Smart Grid: A Survey of Architectural Elements, Machine Learning and Deep Learning Applications and Future Directions

Navod Neranjan Thilakarathne [1,*], Rohan Samarasinghe [2], Mohan Krishna Kagita [3], Surekha Lanka [3] and Hussain Ahmad [3]

[1] University of Colombo, SRILANKA; navod.neranjan@ict.cmb.ac.lk
[2] University of Colombo, SRILANKA; rohan@ict.cmb.ac.lk
[3] Charles Sturt University, AUSTRALIA; mohankrishna4k@gmail.com
[3] Stamford international university, THAILAND; surekha.lanka@stamford.edu
[3] Gomal University, PAKISTAN; hussaintajazai@gmail.com

* Correspondence: navod.neranjan@ict.cmb.ac.lk

Abstract

In the 21st century, the Smart Grid (SG), also known as the next-generation power grid, arose as a substitute for inefficient power systems, ensuring a reliable and efficient power supply. It is projected to improve the reliability and efficiency of energy distribution while having minimal side effects because it is coupled with modern communication and computation capabilities. The huge infrastructure it possesses, as well as the system's underlying communication network, has resulted in a large number of data that necessitates the use of diverse approaches for proper analysis and decision making. When it comes to analyzing this huge amount of data and generating significant insights from it, big data analytics, machine learning (ML), and deep learning (DL), all play a key role. These insights are useful for anomaly detection, fraud detection, price confirmation, fault detection, monitoring energy consumption, and so on. Hence constant and continuous data analysis is an essential part, of the modern smart grid, for its existence. Inspired by providing a reliable and efficient energy distribution, this paper explores and surveys the smart grid architectural elements, ML and DL based applications, and approaches in the context of SG. In addition in terms of ML and DL based data analytics, this paper highlights the limitations of the current research and, highlights future directions as well.

Keywords: Smart Grid, IoT, Internet of Things, Machine Learning, Deep Learning, Cyber Physical Systems

1.Introduction

Over the years it is evident that , there has nothing changed in the basic structure of the electrical power grid and it is observed that it has become obsolete and ill-suited ; that it cannot cater to the demand and supply in the 21st century [1],[2]. Even though we are in the 21st century, electrical infrastructure has remain unchanged over the years. But the demand for electricity has being risen with the increased consumption and the population. According to the U.S department of Energy, they have stated that consumption and the demand for electricity in the U.S have increased 2.5% annually over the last twenty years [1].Hence it is evident that, this traditional energy distribution approach is

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

ill-suited for catering to the increasing demand and it has many deficiencies such as poor and slow response time, lack of on demand analysis and lack of situational awareness, which ultimately caused to the blackouts happening over past years. In order to overcome the challenges of existing obsolete electrical power grid, the new SG concept has emerged. This is regarded as the next generation electrical power grid which uses two way flows of electricity and information to create an automated and distributed energy delivery network [2]-[6].This SG is also called as intelligent grid or intelligrid. The conventional power grid supplied power to a large number of customers from the central power plant or from central generators, while SG uses bidirectional information and electricity flows to create an integrated and distributed advanced energy supply network. The modern SG relies heavily on the Internet of Things (IoT), which acts as its primary enabler. It also relies heavily on Cyber Physical Systems (CPS) that can track, exchange, and handle information and activities and serve as an integral part of the SG [6]-[8]. Cyber Physical Systems are a mixture of computational and physical characteristics and can be widely found in different domains, including the modern SG [8]-[10].

Basically, SG is a vast electricity network which uses real time intelligent monitoring, communication, control, and self-healing technologies to enable versatile options for prosumers. It's a complex CPS by its very nature and features a centralized approach where few central stations distribute energy to different consumers who are located geographically [10]-[15]. Over the years, energy systems have been developed from traditional power systems to SG's and CPS's in energy [16].

