ii. SG Interface Reference 2 (Smart Meter/AMI & Network Communication layer)
This interface supports exchange data as well as logical transactions via the vendors/operators and service providers through the end-user. The activities at this reference include [18]:
- Meter Management, Aggregated meter reading retrieval from the Cloud service provide operations centre.
- End-user full interaction using EMS for information exchange (energy pricing, demand-side/response (DS/RR) data as well as load shedding updates and various energy automation tasks.
- Billing in Cloud Service provider layer via end-user meters.
- AMI/Smart meter duplex interaction with Cloud provides billing service
- AMI/Smart meter full-duplex reliable communication.

iii. SG Interface Reference 3 (End-user Client & Network Communication layer) This provides a seamless link between the vendors/operators and Cloud Service providers via the customer edge devices. The use case scenarios include [18]:
- Home Area Network (HAN) communication with Reference 3 via a gateway (SMS/IP).
- Energy Services Interface (ESI)/HAN gateway interaction with metering, billing, and utility back-end using the provided link (Operations);
- Energy Services Interface (ESI)/HAN gateway interaction with the load management/demand-side/response platform at the Cloud service provider layer (Operations)
- End-user EMS interaction with the energy service provider in the Cloud end.
- Cloud service provider billing with edge consumer layer.
- End-user EMS interaction with distribution management layer in Grid cluster;
- End-user interaction with aggregator/ retail energy provider at Cloud provider end
- Information tracking/Monitoring and control for DER generation from the Customer clustered domain.

iv. SG Interface Reference 4 (Cloud Service provider & Network Communication layer). This reference layer supports service communications services and dedicated software apps at the Cloud service vendors especially for participants to carry out SG roles highlighted previously.

v. SG Interface Reference 5 (AMI/Smart metering layer & Client-end) as well as various services orchestration via ESI. Classical use cases include [18]:

- AMI interaction with edge nodes, not excluding client EMS, residential devices.
- End-user layer not excluding client EMS, client EMS, residential devices, home devices interacting with AMIs.

As depicted in [6], the associated layered model for the NIST framework domain is the reference architectural block diagram depicting the conceptual data flow interactions among various domains in SG ecosystems. Figure 3.0 presents the abstracted perspective of the SG ecosystem with an emphasis on communication interface sharing. The Cloud connects communication depicts the network interactional models linking various logical nodes/devices in the SG ecosystem. Of course, the network connections could be domesticated within or across various domain layers/boundaries. These network connections offload data traffic depending on the priority (best effort, real-time) and other network considerations [77,78,79,80].

Smart Grid Functionality Architecture

Every SG model normally will have its functionality model associated with the reference architecture in Figure 3. Figure 5. illustrates the necessary functionalities within an SG ecosystem as well as the mapping relationship functions as shown in the circled blue lines at both ends. Within each domain, the following functions are visible viz: Grid Power functions (Grid domain), AMI/Smart metering, End-user functionalities, Network communication (IP/Non-IP based); Cloud Service Provider functions/application context, Cloud security/management functions. Hence, the functionality system depicted in Figure 5.0 highlights the SG primary group clusters including the following functions: Customer/client, Software/application, AMI/Smart metering, management, energy control, network security, and energy grid functions. The major functionalities found in each group are depicted and summarized in various box diagrams. The data flow and link interactions are represented with function lines across them.

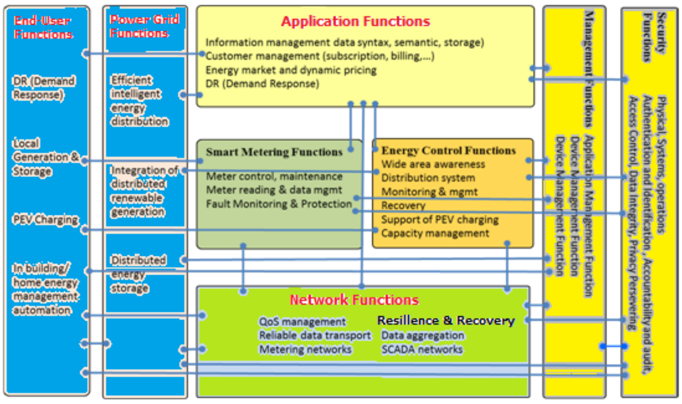

Figure 5. SG Functionality Architecture (5-Block model)

There are clear functions depicted in Figure 5, the various functional blocks are described below.

i. The end-users, and domain systems (Block-1): This comprises demand response, home building energy management automation [19], local energy generation/storage [20], PEV charging. The user function vis-à-vis domain systems handshakes with DR solutions for flexible pricing system, home energy controls linked with distributed volume management in bi-direction transmission mode.

ii. The power grid system functions (Block-2): This block carries out the function of intelligent/efficient energy distribution and integration of DER sources. This interacts with functions in block-1 and block-3 for effective energy transmission [21].

iii. The Core SG functions (application, smart metering, energy control, and network isolated functions (Block-3):

This is core subsystem comprises the following viz:

- Application function sub-block takes care of the application ICT management (volume storage, data-syntax/semantics), end-user information management (such as subscription, billing), flexible/dynamic pricing, energy market structures, DR control, and management. This works with the end-user block-1, smart-metering, and energy control functions.
- Network function sub-block works with other neighbouring functions and offers QoS provisioning [22], fault tolerance/resilience/recovery, reliable data transmission, meter-data transfer function, energy-data aggregation, deterministic data transfers, etc. In context, resilience and recovery offer the potential to efficiently avoid and react to outages/interferences resulting from security vulnerabilities, human errors, failures (hardware/software), etc. Reliable network communication is fundamental to SG ecosystems.
- Quality of Service (QoS) sub-block Management Function: This is used to derive acceptable bandwidth performance (e.g., throughput, bandwidth, end-to-end delay, jitter, etc). This gives the capacity to identify needed potentials to prioritize data traffic originating from ubiquitous sources (such as AMIs, grid substations, and appliances) thereby supporting optimal data delivery across the grid platforms. With QoS management procedures, this can distinguish various types of data and events from the SG devices relative to physical activities. For instance, QoS management can be used to derive traffic associated with DR signals, SCADA control sensing coming from AMI captures with similar non-critical/best effort applications.
- Data Transportation Core Function: The role is to give security and effective network signalling as well as data transport planes through WANs. This enables interface interaction data exchange with other block functions.
- Advanced Smart Metering Function: This sub-block is responsible for customer interactions with the network, security, and management functional areas. With the Cloud application interacting with the AMI, billing, and network blocks, meter data aggregation and transportation facilitates real-time activity monitoring and security through alert reporting and audit log processing.
- The Energy control block function: This monitor and manages DER while offering supports to electric vehicles (PEVs) charging for capacity modelling.
- The Security layered functions: This considers end-to-end security such as physical, system, operational, etc. This function takes care of the identity and authenticates role, audit, and account reviews of records in the smart grid to reveal the strength of the security criteria, policy, and procedures. Other functions in this regard include access control, data integrity, and privacy preservation regarding SG systems. A comprehensive requirement and analysis of the security functions can be found in the guideline for NISTIR 7628 Smart Grid Cyber Security [23].
- Management functions offer operational management procedures needed to satisfy users-expectations. The device-level management roles support communication with various devices and interfaces at the field, substations. It offers effective full-duplex data movements from these highlighted entities.
- Network Management gives troubleshooting and network housekeeping roles for network resources including their parameter configurations for excellent QoS. The network data is

obtained in real-time via a bi-directional connection between the network management layer and other layers/groups.

