Networking Paradigm in Smart Grid Communications – Architecture and Challenges

Mena Maurice Farag

February 3, 2024

Networking Paradigm in Smart Grid Communications – Architecture and Challenges

Mena Maurice Farag
Electrical Engineering Department
University of Sharjah
Sharjah, UAE
U20105427@sharjah.ac.ae

Abstract— **The global increase in energy demand has led to the modernization of existing power grids into bidirectional multi-layer grids known as Smart Grids. Effective communication and routing technologies are the fundamental base of smart grid architectures that ensure reliability and stability of the established power grid. Initially, the proposed smart grid multi-layer architecture has been proposed to consist of three network layers being WANs/NANs/HANs that are composed of multiple applications from power generation and distribution up to the smart appliances at homes. In this paper, the smart grid network architecture is discussed from the perspective of the network requirements to match its suitable application and the classification of routing protocols that are present to deliver data between layers. Furthermore, prominent challenges are discussed that are possible with the modernization of the existing power grid and proposed solutions are offered. Finally, recommendations are presented that ensure the continuous development of real-time smart grid internetworking that ensure to cope with recent generation communication technologies.**

Keywords—Smart Grids, Networking architecture, routing technologies, cybersecurity, communication challenges

I. INTRODUCTION

The advancements in current established electrical networks has in hand played a huge role in the expansion of the on growing energy demand that has been a focal point in the recent decade [1]–[5]. Present advancements in the present electrical network do not solely rely on the advancements in electrical power system tools, however the modernization of such electrical grids rely on the major role of communication technology and the efficient networking between multiple clients to achieve the ideology of Smart Grids (SG) [6]–[10]. Smart Grids have grew popular over the past decade due to their fundamental concept of bidirectional communication and control applications built within the power system [11], [12]. The fundamental model created by the National Institute of Standards and Technology (NIST) founded a multiple-layer architectural model for its integration with the smart grid technology. The model consisted of sections that are categorized by the consumers, the relevant market, service provider, mass generation, transmission, and distribution. The developed model provided smart identification techniques to the multiple domains and communication paths within the smart grid network [13], [14]. Furthermore, through this architecture interactions between internal and external domains can be recognized and the possible applications in such domain interaction. As illustrated in fig 1 (b), the inter-communication between the multiple domains is done through direct or indirect hops based on their position within the network architecture i.e., the smart grid model. On the contrary, the exhaustion of traditional grids with the excessive energy demand that is required to be supplied has resulted in an obsolete electrical infrastructure that may not cope with multiple power quality issues [15], [16].

Therefore, the subsequent upgrade from unidirectional grids to bidirectional smart grids has introduced various schemes such as advanced meter Infrastructure (AMI) and reading (AMR) as employed applications within the proposed smart network advancements.

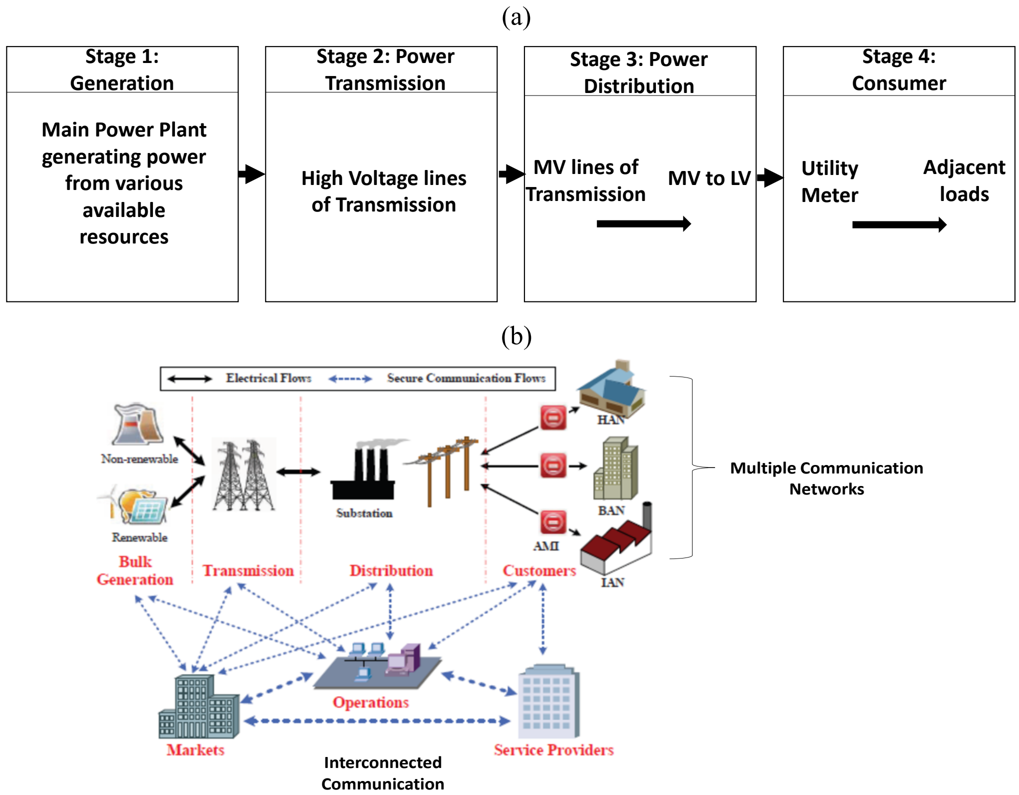

Fig. 1. Comparison between (a) unidirectional electrical grids (b) bidirectional smart grids [17]

Moreover, communication paths are directed through implemented routing protocols that in hand determine the path of data within the smart electrical network. Consequently, the effective rate of communication within the network is heavily dependent on the employed routing protocols, hence the smart grid's complete efficiency is considered variable based on its routing protocols.