It is no doubt that electricity is vital for the existence of human life, hence this SG requires high reliability where the faith of the country's economies are heavily dependent on the existence of this SG [17]-[21],[18]. The functionality of this modern SG can be broken down into four parts [22]-[29].

1. **Generation:** In this phase electricity is produced in many ways. (e.g. burn of fossil fuels, wind, solar, nuclear reaction)
2. **Transmission:** This transmission of electricity happens though a very high voltage electronic infrastructure.
3. **Distribution:** This consists of distribution of energy to the consumers.
4. **Consumption:** Finally various industries, residents are using electricity for various purposes.

When it comes to the traditional grid outages are often recognized only after consumers report [27], which makes it a time consuming process. Also, it is evident that it is difficult to match generation to demand because utilities do not have clear cutting methods to forecast demand and request demand reduction. As a result, it leads to the generation of excess electricity, which will be costly and will lead to greenhouse gas emissions and waste of energy if not managed well. Also, renewable power sources like wind, solar power, are hard to integrate with the traditional grid as a result of this variable power generation [30]-[36].

In general, SG offers several advantages over traditional power grid. Using the underlying intelligent communication and load shedding which is implemented to flatten the peak demand, it can reduce the need for additional power generation plants to be brought online. With the use of ML and DL approaches to conduct predictive analysis, the utilities may keep power adequately balanced in the modern SG. As new energy storage technologies emerge on the utility scale, intelligent demand prediction would also be benefit from the inclusion of these devices [37]-[39]. In the next subsection we discuss about the main enabler technology that the SG is built upon; that is Internet of Things.

A. Internet of Things in the Smart Grid

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

The ongoing rapid advancement of the Internet of Things [33]-[39],[40], provides solutions to overcome the emerging challenges of SG. The SG uses IoT enabled technologies for creating various intelligent services that are essential for its effective functioning [40]. Nevertheless, it is evident that, most of the development aspects of SG have enhanced by IoT enabled applications. The typical IoT architecture of SG comprises of three main layers. That is.

1. Perception layer
2. Network layer
3. Application layer

These IoT applications/solutions are used for various purposes in the modern SG, such as monitoring of power transmission lines, management of smart homes, management of electric vehicles, and smart patrols. In addition, IoT technologies play an important role in SG, such as network design, network security management, operation and maintenance, data collection, security monitoring, and user interaction. Potential IoT applications can be extended to all facets of the power system, including generation, transmission, transformation, distribution and utilization of electricity.

B. The Basic Architecture of Smart Grid

The modern SG includes automated control, modern energy management techniques, novel communication infrastructure, power converters, sensing and measuring technologies and the underlying infrastructure capable of facilitating for reliable and efficient delivery of energy. Importantly this new SG is much different and complex than the traditional one. The traditional grid lacks communication capabilities whereas this modern SG infrastructure comprises of advanced controls and distributed delivery system, as depicted in Figure. 1.

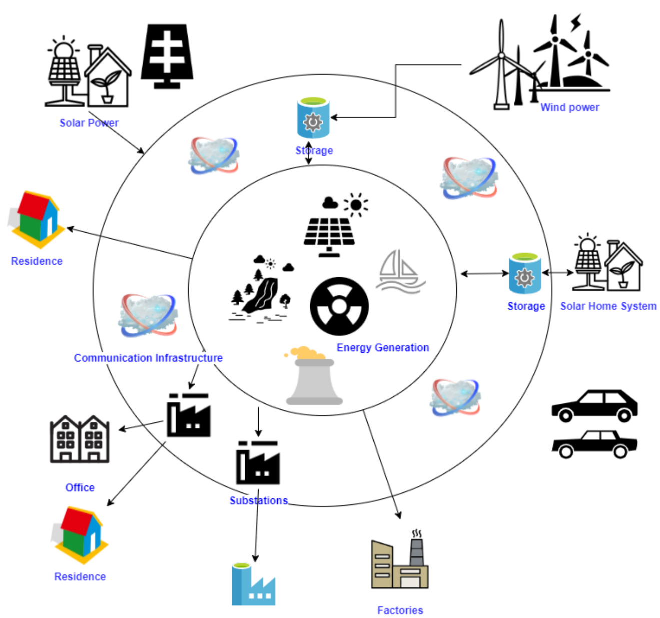

Figure 1. A basic structure of SG.

