A Review on the Efficiency Increment in a Power System Using Smart Grid Technologies

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***Abstract*— It is known that there is huge amount of power loss from production to end users in a power system. In the literature, it is mentioned that 33% of the generated energy is only delivered to the end users and 2/3 of it is used as the primary energy and therefore released as the waste energy. Therefore, many countries in the Europe has planned to reduce lost energy to 50%. On the other hand, the smart grid technology plays unavoidable significant role in the power system from generation to the end users in order to provide efficient, reliable, safe and controllable energy for the users, prosumers, policymakers, and system operators. This paper introduces current smart grid technologies and their impacts on the efficiency increment in a power system.**

Keywords: Efficiency increment, smart grid, power factor, inverter tests, power inverter standards

I. Introduction

Generation, transmission, and distribution of the electrical energy systems are known as a power system [1]. Generation unit consists of energy sources like solar energy, wind energy, diesel generator, hydropower systems, biomass energy, geothermal energy, transformers and so on. Likewise, transmission unit includes many power switches, breakers, reactive power compensation units and transmission lines as the distribution units incorporates transformer, power switches, and distribution lines [2-4].

Due to the numerous numbers of component used in a power system, there is huge amount of power losses from production to end users. It is mentioned in Ref. [5] that 33% of the generated energy is only delivered to the end users and 2/3 of it is used as the primary energy and therefore released as the waste energy. So that some countries in the Europe has planned to reduce lost energy to 50%.

Increasing energy consumption of nations due to advancing technology and the environmental problems caused by the production of electrical energy based on fossil fuels with limited capacity have revealed the need to modernize traditional electricity grids [6]. Traditional mechanical grids with centralized power generation, one-way information and power flow have been incorporated with the information and communication technologies in order to make the power system as the smart grid system. This combination makes the smart grid technology to play unavoidable significant role in the power system from generation to the end users in order to provide efficient, reliable, safe and controllable energy for the users, prosumers, policymakers, and system operators [7-9]. Thanks to the fact that smart grids facilitate the grid integration of renewable energy sources and battery storage, it has led to the existence of many prosumers with small power values. Figure 1 shows the basic smart grid system.

The smart grid presents many simplicities for users and utilities. First of all, the remote reading is allowed by smart grid technology therefore the monitoring and shedding of loads in urgent situations are easily provided. Remote reading and control, which is widely used in smart grids, allows increasing the data density of the power system. In addition, smart grids make available the demand forecasting and management by using the previous consumption and generation data [10-11]. Data transmission methods, communication technologies and security issues have been investigated from different aspects in the smart grid environment. In this respect, smart metering is of great importance in energy generation, transmission, and distribution. For example, by determining critical load thresholds, subscribers can be prevented from being de-energized in case of power shortage in the grid [12-14]. In addition, thanks to the smart grid's facilitating the integration of renewable energy sources into the grid and energy storage, the AC power system is supported by DC power and the interruptions that may occur can be prevented. In addition to increasing grid reliability, energy storage enables different applications in smart grids such as electric vehicles, energy policies and power system management [15-17].