As the abundant attention increases in smart grid development and its internal components [18], extensive focus is required on the communication protocols and routing metrics. Smart Grids by nature communicate with various interconnected networks such as HANS, NANs, WANS. Such networking schemes have their own corresponding routing protocols and Quality of Service (QoS) metrics that are significant for defining the performance of the smart grid internetworking. Furthermore, present challenges that relate to security and privacy of networks allocated within the grid, for instance present appliance's power consumption needs to be protected from the consumer side. Therefore, routing protocol classification need to be assessed and discussed as their comparison identifies the different networking types that are aligned with the specific protocol.

Therefore, this paper will elaborate on the present communication technologies that structure the multi-layer smart grid communication architecture between different stages. Such communication technologies present certain network requirements that are aligned with the application situated in the different layers of the architecture. Furthermore, classification of the routing protocols for HANs and NANs will be elaborated to provide an overview of their distribution. In addition, prominent challenges in the networking architecture are discussed to discuss the possible tradeoffs faced in the smart grid multi-layer architecture and proposed solutions.

II. PRESENT COMMUNICATION TECHNLOGIES AND PROTOCOL CLASSIFICATION

As aforementioned, the extensive requirements for successful interconnected networks that form the smart grid infrastructure rely on the networking requirements that are essential for its successful implementation and the data communication between different clients within the network. Various requirements such as delays, reliability and bandwidth capability are essential when applying such routing technologies to specific applications to meet a global network standard. Furthermore, common standard networking schemes are present such as Home Area Networks (HANs), Neighbor Area Networks (NANs) and Wide-Area Networks (WANs). The discussed networks various networking requirements that distinct them from each other. In addition, associated communication technologies are linked with various routing protocols that are particularly designated to match the network requirements.

A. Smart Grid Networking Architecture

As previously mentioned, the smart grid architecture allows for bidirectional communication between various utilities establishes a collaborating structure between multiple networking layers. The subsequent architecture consists of five layers that make up the smart grid topology. Moreover, the present multi-layer architecture consists of the power generation layer that is responsible during power transmission from stations, the power control layer that is solely for the smart monitoring purpose, the communication layer that is key to ensure bidirectional communication within the network, the security protocols to ensure data protection from both consumer and utilities and the application layer that ensures successful delivery of to the consumers based on existing smart grid interfaces [19]. The most fundamental example that is applicable to smart grid applications is smart metering applications, which fundamentally establishes all present layers for successful communication from utility grid up to the smart metering application interface that enables bidirectional communication [20].

Furthermore, the presence of the communication layer is a crucial aspect to enable the bidirectional environment within the integrated applications from both utility and user-end operators. The present communication layer is classified into a hierarchy that positions them based on the factors such as the delivered data rate and the area coverage the network can handle. The prominent networks present in the communication layer comprise of the following:

- Small Area networks that consist of Home Area Networks, Building Area Networks, and Industrial Area Networks.
- Medium Area networks consist of Neighborhood Area Networks and Field Area Networks.
- Large Area networks consist of Wide Area Networks.

Fig. 2 provides the classification of the communication network hierarchy with their relevant requirements. Furthermore, Table I briefly recaps the discussed architecture that composes of five different network layers that are allocated to fundamentally complete the establishment of the smart grid architecture.

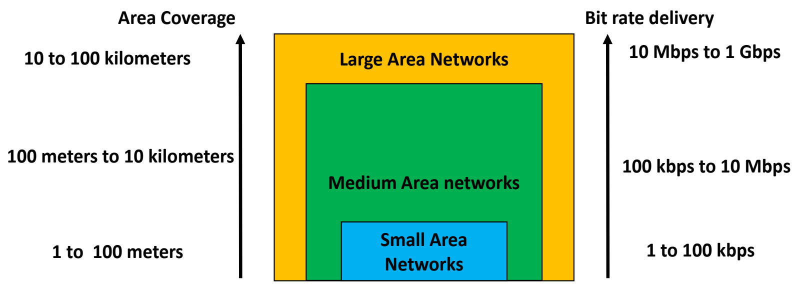

Fig. 2. Classification of communication hierarchy based on allocated network requirements

TABLE I. CLASSIFICATION OF SMART GRID ARCHITECTURE LAYER

Layer Hierarchy	Layer Name	Layer Utilization
(1)	Power System	Responsible for Transmission and Generation stage at power stations
(2)	Power Control	Responsible for smart monitoring of power performance through metering units and sensor applications
(3)	Communication	Performs bidirectional communication between utilities and consumers through various area networks and routing schemes
(4)	Security	Main purpose of data protection and encryption
(5)	Application	Delivered smart grid applications for consumer and utility visualization

B. Communication Technlogies and applications for designated networks

As aforementioned, the interactive Smart Grid architecture provides communication between various domains present from utility and consumer side as illustrated in Fig. 1(a). This in hand applies the present communication hierarchies to serve appropriately based on the data transmitted for the designated application. Various communication technologies are applied to match the bit delivery and area coverage in light of the application utilized and the applied routing mechanism i.e. the type of network [21].