Smart Grid Architecture (Micro Functional Model)

As shown in Figure 6.0, SG model integration includes a power supply for bloc-2, electric power distribution and renewable energy administration, electric vehicles to grid, grid monitoring, and load management, and intelligent measurement of energy. Considering the functionality model, let's look at the load management and AMI/smart metering in Section 2.1.4. The smart metering system often referred to as Advanced Metering Infrastructure (AMI), with PEV charging supports and DER will be discussed. In this regard, the SG measurement monitoring as well as control to satisfy system reliability and grid availability will be analysed. Energy management for usage and energy distribution for well-balanced energy demand and supply levels will be analysed in the SG macro functional model.

SG Metering and Load Control Architecture

The AMI or smart metering functionality model and load-weighted control application are shown in Figure 6.0. Enclosed are the data flow and link interaction depicting how metering information and end-user function are coordinated [6]. Throughout the model, the management functionality layer hardly interacts with the end-user or power grid layers, but the security layer maps with all the layers.

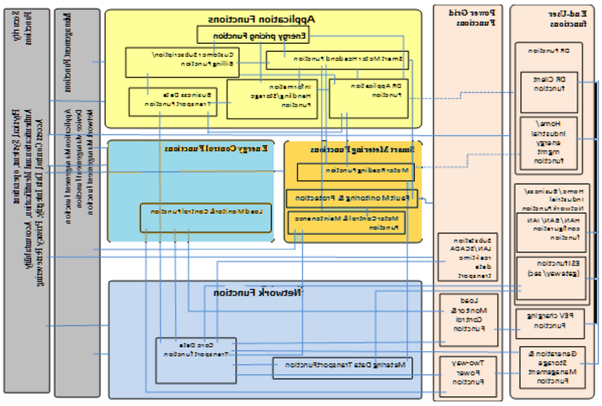

Figure 6: SG Functionality model for AMI/Smart Meters and Load Service Control.

SG User Domain Functions

From Figure 6, the user domain takes care of all activities found at the end-user end of the SG ecosystem. This enables customer interaction with the AMI and service providers via energy management systems (EMS). The components at this sub-layer include [23]:

i. Demand Response: The Client function connects with the DR service application for subscriptions and pricing information (dynamic). In the case of enterprise consumers, this facilitates large-scale industrial energy management based on their demands.

ii. EMS Role/Functionality: The residential-home energy management service looks at the consumption profile of the home user devices as well as the dynamic pricing details. It links with a residential entity to manage/control devices, storage, and power generation on-premises. Power alert signalling by notification to utility, mitigation reactions, and signal recovery at designated or unplanned outages happens via the EMS.

iii. Grid AMI Retrieval Records: Meter consumption profile can be retrieved via direct meter reading or indirect reading using the AMI application function in Figure 6.0.

iv. Enterprise Network Functionality (ENF): For the home, business, or industrial networks, the use of Home Area Network (HAN), Business Area Network (BAN), and Network for Industrial Areas (IAN) is applicable with the appropriate set of protocols [24]. These networks are interconnected with all the devices, appliances, and equipment. It also connects the AMIs, storage, DERs, PEV charging pumps, and EMS. To achieve optimality in ENF, the following subsystems are identified, viz

- HAN/BAN/IAN Configuration is responsible for device entrance and exit from the network under a highly secured authentication policy. This sustains encryption key tokens at all times.

- HA/BAN/IAN Bridge –This comprises cascaded transport or transmission path using physical/MAC layer guidelines. This jumper function is supported at the network link layer and ensures that the EMS interacts with all the HAN subscribers seamlessly. The BAN/IAN transmits energy data within devices/nodes in both industrial and business premises. In this regard, connectivity with AMI, DER, PEV charging terminals, energy-smart home systems [25], etc are achieved. The BEMS tracks/monitors, and controls the legacy building automation system (BAS) including the facility management system [26].
- Home Gateway Service Function: In the system, the energy service interface (ESI) [27] or gateway primarily interfaces the HAN/BAN/IAN with the other upper-layer network functions using logical paths. In the cases of IAN, it offers a bi-direction logical flow that enables information interaction from the SG entities to the industrial energy automation links.
- Other functions include PEV Charging (PC), generation and storage management (GSM). While the energy control and billing application functions interact with the PEV charging system, the GSM links with the EMS for power switching to enable demand consumption on-premises. Also, power switching from the DERs to the grid is still feasible here. Finally, energy controls from power feed into the grid are equally feasible.

SG DER Architecture - Energy Distribution, management, Control & Monitoring

In the SG system, a functional reference architecture depicting energy distribution and management is shown in Figure 7. The design is intelligent, reliable, self-repairing, and self-optimizing [6]. Energy distribution and management application have two areas of applications, viz:

- Surveillance, gauging, and control of the power line to ensure grid reliability and availability.
- Management of energy usage and energy administration to equalize demand and supply.

The introduction of a complex array of sensor area network and device measurement systems as well as data logger software could offer grid optimization and management of grid components, grid behaviour, and performance [28]. This could expect, predict, prevent, or respond to the spikes/issues before unexpected disruptions.

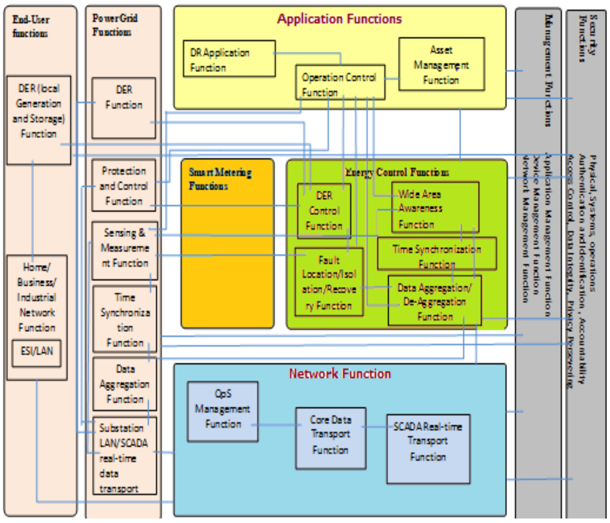

Figure 7: SG power Monitor/Control Functional Model.

As depicted in Figure 7, the SG functional model can carry out monitoring and control functions. Figure 8 illustrates the energy usage and distributed management functional model with eight distinct subgroups namely: application, network, power grid, end-user, energy control, smart metering, administration, and security dealings. Various functions are associated with each functional group, thereby facilitating data flow interactions in the SG ecosystem [6].