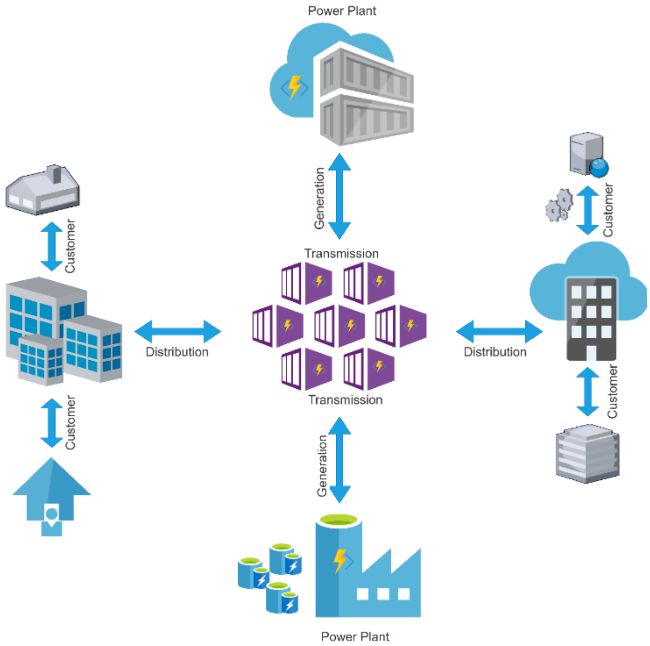

Fig. 1. Smart grid basic

On the other hand, the fact that many small power consumers are also producers at the same time and they can cause big problems such as voltage and frequency fluctuation in the grid. Therefore, the impacts of distributed energy sources connections to the grid and the smart inverter mitigating these adverse effects attract many researcher [18]. The smart inverter is one of the multifunctional power electronic systems used to convert DC to AC power. The smart inverter plays an important role in the efficient and safe operation of a grid-connected solar or wind energy system [19]. Many researchers have presented the usage of the smart inverter in various fields [20-24]. This paper presents the conditions used in the analyzes of smart inverter grid support functions. For this purpose, it is checked whether comprehensive, uniform and consistent test methods are provided as much as possible. The four key items taken from the tests are showed in the below Fig. 2[25].

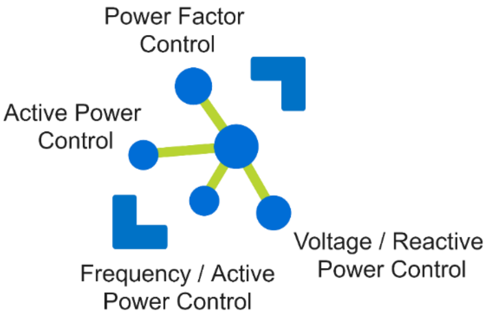

Fig. 2. Basic test methods [25]

Due to many reasons such as the development of technology and the increase in electronic devices used, capacity limitations of electricity production, increasing population, and climatic conditions, the electrical energy distribution network becomes very complex, but it also brings along many problems such as system slowdown, power cuts, and noise in the system. For this reason, a smart network is needed in order to develop the network, that is, to enable the system to be used more efficiently, reliably and quickly. For this reason, many tests and factors are used to support the smart network [26].

Power factor in a power system has a significant effect on energy saving. Low power factor means high reactive current drawn from the grid that reduces the active current capacity of the power system. So that, systems with high reactive current draw will increase the cost and power losses of the network. On the other hand, high power factor decreases the reactive current and increase the active current drawn from the grid. Therefore, the system will be more efficient and the cost will be reduced. Another important point is that the delay of the power factor correction will cause the power losses in the network to increase. In order to increase the stability of the system, several tests performed to fix the power factor play important roles like minimizing power losses in the smart network, and creating more reliable and fast power transmission environment [27].

Another important issue is that especially if renewable energy systems are integrated into the grid, they cause fluctuations in frequency and voltage. So that, it is important to stabilize the voltage and frequency in order to mitigate these fluctuations. Power electronics technologies are mostly used for a smooth grid interactive inverter that are required to be tested in order to meet several requirements. These tests include some functions while providing energy transmission to a network. These functions include situations such as adapting to frequency and voltage changes in the system.

Thus, voltage/reactive power test, frequency/active power test, voltage/active power test and active/reactive power test are done in order to balancing the active power, minimizing the frequency fluctuation, and contributing the reliability and infrastructure of the power grid [28].

II. Material and Methods

The customers undertake responsibility for increasing energy efficiency in smart grids. All subscribers in the grid can contribute to the energy delivering efficiently, especially with the selection of controllable efficient equipment and its use at the appropriate time. By changing their current energy usage habits, consumers will support the grid to be more secure and minimize technical losses. Energy efficient use of resources within the scope of energy supply and demand from the grid with average energy consumption can be made with smart grid management. The power and information flow of traditional grid is given in Fig. 3 [29]. The power flow, which is from the central power generating stations to the consumer, and the information flow are unidirectional.

