Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

A Proposed Framework For Integrating Mobile Edge Computing In Smart Grid

Solomon Nsor-Anabiah[1], Ruhiya Abubakar[2], Michael Agyare[3], Joseph Wumboranaan Nanjo[4], Emmanuel Atebawone[5]

[1]Telecommunication Engineering Department, Ghana Communication Technology University, Accra-Ghana, [2]Electrical/Electronics Engineering Department, Ghana Communication Technology University, Accra-Ghan, [3]Telecommunication Engineering Department, Ghana Communication Technology University, Accra-Ghana,
[4]Electrical/Electronics Engineering Department, Sunyani Technical University, Sunyani-Ghana,
[5]Department of Information Technology Studies, University of Professional Studies Accra-Ghana.
[1]s.nsor-anabiah@gctu.edu.gh,[2]rabubakar@gctu.edu.gh, [3]magyare@gctu.edu.gh,
[4]joseph.nanjo@stu.edu.gh, [5]emmanuel.atebawone@upasmail.edu.gh

The increasing demand for power across the globe has necessitated various power generations especially, the renewables. The acquisition, analysis and utilization of massive data from energy producers and consumers must be efficiently handled by Smart Grids (SG). The reformation of SGs to handle this new role requires Mobile Edge Computing (MEC) which is an evolving novel computing phenomenon with potential to support big data analytics in the SG digitization drive. The aim of this study was to propose a comprehensive framework that will integrate MEC technology into SG systems, focusing on architecture, use cases, benefits, challenges, and future directions. The findings show that leveraging MEC, Smart Grids can achieve real-time data processing, reduced latency, improved efficiency, reduced bandwidth use, improved resource management, and predictive maintenance. The results further reveal that the framework can be robust when challenges like scalability, interoperability, security vulnerabilities, and infrastructure cost are resolved. Additionally, standardization, integration of advanced AI, and sustainability initiatives can boost the proposed framework.

Keywords: mobile edge computing, smart grid, robust framework architecture, use cases, real-time implementation infrastructure.

1. Introduction

The Smart Grid represents a modernized electrical grid that utilizes digital technology to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. With the increasing penetration of renewable energy sources, electric vehicles, and IoT devices, the need for efficient data processing and communication has become paramount. Mobile Edge Computing (MEC) offers a promising solution by bringing computation and storage closer to the data source. Fundamentally, data analytics and related concepts are dependent on technologies that perform critical tasks during data collection, transmission, processing and storage [1]. Centralized cloud computing was first envisaged as the best feasible solution for the SG phenomenon because its geo-distributed equipment and devices are closely connected together via cloud sited data centers, as such, making decisions from a centralized position the issuance of control orders [2]. MEC provides great benefits including its ability to significantly reduce system delay, improve system availability and scalability, effectively reducing the burden of data centers, and data privacy and security in cloud computing [3]. Following this, many companies within the ICT industry have launched research and production of commercial MEC products. Suppliers of traditional equipment in the power sector have also decided to invest in MEC technology and the production of related equipment [4].

1.1 Motivation

The traditional centralized cloud computing model faces challenges such as latency, bandwidth limitations, and security concerns. MEC addresses these issues by enabling localized processing, thereby enhancing the responsiveness of Smart Grid applications. The objectives of this study are to propose a comprehensive framework for integrating MEC into Smart Grids, identify use cases and applications, discuss the potential benefits and challenges.

2. Literature Review

This section discusses the literature closely linked to the specific area of study.

2.1 Evolution of Mobile Edge Computing

The development of MEC is connected to the service platform of computing that introduces an evolved network architecture, which significantly reducing the link from end users to the computing resources. The transformation has led to numerous advantages in service delivery, data processing, and resource optimization [5]. Major technology companies such as Nokia, Siemens Network, and IBM have widely adopted MEC to provide services to mobile users. The core idea of MEC is to shift resources from distant cloud data centers closer to mobile users, thereby enhancing the use of storage and computing capabilities. According to [6], the rise of MEC is closely tied to the rollout of 5G technology, which offers mobile internet speeds up to ten times faster, with latency nearing a millisecond and increased bandwidth. As noted by [7], edge computing was first introduced in 2002, focusing on delivering applications from data centers situated in the cloud to businesses operating at the network edge. Studies also explain edge computing as the description of a system capable of distributing programming methods and associated data to the network's edge, improving overall system performance. Since then, MEC has evolved to address many challenges associated with cloud computing, providing end users with flexible resources at the network's edge—a feature not available in traditional cloud computing.

