A Reliability Perspective of Distribution Systems in Smart Grid Communication Networks

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Abstract**—** The ever-increasing demand for electricity has posed reliability, security, economic and environmental challenges in front of the current electricity power system. A smart grid concept is a key solution to these issues because it uses digital technology to revolutionize the conventional electricity power system. The electricity power system contains three sections, namely generation, transmission and distribution. This paper discusses the important aspects and concepts of the reliability in the distribution section. Since reliability in Distribution Systems (DSs) has always been a major concern for utility providers, we have surveyed existing reliability methodologies and recent research works to improve reliability and calculate reliability indices. The integration of renewable based Distribution Generation (DG) and Energy Storage Systems (ESSs) into grid solutions is also considered in this paper as they can provide reliable power to consumers and reduce electricity losses, reliance on centralized plants as well as the environmental impacts. Furthermore, this paper highlights future challenges and directions in smart grid communication networks from a reliability perspective.

Index Terms**—**Distributed generation, distribution networks, energy storage systems, reliability, renewable energy sources, smart grid communication

I. Introduction

As digital technology has changed the way we live, the demand for electricity is increasing and will increase significantly in the future. The electric power is provided through the electricity grid, where it is generated, transmitted, distributed to customers over long distances. The traditional or current electricity grid is an environmentally extravagant and a limited one-way interaction system, which makes it difficult to meet ever-increasing energy demands in the 21st century. As a result, many challenges are faced in terms of reliability, power quality, security, environmental, and economic issues. The solution to all these problems is to make the system smarter, i.e. a smart grid. The smart grid [1] is a combination of the electricity grid with information and communication technologies (ICT). It is made by two-way communication technologies, where electricity and information can be exchanged between providers and customers. The advantages of smart grid technology [2], [3] are numerous. The smart grid technology in comparison with today's electricity grid will be able to:

- Enhance the reliability of the power supply by reducing the duration of interruptions.
- Provide more efficient and flexible operations.
- Provide customers with real-time information on their energy use and costs.
- Accommodate all renewable energy resources while minimizing environmental impacts.
- Monitor equipment remotely and control the whole system.
- Deliver enhanced levels of the security and safety of the system and withstand physical and cyber-attacks [4].
- Reduce consumption and the cost of delivered electricity.
- Create new job opportunities, resulting in economic growth [5].

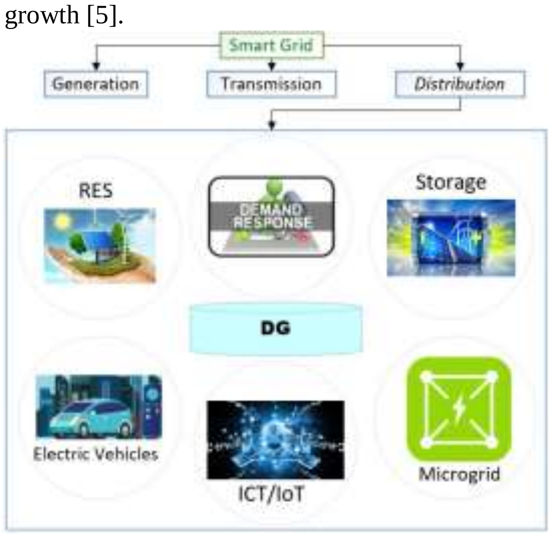

Fig. 1. A classification of DS.

The electrical power system can be divided into three sections: generation, transmission, and distribution, which are all equally important, as illustrated in Fig. 1. The power system brings along several research challenges,

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among which we concentrate on reliability as it emerges to be a sensitive issue for end-users and utilities alike. As around two-thirds of reliability are allocated to the Distribution System (DS) and a third to the generation and transmission systems, considering the reliability of the DS is more important when designing the future electrical system [6].

Distribution as transmission carries power towards customers with lower voltages. The distribution grid is an important infrastructure for the global economy since it ensures durability and stability of power supply, making the greatest contribution to the reliability of the power system. Consumers and utilities require an uninterrupted power supply and in the current scenario, the major problems arise because of faults in DS. Hence, it is the need of the hour to improve the reliability of the current DSs.

Distributed Generation (DG) meets the quality and reliability of energy as well as power supply. DG is also highly efficient with the performance varying between 65% and 95% [7]. Although the participation of renewable energy sources (RESs) in the DG has made it more complex, it created a path for the realization of the smart grid. This complexity includes the high variability of output and to solve this issue, Energy Storage Systems (ESSs) are integrated into the DG. ESSs, when coupled with RESs, can smooth output fluctuations and balance the power flow in the network to meet energy demand sustainably and reliably [8]. DG provides an excellent backup and even faster recovery to the existing power grids in case of system failures and adverse scenarios such as the destruction of power plants during wars and terrorist attacks [9]. Apart from these advantages, DG also helps in meeting the high loads at the remote locations and hence saves upon the cost of developing and maintaining additional infrastructure in adverse terrains.