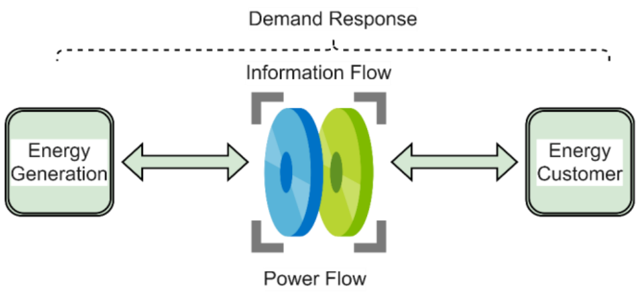

Fig. 3. Power and information flow under the smart grid [29]

Considering the grid, energy generation, transmission, and distribution as a whole, smart grids provide energy efficiency by giving priority to renewable energy sources. If renewable energy is produced more efficiently under current conditions, energy storage is an alternative idea that can increase efficiency. Giving the precedence to renewable energy sources and energy storage applications will bring a dynamic structure to distribution networks, the supply-demand balance will be maintained, and carbon emissions will be reduced [30-32]. Promoting demand-side management and demand response programs in smart grids involving Information and Communication Technologies is an important priority. The operating stability of grid and user efficiency can be achieved by protecting the grid from overload with various price and incentive-based demand response programs [33-34].

The smart meter is one of the important smart grid technologies used to increase energy efficiency. In literature existing studies to increase energy efficiency, it has been determined that the feedback of the energy used at home to the consumers through the screens leads to a reduction in energy consumption. In this context, one of the most important tasks of smart meters is to notify consumers of the energy profile they use at any time [35]. In addition, by using the data communication networks in the structure of smart grids, it can offer the consumer to evaluate the energy usage data according to the region. In this way, consumers can be motivated to use energy efficiently. In addition to real-time time display of energy usage, smart meter has the capability of bidirectional communication with the center and remote disconnection [36].

Another technology to increase efficiency in smart grids is demand side management, which consists of two parts as load management and demand management. Load management means that the electrical loads used are categorized and used at certain times, or in other words, their usage time is shifted [37-39]. In this way, by changing the load profile of the network, the total peak load of the system can be reduced, and the load factor can be improved. Demand management means optimizing consumption values according to the price and reliability needs of customers. Studies show that demand management can reduce total peak load by 14% and total consumption by 8% [40].

There are several different tests for PV inverters such as safety, grid-code, Electromagnetic Compatibility (EMC), efficiency and power quality. Especially depending on the country, some parameters can be changed due to different power grid standards. However, some standard tests are essential for all countries such as EMC tests and Grid-code tests.

Electromagnetic Compatibility test [41] means it should not adversely affect the operation of other electronic devices around the emissions transmitted or emitted by the inverters to the system. In other words, it contributes by making the necessary tests to minimize the effect the operation of others. EMC has international standards, which accepted by all such as The Federal Communications Commission (FCC) and Europe International Special Committee on Radio Interference (CISPR). Both standards are very similar parameters to each other. For this reason, it is thought that meeting one of the two standards will also meet the requirements of the other standard. Furthermore, specification standards are different for conducted and radiated emissions.

The grid code is a technical specification that defines standards and parameters according to certain rules to ensure the safe and smooth functioning of the electrical system [42]. In fact, it covers many issues such as evaluating any electrical effect for the distribution and transmission of electrical energy on electrical systems, checking or simulating that it contains the necessary parameters and standards. Grid-code test is very basic and important test to analysis and control the several different points related about the grid such as frequency stability, voltage stability, reactive power capability, grid management, dynamic grid support etc. It is standard test for safety because, the technology is developing rapidly and its advanced smart inverters contribute to the electricity grid in many ways, such as balancing active power and keeping the frequency constant etc. Thus, grid-code test is necessary for all type inverters and electric devices to improve system reliability and efficiency.

III. Discussion

Grid integration of renewable energy sources at low power level does not pose a significant problem for the power system. However, many distributed energy sources and high-capacity grid connections cause significant problems. Consequently, the grid connection of large-scale distributed energy resources affects the power flow in the power system and so they have to perform special requirements pertaining to electrical properties. There are internationally accepted standards such as CA Rule 21, UL 1741, IEEE 1547 and IEEE 1547.1 in the USA, and IEC 61850 in Europe to test the grid support functions of inverter and regulate the grid connection of distributed energy sources [43-48]. Although the standards accepted internationally are applied for the tests of the grid support functions of inverter, each country applies the electrical requirements according to its own power system. Thus, a valuable standard for inverter test systems has been established and a power system has been obtained in which a renewable energy sources can be safely connected. Connecting distributed energy sources to the grid by fulfilling the determined electrical characteristics can regulate the power flow, which is one of the most important problems of power systems. Solving the power flow problem means reducing losses and minimizing voltage deviations. To test the functions of grid-connected inverters, it is important to collect a large number of measuring points and fully automate the tests. For this reason, it should not be forgotten that coordination and adjustments are also important factors affecting the results before performing the measurements. Timing parameters important for control functions, such as ramp rates and delay times, will also need to be tested in the future and standardized definitions among these parameters.