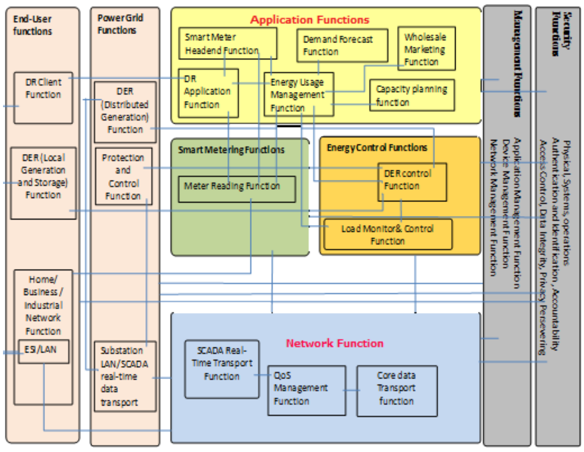

Figure 8: Energy Usage/Distribution Management Functional Model.

SG Energy Distribution/Power Grid Functions

At the SG power station, there are critical functions executed maybe in the bulk-generation site, a sub-transmission and distribution grid, transmission lines, or a mini-grid for distribution and storage infrastructures. In general, this is the key performance required for effective and efficient management of energy Genco's, Transco's, and Discos, including DERs [29]. These activities include [30]:

Distributed Energy Resource Functions: Distributed generation and storage devices connected with the DER function can be integrated into transmission/distribution systems or distributed micro-grids. Those DERs, therefore, need to work with the DER Control Function machinery in the Energy Control Functions work station for continuous uptime, and the output is challenged into the grid. It enables the industrial customer to freely integrate production and storage into the grid.

Control and Protection Tasks: This function, either in command of the operation control group in the application task group or is automatically started based on location or measurement data, performs the necessary protection, retrieval, and control functions on the Power Grid - transfer, or distribution channel. It interacts with the performance management function through the LAN / SCADA Network Function.

- Sensing and Measurement Function: This function is provided by sensors and measurement devices located at the power distribution system. A new generation of devices, such as Intelligent Electronic Devices (IED) and Phasor Measurement Unit (PMU), could provide more accurate, real-time information operation control function and energy control functions to manage the operations of the power grid.

- Time Synchronization Function: This function is provided by sensors and measuring devices found in the energy distribution system. A new generation of devices, such as Intelligent Electronic Devices (IED) and the Phasor Measurement Unit (PMU), can provide more efficient, real-time data management functions and power management functions to manage power grid functions.

-Time Sync function: This function stores and synchronizes high-resolution clocks on stations and power grids. Measurement data (e.g., PMU data) requires accurate time stamps before transferring to a power management task group.

- Data Consolidation Activity: Evaluation/measurement data can be compiled prior to transfer to the Power Management Task Team, which will be mined for further processing.

- Substation LAN / SCADA Real-time Data Transport Function: This function enables the communication between devices in the Power Grid station and between these devices and the External Task station via SCADA Real-time Transport Function and Core Network Transport Function. This function provides for the delivery of secure and real-time data management and information to the SCADA control.

SG Application Layer Function

As depicted in Figure 8.0, this layer or group offers functions executed at the operation centre of the utility industry, regional transmission firms (RTF), or independent-system operators (ISO) [31], as well as other energy provider domains. Figure 9.0 shows the application deployment contexts in an SG ecosystem deployed via a web-based integration middleware. The SG Interoperability Panel (SGIP) depicting all the stakeholders across the value chain is shown in Figure 10[32].

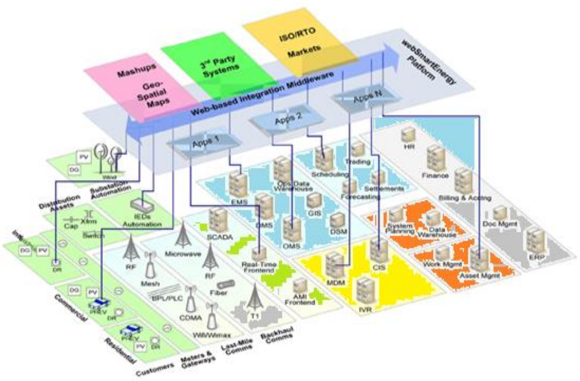

Figure 9: SG Management System on top of Legacy Systems (Source: Ipakchi, 2009)

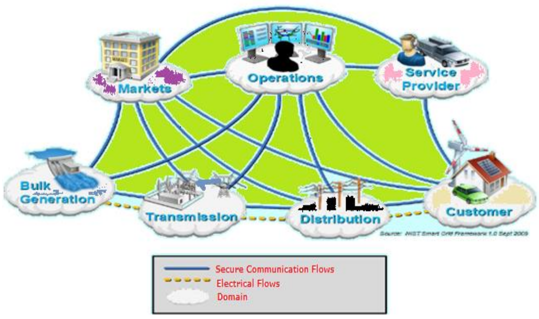

Figure 10: NIST SG Model (Source: NIST, 2010)

The application function group in Figure 7.0 executes the functions such as monitoring and control of the power distribution system performance, analyses the operating environment, and controls the supply and the use of electricity. It also includes office background functions such as a subscriber database, a list of resources as shown in Figure 10. It works with end-user functions, power grid functions, power control functions, and security functions through network functions.

- Task Manager (Operation Control Function): This takes care of daily grid monitoring. It ensures the reliability, frequency, and durability of the power supply, the passing/transient angular stability, and the stability of the small-signal in the power system. Provides practical monitoring of the status of controlled processes, modifying control settings, and manually recording automatic control tasks in an emergency. This function also integrates with all app functions, especially the power management function to ensure that the provision meets the requirements. This function includes simulation and prediction.

- Asset Management Function: In addition to the general business function, this function can be established and used to compile evaluation reports, demonstration, and operator reports in performance management, maintenance, and improvement systems.

- Efficiency Energy Management function: This function, in conjunction with the Operation Control function and other functions, controls the response to electricity demand. On the supply side, it works with Capacity Planning Function to measure short-term and long-term needs, as well as the Wholesale Marketing Function to determine availability. On the demand side, it interacts with the DR Application function using dynamic pricing and other methods (e.g., volume) to control energy consumption.

- Wholesale Marketing Function: The open market provides efficient distribution channels between suppliers and power distributors. It affects other functions such as bringing DER online, converting DR prices, and more.
- Capacity Planning Function: Power planning by Performance Viewing is primarily temporary planning in the projected provision available so that Power Management and Quality Marketing Services can take appropriate actions.
- Demand Forecast Function: This function provides short-term demands based on usage patterns and other information such as weather information.
- DR Application Function: This function controls the Pre-Discussed Response App. It receives information on power allocation and demand from Operation Control Function and liaises with Wholesale Marketing Function to actively determine the price of energy. It is responsible for managing energy demand and supports resources to balance demand and accountability for efficient energy delivery and utilization.