In this paper, we have striven to cover the following aspects of the reliability of the DS in smart grid communication networks:

- Renewable DG: Renewable DG brings commercial, operational and ecological benefits. In this section, first, we provide a brief overview of RESs, the major RESs including their pros and cons, then, we discuss the role of DG on DS reliability.
- ESS: Owing to the crucial role of ESSs in enhancing grid stability, reducing energy wastage and greenhouse gas emissions, we review the challenges and future prospects of ESSs in certain countries. Moreover, we highlight how the integration of RESs with ESSs affects effectively and efficiently in the reliability improvement.
- Reliability assessment: In this part, we cover a reliability analysis of the relevant studies and striven to highlight the various concepts of the reliability of distribution network (DNs) from different perspectives and the influence of some other factors on power system reliability.

The remaining paper is organized as follows. Renewable distributed energy resources (DERs) and EESs are presented in Sections II and III respectively. The reliability analysis of DNs is comprehensively considered in Section IV. Finally, the paper contains concluding remarks, future challenges as well as directions in Section V.

II. Renewable Distributed Energy Resources

A. Renewable Energy Sources

A renewable energy is defined as a source of energy derived from nature that is not depleted by usage [10]. While the usual sources of energy have their presence limited to a selected few countries around the world, the renewable resources are devoid of this limitation and can be found over a large geographical area [11]. The costs of renewable energy systems are decreasing at an extremely high rate with a proportionate increase in efficiency and quality [12]. There are several types of RESs [13] and some of them are given in Table II including advantages and disadvantages.

Approximately 61.4% of greenhouse gas emissions come from the electricity sector and most of those emissions come from fossil fuels like coal and natural gas [14]. The global warming emissions associated with renewable energy are generally much lower than those of coal- and natural gas-fired power plants. Owing to the minimal air emissions associated with geothermal, biomass systems, and no air pollution emissions associated with wind, solar, and hydroelectric systems, most of the negative health impacts come from the air can be significantly mitigated. It can be seen from Table I that every alternative energy source has some drawbacks such as technical challenges or high initial investments. Although renewable energy facilities require start-up costs to build, they can then operate at very low cost, stabilizing energy prices in the future. Despite given disadvantages, alternative sources of energy should be used to reduce global warming, enhance public health, stabilize energy prices, meet the ever-increasing energy demand and provide sustainable energy to consumers.

TABLE I: Advantages and Disadvantages of RESs.

RESs	Advantages	Disadvantages
Biogas	High capacity factor; improved water and soil quality; eco-friendly; improvement in sanitation and hygiene.	Few technological facilities; high production cost; power quality issues; less suitable for urban areas; unstable in nature.
Biomass	Reliable baseload power; widely available; reduce landfill waste; creation of different products; suitable for rural areas; distributed generation; carbon neutral; less dependency on fossil fuels.	High transportation cost; risk of deforestation; inefficient compared to fossil fuels; not very clean when burned; oxygen deficiency due to methane gas; biodiversity issues; need sufficient water sources.

Geothermal	Environmentally friendly and renewable; a stable or reliable resource due to its availability all year long unlike solar or wind; potential capacity; high efficiency and accessibility.	High up-front costs for heating and cooling systems; increased seismic activity; surface instability; green gas emissions: sulfur dioxide, methane, ammonia; distribution costs.
Hydro-power	Reliable and flexible; low LCOE; high conversion efficiency; no emissions; provide electricity constantly; inflation-resistant; tourist attractions; cost-effective.	Soil erosion; limited places to build hydroelectric dams; safety concerns: dam failure; changing water table level; affecting aquatic eco-system; geological damage.
Solar	Nonpolluting; cost-effective after installment; energy independence; a proven and durable technology; multiple applications.	Intermittent by nature; require supplemental energy resources; use a lot of space; solar ESSs are expensive; high start-up costs to install.
Wind	Available everywhere; remote power solution; pollution-free; enormous potential; low operational costs.	Fluctuated output; noise pollution; threat to flying animals; high initial investments of wind turbines

In conclusion, technical and economic challenges associated with the integration of renewable generation to the existing grid should be minimized because renewable energy remains on course. Potential solutions require new technologies to minimize costs, increase reliability and energy production. Furthermore, accurate modeling, simulation, and analysis tools are needed to address variability and uncertainty issues of RESs.

B. Distributed Energy Resources

DGs, also known as DERs, are generation plants connected to the distribution network, which can consist of nonrenewable and renewable generation, storage devices, electric vehicles, controllable loads, inverters, management and smart grid technologies. Several studies have been conducted to enhance the DNs reliability and some of them include DERs as shown in Table II. Renewable DERs can mitigate the effects of environmental issues and serve as a backup to the grid while enhancing power quality, thus, resulting in a positive influence on the system reliability. Although DERs offer operational and ecological benefits, it poses some challenges such as a high variability of the output which should be minimized when considering the future power system.