IV. Conclusion

The smart grid technologies and their impacts on the efficiency increment in a power system has been reviewed in this paper. Specially, the smart inverter technologies have been highlighted by introducing their invaluable roles in the grid systems in order to increase the efficiency of a power grid system. Moreover, the smart inverters' test provided by the producers have been addressed. Finally, international standards of the smart inverter test have been given for the validation of the tests done.

References

[1] B. Rona, O. Guler, "Power system integration of wind farms and analysis of grid code requirements", Renewable and Sustainable Energy Reviews, Volume 49, September 2015, Pages 100-107.

[2] I.N. Trivedi, Jangir, P., Bhoye, M. et al. "An economic load dispatch and multiple environmental dispatch problem solution with microgrids using interior search algorithm". Neural Comput & Applic 30, 2173–2189 (2018). https://doi.org/10.1007/s00521-016-2795-5.

[3] M. B. Siddique, J. Thakur, "Assessment of curtailed wind energy potential for off-grid applications through mobile battery storage", Energy, Volume 201, 2020, https://doi.org/10.1016/j.energy.2020.117601.

[4] R. Belfkira, L. Zhang, G. Barakat, "Optimal sizing study of hybrid wind/PV/diesel power generation unit", Solar Energy, Vol. 85, Issue 1, 2011, Pages 100-110, https://doi.org/10.1016/j.solener.2010.10.018.

[5] M. Metcalfe, "Grid Efficiency: An Opportunity to Reduce Emissions", August 10, 2017.https://energycentral.com/c/ec/grid-efficiency-opportunity-reduce-emissions

[6] H. Farhangi "The path of the smart grid", IEEE Power Energy Mag 2010;8(1):18–28.

[7] I. Colak, S. Sagiroglu, G. Fulli, M.Yesilbudak, C-F. Covrig, "A survey on the critical issues in smart grid technologies, Renewable and Sustainable Energy Reviews 54 (2016) 396–405.

[8] A. H. Al-Badi, R. Ahshan, N. Hosseinzadeh, R. Ghorbani, E. Hossain, "Survey of Smart Grid Concepts and Technological Demonstrations Worldwide Emphasizing on the Oman Perspective" Appl. Syst. Innov. Vol.3 (1), no.5. https://doi.org/10.3390/asi3010005.

[9] K.S. Reddy, M. Kumar, T.K. Mallick, H. Sharon, S. Lokeswaran, "A review of Integration, Control, Communication and Metering (ICCM) of renewable energy based smart grid", Renewable and Sustainable Energy Reviews, Volume 38, 2014, Pages 180-192,https://doi.org/10.1016/j.rser.2014.05.

[10] S. Maharjan, Q. Zhu, Y. Zhang, S. Gjessing, T. Başar, "Demand response management in the smart grid in a large population regime" IEEE Trans Smart Grid 2016;7(1):189–99

[11] Li, Wen-Tai , Yuen, Chau , H. Naveed Ul , T. Wayes , W. Chao-Kai, W. Kristin, L. H. Kun, and L. Xiang (2015). "Demand response management for residential smart grid: from theory to practice" IEEE Access 3 7336481 2431-2440. https://doi.org/10.1109/ACCESS.2015.2503379.

[12] M. Erol-Kantarci, H. T. Mouftah "Energy-efficient information and communication infrastructures in the smart grid: a survey on interactions and open issues" IEEE Commun. Surv. Tutor 2015;17(1):179–96.

[13] S. Elisa, N. Luca, P. Stefano Di, I. Giuseppe "Last meter smart grid embedded in an internet-of-things platform" IEEE Trans Smart Grid 2015;6(1):468–75.

[14] R. Bayindir, I. Colak, G. Fulli, K. Demirtas, "Smart grid technologies and applications", Renewable and Sustainable Energy Reviews 66 (2016) 499–516.