- Smart Meter End Function: This is the part of the DR app that acquires power consumption information for the power management function.

Functions of SG Energy Control

Similarly, the energy control group supports the smart, reliable, and efficient use of energy and distribution and provides self-healing and accountability for power grid management. The rest of the functions includes [32].

- Distributed Energy Resource Control Task: Distributed Energy Resource function in the Power Grid Tasks group monitors the state of energy resources and the distribution of electricity flow across the grid.

- Load Monitoring and Control Function: This function provides the ability to monitor and control power transmission and power distribution. It may initiate load balancing functionality on the power grid, or partner with DER Control to deliver energy resources online or offline. It also co-operates with the power management function of the system for comprehensive control and demand management. It should be noted that DER can be independently or locally controlled as well controlled by the DER Control Function.

- Fault Location/Isolation/Recovery Function: This function enables error/problem detection and grid infrastructure restoration. It works with the Sensing and Measurement function and the DER Control Function to improve power distribution reliability by quickly detecting errors, providing quick error detection, and taking effective system recovery measures such as notifying the power grid status, responding to information from others, and predicting and preventing the impact of the control function to other grids.

- Wide Area Situation Awareness (WASA): This task is to monitor the power grid in all wider geographic areas. The WASA function in the workgroup integrates with the WASA Smart Gird function of other resources, exchanges the status of the grid to each other, respond to status information from others, and highlight the impact of local control action on other power grids.

- Time Synchronization function: As a Time Synchronization function on power grid stations, the home power control office needs to store and synchronize clocks, so that events in the grid align with other functions are translated as status data, and act accurately.

- Data Consolidation / De-aggregation Function: This function integrates with the Sensing and Management Function to filter data from grid monitoring devices (e.g., PMU and others) and aggregate control data to be sent downstream [81,82,83,84,85].

Smart Metering Functions

From Figure 6.0, the AMI/smart metering functions group has a unique function in the energy distribution: The meter reading function just like the smart metering and load control explained previously, transmits read data with the main(core) network transport function. It interacts with the DR deployment function and the power management function. Electric meters can provide meter readings for end users' activities using the power service interface (ESI), which may be part of the meter or, interact with network functions. It also provides end-user information to help energy management Stations to identify real-time power manage [86,87,88,89,90].

Network Functions

This Module/workgroup creates communication among all the functional groups. The ability to disseminate sensitive real-time data and delay possibilities is a key factor. The traditional SCADA network is used to accomplish this task. Strong QoS control is needed if a shared transport network, such as an IP network, is adopted [33]. The real-time contact between the power grid function group and the energy control functions/operation control function groups is assisted by the SCADA Real-time Transport Function. In the ecosystem, the QoS management feature and the core data transport function are all important [91,92,93,94,95,96,97,98,99,100,101].

Organizations, and researchers active in Smart grid technologies researches (RQ3)

This work reviewed several works on the smart grid and its associated technologies by several authors. Some notable research groups/organizations in several countries are distinguished by this work based on their volume of works/publications on the smart grid, though not all their works on the smart grid are represented in this work due to space. Table I presents notable among them:

Table 1: Organizations, and researchers active in researching Smart grid technologies

Organization	Author(s)
University of Saskatchewan (SMARTGEN Lab) Canada	Tony C.Y. Chun, Ramakrishna Gokaraju, Sherif Fariedg, Rajesh Karki, Xiaodong Liang
University of British Columbia	Martin Ordonez, Galiano Zurbriggen, M. Manbachi, M. A. Bianchi,M. Amyotte
H-UTokyo Lab/ Hitachi, Japan	Onoda Manabu, Yoshimura Shinobu, Akiyama Yuki,Ishida Tetsuya, Ito Tomomichi, Onoda Manabu, Kawamura Tsutomu, Komiyama Ryoichi, Sakata Ichiro, Sasaki Koji, Sato Yasuo, Shiroyama Hideaki, Sugiyama Masahiro, Suzuki Tomoko, Tanaka Kenji, Hatakeyama Tomoyuki, Baba Atsushi, Baba Jumpei, Fukumoto Takashi, Fujii Yasumasa, Morita Ayumu, Yamada Tatsuya, Yokoyama Akihiko,
Florida International University (Energy system research laboratory), USA	Osama A. Mohammed,Antonello Rosato, Massimo Panella, Amedeo Andreotti,, Rodolfo Araneo,Mohammad ,MahmoudianEsfahani ; Hany F. Habib ;
City University of New York (Smart grid interdependency laboratory), USA	**Ahmed Mohamed Oindrilla Dutta,Tamer Ibrahim, Yusef Esa,** Lizzette Salmeron,Mahmoud Saleh, Yusef Esa, Mohamed El Harri
New York University, USA	Yury Dvorkin,CharalambosAvraam, Robert Mieth, Samrat Acharya, Zhirui Liang, Alice Nuz, Mahmoud Saleh, Yusef Esa, Mohamed El Hariri
University Bremen, Germany	Christine Brandstätt, Marius Buchmann, Julia Kusznir, Roland Meyer, Gert Brunekreeft, Anna Pechan
Easy Smart Grid Research cooperation with EIFER (European Institute for Energy Research), Germany	Thomas Bruckner, Rolf Hasse, Deutschmann, O , Ullrich Heilemann, Robert Holländer, Frank Schuhmacher, Fleuchaus, P,ReinerKümmel, H-M Groscurth, Hendrik Kondziella, Salomon, R
cranfield University (Electric Power and Drives Group) UK	Jerry Luo,,Nii Christopher Sansom , OkyneAdjei,Zhang G, Zhang F, Wang X &Xin Zhang Hernando-Gil I, Christopher Sansom
University of Kurdistan(Smart/Micro Grids Research Center), Kurdistan	Sharara Rehimi,,Farzad Abdollahpour, Abbas Ahmadi, Shahabeddin Najafi, SirwanShazdeh, Mohsen Ehsanga, Hassan Bevrani, Hassan Bevrani, Masaki Imanaka, Takeyoshi Kato,
University of Birmigham, Uk	Peju Oyewole,Kai Lin, Ying Xue, Cong Wu, JianingLi,Puyu Wang, Hussaini Ali Adamu, Zuanhong Yan, Conghuan Yang, Min Zhao, Rui Guan, Zuanhong Yan, Jingchao Deng

Table 1:Organizations, and researchers active in researching Smart grid technologies (Continue)

