A Critical Review of Edge and Fog Computing for Smart Grid Applications

Gilbert M. Gilbert, Shililiandumi Naiman, Honest Kimaro, Burchard Bagile

A Critical Review of Edge and Fog Computing for Smart Grid Applications

Gilbert M. Gilbert, Shililiandumi Naiman, Honest Kimaro, Burchard Bagile
University of Dar es Salaam, Dar es Saaam, Tanzania
gilly.map@gmail.com, smakere@gmail.com,
honest_c@yahoo.com, bbagile@yahoo.com

Abstract. Smart grid and cloud computing architectures have been perfectly suiting each other naturally. As a result, over the years cloud computing architectures have dominated the implementations of smart grid applications to address computing needs. However, due to continuing additions of heterogeneous (sensing and actuating) devices, emergence of Internet of Things (IoT), and massive amount of data collected across the grids for analytics, have contributed to the complexity of smart grids, making cloud computing architectures no longer suitable to provide smart grid services effectively. Edge and Fog computing approaches have relieved the cloud computing architectures of problems related to network congestion, latency and locality by shift of control, intelligence and trust to the edge of the network. In this paper, a systematic literature review is used to explore the research trend of the actual implementations of edge and fog computing for smart grid applications. A total of 70 papers were reviewed from the popular digital repositories. The study has revealed that, there is significant increase in the number of smart grid applications that have exploited the use edge and fog computing approaches. The study also shows that, considerable number of the smart grid applications are related to energy optimizations and intelligent coordination of smart grid resources. There are also challenges and issues that hinder smooth adoption of edge and fog computing for smart grid applications, which include security, interoperability and programming models.

Keywords: Smart Grid, Applications, Edge Computing, Edge Computing.

1 Introduction

Electric power systems are the most important infrastructures to drive the industrial economy of any state. These infrastructures are linked to many aspects human development and well-being. As the demands for more energy keep on increasing, so is the need of technologies for effective and intelligent management of power grids. Smart grid is a type of cyber-physical system (CPS) that enables the electric power grid to co-exist with information and communication technologies (ICT). As defined in [1] and [2], smart grid:

"uses sensing, embedded processing and digital communications to enable the electricity grid to be observable (able to be measured and visualised), controllable (able to be manipulated and optimised), automated (able to adapt and self-heal), fully integrated (fully interoperable with existing systems and with the capacity to incorporate a diverse set of energy sources)".

This modernized infrastructure is considered as intelligent, secure, reliable, economic and friendly to environment. However, smart grid infrastructures are still very complex due to sheer number of different (heterogeneous) devices (sensors, smart meters, and actuators), huge geographical size and the use computationally intensive models for control, analysis, optimization and simulation [3]. Over the years, cloud computing infrastructures have been the dominant solutions to handle heavy computational tasks related to smart grid applications [4]. Cloud computing offers its services on-demand, which enables data, gathered across the grid to be processed in an efficient manner. Therefore, the architectures of smart grids and cloud computing are suiting each other perfectly as natural partners [5].

As the number of devices in smart grid continues to grow as well as the rise of Internet of Things (IoT), cloud computing can no longer satisfy all the computing requirements needed by smart grid applications. Cloud computing is susceptible to high latency and network congestions, and it is insensitive to locations or source of data and mobility. Therefore, some delay-sensitive applications are seriously affected and their outcome can escalate to wrong grid states. To enable de-centralized computing, as opposed to cloud computing, some computations need to be performed close to the source (edges) of the data to minimize data movement and unnecessary computations at the cloud [6]. Moreover, latency-sensitive and geo-based applications can benefit from this approach. Edge computing compliments the cloud computing by extending the services to the edges of the network, and hence improving quality of services and experience.

In edge computing, there is a transfer of a control from a central system to the extreme nodes. Moreover, some intelligence, trust and data are retained at the network peripherals [7]. There are variants of edge computing approaches including fog computing, dew computing and mobile edge computing. Some researchers do treat these approaches as different by arguing that edge computing approaches mean edge routers, base stations, and home gateway, while fog computing is inclusive of cloud, core, metro, edge, clients, and things [8]. Others postulate that, with edge computing control resides on the device itself (sensor or actuator), while in fog computing control is down to the level of local area network [9]. A number of researchers still agree that edge computing and fog computing can be used interchangeably as related field [7]. However, many studies in smart grid have addressed their research using fog computing. Despite the differences of these concepts in terms of implementation, there is a common consensus on modality of their operations, that, peripheral nodes are expected to respond to computing demands.