2.2 Use Cases of MEC

Existing literature highlights several advantages of MEC, including low latency, high bandwidth, enhanced data security, and the proximity of computing and storage resources to where they are most needed. [8] discussed research by STL Partners aimed at helping the proponents of edge ecosystem to realize key use cases of the technology. This research also sought to identify lucrative opportunities for monetizing edge services and inform partners about effective market strategies for leveraging edge computing. While there are numerous applications of MEC, this section focuses on some key ones. [9] views MEC as fundamental to the future of wireless communication systems integrated with 5G technology. The paper identifies significant MEC applications such as energy management, big data analytics, autonomous vehicles, augmented and virtual reality, healthcare, education, and customer service. Studies conducted by [10], [11] have categorized MEC applications into areas like Smart Grid, Smart Transportation, Smart Homes, IoT, Surveillance and Video Analytics, and Mobile Big Data Analytics, etc. As emphasis on the applications, [12] pointed out that MEC's low latency enables critical computations for time-time deployments such as virtual reality, which drives its relevance. Consequently, Smart Grid, Edge Content Caching, and Traffic Management have been identified as some of the most sought for applications today. According to [13], other use cases that illustrate the application of MEC in Smart Grids are:

- Real-Time Monitoring: Local processing of data from sensors for immediate fault detection and response.
- Demand Response Management: Analyzing consumer energy usage patterns at the edge to optimize energy distribution.
- Distributed Energy Resource Management: Coordinating local generation sources such as solar panels and batteries through edge computing.
- Load Balancing: Distributing workloads across edge servers to prevent bottlenecks.
- Data Caching: Storing frequently accessed data at the edge to reduce latency.
- Security Management: Implementing security protocols at both the edge and core layers to protect sensitive data.

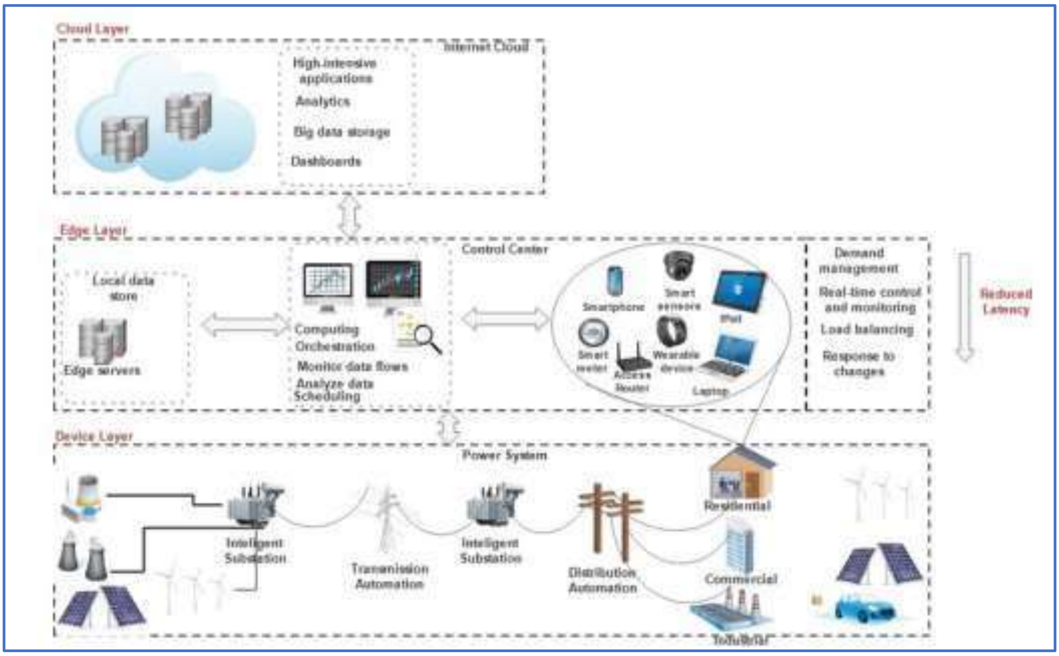
2.3 Overview of Mobile Edge Computing in Smart Grid