Organization	Author(s)
University of Cambridge	Luis(Nando) Ochoa,Michael Liu, William Nacmanson, Dillon Jaglal, Arthur Givisiez, Vincenzo Bassi, Vincenzo Bassi
University of Singapore	Joymala Moirangthem, Sanjib Kumar Panda, Krishnanand Kaippilly Radhakrishnan
Indian Institute of Technology Bombay, India	Subhranil Barman, Arup Ratan Joel Jose and Anupama Kowli Paul, and Himanshu J. Bahirat,
Uppsala University, Sweden	Cecilia Boström, Fregelius Martin, Temiz Irina, Potapenko Tatiana, Hjalmarsson Johannes
University of Sydney, Australia	Gregor Verbic,Diwei ZHANG, Shariq Riaz, HesamoddinMarzooghi, Archie C. Chapman, David J. Hill
Korea University, South Korea	Sung-Kwan Joo ,Minseok Jang, Jinyeong Lee, DongsubYoun
Power Systems Lab (GIST) South Korea	Yun-Su Kim, Hamza Abunima, Seung-Il Moon, Yun-su, Park, HyeKyoung, Seung-Il Moon
Tsinghua University China	Yi Wang;NingZhang;YushiTan;TaoHong;Daniel S. Kirschen;Chongqing Kang, Yuxiao Liu, Jiawei Zhang
Southern University of Technology China	ZaiyueYang, Honglin Fan, Liu Yukun, Runfa Zhou,WayesTushar;ChauYuen;BoChai;ShishengHuang;Kristin L. Wood;SeeGimKerk;Zaiyue Yang

Active Conferences and Journals on Smart grid (RQ4)

This study noted the following conferences and Journals as the key Conferences and Journals on Smart grid on smart grid technologies as shown in table 2 and 3 respectively below:

Table 2:List of active Journals

Acronym	Conference Full Name
ijSmartGrid	International Journal of Smart Grid
SGGC	International Journal of Smart Grid and Green Communications
IET Smart Grid	The institution of Engineering and Technology on smart grid
IJSGSET	International Journal of Smart Grid and Sustainable Energy Technologies
IJESG	International Journal of Energy and Smart Grid
SGCE	International Journal of Smart Grid and Clean Energy
JECER	Journal of Electronics and Communication Engineering Research
TSG	IEEE Transactions on Smart Grid

Table 3a: List of active conferences

Acronym	**Conference Full Name**
icSmartGrid	International Conference on Smart Grid
IGBSG	International Conference on Intelligent Green Building and Smart Grid
ICASGT	International Conference on Advances in Smart Grid Technology

Table 3b: List of active Conferences

Acronym	**Conference Full Name**
ICSGTGE	International Conference on Smart Grid Technologies and Green Energy
IEEESmartGridComm	IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids
ICRESG	International Conference on Renewable Energy and Smart Grid
CEECT	The 3rd International Conference on Electrical Engineering and Control Technologies
SEGE	international conference on Smart Energy Grid Engineering
SMARTGREENS	International Conference on Smart Cities and Green ICT Systems
ICRESG	International Conference on Renewable Energy and Smart Grid
SGGE	International Conference on Smart Grid and Green Energy
UPIOT	International Conference on Ubiquitous Power Internet of Things
PSGEC	Power System And Green Energy Conference
CoSGE	International Joint Conference on Smart Grid and Energy

Distributed energy systems, Smart Meter, Demand Side Management, and Demand Response (RQ5)

In the smart grid ecosystem, several pieces of research that addressed Distributed energy systems, Smart Meter, Demand Side Management, and Demand Response has been done by several researchers. The Table 4 present researches in these areas

Table 4a: Summary of the works on Distributed energy systems, Smart Meter, Demand Side Management, and Demand Response

Author	Objective	Data	No.of PC/ YP	Maturity	Method	Findings
Arun S Nair1 et al	To review work on the design of a distributed approach to the problem of resource allocation that permits for inter-node information exchange and decision making in the energy grid		99,2018		Literature survey	Using various computational techniques of multi-agent technology is a promising and scalable platform for implementing distributed resource scheduling and allocation.
Ha. B et al[35]	To exam the statistics behaviors of electricity grids.		No Citation,2016	Implemented	Live testbed experiment	This improves the power network's performance and ensures the use of a network empirical approach to determine whether certain architectures will scale excellently.

Table 4b: **Summary of the works on Distributed energy systems, Smart Meter, Demand Side Management, and Demand Response**

Author	Objective	Data	No.of PC/ YP	Maturity	Method	Findings
Min B et al	A framework for a novelfsmart grid cascading attacks involving trigger mechanism disaggregation and central smart grid services.		20,2016	Proposed	Numerical experiment	The results of the analysis and evaluation show that the proposed threats have the potential to cause significant service interruptions in the smart grid.
Ali et al	To Secure the energy Grid using Machine Learning algorithm		40, 2013	Proposed	Machine learning algorithms/modelling	Machine learning can help distinguish a threat from an activity because it can work with multiple system performance parameters at the same time, which is impossible for humans to do.

Montazeri et al	To select proper/best spoke technologies for power smart grid systems in a multi-criteria decision-making process in iran.		13, 2016	Proposed	Hybrid methodology	The work identified 26 techniques and 9 criteria to calculate the weight of criteria and to prioritize technologies for smart power grid
X. Wang et al	To solve the issue ofgeneric changing of renewable energy sources and reduce energy cost		38,2020	Proposed	Stochastic dual-sub gradient method	The approach is efficient without knowing the possibilities of foundation strength stochastic processes
H. Haghigh et al	To design a bi-level feasible solution that will find a working day in the electricity market, processing the island's smart grids using a mixed number conic system and line		22; 2020	Proposed	Numerical Experiment	Bi-level optimization system for capturing ISO integration with multiple independent smart grids increases the efficiency of the gaming day in the electric market
I.Yuksel et al	Reduction of Co2 emission	Real Data	15,2015	implemented	Analysis	The reduction of emissions can only be achieved when policies are supportive and well targeted, standards and incentives are realistic and flexible, and the public is actively responsive to environmental degradation

Table 4c: **Summary of the works on Distributed energy systems, Smart Meter, Demand Side Management, and Demand Response**

Author	Objective	Data	No.of PC/ YP	Maturity	Method	Findings
I. Davidson et al	Using Power Electronics to turn African power grids into a single large grid that will encourage, without undermining, the widespread integration of renewable energy sources efficiency		13,2020		Analysis	Integration of multiple renewable energy sources is possible with an Ultra-high voltage current (UHVDC) and alternating current converter
Y. Kumar et al	Xray distribution system automation as part of intelligent grid efforts and its functional features		21,2015		Analysis	Various features of the smart grid such as automatic distribution, its associated technologies, and standards of automation and obligations for each level are defined
Alcaraz et al	wide-area Situation awareness technology		12,2013		simulation	A comprehensive state of awareness framework (AWF) with a set of awareness built-in requirements can help develop and deliver future AWF cyber defence solutions.
P. V. Chernyaev et al	To optimize the recommended Transmission capacity calculations for interconnections of consolidated power Systems.		5,3016	Proposed	Mathematical computation modelling	Mathematical computation model is effective for predicting electricity transmission capacity.
D.Javor et al	To reduce the cost of electricity using demand-side management		7,2020	Proposed	Simulation using program Lingo	Adjusting power demand time used for some Changeable loads lead to lower energy costs
D.Karna et al	To design a smartenergy control and monitoring system at the customer and utility end		7,2020	Proposed	Simulation, fuzzy rule-based on Python	Logic optimization employed on smart meters can save a maximum of 15% power in excellent conditions

Table 4d: **Summary of the works on Distributed energy systems, Smart Meter, Demand Side Management, and Demand Response** (Continue)

V. H. Dong et al	To develop an efficient power Wind-diesel-solar mixed generation strategy; Using the dynamic scheduling energy interface storage system Process	Real data and synthetic data	11,2020	Proposed	Numerical experiment	Energy generation by diesel engine, The inverter power in the system, including two diesel generators, is charged / discharged adequately following the input of wind and solar energy and load fluctuations. tolerance, i.e. > 5%
S. A. Abbas et al	To develop a way to predict the consumer's daily electrical energy habitual actions from their monthly payment data.	real data of 4000 customers	2018			Payment information for users in the feeder may be used to evaluate the appropriate power plant scale for each customer.