As depicted in Figure. 1 various components of the grid system, are linked together with sensing nodes and communication paths to provide interoperability between them. In the SG real time information and data analytics becomes the key factor for ensuring consistent and reliable delivery of energy, from energy generating units to the

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

customers. In case of equipment failures, natural disasters, and power disturbances and outages SG provides protection by real time condition monitoring, real time diagnostic, and outage monitoring. Especially for the existence of SG, automated control, and for billing purposes secure information transportation and storage is highly required. As many Internet connected devices are present and connected to the communication network, forming a large IoT network, efficient security mechanisms should also be devised in order to avoid malicious cyber-attacks, and to enhance the security of SG [30]-[39]. In the second section of this paper, we describe various aspects of ML and DL applications for SG. Then in the following section, we describe the future directions, and in the third section, we describe about the limitations of the current research. Finally, we conclude our paper with the conclusion, summarizing key findings.

2. Machine Learning and Deep Learning Applications for Smart Grid

In the context of SG, ML and DL appeared as an innovative tools for the analysis of the big data generated by the underlying IoT devices, critical infrastructure, and the massive communication networks in order to properly analyze and make timely decisions to run the SG without any hassle. Big data refers to large amounts of data that require more advanced technologies to acquire, curate, manage, and analyze [8],[12],[17]. Continuous learning and predictions from available data are referred to as machine learning (ML). It is made up of many algorithms that analyze data and make choices or predictions about the present situation using a set of instructions. On the other hand, DL algorithms [28]-[30] are a subfield of ML that deals with algorithms inspired by the structure and function of the human brain. ML and DL functionalities in the context of SG includes predicting about,

- Energy generation
- Price
- Energy consumption
- Fault detection
- Sizing
- Network anomaly detection
- Security breach detection
- Fraud detection
- Optimum schedule
- Stability of the SG

Figure. 2 depicts the various ML algorithms that is used for data analysis, in the context of SG.

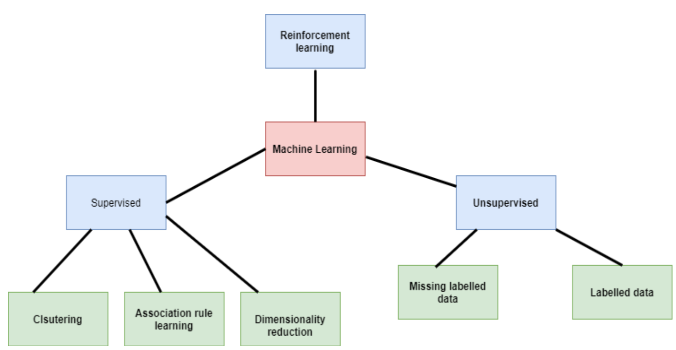

Figure 2. Categories of ML algorithms.

In the following next two subsections, we discuss key application areas of ML and DL, in the context of SG. That is about; energy forecasting and the protection and the security of SG. Then in the next subsection, we discuss the rest of the ML and DL application areas that are devised in the context of SG.

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

A. ML and DL Applications in Energy Forecasting

Solar energy is considered as one of the major renewable energy source which is actually threatened by many impediments such as seasonal changes, weather condition, topographic elevation and etc. As a result, clear forecasting is required to obtain accurate details of energy generation. Further wind power is also considered as a rapidly growing energy source. Same like solar power, wind power poses many obstacles especially when it comes to power generation and transmission, such as varying wind speed which leads to fluctuation of the output in the wind power plant. Such things will lead to instability of the SG, and require accurate forecasting where we can use this ML and DL forecasting models to forecast such things. In the following Table 1, we summarizes the ML and DL applications that are introduced and devised for SG energy forecasting.