[15] The Impact of Control Technology, T. Samad and A.M. Annaswamy (eds.), 2011. Available at www.ieeecss.org.

[16] K.K. Zame, C.A. Brehm, A.T. Nitica, C.L. Richard, G. D. Schweitzer III, "Smart grid and energy storage: Policy recommendations", Renewable and Sustainable Energy Reviews, Volume 82, Part 1, 2018, Pages 1646-1654, https://doi.org/10.1016/j.rser.2017.07.011.

[17] H. Lund, A.N. Andersen, P.A. Østergaard, B.V. Mathiesen, D. Connolly, "From electricity smart grids to smart energy systems–A market operation based approach and understanding", Energy, Volume 42, Issue 1, 2012, Pages 96-102, https://doi.org/10.1016/j.energy.2012.04.003.

[18] M. Hansen and B. Hauge, "Prosumers and smart grid technologies in Denmark: developing user competences in smart grid households", Energy Efficiency (2017) 10:1215–1234.

[19] B. Zhao, Q. Song, W. Liu and Y. Xiao, "Next-Generation Multi-Functional Modular Intelligent UPS System for Smart Grid," in IEEE Transactions on Industrial Electronics, vol. 60, no. 9, pp. 3602-3618, Sept. 2013, https://doi.org/10.1109/TIE.2012.2205356

[20] A. Luo, Q. Xu, F. Ma and Y. Chen, "Overview of power quality analysis and control technology for the smart grid," in Journal of Modern Power Systems and Clean Energy, vol. 4, no. 1, pp. 1-9, January 2016, https://doi.org/10.1007/s40565-016-0185-8.

[21] R. Brundlinger et al., "Lab Tests: Verifying That Smart Grid Power Converters Are Truly Smart," in IEEE Power and Energy Magazine, vol. 13, no. 2, pp. 30-42, March-April 2015, https://doi.org/10.1109/MPE.2014.2379935.

[22] I. Vairavasundaram, V. Varadarajan; P. J.Pavankumar, R. K. Kanagavel, L. Ravi, S. Vairavasundaram, "A Review on Small Power Rating PV Inverter Topologies and Smart PV Inverters" Electronics 10, no. 11: 1296, 2021. https://doi.org/10.3390/electronics10111296.

[23] A. Teke and M. B. Latran, "Review of Multifunctional Inverter Topologies and Control Schemes Used in Distributed Generation Systems," Journal of Power Electronics, vol. 14, no. 2, pp. 324–340, Mar. 2014.

[24] F.H. Rafi, M.J. Hossain, S. Rahman, S. Taghizadeh, "An overview of unbalance compensation techniques using power electronic converters for active distribution systems with renewable generation", Renewable and Sustainable Energy Reviews, Volume 125, 2020, https://doi.org/10.1016/j.rser.2020.109812.

[25] J. Hashimoto, T. Selim Ustun, K. Otani, "Smart Inverter Functionality Testing for Battery Energy Storage Systems", Smart Grid and Renewable Energy, 2017, 8, 337-350.

[26] B. Rajesh Kumar and S. Ishwarya, "Smart grid-Power factor Correction and Maintenance in Consumer Side Using RFID Based Power Line Carrier", Journal of Advances in chemistry, vol.12, no.15, November, 2016. (https://core.ac.uk/download/pdf/322470153.pdf) (Last accessed on 20.06.2021)

[27] S. Khanchi, V. Kumar Garg "Power Factor Improvement of Induction Motor by Using Capacitors" International Journal of Engineering Trends and Technology (IJETT) – Volume 4 Issue 7- July 2013.

[28] S. Nii and M. Kato, "Power Electronics Technology that Supports Smart Grid", Vol. 57, No. 4, FUJI ELECTRIC REVIEW (https://www.fujielectric.com/company/tech/pdf/57-04/FER-57-4-140-2011.pdf) (Last accessed on 20.06.2021)

[29] F. Rahimi, A. Ipakchi "Demand response as a market resource under the smart grid paradigm", IEEE Trans Smart Grid 2010;1(1):82–8.

[30] https://www.irena.org//media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf.