PC/ YP = Paper covered/Year of Publication

Regularization Activities for Smart Grid Connectivity (RQ6)

Several regulatory activities are underway in smart grid communication, as communication infrastructure is a critical component in the development of smart grid's success. In both the design and operation of a smart grid, a scalable and ubiquitous communication infrastructure is critical. Table 5.0 presents some communication regulatory activities currently going in smart grid ecosystem

Table 5a: Regularization Activities for Smart Grid Connectivity

Communications technologies	Standardization activities	Status	Note (related works)
IMT& EISA-NIST	Family of ITU-R-IMT-2000	Already reviewed	CS-SGVP NIST SGIP PAP02
	Advanced Family of ITU-R- IMT-2000		
	ITU -T SG13		
	3GPP		
Local-area broadband networks	IEEE 802.11 Protocol for Wireless LANs IEEE 802.11s Protocol for Mesh Wireless LAN	Already reviewed	Wireless LAN MIMO antennas
Wireless Personal Area Network	ITU -T SG15 Q4	Already reviewed	G.9959 (G.wnb) for critical mission
	PAN wireless low rate- IEEE 802.15.4 Protocol	Already reviewed	Wireless Mesh- Zigbee Alliance, Bluetooth SIG, , etc.
	IEEE802.15.4g Protocol for SUN	Already reviewed	

Table 5b: Regularization Activities for Smart Grid Connectivity

Communications technologies	Standardization activities	Status	Note (related works)
Wireless Personal Area Network	IEEE802.15.5 protocol for Mesh connectivity	Already reviewed	Accepted Superior Technique
	IETF 6Lo-Wireless Personal Area Network-WG	Already reviewed	RFC 4919 (Informative), RFC 6282 (Proposed Guidelines)
	Internet Engineering Task force-WG	Already reviewed	Route specification is already done. Routing protocol (RPL) is being researched. Proposed statement on AMI
Broadband over WiMAX	IEEE 802.16 bench mark for Wireless Metropolitan Area Networks	Already reviewed	SRR and CSRR structure,
	IEEE802.16j standard for Mobile Multi-hop Relay	Already reviewed	a model of 3-hop IEEE802.16j network
Wireless connectivity for short distances	IrDA Guidelines	Already reviewed	Infrared Data Organization
Data communication overAC power lines	ITU-T SG15 G.9960/9961 (G.hn), G.9963 (G.hn-MIMO), G.9972 (G.cx), G.9955/9956 (G.hnem)	Already reviewed	
	Guidelines by IEEE 1901	Already reviewed	IEEE1901.2
	Guidelines by ISO/IEC	Already reviewed	ISO/IEC15118 (V2G CI)
Technology via coaxial cable	ITU-T SG15 G.9954 (HomePNA), G.9960/9961 (G.hn)	Already reviewed	
	DOCSIS (Data Over Cable Service Interface Specifications),	Already reviewed	
Technologies via twisted pairs, access network	ITU-T SG15 G.992 sériés, G.993 series (xDSL), etc.	Already reviewed (Extra work is needed)	G.fast (FTTdp)
	ITU-T SG9 Q9 (HNW)	Review in progress	
Technologies via fibre cable	ITU on 5G: G.983 series (B-PON), G.984 series (G-PON), G.987 series (XG-PON), G.985/G.986 (point-to-point Ethernet based optical access system),	Review in progress	NG-PON2
	IEEE 802.3ahguidelines for hardware service layer IEEE 802.3av (10G-EPON), Guidelines on computer system connectivity with telecom provider services	Already reviewed	

Table 5c: Regularization Activities for Smart Grid Connectivity

Network Architecture for the Home Area Network	ITU -T SG15 Q1 (HNW Construction) G.9970, G.9971, G.9973	Already reviewed	
	ITU -T SG13 Q12	Already reviewed (Extra work is needed)	
Network Design of neighborhood area network(NAH)]	ITU -T SG15 Q4	Already reviewed (Extra work is needed)	
Network Design of wild area network(WAN)[61]	IETF (network based on IP) RFC (RFC6272)	Already reviewed	
	ITU -T SG15 Q12 (Transport network design) G.803,G.872	Already reviewed	
	ITU -T SG13 (Next Generation Network)	Already reviewed (Extra work is needed)	

The Research Gaps from Regularization Activities for Smart Grid Connectivity (RQ7)

Looking at various efforts in the reviewed literature as summarized in Table 5 above, several gaps boarding on the communication schemes are identified with regard to SG supporting infrastructure. This includes:

- There are many data models and communication protocols in SG which are still ongoing reviews; therefore, there is a need for unification of existing standards.
- There are no official standards for the requirements of SG, Home Area Network (HAN), neighbourhood area network (NAN), and Wild Area Network (WAN).
- HAN and WAN network architecture is not yet fully established thus; more work is needed at SG. Also, no activities have been found in the NAN domain.
- While there are several communication standards applicable to SG systems, new information about how to use these standards in a framework that best meets Smart Grid needs must be developed for network integration.