Local area networks classified as HANs/BANS/IANs are specifically designated for utilization within the consumer premises. Such applications are designated to measure electrical data within the area of consumers through their appliances within their allocated places. Applications designated with local networks such as home energy management and building automation are relevant useful applications within local area networks [22]. Local area networks are not obligated to transmit data at high frequencies, which correspondingly indicate reduced power consumption, cost-friendly and protected communication due to its small area. As aforementioned, the minimum coverage such networks provide that range between 1-100m of length and a bit rate of maximum 100kbps rely on communication technologies that are mainly relevant for the premises perspective. Examples of applicable technologies consist of Wi-Fi technology, Bluetooth, and Ethernet technologies as well as power line carrier (PLC) communication technologies. This indicates the support of wired and wireless type technologies for HANs/BANS/IANS.

The second classification of communication networks are medium area networks that are presented by neighborhood / field area networks. Such networks provide a medium of communication between wide area networks (WANs) and local area networks. Applications that deal with data collection such as a smart metering networks or demand response that capture electrical usage data from bulk consumers and field devices to the electrical utility companies that take place in the form of substations or data collectors [23]. As Illustrated in Fig. 2, the prominent upgrade in network requirements is a crucial aspect to support such kind of applications. Higher rate of data is accountable, and a wider area coverage is supported through the provided technologies. As a result, established communication technologies can be utilized to support medium area networks applications, which are classified into wired and wireless communication technologies. Among the multiple technologies present to implement medium access networks are mesh networks that are implemented through ZigBee or Wi-Fi technologies as well as Coaxial cables, Digital Subscriber Line (DSL) and WiMAX.

The third and most crucial classification of network types in the discussed multi-layer architecture are the Wide Area Networks. Major applications that monitor control and protection of power transmission lines and power stations utilize these types of networks for fast data response. Applications require the rapid transmission of numerous data point entries at very high frequencies i.e. in real time operation [24]. Therefore, maintenance of power system stability through smooth communication is very essential to ensure power quality issues avoidance and real time monitoring response. Essentially, high network requirements are associated with WAN communication to support large area coverage and rapid transfer of data. Prominent communication technologies that adopt high network requirements are optical based communication mediums. Such communication mediums provide high data transfer rate capacities with minimal delays ensuring smooth communications between substations at transmission and distribution stages i.e., HV to MV transmission lines. Furthermore, present wide coverage communication technologies such as Cellular and WiMAX provide large, transmitted data throughput. Additionally, real time communication technologies such as orbital satellites that are adapted for substations at rural locations to provide real time response communication at critical levels. Therefore, wide area networks are highly suitable to deal with possible power system collapse and contagious failure, providing automatic self-healing abilities to ensure the stability of enormous power plants. Such networks are responsible to deal with the control of equipment that are instantaneous such as high-voltage direct current (HVDC) devices where delays are ensured to be minimized in seconds and even milliseconds to ensure large power system stability through quick data communication.

With present wired and wireless communication technologies, the latter has been more profound due to flexibility and instant deployment within the smart grid integration. Table II provides a wide range of smart grid applications with their relevant network requirements. Applications have variable data sampling rates based on the importance of the application within the smart grid architecture, especially applications related to the protection and control aspects of large power system networks. In addition, Fig. 3 provides a recap of the smart grid multi-layer architecture that introduces multiple communication hierarchies relevant to the applications.