Table 1 . ML and DL applications for energy forecasting

Reference	Year	ML/DL Technique	Application
[20]	2006	Adaptive neuro-fuzzy inference	Authors have predict the short term wind for power generation
[21]	2006	Recurrent neural network	This model deals with the problem of long-term wind speed and power forecasting based on meteorological information
[22]	2012	Fuzzy modeling	A model for short term wind farm power output , is introduced
[23]	2013	k-nearest neighbor (k-NN) classification	This model deals with very short term wind speed prediction
[24]	2013	Least median square (LMS), multilayer perceptron (MLP) and support vector machine (SVM)	This devised application , deals with the improving the accuracy for solar power prediction
[25]	2014	Extreme Learning Machine	This study focuses on predicting the daily global solar radiation
[26]	2016	Artificial neural networks (ANN) and support vector regression (SVR)	This study focuses on predicting the energy productions from a solar photovoltaic (PV) system
[27]	2017	Regression tree, random forest, gradient boosting	This study focuses on predicting the solar irradiance
[28]	2016	Support vector regression (SVR), gradient boosted regression (GBR), Random forest regression (RFR)	This study focuses on predicting the solar radiation values
[29]	2018	Weighted regularized extreme learning machine	This model focuses in improving the wind speed prediction accuracy

B. ML and DL Applications for Securing the SG

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

Before discussing about the, applications of securing SG using ML and DL, first we discuss about the security objectives and security requirements , that every SG must met.

1) Smart Grid Security Objectives

As discussed on [4],[7], following are the three main security objectives that an every SG should meet.

- Confidentiality: This ensures only authorized personnel will have the access to the critical and confidential information which is really necessary for preventing unauthorized disclosure of information.
- Integrity: This ensures data will not be tampered during the storage or the trans-mission which may lead to incorrect decisions in energy management.
- Availability: This ensures timely and reliable access to information whenever it is necessary and this guarantees the system reliability.

In order to ensures a timely and reliable delivery of energy, these three main key security objectives needed to be met.

2) Security Requirements

Apart from the previously mentioned high level security objectives, following security requirements needed to satisfy for covering most aspects of the physical security, network security and the cyber security in the context of SG [4],[7],[25].

- Identification and authentication: SG network infrastructure comprises of millions of devices and users, which should be verified and authenticated before granting access to the network and critical resources.
- Access control: This ensures that resources are only accessed by verified authorized personnel only.
- Secure communication protocol: As the information that flows contains, timely critical information, appropriate secure protocols must be devised ,in order to guarantee the security of communication.
- Attack detection: As opposed to the traditional power grid, SG comprises of massive communication networks spawns over a large geographic area. Therefore it is impossible to say any part of the network is not vulnerable to network attacks. Therefore mechanisms should be placed to perform filtering, testing and comparison of network traffic to detect and identify any anomalies present and then to take timely actions.
- Self-healing: In the presence of an attack (e.g.: Denial of Service) network and the other mission critical devices must have the ability of self-healing for continuing, its work even under an attack.

These security requirements along with the objectives will empower the smart grid with adequate security capabilities for withstanding against most of the cyber-attacks and successfully mitigating them in a timely manner.

3) Example ML and DL Applications

The SG requires a higher degree of consistent network connectivity to function smoothly. This constant access to network connectivity, poses huge potential to open up for new vulnerabilities that comes through the network [6],[9],[31],[32],[67]-[70]. In the following Table 2, we summarizes the ML and DL applications that is introduced and devised to secure SG.

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

Table 2 Machine learning applications for securing Smart Grid.