The revolution in Smart Grids (SGs) is giving way to the adoption of massive data for services and operations. Information and communication technologies (ICTs) are a critical part in this revolution, especially in the area of computing, that describes data analysis within the smart grid. MEC an evolving novel which offers high potential for the digitization of SG. [13] researched on the applications of MEC in SG and determined that SG benefits immensely from MEC. The findings also show that the integration of MEC and SG supports MEC to become more sustainable. Definitions available are industry related, depicting different concepts since different fields of industry have their own requirements for MEC [14]. For instance, in mobile communication applications, MEC is defined as a computing architecture responsible for providing IT services in terms of cloud computing capabilities close to the edge of a mobile network. This happens within the perimeter of a radio access network, very close to the mobile subscriber [15]. Within the IoT environment, MEC is described as an enabling technology that permits high-rate performance of computation of downstream data at the edge of the network for cloud services and upstream data on behalf of IoT services. According to [16], despite the various definitions for MEC, they possess a common characteristic such as the deployment and application of computing resources in proximity to data sources. Considering SG in particular, "edge" describes to areas data is produced close to electrical users and equipment [17]. In fact, edge application covers "the last mile" side of power transmission. Areas close to data sources on power transmission lines should be considered in the edge discussion. In the case of power system operators or companies, substations are not part of the end user section of power transmission, but because large power rates are generated, data through the activities of various sensors have to be put under the domain of edge. For example, the 4Cs, represented by, computation, communication, caching and control should be seen as critical within the functions of MEC [18]. Conventionally, the functions of the 4Cs are executed in core data centers by default, but moving it to edge will only complement edge cloud computing but not cannibalize it. Through the capabilities of MEC, the edge cloud resources and electrical devices are integrated into a cloud of things continuum [19].

2.3.1 Architecture of MEC for Smart Grid

The architecture of MEC in Smart Grids involves three main layers. Figure 1 depicts the integration of MEC into smart grid, which is divided into three platforms namely, device layer, edge layer and core layer [20].

Figure 1. Mobile Edge Computing in Smart Grid Architecture



Device Layer: Comprises smart meters, sensors, and IoT devices that generate data. The overall grid deployment, management and updates are directly performed within the edge layer and then transported to the cloud for storage in the data centres.

Edge Layer: Consists of edge servers that process data locally, reducing latency and bandwidth usage. The edge platform which is made of IoT connectivity, data storage, analytics/control, cloud connectivity and distributed energy resources (DERs) interoperability is enabled to acquire and control data in real-time from local power stations connected to MEC [21]. The edge system communicates with the different groups of equipment through a plethora of protocols in order to acquire and normalize data emanating from disparate endpoints. The fusion of these multiple sources of data makes it possible for MEC to control, monitor and perform efficient analytics as required [22].

Core Layer: Centralized cloud infrastructure for long-term data storage and advanced analytics. Only processed data that is not urgently or immediately needed is stored.

2.4 MEC Characteristics and Strengths

A latency capacity that helps in transmitting and executing SG data analytics is expressed in the following equation:
Equation:

$$D = \sum k\ (t_{que,k} + t_{proc,k} + t_{tra,k}) + \sum i\ t_{prop,i} + t_{exe} \qquad \text{Eq. (1)}$$

Where:
k denotes the communication subscripts within the middleware within the path of data transmission.
i indicates subscripts of the links along the same communication path.
$t_{que,k}$, $t_{proc,k}$, and $t_{tra,k}$ represent queuing delays, processing delays, and transmission delays, respectively, within middleware k.
$t\ prop,i$ describes transmission delay across path i, while t_{exe} refers to the hop required for data analysis.