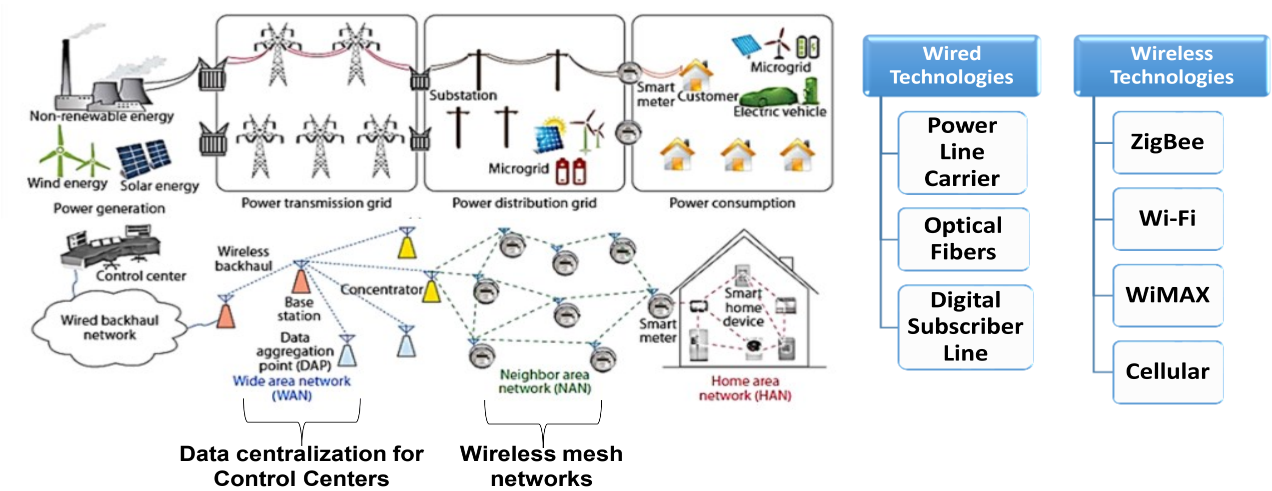

Fig. 3. Established architecture for multi-layer smart grids and adjacent communication technologies

TABLE II. EXAMPLES OF SMART GRID APPLICATIONS BASED ON NETWORK REQUIREMENTS

Network type	Application	Data size	Delay	Reliability
Premises Networks	Automation of Homes	10 - 100 bytes	sec	>98%
	Automation of Buildings	>100 bytes	sec	>98%
Medium Area Networks	Scheduled Advanced metering Infrastructure	1600 - 2400 bytes	<4 hrs	>98%
	Electric vehicles applications	100 – 255 bytes	<15 sec	>98%
	Bidirectional communication between consumer/utility	50 bytes / 200 bytes	<15 sec	>99%
Wide Area Networks	Protection of wide area power transmission	4 – 157 bytes	< 0.1 sec	>99.99%
	Control of fast response power transmission devices	4 -157 bytes	<5 sec up to 2 min	>99.99%
	Monitoring of Wide area power systems	>52 bytes	<0.1 sec up to 2 min	>99.99%

C. Classification of routing protocols

As aforementioned, various communications networks were classified by the IEEE organization in the year 2010 that in hand introduced multiple communication technologies that meet the routing requirements for data transmission and permissible delay as per the utilized application within the multi-layer smart grid architecture. Forwarding protocols are generally categorized based on the type of communication technology used i.e., wired and wireless communications. Extensive discussion about the multiple routing protocols was elaborated in the literature based on the communication technology criterion that discussed various routing protocols that adapt to HANs, NANs and WANs [6], [13], [25]. Power line carrier communication technology is highlighted amongst all discussed wired communication technology due to their present deployment in the transmission and distribution network that presented a larger focus in routing protocol designs [26]. Prospective challenges related to node communication in PLC networks have raised the intensive research to address challenges related to reliability and data response time. Furthermore, wireless network topologies are equally important and the reliable communication between nodes is essential to avoid issues of congestion and data loss due to network noise and other affiliated factors. Extensive focus has been made on wireless mesh networks (WMNs) due to their communication nature as compared to other similar wireless communication topologies. The fundamental idea of wireless mesh networks is the composition of various nodes within the same adjacent network [27].

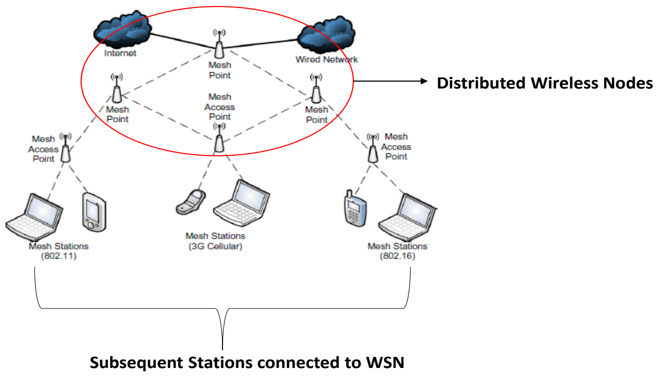

Fig. 4. Illustration of Wireless Mesh Networks utilizing IEEE standard notations [2]

Nodes that take place such as smart home appliances or metering cabinets are presented as nodes within the network, and they undergo multiple hops rather than a single hop before successfully being delivered to the transmission utility that is located at the wide area network. Moreover, the successful node coverage within the network would provide smooth communication that meets the delay and data transmission requirements. The development of wireless mesh networks has raised the investment in routing protocol development for both HAN and NAN based networks and their proposition has been comprehensively elaborated in the literature and their working. Adoption of communication protocol standards associated with HANs and NANs used ZigBee and IEEE 802.11 communication protocol standards respectively.

The classification criteria for both HANs and NANs communication protocols presents a wide range of implemented protocols that have been elaborately discussed within the literature with each communicating through different algorithms. Type of communication technology i.e., wired and wireless technologies is a fundamentally used to classify communication protocols for both HANs and NANs networks. An additional metric that classifies NANs is mainly the security and quality of service requirements that ensure performance is maintained throughout the application of such routing protocols in bidirectional communications. Fig. 5 presents the classification of routing protocols for premises networks and medium area networks respectively. The illustrated demonstration branches out a set of routing protocols that are employed such as IPv6 routing algorithms, ZigBee standard routing algorithm, RPL routing protocol associated for low power consumption mesh networks and many more exponentially increasing routing protocols that are integrated for various networking topologies.