Several reviews and surveys have been published to address edge and fog computing concepts. These studies [10–13] have to a greater extent discussed about advantages, architectures, applications and research issues. To the best of the authors' knowledge, there is yet to be found any publication that systematically review literatures on edge and fog computing implementations for smart grid applications. Studies by [6] and [14] provide promises on the suitability of these computing platforms to smart grid applications. This paper uses systematic literature review to investigate research trend in the adoption of edge computing approaches for smart grid applications from existing literatures. This review provides a comprehensive picture of the status of smart grid applications implementations using edge computing platforms. The review aims at summarizing and obtaining the comprehension of edge and fog computing with respect to its usage, applications and challenges in smart grid by answering the following three research questions:

1. What are the current edge and computing requirements and usage for smart grid (electric power systems) applications?
2. Which smart grid applications currently are benefiting from edge computing implementation?
3. What are the potential challenges with edge computing for smart grid applications?

2 Methodology

After reviewing the literature on edge and fog computing, it was found that there are significant number of studies that have conducted literature review on this field. Most of these studies offer overview of edge and fog computing in terms of principles, architectures and applications. Therefore, the author chose to conduct a systematic literature review in an effort to attain an outline of the edge and fog computing for smart grid applications focusing on real and practical implementations. This review is conducted using the reference manual adapted from [15].

2.1 Data Search Strategy

In the context of this study, the types of publications considered were journal articles, books, book chapters, conference papers and book reviews. Studies relevant to edge and fog computing for smart grid applications were searched using a combination of agreed-upon keywords. The publications were searched based on popular digital repositories which include Google scholar, ScienceDirect, EBSCO, Education Resources Information Center (ERIC), Taylor & Francis, IngentaConnect, Emerald, Institute of Electrical and Electronics Engineers (IEEE) Xplore Digital Library, Computer Society Digital Library (CSDL), Association for Computing Machinery (ACM) Digital Library, Springer Link and Wiley Online Library.

The list of keywords used to define the search string are: edge, fog, mobile, computing, architecture, smart grid, electric power system, application, challenge, integration, orchestration, coordination and issue. To generate the final search term, the two Boolean operators AND and OR were employed to connect the keywords together. A quotation mark is also used for exact text. As a result, the ultimate search strings are:

"Edge computing" AND (("smart grid" OR electric "power system*" OR “smartgrid”) AND (application* OR service*) AND (integration OR orchestration OR coordination OR interoperability OR integration) AND (challenge* OR issue*))
"Fog computing" AND (("smart grid" OR electric "power system*" OR “smartgrid”) AND (application* OR service*) AND (integration OR orchestration OR coordination OR interoperability OR integration) AND (challenge* OR issue*))

This research query was used retrieve publications from IEEE, ScienceDirect, Springer and Arxiv. ACM library does not support a query with Booleans, therefore its search queries were: *+("edge computing")+("smart grid" "challenge" "application")* and *+("fog computing")+("smart grid" "challenge" "application")*

In choosing the publications, the search strings were applied in each of the selected databases in the advanced search option. Irrelevant papers were omitted after filtering the results. Then, inclusion and exclusion criteria were considered to narrow down the results by studying abstracts of the papers. To confirm their inclusion, the remaining papers were read in full-text.

Table 1. A set of inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
1. Papers that explicitly discuss edge and fog computing and their varieties in smart grid applications. 2. Papers that mention and analyze an architectures for the edge and fog computing in smart grid applications. 3. Papers that detail how edge and fog computing are advantageous to an application or a domain, in this case smart grid applications 4. Papers that are focused on presenting present challenges with edge and fog computing and smart grid application integration. 5. Papers that are discussing edge and fog with Internet of Things (IoT) in smart grid applications 6. Papers that are accessible and retrievable. 7. Papers that are from 2015 since edge (and fog) computing is a relatively new paradigm.	1. Papers that do not have edge and fog computing for smart grid applications as a primary study. 8. Papers that are mainly discussing cloud computing or Internet of Things (IoT) issues. 9. Papers that are inaccessible

2.2 Study selection procedure

After publications retrieval, unrelated papers were removed by applying a set of inclusion and exclusion criteria as shown in Table 1.

2.3 Data extraction and Analysis

Papers information were recorded in an Excel form that was created as instructed in the guideline by [15]. The information was used to separate primary studies and align the papers according to research questions. The collected information includes papers' titles, source, and accessibility. The other fields were used for filtering, that is, if titles, abstracts and full-texts meet criteria. A note filter was also included to store comment of why the paper has been retained or removed. The papers that met the specified criteria as Yes were then recorded to a new sheet for addressing the research questions.