Data execution is performed closer to various data sources. As a result, Multi-access Edge Computing (MEC) significantly reduces both the communication delays $\sum k\ (t_{que,k} + t_{proc,k} + t_{tra,k})$ and the distance of propagation $\sum i\ t_{prop,i}$. In traditional power grid systems, the monitoring delay for wide-area applications typically falls within 100ms for Distributed Energy Resources (DER), while stability control delays are generally between 150 and 200ms [23].

It is also possible to realize one-hop delay in 1ms with MEC, using picture processing in accordance with existing standards [24]. Additionally, to ensure jitter reduction and low latency, the phenomenon called task offloading technology is deployed to schedule and distribute tasks among MEC resources. Consequently, tasks can be automatically migrated to areas where latency is low, particularly when the closest MEC resource is engaged or a communication link congested. Other characteristics of MEC which contribute to its uniqueness and effective handling of smart grid challenges. MEC resources only require to be responsible for users and devices within their proximity [6-new]. For this reason, there is great advantages in perceiving environmental information and the understanding of the diversified requirements. MEC provides an extended flexibility even at the planning and operational phases so as to create a self-correction system [25]. Finally, MEC offers reliability in the physical operational security, data security and privacy [26]. It is also uninterrupted and safe as the first priority and security analysis form the best criteria for SG. The single-point of failure exhibited by MEC only affects a very small scope.

2.5 Key Enabling Technologies for MEC

There are four key enabling technologies for MEC in SG grouped into, physical level, presentation level, task level, and the application level.

Physical Level Technology: This is fundability deployed in industrial integrated circuits such as in-memory computing, heterogenous computing, lightweight function library, and machine learning (ML) processors. Lightweight function libraries and heterogenous computing are designed to increase performance in existing embedded chips. In this case, the MEC nodes in SG may be made of special mature and commercial microprocessors.

Presentation Level Technology: This level of technology provides translation and presentation of a detailed implementation design of ICT, for which service providers and operators have no expertise. These techniques are generally used as abstract and virtualization.

Task Level Technology: This mainly concerns smaller and executable units for specific applications. The technology, also called task offloading is used to reschedule and dispatch smart grid tasks. Task offloading is a phenomenon directly linked to network optimization.

Application-Level Technology: MEC is used to perform data analytics in SG, with most of the algorithms dependent on ML. In fact, application-level technologies are responsible for analytics in MEC, with specific reference to ML on MEC, but are sometimes called edge intelligence.

3. Proposed MEC in SG Framework Overview

The proposed framework consists of nine main components as demonstrated in Figure 2. Some existing frameworks include; Fog Computing Frameworks, Edge Computing Architectures, 5G-Enabled Smart Grid Frameworks, Data Management and Analytics Frameworks and Security Frameworks. However, the proposed MEC is more comprehensive for this context [25].