Numerous routing protocols are exponentially introduced with various packet routing mechanisms that ensure improved performance metrics such as identification of shortest possible path for packet delivery, success ratio of delivery, possible packet delay and the possible number of transmissions within the network. In addition, application-based performance indicators are reflected such as the packet delay variation (PDV) i.e., jitter rate that indicates the quality of service for the given network as per the utilized application within the multi-layer smart grid architecture.

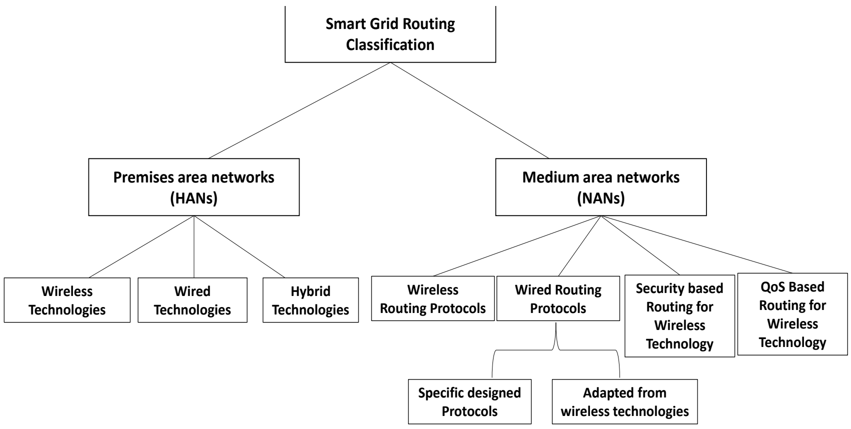

Fig. 5. Routing protocols based on network classification criterion

III. PROMINENT CHALLENGES IN SMART GRID MULTI-LAYER COMMUNICATION MODEL

The smart grid multi-layer architecture provides numerous benefits that possibly enhance the concept of power flow communication between utility and clients through multiple networking schemes. However, networks are prominent to have tradeoffs that needs to be considered and multiple factors are required to maintain the performance of the established network. Furthermore, the arising upgrade in the present communication-networking infrastructure that shifts from unidirectional to bidirectional raises multiple challenges that are elaborated in the following subsections.

A. Lack of Interoperability and node communication

Heterogeneity between nodes communicating in the smart grid multi-layer architecture may cause a serious problem in successful exchange of data between different entities that deploy different routing protocols. Therefore, the ability for successful communication between various entities within the highly complex smart grid architecture is such an important aspect. To overcome communication obstacles between multiple entities, the possible integration of IP gateway nodes to identify various types of protocols that are incoming from the present applications and interfaces, this in hand would successfully bring upon communication of different protocols. Conversely, the possible deployment of gateway nodes throughout all layers of the network may not be completely feasible. This would possibly introduce the need for protocol unification between network layers and deploying standard routing protocols to address the communication between the multi-layer architecture. Example of IPv6 protocols may be common between nodes for common communication capability.

B. Support for established Power Grid Architecure

Established power grids were designed for unidirectional power flow communication without the long-term consideration of communication schemes that enable bidirectional power flow i.e., smart grid topologies. Such obstacle poses a threat for data centralization from associated consumers and applications that are in communication with the utility side. The major communication link that is majorly influenced by this are the medium link communications i.e., NAN/FAN interfaces that communicate between large area networks that take place in the form of distribution stations. In practice, data concentrators are employed to transmit premises network applications to wide area utility networks. Possible connection is done through the deployment of wireless mesh networks that utilize various connection technologies as aforementioned. This in fact enables control of user-end appliances through the network hierarchy.

C. Cybersecurity management and data integerity

A crucial challenge that the smart grid architecture fully relies on is the security requirement. Important nodes that are responsible for the power transmission and distribution are mainly prone to possible insecurity and highly threatened external outbreaks [28]–[30] The necessary need for complete security would prevent external and unauthorized infiltration that could alter the existing routing table mechanisms or network identification data that may lead to possible data alteration during communication of data between established nodes within the network. Furthermore, data protection is highly significant to be maintained since consumers communicate their power consumption to the utility through the smart metering infrastructure and the control servers, leading to essential equipment of concealment of such information. As a result, routing data schemes may be employed to take specific routing paths, which goes through a designated utility or third part company without external infiltration [31], [32] Therefore, fundamentally designing routing protocols to support data protection for multiple smart-grid applications to provide authentication and integrity for the routing of data within the multi-layer network. Fig. 6 illustrates the subsequent infiltrations and security threats that smart grid network communications are a continuous threat to be tackled through various cyber security management measures.