The search process was conducted between September and October 2018, with initial total of 830 of articles published between 2004 and 2019. However, in this paper, the search considered only papers published from 2015 to 2019 for analysis. This is due to maturity of these computing technologies started in the early 2015. Articles that were opinion articles, conceptual articles, or technical notes were not considered. Other articles were removed as a result of titles, keywords and abstracts analysis. The paper filtering process is shown in Table 1.

Table 1. Publications filtering process

Digital Repository	Initial Results before filtering	Title and Keyword selected	Abstracts selected	Full Text Selected

ACM	308	144	36	6
IEEE	94	62	41	28
Science Direct	181	51	36	10
Springer	188	65	22	15
Wiley Online	44	26	5	4
Arxiv	15	7	7	7
Results	830	355	147	70

3 Analysis and discussion

3.1 Analysis

Out of the 70 publications chosen for full-text reading, 62 papers were considered as primary studies. They were then mapped into three aforementioned research questions. Table 1 shows the results of the final literature review.

Table 1. Mapping of research questions to publications

Research Question	Publications
1	[6, 16–52]
2	[19, 24, 26, 30, 34, 36, 38, 46, 48, 53–64]
3	[13, 21, 23, 27, 35, 41, 42, 55, 65–69]

As shown in Table 1, edge and fog computing technologies have been increasingly attracting the attention of power system researchers and practitioners. There is significant increase of publications year after starting from 2015. However, it should be noted that, 2019 articles that were considered are those that were scheduled to be published in 2019 when this study was conducted.

Table 1. Publications trend between 2015 and 2019

Digital Repositories	Year				
	2015	2016	2017	2018	2019
ACM, IEEE, Science Direct, Springer, Wiley Online, Arxiv	11	49	148	262	52

3.2 Discussion

Research question one.

Various researchers [3, 14, 16, 21, 70] have proposed features of edge computing that fit to the requirements of smart grid applications implementation. The following are the features: Support for real-time, that is, reducing latency and responsive time [38, 47–51], Support for Scalability [68], Decentralization [6, 16–18, 51, 52, 68], Consistency [19], Heterogeneity [20–22] , Intelligent coordination [23–27] , Optimal design / Resource utilization [28–36], Privacy and Security [16, 17, 37, 39–42], Data Mining and Storage [43–45], Virtualization [46], Energy Efficiency [51, 71].

With regard to supporting real-time applications, Islam and Hashem [38] suggested a hierarchical infrastructure for big data management for customer's real-tine services. Zhang et al. [47] demonstrated application of power internet of thing by taking advantage of reducing dependence on the cloud center.

In the context of scalability, Bakken et al. [68] proposed an architecture that consisted of three layers in terms of ICT platform services, power services, and power applications to reduce stress in power grids. They then reviewed algorithms for enhancing edge services in power grid.

As far as decentralization is concerned, Yan and Su [52] introduced an implantable data storage-and-processing solution for reducing the workload in centralized-based information processing architectures. In their work, researchers Eisele et al. [18] presented a component-based decentralized software platform for resiliency by allowing applications to discover each other.

Intelligent coordination of resources and applications is one of the features of edge computing that has been greatly exploited by researchers to develop smart grid applications. A research work by Wang et al. [27] devised a software based scheme to coordinate tasks for scheduling and collaboration. Moreover , Al-jarood et al. [25], put forward a service-oriented middleware to facilitate effective integration and utilization of computing resources.

Many studies for smart grid applications have well delved in optimal design and resource utilization. Zahoor et al. [28] modelled cloud-fog a hierarchical structure with algorithms for resource management. Another work by Fatima et al. [32] provide a resource allocation model to optimize resources in residential buildings. Similar works can also be found in [34, 72].

Edge and fog computing approaches provide a platform for local computing that can address geo-restriction regulations, local security and privacy effectively compared to cloud computing. Han and Xiao [40] demonstrated the possibility of overcoming big data security challenges in smart grid by proposing a Map-Reduce style algorithm to detect non-technical fraud loss. In their work, Lyu et al. [42] used Gaussian mechanism to preserve privacy during smart meter data aggregation.

Data mining and storage in edge and fog computing help to reduce the burden of accessing large data sets from the central repository. Qureshi et al. [43] designed a strategy based in Map-Reduce to store in-place, partition-based and multi-homing block replica data blocks to edge nodes. Jaradat et al. [45] discussed techniques used for management of big data in smart grids.