[31] Dolf Gielen, Francisco Boshell, Deger Saygin, Morgan D. Bazilian, Nicholas Wagner, Ricardo Gorini, " The role of renewable energy in the global energy transformation," Energy Strategy Reviews, Volume 24, 2019, Pages 38-50, https://doi.org/10.1016/j.esr.2019.01.006.

[32] P. A. Owusu, & S. Asumadu-Sarkodie, "A review of renewable energy sources, sustainability issues and climate change mitigation". Cogent Engineering, 2016 3(1), 1-14. [1167990]. https://doi.org/10.1080/23311916.2016.1167990.

[33] P. Palensky and D. Dietrich. "Demand side management: Demand response, intelligent energy systems, and smart loads." Industrial Informatics, IEEE Transactions on 7.3 (2011): 381-388.

[34] M. Erol-Kantarci and H. T. Mouftah, "Wireless sensor networks for cost-efficient residential energy management in the smart grid." Smart Grid, IEEE Transactions on 2.2 (2011): 314-325.

[35] R. Moghaddass, J. Wang, "A Hierarchical Framework for Smart Grid Anomaly Detection Using Large-Scale Smart Meter Data," in IEEE Transactions on Smart Grid, vol. 9, no. 6, pp. 5820-5830, Nov. 2018, doi: 10.1109/TSG.2017.2697440.

[36] C. B. Yahya, S. El-Nakla, O. K. M. Ouda, F. Al-Taisar, S. Al-Saif, W. AlKhawaher, "Smart Grid Technologies and Electricity Demand Management in KSA", 2018 Renewable Energies, Power Systems & Green Inclusive Economy (REPS-GIE), https://doi.org/10.1109/REPSGIE.2018.8488824.

[37] T. Chiu, Y. Shih, A. Pang and C. Pai, "Optimized Day-Ahead Pricing With Renewable Energy Demand-Side Management for Smart Grids," in IEEE Internet of Things Journal, vol. 4, no. 2, pp. 374-383, April 2017, https://doi.org/10.1109/JIOT.2016.2556006.

[38] L. Gelazanskas, K.A.A. Gamage, "Demand side management in smart grid: A review and proposals for future direction", Sustainable Cities and Society, Volume 11, https://doi.org/10.1016/j.scs.2013.11.001.

[39] L. Ren-Shiou, H. Yu-Feng, "A scalable and robust approach to demand side management for smart grids with uncertain renewable power generation and bi-directional energy trading", International Journal of Electrical Power & Energy Systems, Volume 97, 2018, Pages 396-407, https://doi.org/10.1016/j.ijepes.2017.11.023.

[40] http://www.ecra.gov.sa/documents/Studies%5CDSM.pdf. (last accessed on 20.06.2021)

[41] Electromagnetic Compatibility of Power Converters ,A. Charoy AEMC, Sassenage, Franc, Published by CERN in the Proceedings of the CAS-CERN Accelerator School: Power Converters, Baden, Switzerland, 7–14 May 2014, edited by R. Bailey, CERN-2015-003 (CERN, Geneva, 2015).

[42] Grid Codes in Europe for Low and Medium Voltage, Roland Bründlinger AIT Austrian Institute of Technology,6th International Conference on Integration of Renewable and Distributed Energy Resources Kyoto November 18, 2014.

[43] Recommendations for Utility Communications with Distributed Energy Resources (DER) Systems with Smart Inverters, (2015), California Public Utilities Commission.

[44] Staff Proposal on Reactive Power Priority Setting of Smart Inverters (2017) California Public Utilities Commission.

[45] J. Johnson, S. Gonzalez, T. Zgonena, M. Mcgirr, J. Hopkins, B. Seal, F. Cleveland, T. Tansy, and B. Fox, "Draft Electric Rule 21 Test Protocols for Advanced Inverter Functions", December 2014.

[46] T. S. Ustun, C. Ozansoy, and A. Zayegh, (2012). Modeling of a centralized microgrid protection system and distributed energy resources according to IEC 61850-7-420. IEEE Trans. Syst. 27, 1560–1567. doi: 10.1109/TPWRS.2012.2185072

[47] IEEE 1547-2018, "IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces", STANDARD by IEEE, https://www.techstreet.com/standards/ieee-1547, 04/06/2018.

[48] Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL Standard, Standard 1741, Edition 2Edition Date: June 10, 2021. https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL1741