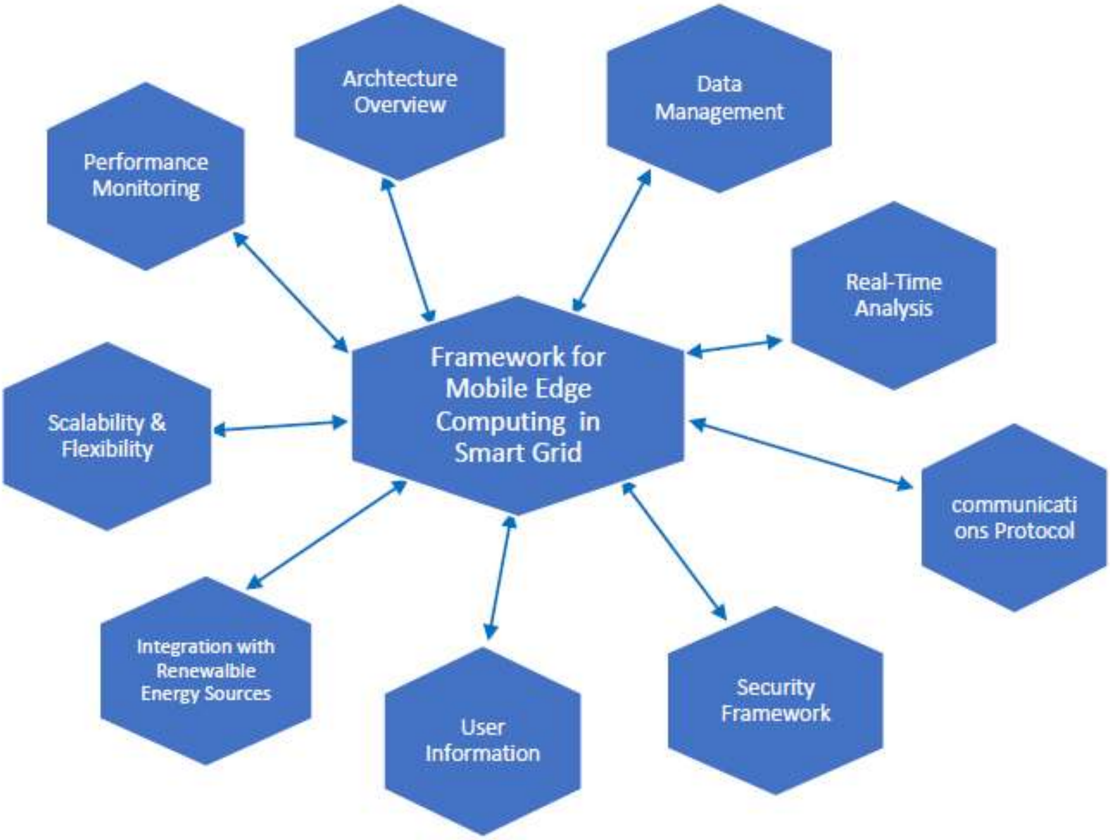


Figure 2. Architecture of the Proposed Framework for Mobile Edge Computing in Smart Grid (Nsor-Anabiah,2024)

3.1 Architecture Overview

The framework's architecture consists of the following [20]:

- Edge Nodes: Deploy MEC servers at strategic locations within the grid (e.g., substations, distributed generation sites) to process data locally.
- Core Network: Integrate MEC with existing communication infrastructure (5G, LTE) to ensure seamless connectivity between edge nodes and central management systems.
- End Devices: Include smart meters, sensors, IoT devices, and consumer appliances that communicate with edge nodes for data collection and control.

3.2 Data Management

Resource management in MEC is represented in three dimensions [27].

- Data Collection: Utilize IoT sensors to gather real-time data on energy consumption, generation, and grid status.
- Data Processing: Implement local data analytics at edge nodes to reduce latency and bandwidth usage. This includes anomaly detection, demand forecasting, and predictive maintenance.
- Data Storage: Store critical data locally at edge nodes while ensuring that essential data is transmitted to the central cloud for long-term storage and analysis.

3.3 Real-Time Analytics

- Load Balancing: Use MEC to analyze load patterns in real-time to optimize energy distribution and prevent overloads.
- Demand Response: Implement local algorithms to manage demand response strategies, allowing for immediate adjustments based on user behavior and grid conditions.
- Fault Detection: Leverage machine learning algorithms at the edge for real-time fault detection and diagnostics to enhance grid reliability.

3.4 Communication Protocols

- Low Latency Communication: Employ protocols optimized for low latency (e.g., MQTT, CoAP) to facilitate quick data exchange between devices and edge nodes.
- Secure Communication: Implement encryption and secure authentication mechanisms to protect data integrity and privacy.

3.5 Security Framework

Security in the MEC technology is very critical to robustness of the network [28].

- Access Control: Define strict access control policies to manage who can access the edge computing resources and data.
- Intrusion Detection: Deploy edge-based security solutions to monitor for anomalies or breaches in real time.
- Data Privacy: Ensure compliance with regulations (e.g., GDPR) regarding personal data handling and user consent.

3.6 User Interaction

- Consumer Applications: Develop mobile applications that allow consumers to monitor their energy usage, receive alerts, and participate in demand response programs.
- Feedback Loop: Create mechanisms for users to provide feedback on grid operations which can be analyzed at the edge for continuous improvement.

3.7 Integration with Renewable Energy Sources

- Distributed Energy Resource Management: Use MEC to coordinate the integration of renewable energy sources (solar panels, wind turbines) with real-time grid management.
- Energy Trading Platforms: Facilitate peer-to-peer energy trading using local computation to match supply and demand efficiently.