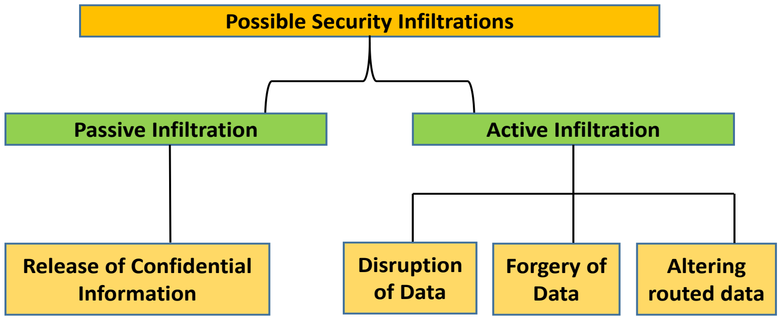

Fig. 6. Classification of potential cyber security attacks on smart grid communications

D. Employed Delay requirements for effective data transmission

The process of data transmission and centralization is subject to possible delays during the routing process. Critical selection of latency is required for wide area network applications that are associated with the transient stability of the power systems that supply to the whole network. As demonstrated in Table II, network requirements for such WAN applications explicitly rely on the minimum delay requirement and reliability to transmit data appropriately. For instance, the common control center that monitors and commands over the electrical network requires sending commands over the distribution lines at minor intervals that are equivalent to milliseconds. This in hand appropriately aligns the commands to operate in real time conditions and avoid subsequent outage within the electrical network that may affect it severely. Employment of such network requirements can be realized through the deployment of high-end communication technologies that support high data transmission rates that cover the scale of wide area networks. Relevant communication technologies that are implied such as fiber optics technologies that suit high-speed data transmission suitable for minor network latency at delay sensitive applications. Apart from utilizing high bandwidth communication technologies, delay minimization can be achieved through the possible congestion control techniques that eventually would give higher importance of certain channels within the network of which its essential for their information to be transmitted without congested delay [28].

IV. CIRITICAL REVIEW & FUTURE PROGRESSION

The IEEE founded the multi-layer smart grid architecture standards in the year 2010. The architecture was founded through the implementation of three area networks that comprise that are hierarchical in nature each serving multiple applications from the consumers' households all the way to the distribution and generation stations that are operated under various bandwidth and latency requirements to ensure real time operation for the power grid. Extensive discussion in the literature discusses the fundamental concept of these networks with their proposed communication and routing schemes.

However, current rapid progression in communication technologies and advancements in networking such as the recent 5th generation and upcoming 6th generation communication algorithms, the communication bandwidth is exponentially scaling that would lead to enlarge the smart grid implementation on large scale electrical networks across country level scale. Cloud computing technologies and artificial intelligence forecasting would lead to massive improvement in broadband technologies that in fact would provide higher reliability in the smart grid communication model. Therefore, large improvement on the communication and networking prospects can be sought for to shift from the fundamental proposed networking structure to a largely improved networking architecture that can easily cope with the present communication advancements.

Furthermore, the steady introduction of the Internet of Things (IoT) phenomena would enable the smart communication between the various components that are present within the smart grid architecture [33]. Such reliable and prospective communication technology that centralizes data communication between devices would ensure effective communication in real time between different layer applications. However, major research requirements are necessary for its deployment due to the various concerns that may be presented. Major security threats that deal with character impersonation and possible data integrity issues that deal to losing data confidentiality and possibly alter them that could possibly harm the electrical network as a result. This would in hand propose various security schemes that capture infiltrators bypassing the possible user authentication.

Nevertheless, performance enhancement and routing of data between consumers and utilities through the IoT data centralization provides major research interest. This provides much more convenient data communication and real time performance between premises and wide area networks that would sustain the network from possible cascading outages that could heavily affect the stability of connected nodes within the network i.e., consumer appliances or smart meters. Furthermore, gateway nodes can be reduced through the centralization of IoT communication technologies that utilize common routing protocols that would share data within the neighborhood/field area networks region, and this tremendously reduces cost consumption and potential error correction within the network. Therefore, enhancement of communication technologies and coping within the recent advancements of communications such as 5G and upcoming 6G technology would present large feasibility for bidirectional smart grid technology and an improved networking architecture that serves up to the highest standards for practical cases.

V. CONCLUSION

In conclusion, the foundations of the networking paradigm presented by the IEEE in the year 2010 through the NIST proved to pave the way to modernize the existing unidirectional conventional power grid through the introduction of a bidirectional smart grid. The interconnecting network established various communication schemes between the various smart applications to ensure proper data usage between consumer and utility companies. Furthermore, proper data usage between premises network and control centers would enable smart adjustment of electricity to meet the energy requirements during different phases of the day. Substantial upgrade in existing power grids would enable large interconnection between countries under enhanced security and communication advancements to cope with the recent communication technologies such as 5G and upcoming 6G technologies. Furthermore, real time data centralization at utility control management centers would lead to effective data communication during all phases of the day. Simulation and practical implemented models are heavily required to test appropriate routing protocols to match the requirements needed by each network layer present within the smart grid multi-layer architecture to overcome the node heterogeneity challenge as well as multiple security challenges that may be a result of such smart network.

ACKNOWLEDGMENT

The authors would like to acknowledge the University of Sharjah for their complete support.