Virtualization technologies are vital in both cloud and fog computing approaches by providing abstract platforms for multiple operating systems and applications to be able to run on the same hardware at the same time. A research work by Meloni et al. [46] proposed and validated a Cloud-IoT-based architectural solution for processing measurement data by exploiting virtualization technologies.

When it comes to energy management in edge and fog computing, Aujla and Kumar [71] proposed an energy management scheme for sustainability of cloud data centers in the edge cloud environment using Software Defined Network (SDN). Similarly, a study by Minh et al. [51] proposed a novel service placement mechanism for balancing energy consumption of computing entities.

Research question two.

From the literature, varieties of smart grid applications are improved by edge and fog computing. The applications are: Advance metering [52, 63, 73], Electricity market analysis ([26]), Dynamic analysis and control / state estimation [46], Load and reactive power balance [30, 53, 54, 64], Power system protection / Monitoring [19, 54, 55], Distributed generation / automation ([36, 58, 59]), Data Management [38, 59], Energy Management [24, 34, 48, 60–63].

Research question three.

What are the potential challenges and research issues with the adoption edge computing for smart grid applications?

From the literatures, there still exist a number of potential challenges in the use of edge computing for smart grid applications. The following are the identified challenges and research issues that need the attention of the scholars and stakeholders.

Programming model [27, 68]: The heterogeneity of devices and platforms in edge computing causes difficulties for programmers to develop applications that are cross-cutting. In addition, research effort is needed on how to manage many applications and movement of edge servers, cloud and nodes.

Formal Specification [16]: In complex system and software engineering, formal systems are used to model the interactivity of different components. In smart grid applications, a lot of effort has been on the practical aspects, therefore, attention is lacking on formalism [74, 75].

Security [21, 41, 55, 65]: Despite the promise of edge computing approaches to minimize security issues, there are still some challenges. As data are processed at the edge of the network, attackers could exploit the weak security systems of edge devices. Attackers could also temper with smart gateways. Yu et al. [13] and Abbas et al. [12] have expanded the dimensions of seriousness of security issues in edge and mobile computing. Research is needed to balance real-time requirements and delay due security processing at edge nodes and gateways.

Integration and interoperability [14, 25, 66]: Edge and fog computing systems are mostly heterogeneous. There are always challenges in management of applications running in different platforms. Computational offloading could be difficult to orchestrate due to heterogeneous processor architectures [12]. Research direction on this aspect efficient computational offloading model for real time scenario [67].

Data aggregation [35, 42, 65]: In smart grid, data aggregation is an important process in power analytics for prediction power consumption, network planning and power pricing. The major challenge in data aggregation is privacy and security of measurements. Since aggregation can be done regional-wise, employed techniques can also be an issue due to data integration and consistency. Research is needed on speedy aggregation techniques and workload distribution among nodes.

Edge devices placement planning [67]: Placement of edge nodes and devices should carefully planned to meet computational needs. This is to ensure consistency of connectivity as well as load balancing. Since presence or absence of edge device may influence resource management schemes, research is needed on the policy to ensure efficient distributed workload system.

4 Conclusion

This paper presents a literature review on edge and fog computing and their adoption in smart grid applications. Out of 830 papers, 70 met the specified criteria, and were critically reviewed. From the study, it could be revealed that, currently smart grid applications are being developed to exploit edge-computing technologies. Compared to previous studies that concentrated on the concepts and principles of edge and fog computing generally, this study have shown an increase in the adoption of edge and fog computing approaches in real, practical and field implementation of smart grid applications year after year. However, despite the promises and opportunities of edge computing presented in this paper, there are still some clear challenges related to security, interoperability and common platform of programming models. Moreover, most of the reviewed articles are from developed countries in Europe, American and Asia, which suggest how far they are in smart grid implementations. Future research directions, therefore, need to address the state of smart grid implementations in developing world [76]. Researches should go deeper into determining the cost-effectiveness of computing technologies, accessibility, data management as well as security and privacy as decisions to smart grid move are made. A study could also be widened to include other academic databases to ascertain the practicability of edge computing in smart grid.