3.8 Scalability and Flexibility

- Modular Design: Ensure that the MEC architecture is modular, allowing for easy upgrades and integration of new technologies.

- Interoperability: Promote standards that enable different devices and systems within the smart grid to communicate effectively.

3.9 Performance Monitoring

This part of the framework makes provision for the performance of the network to be monitored continuously [29].

- KPIs Definition: Establish key performance indicators (KPIs) to measure the effectiveness of MEC deployment in terms of latency, reliability, energy efficiency, and user satisfaction.
- Continuous Improvement: Use performance data for iterative improvements in MEC applications within the Smart Grid.

The integration of Mobile Edge Computing in Smart Grid systems has the potential to significantly enhance operational efficiency, reduce latency in decision-making processes, and improve overall user experience. By implementing a structured framework that addresses architecture, data management, analytics, security, user interaction, scalability, and performance monitoring, stakeholders can harness the full benefits of MEC in smart grid applications.

4. Analysis of the Proposed Mobile Edge Computing Framework for Smart Grid System

Mobile Edge Computing (MEC) is increasingly recognized as a transformative technology for Smart Grids, enabling real-time data processing and enhanced decision-making capabilities. This analysis explores the implications, benefits, challenges, and future directions of MEC within the Smart Grid context [30].

4.1 Implications of MEC in Smart Grids

This section reviews the some of the critical importance of integrating MEC into smart grids.

4.1.1 Real-Time Data Processing

MEC allows for localized data processing at the edge of the network, significantly reducing latency. This capability is crucial for applications as explained by [31].

- Demand response: Immediate adjustments to energy consumption based on real-time data processing.
- Fault detection: Rapid identification and isolation of faults in the grid.

4.1.2 Enhanced Communication

MEC facilitates efficient communication between devices and systems, leading to:

- Improved data transfer rates.
- Reduced bandwidth consumption by processing data locally before sending it to centralized systems.

4.1.3 Scalability and Flexibility

The distributed nature of MEC supports scalability, allowing for the integration of more devices without overwhelming centralized cloud infrastructure.

4.2 Benefits of MEC in Smart Grids

The integration of MEC in Smart Grids offers several advantages, it plays the important role of an intermediary, facilitating communication and storage between the smart grid controlling the center of things and the competing resources [32]. There are several benefits of MEC in SG, the key ones include:

- Reduced Latency: By processing data closer to its source, MEC minimizes delays, which is critical for time-sensitive applications like grid management and automated responses to energy demand fluctuations.
- Bandwidth Optimization: MEC alleviates network congestion by reducing the volume of data sent to the cloud. Only essential information can be transmitted, optimizing bandwidth usage.
- Reduced Bandwidth Use: The greatest incentive in the renewable ecosystem for demand and supply is the ability to save cost. If more energy is generated by users than needed, they are able to sell back to the grid.
- Data Privacy and Security: In smart metering and smart homes, there are increasing volumes of private and sensitive information from users that have to be delt with by smart grids. MEC is able to select which data goes to the cloud and the rest to be used locally.
- Enhanced Security: Localized data processing can improve security by limiting the amount of sensitive data transmitted over networks, thereby reducing exposure to potential attacks.
- Enhanced Reliability: Localized processing can continue even if connectivity to the central cloud is lost.
- Others: Apart from the benefits explained above, MEC in SG supports resilience, boosts performance, and supports AI/ML applications.

4.3 Challenges of Implementing MEC in Smart Grids

Despite all the benefits and advantages of MEC, it comes with some challenges that must be overcome [33, 34].

- Scalability: Managing an increasing number of devices and data points without degrading performance.
- Interoperability Issues: The integration of diverse devices and systems poses challenges in achieving seamless communication and data exchange across different platforms.
- Security Vulnerabilities: While MEC can enhance security, it also introduces new vulnerabilities at the edge that need robust management strategies to prevent breaches.
- Infrastructure Costs: Deploying MEC requires investment in edge computing infrastructure, which can be a barrier for some utilities, especially smaller ones.