Smart Grid Distributed Data Centre Networks(RQ8)

Data centre is at the heart of smart grid computing; the rapid growth in the number of smart grid energy users results in massive data generation. This necessitates the need for robust data centre network design in terms of both network structures and associated protocols to interconnect thousands to hundreds of thousands, of servers, storage devices, and network equipment. The following table summarizes Smart grid data centre topologies

Table 6a: Summary works on promising distributed data-centre networks computing for smart grid

Author	Objective	No# of Paper covered/ year of Publication	Maturity	Method	Findings
Z. Li et al[62]	To con figure recursively defined topology into both symmetric and asymmetric Backup mechanisms to address the various needs of applications that cannot be used on legacy server-centric networks	24,2020	Proposed	simulation	The designed recursively topology provides the best possible energy efficiency and good deterioration performance over many other DCN topologies

Table 6b: Summary works on promising distributed data-centre networks computing for smart grid(Continue)

Author	Objective	No# of Paper covered/ year of Publication	Maturity	Method	Findings
J. Huang et al	To develop a Packet Slicing support scheme, which transforms the IP packet into a widely used asset switch.	34,2020	Proposed	NS2 simulation and a physical testbed.	Packet Slicing generally enhances the goodput of various TCP data center methods by approximately 26x, although having no effect on the switch performance
H. Zhang et al	To develop a stochastic procedure for data center operators (DCOs) to deliver a small game solution	46,2020	Proposed	simulation	All DCOs compete with the advantage of switch servers and all DCOs follow the suggested gradient strategies to achieve the game's highest social welfare.
Q. Shi et al	To design a new load balancing system that includes end-to-end host monitoring of each flow packet condition with flowlet switch on adjusted switch.	38, 2020	Proposed	Experiment	The findings show that under asymmetries, IntFlow packs produce 32 percent and 28 percent better results than CONGA and Hermes, accordingly.
N. O. Ahme	To build a Byzantine Fault Tolerant (BFT)	37,2020	Proposed	Experimental Setup	The results of cloud

det al	resistance and failure systems in Data center network (DCN)				infrastructure-embedded BFT-SMaRT (OpenStack-Kilo) programs show that BFA achieves the necessary BFT durability features and installs other DCN properties.
D. Li et al	An overview of the design and operation of the Datacenter Optical switch (DOS) designed for high-performance communication within a data center.	43,2010	Proposed	Simulation	DOS shows lower delays and higher penetration even at higher input loads compared to electronic switching or asset transfer formations
Z. Guo et al	To reduce the release ofelectrical packet-switched sharing network on Hypac DCNs	27,2014	Proposed	comprehen sive simulation s,	In addition to dramatically reducing overall packet latency, Collaborative Bandwidth Distribution (CBA) also significantly enhances network prediction and performance under predictable traffic.
Xiaoli n Li et al	To reduce energy consumption by the Spine-Leaf topology-based DCN.	21,2016	Proposed	extensive simulation using CloudSim	The dynamic energy-aware system can save energy up to 63% of the energy used by a datacenter containing the static set of Spine switch

Table 6c: Summary works on promising distributed data-center networks computing for smart grid (Continue)

Author	Objective	No# of Paper covered/ year of Publication	Maturity	Method	Findings
J.Mao et al	To build a FRING framework and to increase the capacity of Ethernet Datacenter Network (DeN).	5, 2015	Proposed	simulation experiments	Test results show that the total number of rules on all network devices can be greatly reduced by FRINGE, which also compresses most transmitted packets that do not operate in DeN.
I.Fujiwara et al	To achieve both low latency and reduced cable length in the data center network	22, 2014	Proposed	Graph analysis and discrete-event simulation	The important finding indicates that Skywalk is inexpensive, low-latency degree-average, and has low cable length, thus, Skywalk is promising.
C. C. Udeze et al	Reconstruction of the Data Center (R-DCN) for active web application integration	25, 2014	Proposed	Simulation experiment	Network installation, network error/capacity tolerance, usage, delays, service availability, distribution and Reengineered DataCenter (R-DCN) integration results were satisfactory compared to the BCube and DCell builds.
C.Guo et al	To design fault-tolerant and recursive data center architecture	25,2008		theoretical analysis, simulations, and experiments	DCell is a powerful interlink scheme for DCN
C Guo et al	To design fault-tolerant and recursive data center architecture	23,2009	Implementation	theoretical analysis, simulations, and experiments	BCube establishes one-to-x patterns dramatically and provides high network ability for all traffic centres in a DCN

Z. Jiang et al	To address challenges with Dcell and FiCome with server and developedan enhanced server DCN	40,2014	Proposed	Analysis and simulations	A cache sharing mechanism using Bloom filter in DCP reduces routing algorithms of a data center. .
D. Li et al	To build a low-cost connections structure without using high ends switches data center network	10, 2009	Proposed	Simulation	FiConn routing methodsmeasure/ equalize different levels of connections and know about all traffics to better maximize connectivity according to traffic engineering, and is robust

Table 6d: Summary works on promising distributed data-centre networks computing for smart grid (Continue)

Author	Objective	No# of Paper covered/ year of Publication	Maturity	Method	Findings
Deke Guo et al	To built low-cost and robust HCN and BCN routes.	20, 2013	Proposed	Mathematical analysis and comprehensive simulations	Test observation show that HCN and BCN have excellent design orientation and are strong DCN network structures
Y. Liao et al	To design a simple and effective routing scheme that maintains short path length in server communication.	17,2010	Implementation	Prototyping and Simulation	DPillar router schemes are simpler, more efficient, with efficient network schemes for surviving networks failures
Cong Wang et al	To create a Datacenter network with high capacity and a low-cost building structure that small and medium-sized companies can afford	12, 2010	Proposed	Simulation on an IBM X3650 server with NS2. A testbed of MCube4, which	MCube tolerates errors, balances loads, and sustains bandwidth-demanding apps.

				contains 300 servers and 125 mini-switches.	
Z. Zhang et al	Toachieve scale-upin a Data Center Network Architecture	42,2019	Proposed	The simulation experiments	In contrast to constructing a modern data center network, the High Scalability Data Center Network Architecture strikes a fine balance between diameter, bisection width, cost, and power usage.
S.Kan et al	To study and analyze data communication, error tolerance, and non-node BCDC methods using practice tests. To provide an important foundation for the construction and implementation of a new data center network.	15,2019	Evaluation/ Proposed	Practical experiments	In data communication, BCDC is superior to DCell and Fat-Tree as regards error tolerance and unrelated routes, and BCDC performance is not worse than DCell and FatTree.
K. C. Okafor et al	To create a two-tier level Smart Green Energy Management System (SGEMS) with an Open Flow Load Balancer (ISOLB) to achieve scalability and reliability.	15, 2015	Proposed	Experimental simulation	SGEMS offers higher reliability and scalability than DCell and Bcube and energy policy actorscan leverageon such discovery
Claudio Fiandrino et al	To design a set of new metrics for evaluating cloud computing communication systems, processes, and protocols	63,2017			Conventional communication system characteristics such as network latency, available bandwidth, etc were analyzed using new metrics performance

SG Distributed Data Centre Network Optimization Schemes Research Gap (RQ8)

The typical hierarchical structure is difficult to fulfil the Data Centre Networks (DCNs) requirements for enterprise solution like smart grid from the literature survey in Tables 6 above. The development of various DCN novels has been suggested over the past decade but not well-integrated into the environment of the smart grid (SG). This technology falls into two groups, namely, switch-centric architecture and server-centric designs, considering whether networking smartness is applied to switching or servers. Switch-centric designs have trouble fulfilling the need for connectivity needed in SG structures with their functionality. However, while it is not appropriate to change the servers for connection purposes, there is also a need for a high-end switch that will enhance communication. Predictive neural cross-bars switch core with packet relay node servers tend to be essential in a well-defined switch centric data centre architecture. The Server-centric models have the merits of using low-end layer-2 switches that are inexpensive, and affordable. In SG models, a higher degree of configurability is provided by putting the communication intelligence on the servers. A major drawback of SG ecosystem server-centric projects, however, is that servers often have considerably higher processing (service) delays than switches; and the excess and/or workload on the servers can be increased by using servers for packet transfer. Servers would need several NIC ports for server-server connectivity and server-switch networking. A switch-to-switch link will also be necessary to enhance the spinal leaf expansion.