References

1. Ekanayake, J., Liyanage, K., Wu, J., Yokoyama, A., Jenkins, N.: Smart Grid: Technology and Applications. (2012).
2. DECC Department of Energy and Climate Change: Smarter Grids: The Opportunity. 30 (2009).
3. Green, R.C., Wang, L., Alam, M.: Applications and trends of high performance computing for electric power systems: Focusing on smart grid. IEEE Trans. Smart Grid. 4, 922–931 (2013).
4. Naveen, P., Ing, W.K., Danquah, M.K., Sidhu, A.S., Abu-Siada, A.: Cloud computing for energy management in smart grid - An application survey. IOP Conf. Ser. Mater. Sci. Eng. 121, (2016).
5. Birman, K., Ganesh, L., Rennessee, R. van: Running Smart Grid Control Software on Cloud Computing Architectures. Comput. Needs Next Gener. Electr. Grid. 1–1-- 1–33 (2011).
6. Boccadoro, P.: Smart Grids empowerment with Edge Computing: An Overview. (2018).
7. Garcia Lopez, P., Montresor, A., Epema, D., Datta, A., Higashino, T., Iamnitchi, A., Barcellos, M., Felber, P., Riviere, E.: Edge-centric Computing. ACM SIGCOMM Comput. Commun. Rev. 45, 37–42 (2015).
8. Chiang, M., Ha, S., Chih-Lin, I., Risso, F., Zhang, T.: Clarifying Fog Computing and Networking: 10 Questions and Answers. IEEE Commun. Mag. 55, 18–20 (2017).
9. Klonoff, D.C.: Fog Computing and Edge Computing Architectures for Processing Data from Diabetes Devices Connected to the Medical Internet of Things. J. Diabetes Sci. Technol. 11, 647–652 (2017).
10. Thien, A.T., Colomo-Placios, R.: A Systematic Literature Review of Fog Computing. Nokobit 2016. 24, 28–30 (2016).
11. Mouradian, C., Naboulsi, D., Yangui, S., Glitho, R.H., Morrow, M.J., Polakos, P.A.: A Comprehensive Survey on Fog Computing: State-of-the-Art and Research Challenges. IEEE Commun. Surv. Tutorials. 20, 416–464 (2018).
12. Abbas, N., Zhang, Y., Taherkordi, A., Skeie, T.: Mobile Edge Computing: A Survey. IEEE Internet Things J. 5, 450–465 (2018).
13. Yu, W., Liang, F., He, X., Hatcher, W.G., Lu, C., Lin, J., Yang, X.: A Survey on the Edge Computing for the Internet of Things. IEEE Access. 6, 6900–6919 (2017).

14. Hussain, M., Alam, M.S., Beg, M.M.S.: Feasibility of Fog Computing in Smart Grid Architectures Abstract : In: Proceedings of 2nd International Conference on Communication, Computing and Networking. pp. 1–11. Springer (2019).
15. Kitchenham, B., Charters, S.: Guidelines for performing Systematic Literature reviews in Software Engineering Version 2.3. (2007).
16. Okay, F.Y., Ozdemir, S.: A fog computing based smart grid model. In: 2016 International Symposium on Networks, Computers and Communications, ISNCC 2016. pp. 1–6 (2016).
17. Dubey, A., Karsai, G., Pradhan, S.: Resilience at the edge in cyber-physical systems. In: 2017 2nd International Conference on Fog and Mobile Edge Computing, FMEC 2017. pp. 139–146. ACM, Austin, Texas, USA (2017).
18. Eisele, S., Mardari, I., Dubey, A., Karsai, G.: RIAPS: Resilient information architecture platform for decentralized smart systems. In: Proceedings - 2017 IEEE 20th International Symposium on Real-Time Distributed Computing, ISORC 2017. pp. 125–132. ACM, Santa Barbara, California (2017).
19. Yang, Z., Chen, N., Chen, Y., Zhou, N.: A Novel PMU Fog Based Early Anomaly Detection for an Efficient Wide Area PMU Network. In: 2018 IEEE 2nd International Conference on Fog and Edge Computing, ICFEC 2018 - In conjunction with 18th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing, IEEE/ACM CCGrid 2018. pp. 1–10. ACM, New Delhi, India (2018).
20. Risteska Stojkoska, B.L., Trivodaliev, K. V.: A review of Internet of Things for smart home: Challenges and solutions. J. Clean. Prod. 140, 1454–1464 (2017).
21. Jiang, R., Lu, R., Choo, K.K.R.: Achieving high performance and privacy-preserving query over encrypted multidimensional big metering data. Futur. Gener. Comput. Syst. 78, 392–401 (2018).
22. Xiao, J., Kou, P.: A hierarchical distributed fault diagnosis system for hydropower plant based on fog computing. In: Proceedings of the 2017 IEEE 2nd Information Technology, Networking, Electronic and Automation Control Conference, ITNEC 2017. pp. 1138–1142 (2018).
23. Tehreem, K., Javaid, N., Bano, H., Ansar, K., Waheed, M., Butt, H.: A Cloud-Fog Based Environment Using Beam Search Algorithm in Smart Grid. Presented at the September 5 (2019).
24. Yaghmaee Moghaddam, M.H., Leon-Garcia, A.: A Fog-Based Internet of Energy Architecture for Transactive Energy Management Systems. IEEE Internet Things J. 5, 1055–1069 (2018).
25. Al-Jaroodi, J., Mohamed, N., Jawhar, I., Mahmoud, S.: CoTWare: A Cloud of Things Middleware. In: Proceedings - IEEE 37th International Conference on Distributed Computing Systems Workshops, ICDCSW 2017. pp. 214–219 (2017).
26. Shahryari, K., Anvari-Moghaddam, A.: Demand side management using the internet of energy based on fog and cloud computing. In: Proceedings - 2017 IEEE International Conference on Internet of Things, IEEE Green Computing and Communications, IEEE Cyber, Physical and Social Computing, IEEE Smart Data, iThings-GreenCom-CPSCom-SmartData 2017. pp. 931–936 (2018).
27. Wang, P., Liu, S., Ye, F., Chen, X.: A Fog-based Architecture and Programming Model for IoT Applications in the Smart Grid. (2018).
28. Zahoor, S., Javaid, N., Khan, A., Ruqia, B., Muhammad, F.J., Zahid, M.: A Cloud-Fog-Based Smart Grid Model for Efficient Resource Utilization. In: 2018 14th International Wireless Communications and Mobile Computing Conference, IWCMC 2018. pp. 1154–1160 (2018).