4.4. Case Studies and Applications

- Real-Time Monitoring Systems: Several utilities have implemented MEC to enhance their monitoring capabilities, allowing for immediate responses to grid anomalies.
- Distributed Energy Resource Management: MEC has been used to coordinate local energy generation (e.g., solar panels) and storage systems, optimizing their integration into the grid.
- Predictive Maintenance: Utilizing machine learning algorithms at the edge helps predict equipment failures based on real-time data analysis, thereby reducing downtime and maintenance costs.

4.5 Future Directions

Beyond the successful implementation of this comprehensive framework, it is important to consider these for future investigations [35, 36].

- Standardization Efforts: Developing standards for MEC in Smart Grids will facilitate interoperability and encourage widespread adoption.
- Advanced AI Integration: Further research into AI applications at the edge can enhance predictive analytics and optimize grid operations.
- Sustainability Initiatives: Exploring energy-efficient edge computing solutions can promote sustainable practices within Smart Grids.

5. CONCLUSION

Mobile Edge Computing presents significant opportunities for enhancing Smart Grid operations through improved efficiency, reduced latency, reliability and better resource management. By implementing the proposed framework, stakeholders can effectively harness the potential of MEC to address current challenges in energy management. However, challenges such as interoperability, security vulnerabilities, and infrastructure costs must be addressed for successful implementation. Continued innovation and research will be vital in harnessing the full potential of MEC in Smart Grids, paving the way for a more resilient and responsive energy infrastructure.

REFERENCES

1. A. Al-Ansi; A.M. Al-Ansi; A. Muthanna; I.A. Elgendy & A. Koucheryavy, Survey on Intelligence Edge Computing in 6G: Characteristics, Challenges, Potential Use Cases, and Market Drivers (2021). Retrieved October 5, 2024, from https:// doi.org/10.3390/fi1305011.

2. A. Foster, New Edge Computing Solutions Set to Revolutionise the Power Industry (2022). Retrieved July 15, 2024, from https://www.hpe.com/us/en/insights/articles/how-edge-to-

3. Auday et al., Introduction to edge computing (2021). Retrieved October 5, 2024, from https://www.researchgate.net/publication/344218125.

4. C. Feng; Y. Wang; & Q. Chen, Smart Grid Encounters Edge Computing: Opportunities and Applications (2021). Retrieved July 15, 2024, from https://doi.org/10.1016/j.adapen.2020.100006.

5. C. Liu, & Y. Wang, Smart Grid Technologies and Applications: A Review. Journal of Modern Power Systems and Clean Energy, 7(1), 1-12 (2019).

6. C. Pritchard; Y. Beheshti; & M. Sepahi, Mobile Edge Computing Architecture, Use-cases and Applications (2020). Retrieved September 5, 2024, fromhttps://www.researchgate.net/publication/341480948

7. C. Yang; Z. Wang; B. Xie, Cache-aided Multiuser UAV-MEC networks for smart grid networks: A DDPG Approach (2023) Retrieved July 28, 2024, from https://doi.org/10.1111/coin.12616.

8. E. Ahmed & H.M. Rehmani, Mobile Edge Computing: Opportunities, Solutions, and Challenges (2016). Retrieved August 30, 2024, from https://www.researchgate.net/publication/311332346DOI.

9. Ekinops & Dell Technologies, Why Edge Computing really can give you the edge (2021). Retrieved October 5, 2024, from www.ekinops.com.

10. H. Bakhshandeh & M. Keshavarz, Security and Privacy in Mobile Edge Computing for Smart Grids. Future Generation Computer Systems (2021).

11. G. Premsankar, M. Di Francesco & T. Taleb, Edge computing for the Inter- net of things: a case study. IEEE Internet Things Journal, 5(2), 1275-1284(2018).

12. H. Bakhshandeh & M.Keshavarz, Security and Privacy in Mobile Edge Computing for Smart Grids. Future Generation Computer Systems (2021).

13. Huang et al., Mobile Edge Computing for 5G Internet of Things (2018). Retrieved September 24, 2024, from https://www.researchgate.net/publication/333569023.

14. I. Makhdoom, et al., Internet of Things (IoT) in Smart Grid: A Survey on the Applications, Challenges, and Future Directions. IEEE Access, 8, 123456-123478 (2021).