Reference	Year	ML/DL Technique	Application
[1]	2019	Unsupervised machine learning techniques	A scalable anomaly detection engine that is suitable for differentiating cyber-attacks, is introduced.
[2]	2014	Support vector machine	This application focuses on identifying and detecting stealthy attacks
[3]	2015	Combination of supervised and semi-supervised techniques	This application focuses on classification of measurements as being either secure or attacked using the underlying data
[4]	2014	Artificial neural network	This application focuses in examining energy consumption data to report energy fraud
[5]	2017	Wide and deep convolutional neural networks	This application focuses on analysis of data for detecting electricity theft
[6]	2018	Recurrent Neural Networks	This application focuses on detecting false data injection (FDI) attacks on SG's
[7]	2018	Support vector machine	This application focus on detecting covert cyber deception assault attacks from the data that are collected through SG communications network
[8]	2017	Random forest, decision trees, neural networks, support vector machines and naive bayes classification	Intrusion attack detection based on the datasets gathered from synchrophasor devices is introduced.
[9]	2019	Isolation forest	This application focus on detecting covert data integrity assaults in SG communications networks
[10]	2019	Recurrent neural networks	This application focus on detecting fraudulent transactions in the block chain based energy network and network attacks
[11]	2017	Gaussian mixture model	A statistical anomaly detection approach for detecting false data injection attacks is introduced.
[12]	2015	Kalman filter estimation ,Chi-square detector and cosine similarity matching	This application focus on detection of attacks in smart grids communication systems
[13]	2016	Artificial neural network	Contextual anomaly detection for SG is introduced.
[14]	2019	k-nearest neighbors and support vector machine	Detection of stealthy False data injection attacks

C. Other ML and DL Application Ares for SG

The intention of this subsection is to, discuss the rest of the application areas that ML and DL can be used, other than security and energy generation forecasting, based on the existing literature. In addition, we also describe about how this ML and DL are used with other enabling technologies like Cloud Computing, Blockchain, Fog computing, Edge computing, and Big data. Table 3 , summarizes the rest of the areas that ML and DL based applications are introduced and devised.

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

Table 3 Other ML and DL application ares for SG.

Reference	Year	Application
[16]	2020	To forecast the stability of the SG, an unique multidirectional long short term memory (MLSTM) technique is introduced, which employs gated recurrent units (GRU), standard LSTM, and recurrent neural networks (RNN)
[30]	2019	For SG, a unique deep learning and blockchain based energy framework [26,27] is presented. For identifying network threats and fraudulent transactions, it uses a recurrent neural network.
[31]	2020	A framework is introduced that uses sensor processing, smart meter readings, machine learning, and blockchain to detect electricity use irregularities correctly and timely.
[32]	2013	A scalable software platform for the SG CPS which integrated with cloud technologies [34], is introduced. It contains scalable machine learning models trained over massive datasets for agile demand forecasting
[33]	2020	A novel hybrid artificial intelligence classification method focus on the charging behavior profile of Electronic vehicles (EV) based on cloud computing and fog computing is introduced. Through this classification method, target EVs can be accurately identified.
[34]	2020	This study focuses on providing IoT big data analytics with fog computing for household energy management in SGs.

3. Future directions

In the context of SGs, machine learning and deep learning technologies are surely a wonderful way to sift through huge data and extract relevant information that can greatly aid in the recognition of demand and generation trends, generation forecasts, and control. A variety of ways have already been published in the literature, and more unique strategies are being proposed and designed for enhancing the accuracy and performance of analysis. The following section depicts various future directions that we can anticipate in the coming years. It is evident, that comprehensive research and development activities needed to be done to increase the interoperability be-tween devices, data analytic tools and data repositories in SG [34],[42],[60]-[65],[70]-[74].

1. Utilization of heterogeneous data from various sources
   It is believed that in the future there will be advanced applications that can use multiple sources of big data which can help in assessing the dependence of critical infrastructure on power grids. They will effectively be help to uncover crucial hidden information and generate meaningful insights [66].