29. Mishra, J., Sheetlani, J., Reddy, K.H.K., Roy, D.S.: A novel edge-supported cost-efficient resource management approach for smart grid system. Adv. Intell. Syst. Comput. 710, 369–380 (2018).
30. Ismail, M., Javaid, N., Zakria, M., Zubair, M., Saeed, F., Zaheer, M.A.: Cloud-Fog Based Smart Grid Paradigm for Effective Resource Distribution. Presented at the September 5 (2019).
31. Nazir, S., Shafiq, S., Iqbal, Z., Zeeshan, M., Tariq, S., Javaid, N.: Cuckoo Optimization Algorithm Based Job Scheduling Using Cloud and Fog Computing in Smart Grid. Presented at the September 5 (2019).
32. Fatima, A., Javaid, N., Waheed, M., Nazar, T., Shabbir, S., Sultana, T.: Efficient resource allocation model for residential buildings in smart grid using fog and cloud computing. In: Advances in Intelligent Systems and Computing. pp. 289–298. Springer, Cham (2019).
33. Mehmood, M., Javaid, N., Akram, J., Abbasi, S.H., Rahman, A., Saeed, F.: Efficient Resource Distribution in Cloud and Fog Computing. Presented at the September 5 (2019).
34. Ahmad, N., Javaid, N., Mehmood, M., Hayat, M.: Fog-Cloud based Platform for Utilization of Resources using Load Balancing Technique Fog-Cloud based Platform for Utilization of Resources using Load Balancing Technique. (2018).
35. Carvalho, O., Garcia, M., Roloff, E., Carreño, E.D., Navaux, P.O.A.: IoT workload distribution impact between edge and cloud computing in a smart grid application. Commun. Comput. Inf. Sci. 796, 203–217 (2018).
36. Ning, S., Ge, Q., Jiang, H.: Research on distributed computing method for coordinated cooperation of distributed energy and multi-devices. In: 2018 33rd Youth Academic Annual Conference of Chinese Association of Automation (YAC). pp. 905–910 (2018).
37. Alrawais, A., Alhothaily, A., Hu, C., Xing, X., Cheng, X.: An Attribute-Based Encryption Scheme to Secure Fog Communications. IEEE Access. 5, 9131–9138 (2017).
38. Islam, T., Hashem, M.M.A.: A big data management system for providing real time services using fog infrastructure. In: ISCAIE 2018 - 2018 IEEE Symposium on Computer Applications and Industrial Electronics. pp. 85–89 (2018).
39. Beligianni, F., Alamaniotis, M., Fevgas, A., Tsompanopoulou, P., Bozanis, P., Tsoukalas, L.H.: An internet of things architecture for preserving privacy of energy consumption. In: Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion (MedPower 2016). p. 107 (7 .)-107 (7 .) (2016).
40. Han, W., Xiao, Y.: Big data security analytic for smart grid with fog nodes. Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics). 10066 LNCS, 59–69 (2016).
41. Sani, A.S., Yuan, D., Jin, J., Gao, L., Yu, S., Dong, Z.Y.: Cyber security framework for Internet of Things-based Energy Internet. Futur. Gener. Comput. Syst. (2018).
42. Lyu, L., Nandakumar, K., Rubinstein, B., Jin, J., Bedo, J., Palaniswami, M.: PPFA: Privacy preserving fog-enabled aggregation in smart grid. IEEE Trans. Ind. Informatics. 14, 3733–3744 (2018).
43. Qureshi, N.M.F., Siddiqui, I.F., Unar, M.A., Uqaili, M.A., Nam, C.S., Shin, D.R., Kim, J., Bashir, A.K., Abbas, A.: An Aggregate MapReduce Data Block Placement Strategy for Wireless IoT Edge Nodes in Smart Grid. Wirel. Pers. Commun. 1 (2018).
44. Barik, R.K., Gudey, S.K., Reddy, G.G., Pant, M., Dubey, H., Mankodiya, K., Kumar, V.: FogGrid : Leveraging Fog Computing for Enhanced Smart Grid Network. In: INDICON-2017 14TH IEEE India Council International Conference. pp. 1–6 (2017).
45. Jaradat, M., Jarrah, M., Bousselham, A., Jararweh, Y., Al-Ayyoub, M.: The internet of energy: Smart sensor networks and big data management for smart grid. Procedia Comput. Sci. 56, 592–597 (2015).