15. J. Liu et al., Edge Computing for Smart Grid: Opportunities and Challenges. IEEE Communications Magazine (2021).

16. K. Ghafoor et al. Challenges and Solutions for Smart Grid Security: A Review. Computers & Security, 104, 102162(2021).

17. M. Satyanarayanan, The emergence of edge computing. Computer 50(1),30–39(2017).

18. Mehmood et al., Edge Computing for IoT-Enabled Smart Grid (2021). Retrieved July 15, 2024, from https://doi.org/10.1155/2021/5524025

19. Minh et al. (2022), Edge Computing for IoT-Enabled Smart Grid: The Future of Energy. Energies,15.

20. M. Mahshid et al., Computing (MEC) Aided by End Device Computation and Caching: A Survey. Digital Object Identifier (2019). 10.1109/ACCESS.2019.2953172.

21. M.S. Ibrahim; W. Dong; & Q. Yang, Machine Learning Driven Smart Electric Power Systems: Current Trends and New Perspectives. Appl Energy (2020); 272:115237. doi: 10.1016/j.apenergy.2020.115237.

22. N. Abbas; Y. Zhang; A. Taherkordi; & T. Skeie, Mobile Edge Computing: A survey. IEEE Internet Things Journal, 5(1), 450–65 (2018).

23. Niyato, et al., Joint Communication, Computation, Caching, and Control in Big Data Multi-Access Edge Computing. IEEE Trans Mobile Computer: doi: 10.1109/TMC.2019.2908403(2019).

24. Postscapes, IoT edge computing software (2019). Retrieved Septemberv24, 2024, from https://www.postscapes.com/iot-.

25. R. Jasud, Revolutionizing Connectivity: Navigating the Future of Multi-Access Edge Computing. Journal of Network and Computer Applications, 231, 103978 (2024).

26. S. Aghaei et al., Future Directions for Smart Grids: A Comprehensive Review and Research Agenda. Renewable and Sustainable Energy Reviews, 135, 110143 (2021). doi:10.1016/j.rser.2020.110143.

27. S. Bera; S. Misra; & J.J.J Rodrigues, Cloud computing applications for smart grid: a survey. IEEE Trans Parallel Distrib Syst, 26(5),1477–1494 (2015).

28. S. Nikolai,10 Examples of Edge Computing (2020). Retrieved June 24, 2024, from www.stlpartners.com/edge-computing.

29. STL Partners (2021). What is a smart grid?; Why smart grids? Increasing use of renewable energy is posing new challenges on the network (2021). Retrieved September 5, 2024, from https://stlpartners.com/articles/edge-computing/smart-grids-edge-computing/.

30. T. Park; M. You; J. Kim & S. Lee, Fatriot: Fault-tolerant MEC Architecture for Mission-Critical Systems using a Smart NIC (2024). Retrieved July15, 2024, from https://doi.org/10.1016/j.jnca.2024.103978.

31. W. Shi; J. Cao; Q. Zhang; Y. Li, Y.; and Xu L, Edge computing: vision And challenges. IEEE Internet Things J, 3(5), 637–646 (2016).

32. X. Wan, Dynamic Resource Management in MEC Powered by Edge Intelligence for Smart City Internet of Things. J Grid Computing (2024). Retrieved August 15, 2024, from https://doi.org/10.1007/s10723-024-09749-

33. Y. Huang et al., An Edge Computing Framework for Real-Time Monitoring in Smart Grid. 2018 IEEE International Conference on Industrial Internet (ICII) (2018).

34. Y. Zhang; & Y. Wang, Mobile Edge Computing: A New Network Architecture for Smart Grid. IEEE Transactions on Smart Grid (2020).

35. You et al., Resource Management for Mobile Edge Computing: A Survey. IEEE Communications Surveys & Tutorials, 22(3), 1683-1714 (2020).

36. Z.S. Naser.; H. Marouane; & A. Fakhfakh, Traffic Management Based on Cloud and MEC Architecture with Evolutionary Approaches towards AI: A Review (2023). Retrieved September 5, 2024, from https://orcid.org/0009-0005-3219-2371