2. Advancements of predictive algorithms
   In addition to exploiting fine-grained patterns within the data, advanced artificial intelligence based techniques such as DL are important to make the decision process less reliant on human intervention. However underlying SG data will continue to grow with the time. Therefore, the scalability of the ML and DL models will be a huge concern and play a critical role in the future SG data analytics [66].

3. Integrations with enabling technologies
   For better efficiency, scalability, security, cost reduction, and performance ML and DL based data analysis algorithms will integrate with enabling technologies like Cloud, Blockchain, Fog computing, and Edge computing.

4. Integration with real time control and operations
   Data analytics should be integrated into real time analytics, so it can provide real time situational awareness in order to run the grid continuously. Therefore future research and development activities need to put more weight on this.

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

4. Limitations

Analysis of the underlying data is the key to identify meaningful information and resolve many challenging problems that cannot be solved by conventional methods. But because of the intense nature and the massive infrastructure, this ML and DL based applications may have problems like learning from imbalanced data, difficulties in interpretation and difficulties in transfer learning, etc. When it comes to the security aspect of the SG, it is still under development and still there are lot of research activities are being carried out. It is noted that security has to be an integral part of SG. The SG comprises of reinforced communication network architecture which includes heterogeneous devices and protocols that ultimately connect with the Internet for forming a massive network. Therefore SG needs sound security solutions which explicitly designed for distinct network applications and infrastructure. Thus it makes cyber security a very fruitful and demanding research topic in the context of SG. It is no doubt that, SG as a vital infrastructure requires highest degree of protection, hence a comprehensive architecture with safety built in from the sketch is needed.

5. Conclusions

Big data analytics in the SG is a new field of research that has drawn highest attention from the government, academia, and the industry. In this paper, we surveyed and summarized ML and DL based applications that are introduced and devised in the context of the SG. The interconnected devices in the SG and the data they generate give rise to the desperate necessities of proper analysis, as the value it holds. Based on our review we have noted that regular data analysis is indeed essential for the existence of SG as to predict and forecast about various aspects. We also found that currently ML and DL based models are used in various aspects of SG such as fault detection, anomaly detection, energy forecasting, fraud detection and etc. In order to provide a brief review, findings of this study were provided summarizing the key ML and DL based applications based on the literature, including the future directions, limitations and with the key enabling technologies. We hope our study will be an assistance for interested researchers and other personnel who are working in the research areas of SG.

Funding: “This research received no external funding”

Conflicts of Interest: “The authors declare no conflict of interest.”

References

1. Karimipour, H., Dehghantanha, A., Parizi, R. M., Choo, K. K. R., & Leung, H. A deep and scalable unsupervised machine learning system for cyber-attack detection in large-scale smart grids. IEEE Access, 7, 80778-80788. (2019).
2. Esmalifalak, M., Liu, L., Nguyen, N., Zheng, R., & Han, Z. Detecting stealthy false data injection using machine learning in smart grid. IEEE Systems Journal, 11(3), 1644-1652. (2014).
3. Ozay, M., Esnaola, I., Vural, F. T. Y., Kulkarni, S. R., & Poor, H. V. Machine learning methods for attack detection in the smart grid. IEEE transactions on neural networks and learning systems, 27(8), 1773-1786. (2015).
4. Ford, V., Siraj, A., & Eberle, W. Smart grid energy fraud detection using artificial neural networks. In 2014 IEEE Symposium on Computational Intelligence Applications in Smart Grid (CIASG) (pp. 1-6). IEEE. (2014).
5. Zheng, Z., Yang, Y., Niu, X., Dai, H. N., & Zhou, Y. Wide and deep convolutional neural networks for electricity-theft detection to secure smart grids. IEEE Transactions on Industrial Informatics, 14(4), 1606-1615. (2017).
6. Ayad, A., Farag, H. E., Youssef, A., & El-Saadany, E. F. Detection of false data injection attacks in smart grids using recurrent neural networks. In 2018 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT) (pp. 1-5). IEEE. (2018).