46. Meloni, A., Pegoraro, P.A., Atzori, L., Benigni, A., Sulis, S.: Cloud-based IoT solution for state estimation in smart grids: Exploiting virtualization and edge-intelligence technologies. Comput. Networks. 130, 156–165 (2018).
47. Zhang, Y., Liang, K., Zhang, S., He, Y.: Applications of edge computing in PIoT. In: 2017 IEEE Conference on Energy Internet and Energy System Integration, EI2 2017 - Proceedings. pp. 1–4 (2018).
48. Chen, Y. Da, Azhari, M.Z., Leu, J.S.: Design and implementation of a power consumption management system for smart home over fog-cloud computing. In: IGBSG 2018 - 2018 International Conference on Intelligent Green Building and Smart Grid. pp. 1–5 (2018).
49. Hussain, M., Alam, M.S., Beg, M.M.S.: Fog Assisted Cloud Models for Smart Grid Architectures - Comparison Study and Optimal Deployment. 1–27 (2018).
50. Kumar, S., Agarwal, S., Krishnamoorthy, A., Vijayarajan, V., Kannadasan, R.: Improving the response time in smart grid using fog computing. In: Advances in Intelligent Systems and Computing. pp. 563–571. Springer Singapore (2019).
51. Minh, Q.T., Nguyen, D.T., Le, A. Van, Nguyen, H.D., Truong, A.: Toward service placement on fog computing landscape. In: 2017 4th NAFOSTED Conference on Information and Computer Science, NICS 2017 - Proceedings. pp. 291–296 (2017).
52. Yan, Y., Su, W.: A fog computing solution for advanced metering infrastructure. In: Proceedings of the IEEE Power Engineering Society Transmission and Distribution Conference. pp. 1–4 (2016).
53. Rabie, A.H., Ali, S.H., Ali, H.A., Saleh, A.I.: A fog based load forecasting strategy for smart grids using big electrical data, http://dx.doi.org/10.1007/s10586-018-2848-x, (2018).
54. Jiang, Z., Shah, H., Rojas-Cessa, R., Grebel, H., Mohamed, A.: Experimental evaluation of power distribution to reactive loads in a network-controlled delivery grid. In: 2018 3rd International Conference on Fog and Mobile Edge Computing, FMEC 2018. pp. 199–204 (2018).
55. Cao, H., Liu, S., Wu, L., Guan, Z., Du, X.: Achieving differential privacy against non-intrusive load monitoring in smart grid: A fog computing approach. Concurr. Comput. Pract. Exp. e4528 (2018).
56. Mousavi, M.J., Stoupis, J., Saarinen, K.: Event Zone Identification in Electric Utility Systems Using Statistical Machine Learning. In: 2018 IEEE/PES Transmission and Distribution Conference and Exposition (T&D). pp. 1–9 (2018).
57. Khan, S., Paul, D., Momtahan, P., Aloqaily, M.: Artificial intelligence framework for smart city microgrids: State of the art, challenges, and opportunities. In: 2018 3rd International Conference on Fog and Mobile Edge Computing, FMEC 2018. pp. 283–288 (2018).
58. Tom, R.J., Sankaranarayanan, S.: IoT based SCADA integrated with Fog for power distribution automation. In: Iberian Conference on Information Systems and Technologies, CISTI. pp. 1–4. ACM, Santa Clara, California (2017).
59. Kumar, N., Zeadally, S., Rodrigues, J.J.P.C.: Vehicular delay-tolerant networks for smart grid data management using mobile edge computing. IEEE Commun. Mag. 54, 60–66 (2016).
60. Naeem, M., Javaid, N., Zahid, M., Abbas, A., Rasheed, S., Rehman, S.: Cloud and Fog Based Smart Grid Environment for Efficient Energy Management. Presented at the September 5 (2019).
61. KaleemUllah Khan, M., Javaid, N., Murtaza, S., Zahid, M., Ali Gilani, W., Junaid Ali, M.: Efficient Energy Management Using Fog Computing. Presented at the September 5 (2019).