References

[1] W. Wang, Y. Xu, and M. Khanna, “A survey on the communication architectures in smart grid,” *Comput. Networks*, vol. 55, no. 15, pp. 3604–3629, Oct. 2011, doi: 10.1016/j.comnet.2011.07.010.

[2] M. M. Farag *et al.*, “An Optimized Fractional Nonlinear Synergic Controller for Maximum Power Point Tracking of Photovoltaic Array Under Abrupt Irradiance Change,” *IEEE J. Photovoltaics*, vol. 13, no. 2, pp. 305–314, Mar. 2023, doi: 10.1109/JPHOTOV.2023.3236808.

[3] M. M. Farag and A. K. Hamid, “Experimental Investigation on the Annual Performance of an Actively Monitored 2.88 kW Grid-Connected PV System in Sharjah, UAE,” in *2023 Advances in Science and Engineering Technology International Conferences (ASET)*, Feb. 2023, pp. 1–6, doi: 10.1109/ASET56582.2023.10180880.

[4] M. M. Farag, F. F. Ahmad, A. K. Hamid, C. Ghenai, M. Bettayeb, and M. Alchadirchy, “Performance Assessment of a Hybrid PV/T system during Winter Season under Sharjah Climate,” in *2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, Oct. 2021, pp. 1–5, doi: 10.1109/ICECCME52200.2021.9590896.

[5] M. M. Farag and R. C. Bansal, “Solar energy development in the GCC region – a review on recent progress and opportunities,” *Int. J. Model. Simul.*, vol. 43, no. 5, pp. 579–599, Sep. 2023, doi: 10.1080/02286203.2022.2105785.

[6] N. Saputro, K. Akkaya, and S. Uludag, “A survey of routing protocols for smart grid communications,” *Comput. Networks*, vol. 56, no. 11, pp. 2742–2771, Jul. 2012, doi: 10.1016/j.comnet.2012.03.027.

[7] M. M. Farag, F. F. Ahmad, A. K. Hamid, C. Ghenai, and M. Bettayeb, “Real-Time Monitoring and Performance Harvesting for Grid-Connected PV System - A Case in Sharjah,” in *2021 14th International Conference on Developments in eSystems Engineering (DeSE)*, Dec. 2021, pp. 241–245, doi: 10.1109/DeSE54285.2021.9719385.

[8] T. Salameh, A. K. Hamid, M. M. Farag, and E. M. Abo-Zahhad, “Energy and exergy assessment for a University of Sharjah’s PV grid-connected system based on experimental for harsh terrestrial conditions,” *Energy Reports*, vol. 9, pp. 345–353, May 2023, doi: 10.1016/j.egyr.2022.12.117.

[9] T. Salameh, A. K. Hamid, M. M. Farag, and E. M. Abo-Zahhad, “Experimental and numerical simulation of a 2.88 kW PV grid-connected system under the terrestrial conditions of Sharjah city,” *Energy Reports*, vol. 9, pp. 320–327, May 2023, doi: 10.1016/j.egyr.2022.12.115.

[10] M. M. Farag and A. K. Hamid, “Performance assessment of rooftop PV/T systems based on adaptive and smart cooling facility scheme - a case in hot climatic conditions of Sharjah, UAE,” in *The 3rd International Conference on Distributed Sensing and Intelligent Systems (ICDSIS 2022)*, 2022, pp. 198–207, doi: 10.1049/icp.2022.2448.

[11] P. Palensky and D. Dietrich, “Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads,” *IEEE Trans. Ind. Informatics*, vol. 7, no. 3, pp. 381–388, Aug. 2011, doi: 10.1109/TII.2011.2158841.

[12] S. B. Bashir *et al.*, “Modular Multilevel Converter-Based Microgrid: A Critical Review,” *IEEE Access*, vol. 11, pp. 65569–65589, 2023, doi: 10.1109/ACCESS.2023.3289829.

[13] A. I. Sabbah, A. El-Mougy, and M. Ibnkahla, “A Survey of Networking Challenges and Routing Protocols in Smart Grids,” *IEEE Trans. Ind. Informatics*, vol. 10, no. 1, pp. 210–221, Feb. 2014, doi: 10.1109/TII.2013.2258930.

[14] M. M. Farag, R. A. Alhamad, and A. B. Nassif, “Metaheuristic Algorithms in Optimal Power Flow Analysis: A Qualitative Systematic Review,” *Int. J. Artif. Intell. Tools*, vol. 32, no. 07, Nov. 2023, doi: 10.1142/S021821302350032X.

[15] R. H. Katz *et al.*, “An information-centric energy infrastructure: The Berkeley view,” *Sustain. Comput. Informatics Syst.*, vol. 1, no. 1, pp. 7–22, Mar. 2011, doi: 10.1016/j.suscom.2010.10.001.

[16] N. K. Almarzooqi, F. F. Ahmad, A. K. Hamid, C. Ghenai, M. M. Farag, and T. Salameh, “Experimental investigation of the effect of optical filters on the performance of the solar photovoltaic system,” *Energy Reports*, vol. 9, pp. 336–344, May 2023, doi: 10.1016/j.egyr.2022.12.119.