Problem of Absence of Predictive learning Curve in a Smart grid Systems (RQ10)

A Smart grid system without Predictive learning curves has problems that boarders on smartness. These problems deprive the grid of the benefits of the Predictive learning curves automation and hence suffer the following problems:

1. The problem of Analysis of consumer electricity consumption behaviour [86]: Knowing who is who with respect to energy consumption help to encourage energy availability/provisioning by the DISCO via a demand-side management program. This advantage can only be enjoyed by power grid systems that have built-in analytics for capturing data, data mining, and management of this data as a response to the differences in their customers' behaviours. This is a major drawback of a power grid without or little predictive learning curve. The clustering and identification ability of the predictive learning curve can be utilized to analyse the power consumption behaviour of users, detect abnormal power consumption, and non-invasive load monitoring. Naive Bayes – Support Vector Machines (NBSVM) works very well in this regard. These analyses and schemes offer empirical foundations for the reasonable pricing of a detailed energy system and the enhancement of energy structure, as well as two-way flexible communication among both energy supply and users. For example, using data from AMI to measure power, voltage, and current, predictive scheme clustering, and knowledge mining can be used to recognize to identify the characteristics of different user groups of electricity consumption behaviour as to implement scientific customer segmentation, and then provide individualized marketing and service provisioning
2. Fault diagnosis and protection of flexible equipment in smart energy grid [87]: This is the first line of defence to ensure equipment safety, and it plays an important role in fast isolation of failures, avoiding damage to the equipment, and fault advancement. The fault characteristics of flexible equipment in power systems are influenced by its own variable structure, strong coupling, uncertain dependent variables, and many other factors, making predictive maintenance problematic in a smart energy grid without a predictive learning curve. Through migration learning, deep learning serving as a predictive scheme can obtain deep features of fault specimens of flexible equipment and introduce new insight to expand the sampling unit, allowing failure characteristics of flexible equipment to be expressed clearly at varying tiers.
3. Power network security protection Problem [88]: Any valuable resources automatically give an invitation for both legal

and illegal users to explore it mainly when the resources are distrusted resources such as electricity generation and supply, distributed water or gas system, internet connectivity access, and distributed DCN, distributed computer network resources. A smart grid system that does not have a security predictive learning scheme will be vulnerable to illegal usage and access control by some alleged electricity customers. The power system will be exposed to more threats as a result of the serious information flow interaction. The secondary system can be destroyed due to the attack on the physical power grid, even if the primary equipment is not directly damaged. Baiyes machine learning statistics can help to fish out illegal users of the electricity resources from the legal user based on prior and posterior probabilities and encryption schemes

4. Power load forecasting is the prediction of power needed in the grid by end-users; this is lacking in such power grid systems, and thus the power grid system operates blindly. Predicting power load ensures that power production and load are syncs in real-time, which is an important aspect of power grid operation on a regular basis. Deep learning is becoming increasingly popular in power system load forecasting as technology advances. The long- and short-time memory (LSTM) network is a well-known deep learning concept for function [89][90]. LSTM is well suited for processing and predicting important events in time series with considerably longer intervals and delays. Figure 2 depicts the flow chart of the LSTM network module used to predict power load.

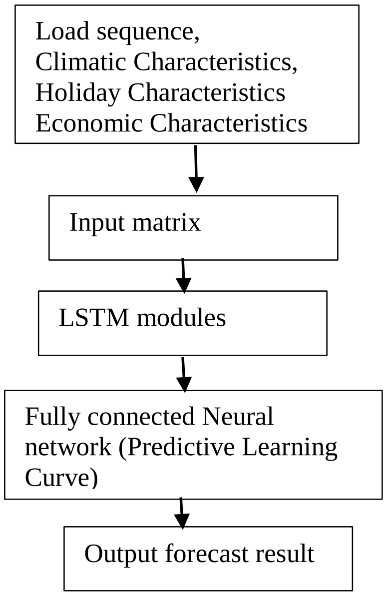

Figure 11.0: Load forecasting flowchart by LSTM

5. The above number 1 to 4 Problem in a smart grid will lead to inefficient and poor orchestration processes in the power grid.

Threats to validity/Constrains

The credibility of the literature tracing research could be hampered by a number of factors. Relevant directives and guidelines were considered in this work to avoid validity threats and its constraints below:

I. Coverage of relevant research questions: This study may not cover all current research elements of smart grid technologies and data centre architectures for smart grid. To tackle this threat, all of the authors collaborated in articulation to determine the most key research questions in the field.

II. Scope of the relevant works coverage: The process of gathering all research articles on smart grid technologies and its data centre topologies cannot be assured. Different literature repositories were used in this survey, and all of the authors used a strategy based on different phrases and synonyms to determine the associated questions.

III. Paper inclusion/exclusion criteria: Personal prejudice and subjective perception could have an impact on the criteria's execution. As a result, the peer consent/scrutiny of all authors was taken into account when omitting or including a work to overcome this problem on the draft copy of this work. Variability of the collected data: Because each author's background influences data extraction, online discussions were scheduled after each author completed their task and the data were considered collectively. During the meetings, the outcomes from each author were compared with other findings to determine the differences and as well reach final consensus.

IV. The Study replicability: Another challenge is whether other researchers will be able to replicate the results of this research report. As a result, the research methodology includes the well-defined procedures and actions taken in this work, as presented in the methodology section of the work.

Future Research on Smart Grid

One of the most viable smart grid benefits is smart grid value-added services. It's also a resultant outcome at a certain stage of smart grid developmental stage(s)and a diverse set of demands. Future works should consider value-added services on the smart grid, enhanced data centre design for SG and built-in predictive learning curve on smart grid while considering the rest of the research gaps highlighted in this work for maximum smart grid glad tidings.

CONCLUSION

This work presents the literature reviews of a detailed theoretical properties of a smart grid trend, its state-of-the-art trend in smart grid research and development. The findings showed that smart grid is a promising area that has attracted more research interest in the year 2022 than any other previous year. However, the complexity of the smart grid ecosystem still has several areas that need more research and development. This work observed the need for a robust smart grid architecture seeing the ever-growing need for electricity in the world today. Also, more predictive learning curves are needed in today's smart grid infrastructure in other to make it smarter. Smart grid technology is still evolving from the exploratory stage to conceptual frameworks. Most of the revied literature in this paper are still in the proposed and evaluation stage, while a few of the works have gained industrial exposure and acceptance. Convergence on the best practices, consistent terminologies and architectures are yet to be established. This literature review research gap has called for future research by the researchers.

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