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

7. Ahmed, S., Lee, Y., Hyun, S. H., & Koo, I. Feature selection–based detection of covert cyber deception assaults in smart grid communications networks using machine learning. IEEE Access, 6, 27518-27529. (2018).
8. Vimalkumar, K., & Radhika, N. A big data framework for intrusion detection in smart grids using Apache Spark. In 2017 International Conference on Advances in Computing, Communications and Informatics (ICACCI) (pp. 198-204). IEEE. (2017).
9. Ahmed, S., Lee, Y., Hyun, S. H., & Koo, I. Unsupervised machine learning-based detection of covert data integrity assault in smart grid networks utilizing isolation forest. IEEE Transactions on Information Forensics and Security, 14(10), 2765-2777. (2019).
10. Ferrag, M. A., & Maglaras, L. DeepCoin: A novel deep learning and blockchain-based energy exchange framework for smart grids. IEEE Transactions on Engineering Management. (2019).
11. Foroutan, S. A., & Salmasi, F. R. Detection of false data injection attacks against state estimation in smart grids based on a mixture Gaussian distribution learning method. IET Cyber-Physical Systems: Theory & Applications, 2(4), 161-171. (2017).
12. Rawat, D. B., & Bajracharya, C. Detection of false data injection attacks in smart grid communication systems. IEEE Signal Processing Letters, 22(10), 1652-1656. (2015).
13. Kosek, A. M. Contextual anomaly detection for cyber-physical security in smart grids based on an artificial neural network model. In 2016 Joint Workshop on Cyber-Physical Security and Resilience in Smart Grids (CPSR-SG) (pp. 1-6). IEEE. (2016).
14. Sakhnini, J., Karimipour, H., & Dehghantanha, A. Smart grid cyber-attacks detection using supervised learning and heuristic feature selection. In 2019 IEEE 7th International Conference on Smart Energy Grid Engineering (SEGE) (pp. 108-112). IEEE. (2019).
15. Hink, R. C. B., Beaver, J. M., Buckner, M. A., Morris, T., Adhikari, U., & Pan, S. Machine learning for power system disturbance and cyber-attack discrimination. In 2014 7th International symposium on resilient control systems (ISRCS) (pp. 1-8). IEEE. (2014).
16. Alazab, M., Khan, S., Krishnan, S. S. R., Pham, Q. V., Reddy, M. P. K., & Gadekallu, T. R. A Multidirectional LSTM Model for Predicting the Stability of a Smart Grid. IEEE Access, 8, 85454-85463. (2020).
17. Thilakarathne, N. N. Security and Privacy Issues in IoT Environment. International Journal of Engineering and Management Research, 10.(2020).
18. Thilakarathne, N. N., Kagita, M. K., & Gadekallu, D. T. R. The Role of the Internet of Things in Health Care: A Systematic and Comprehensive Study. International Journal of Engineering and Management Research, 10(4), 145-159. (2020).
19. Kagita, M. K., Thilakarathne, N., Rajput, D. S., & Lanka, D. S. A Detail Study of Security and Privacy issues of Internet of Things. arXiv preprint arXiv:2009.06341.(2020).
20. Potter, C. W., & Negnevitsky, M. Very short-term wind forecasting for Tasmanian power generation. IEEE Transactions on power systems, 21(2), 965-972. (2006).
21. Barbounis, T. G., Theocharis, J. B., Alexiadis, M. C., & Dokopoulos, P. S.Long-term wind speed and power forecasting using local recurrent neural network models. IEEE Transactions on Energy Conversion, 21(1), 273-284. (2006).
22. Zhu, B., Chen, M. Y., Wade, N., & Ran, L. A prediction model for wind farm power generation based on fuzzy modeling. Procedia Environmental Sciences, 12, 122-129. (2012).
23. Yesilbudak, M., Sagiroglu, S., & Colak, I. A new approach to very short term wind speed prediction using k-nearest neighbor classification. Energy Conversion and Management, 69, 77-86.(2013).
24. Hossain, M. R., Oo, A. M. T., & Ali, A. B. M. S. The combined effect of applying feature selection and parameter optimization on machine learning techniques for solar Power prediction. American Journal of Energy Research, 1(1), 7-16. (2013).