[17] Nist, N. S. Publication, and National Institute of Standards and Technology, “NIST Special Publication 1108 NIST Framework and Roadmap for Smart Grid Interoperability Standards,” *Nist Spec. Publ.*, vol. 0, pp. 1–90, 2014, [Online]. Available: http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf.

[18] X. Fang, S. Misra, G. Xue, and D. Yang, “Smart Grid — The New and Improved Power Grid: A Survey,” *IEEE Commun. Surv. Tutorials*, vol. 14, no. 4, pp. 944–980, 2012, doi: 10.1109/SURV.2011.101911.00087.

[19] M. Kuzlu, M. Pipattanasomporn, and S. Rahman, “Communication network requirements for major smart grid applications in HAN, NAN and WAN,” *Comput. Networks*, vol. 67, pp. 74–88, Jul. 2014, doi: 10.1016/j.comnet.2014.03.029.

[20] C. H. Hauser, D. E. Bakken, and A. Bose, “A failure to communicate: next generation communication requirements, technologies, and architecture for the electric power grid,” *IEEE Power Energy Mag.*, vol. 3, no. 2, pp. 47–55, Mar. 2005, doi: 10.1109/MPAE.2005.1405870.

[21] C. Gomez and J. Paradells, “Wireless home automation networks: A survey of architectures and technologies,” *IEEE Commun. Mag.*, vol. 48, no. 6, pp. 92–101, Jun. 2010, doi: 10.1109/MCOM.2010.5473869.

[22] R. H. Khan and J. Y. Khan, “A comprehensive review of the application characteristics and traffic requirements of a smart grid communications network,” *Comput. Networks*, vol. 57, no. 3, pp. 825–845, Feb. 2013, doi: 10.1016/j.comnet.2012.11.002.

[23] C.-H. Lo and N. Ansari, “The Progressive Smart Grid System from Both Power and Communications Aspects,” *IEEE Commun. Surv. Tutorials*, 2011, doi: 10.1109/SURV.2011.072811.00089.

[24] X. Li, Y.-C. Tian, G. Ledwich, Y. Mishra, X. Han, and C. Zhou, "Constrained Optimization of Multicast Routing for Wide Area Control of Smart Grid," *IEEE Trans. Smart Grid*, vol. 10, no. 4, pp. 3801–3808, Jul. 2019, doi: 10.1109/TSG.2018.2835487.

[25] E. Ancillotti, R. Bruno, and M. Conti, "The role of communication systems in smart grids: Architectures, technical solutions and research challenges," *Comput. Commun.*, vol. 36, no. 17–18, pp. 1665–1697, Nov. 2013, doi: 10.1016/j.comcom.2013.09.004.

[26] J. Heo, K. Lee, H. K. Kang, D. Kim, and W. H. Kwon, "Adaptive Channel State Routing for Home Network Systems Using Power Line Communications," *IEEE Trans. Consum. Electron.*, vol. 53, no. 4, pp. 1410–1418, Nov. 2007, doi: 10.1109/TCE.2007.4429231.

[27] Y. Xu and W. Wang, "Wireless Mesh Network in Smart Grid : Modeling and Analysis for Time Critical Communications," *IEEE Trans. Wirel. Commun.*, vol. 12, no. 7, pp. 3360–3371, 2013, doi: 10.1109/TWC.2013.061713.121545.

[28] K. Kimani, V. Oduol, and K. Langat, "Cyber security challenges for IoT-based smart grid networks," *Int. J. Crit. Infrastruct. Prot.*, vol. 25, pp. 36–49, Jun. 2019, doi: 10.1016/j.ijcip.2019.01.001.

[29] W. Obaid, M. M. Farag, and A. K. Hamid, "Smart Information Recognition on COVID-19 APPs for User Health Identification," in *2022 Advances in Science and Engineering Technology International Conferences (ASET)*, Feb. 2022, pp. 1–4, doi: 10.1109/ASET53988.2022.9735044.

[30] A. K. Hamid, M. M. Farag, and W. Obaid, "Smart information recognition for user health identification through COVID-19 applications," 11,715,312, 2023.

[31] D. He, C. Chen, J. Bu, S. Chan, Y. Zhang, and M. Guizani, "Secure service provision in smart grid communications," *IEEE Commun. Mag.*, vol. 50, no. 8, pp. 53–61, Aug. 2012, doi: 10.1109/MCOM.2012.6257527.

[32] A. A. Omar, M. M. Farag, and R. A. Alhamad, "Artifical Intelligence: New Paradigm in Deep Space Exploration," in *2021 14th International Conference on Developments in eSystems Engineering (DeSE)*, Dec. 2021, pp. 438–442, doi: 10.1109/DeSE54285.2021.9719425.

[33] O. Majeed Butt, M. Zulqarnain, and T. Majeed Butt, "Recent advancement in smart grid technology: Future prospects in the electrical power network," *Ain Shams Eng. J.*, vol. 12, no. 1, pp. 687–695, 2021, doi: 10.1016/j.asej.2020.05.004.