62. Naqvi, S.A.A., Javaid, N., Butt, H., Kamal, M.B., Hamza, A., Kashif, M.: Metaheuristic Optimization Technique for Load Balancing in Cloud-Fog Environment Integrated with Smart Grid. Presented at the January (2019).
63. Matta, N., Rahim-Amoud, R., Merghem-Boulahia, L., Jrad, A.: Putting Sensor Data to the Service of the Smart Grid: From the Substation to the AMI. J. Netw. Syst. Manag. 26, 108–126 (2018).
64. Rasheed, S., Javaid, N., Rehman, S., Hassan, K., Robin, R.: A Cloud-Fog Based Smart Grid Model using Max-Min Scheduling Algorithm for Efficient Resource Allocation. In: Springer. pp. 1–14. Springer (2018).
65. Okay, F.Y., Ozdemir, S.: A secure data aggregation protocol for fog computing based smart grids. In: Proceedings - 2018 IEEE 12th International Conference on Compatibility, Power Electronics and Power Engineering, CPE-POWERENG 2018. pp. 1–6 (2018).
66. Aujla, G.S., Chaudhary, R., Kumar, N., Kumar, R., Rodrigues, J.J.P.C.: An Ensembled Scheme for QoS-Aware Traffic Flow Management in Software Defined Networks. In: IEEE International Conference on Communications. pp. 1–7 (2018).
67. El-Sayed, H., Sankar, S., Prasad, M., Puthal, D., Gupta, A., Mohanty, M., Lin, C.T.: Edge of Things: The Big Picture on the Integration of Edge, IoT and the Cloud in a Distributed Computing Environment. IEEE Access. 6, 1706–1717 (2017).
68. Bakken, D., Askerman, A., Srivastava, A., Panciatici, P., Seewald, M., Columbus, F., Jiang, S.: Towards enhanced power grid management via more dynamic and flexible edge computations. In: 2017 IEEE Fog World Congress, FWC 2017. pp. 1–8 (2018).
69. Akram, W., Niazi, M.A.: A formal specification framework for smart grid components. Complex Adapt. Syst. Model. 6, (2018).
70. Hussain, M.M., Alam, M.S., Beg, M.M.S.: Fog Computing in IoT Aided Smart Grid Transition- Requirements, Prospects, Status Quos and Challenges. (2018).
71. Aujla, G.S., Kumar, N.: MEnSuS: An efficient scheme for energy management with sustainability of cloud data centers in edge–cloud environment. Futur. Gener. Comput. Syst. 86, 1279–1300 (2018).
72. Fatima, I., Javaid, N., Nadeem Iqbal, M., Shafi, I., Anjum, A., Ullah Memon, U.: Integration of Cloud and Fog based Environment for Effective Resource Distribution in Smart Buildings. In: 2018 14th International Wireless Communications and Mobile Computing Conference, IWCMC 2018. pp. 60–64 (2018).
73. Nazmudeen, M.S.H., Wan, A.T., Buhari, S.M.: Improved throughput for Power Line Communication (PLC) for smart meters using fog computing based data aggregation approach. In: IEEE 2nd International Smart Cities Conference: Improving the Citizens Quality of Life, ISC2 2016 - Proceedings. pp. 1–4 (2016).
74. Hackenberg, G., Irlbeck, M., Koutsoumpas, V., Bytschkow, D.: Applying formal software engineering techniques to smart grids. In: 2012 1st International Workshop on Software Engineering Challenges for the Smart Grid, SE-SmartGrids 2012 - Proceedings. pp. 50–56 (2012).
75. Rohjans, S., Lehnhoff, S., Schütte, S., Andrén, F., Strasser, T.: Requirements for smart grid simulation tools. In: IEEE International Symposium on Industrial Electronics. pp. 1730–1736 (2014).
76. Young, J.: Smart grid technology in the developing world. Honor. Proj. (2017).