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021

25. Salcedo-Sanz, S., Casanova-Mateo, C., Pastor-Sánchez, A., & Sánchez-Girón, M. Daily global solar radiation prediction based on a hybrid Coral Reefs Optimization–Extreme Learning Machine approach. Solar Energy, 105, 91-98.(2014)
26. Li, Z., Rahman, S. M., Vega, R., & Dong, B. A hierarchical approach using machine learning methods in solar photovoltaic energy production forecasting. Energies, 9(1), 55. (2016).
27. Voyant, C., Notton, G., Kalogirou, S., Nivet, M. L., Paoli, C., Motte, F., & Fouilloy, A. Machine learning methods for solar radiation forecasting: A review. Renewable Energy, 105, 569-582. (2017).
28. Gala, Y., Fernández, Á, Díaz, J., & Dorronsoro, J. R. Hybrid machine learning forecasting of solar radiation values. Neurocomputing, 176, 48-59. (2016).
29. Wang, J., Wang, Y., & Li, Y. A novel hybrid strategy using three-phase feature extraction and a weighted regularized extreme learning machine for multi-step ahead wind speed prediction. Energies, 11(2), 321. (2018).
30. Ferrag, M. A., & Maglaras, L. DeepCoin: A novel deep learning and blockchain-based energy exchange framework for smart grids. IEEE Transactions on Engineering Management.(2019).
31. Li, M., Zhang, K., Liu, J., Gong, H., & Zhang, Z. Blockchain-based Anomaly Detection of Electricity Consumption in Smart Grids. Pattern Recognition Letters. (2020).
32. Simmhan, Y., Aman, S., Kumbhare, A., Liu, R., Stevens, S., Zhou, Q., & Prasanna, V. Cloud-based software platform for big data analytics in smart grids. Computing in Science & Engineering, 15(4), 38-47.(2013)
33. Shen, Y., Fang, W., Ye, F., & Kadoch, M. EV charging behavior analysis using hybrid intelligence for 5G smart grid. Electronics, 9(1), 80. (2020).
34. Singh, S., & Yassine, A. IoT big data analytics with fog computing for household energy management in smart grids. In International Conference on Smart Grid and Internet of Things (pp. 13-22). Springer, Cham. (2018).
35. Thilakarathne, N. N. (2021). Review on the Use of ICT Driven Solutions Towards Managing Global Pandemics. Journal of ICT Research & Applications, 14(3).
36. Thilakarathne, N. N., Kagita, M. K., & Priyashan, W. M. (2022). Green Internet of Things: The Next Generation Energy Efficient Internet of Things. In Applied Information Processing Systems (pp. 391-402). Springer, Singapore.
37. Priyashan, W. M., & Thilakarathne, N. N. (2020). IIoT framework for sme level injection molding industry in the context of industry 4.0. future, 16, 17.
38. Gopal, R., Parthasarathy, V., Kumar, M. R., & Hemalatha, S. Drap Algorithm for Energy-efficient Malicious Node Detection in Wireless Sensor Networks.
39. Mahendran, R. K., & Velusamy, P. (2020). A secure fuzzy extractor based biometric key authentication scheme for body sensor network in Internet of Medical Things. Computer Communications, 153, 545-552.

DOI: 10.5281/zenodo.5202741
Received: March 13, 2021 Accepted: June 10, 2021