TABLE II: COMPARISON OF SEVERAL STUDIES BASED ON DG.

Ref	Contributions
[15]	A mixed integer linear programming (MILP) based approach for determining the best reliability improvement strategy in the radial DNs with island operation of DGs.
[16]	A mixed integer non-linear model based methodology for optimal planning of low voltage DSs considering the penetration of DGs and network reliability.
[17]	The optimum value based location of DG in a DS from a reliability perspective using a Markov process and state-based modeling techniques.
[18]	Particle swarm optimization (PSO) method to solve the optimal size and location of DG considering natural disaster scenarios for reliability improvements.
[19]	A DN reliability calculation model taking into account adverse weather and DG.

III. ENERGY STORAGE SYSTEMS

The behavior of renewable sources is often unpredictable as well as intermittent, and the only solution is energy storage. Energy storage process involves accumulating energy in such a manner that it can be later reused when the need arises. A comprehensive description of ESSs with classification, features, environmental impacts, benefits and challenges is discussed in papers [20], [21].

In developing countries, energy is perceived to be crucial for encouraging sustained growth. ESSs play an essential role to provide an improved power supply service and enhance the grid stability. The paper [22] presents the role of electrical energy storage in sub-Saharan Africa. An overview of electrical energy storage applications, economic models in sub-Saharan Africa, and the technical aspects like storage capacity sizing as well as interface converters for integration with RESs is described. The status of the development and future prospects of large-scale electrical ESSs in India is presented in [23].

Pros and cons of different storage technologies, existing and developing large-scale electrical energy storage projects, challenges in electrical energy storage development in India are discussed. In paper [24], strengths, weaknesses, opportunities, and threats of energy storage industry in terms of policy, economic, society, technology in China are analyzed. The paper [25] analyzes and systematizes the recent energy storage expansion studies with renewable targets for the U.S, Europe, and Germany.

The impact of integrating distributed energy resources including wind and solar, and energy storage devices in the smart grid is described in [26]. According to the results, integrating distributed energy resources with energy storage devices brings great benefits, such as reducing the generation costs and distribution losses, smoothing the curve of bulk power generation and providing sustainable user service reliability. The paper [27] proposes reliability evaluation models and methods in the power system similar to the size of the Korean island Jeju system employing MC simulation when an ESS is installed into multiple wind farms. The utilization of energy storage in the local DSs, when coupled with renewable energy generation, can considerably enhance the reliability of the bulk power system [28]. This work [28] presents an intelligent operation strategy to improve reliability based on sequential MC approach. The optimal scheduling for an ESS, combined with the conventional generators and RESs, is proposed considering reliability and aging. While the paper [29] proposes a multi-objective approach for optimal operation of DNs at the presence of DG sources and battery ESS to reduce operating costs and improve reliability.

The integration of RESs into the power grid is not sufficient solution due to its stochastic nature [30], hence integrating RESs along with ESSs should be considered as the key factor in the smart power grid.

IV. Reliability Analysis of Distribution Networks from Different Perspectives

In this section, first, we provide reliability evaluation methods for calculating reliability indices, then, we analyze the reliability of DNs from different perspectives and discuss some of the factors that influence the system reliability.

A. Methods

Reliability indices can be calculated by analytical approaches, which uses mathematical models and solutions, and MC simulations. An MC simulation is considered a probabilistic analysis that relies on repeated random sampling. It provides more accurate results compared to mathematical computations. The unpredictable properties to evaluate reliability in DNs can be well-described by using MC simulation [31]. MC methods are divided into non-sequential (random) and sequential methods. In the non-sequential MC method, intervals are randomly chosen to simulate the system behavior. Sequential MC methods are scalable, easy to implement, where a system operating cycle is obtained in chronological order. Sequential MC simulation is the most flexible strategy for evaluating DS reliability since it is able to account for the variability of the load point annual reliability indices. When more detailed information are needed, sequential MC simulation, which requires higher computing time, is used.

Reliability indices can be categorized into two types: load point reliability indices and system reliability indices. The three basic load point indices are failure rate$\lambda_s = \sum \lambda_i$, outage/repair duration $r_s = \frac{\sum \lambda_i r_i}{\sum \lambda_i}$ and annual outage duration $U_s = \sum \lambda_s r_s$ (unavailability). The system reliability indices can be calculated with the help of these three basic load point indices as illustrated in Table III.

B. Islanding

DG units have two operating modes: islanded mode (isolated from the primary substation) and grid-connected mode. Reference [32] describes a generalized systematic approach to assess DS reliability considering intentional islanding with MC simulation. The provided strategy reduces the time consumption of the overall methods. The authors compare the proposed method with the analytical one. The best and the worst results along with the probability distribution of load-point annual outages number and duration are also presented. According to the results, islanding affects reliability positively. DGs are well known for their uncertainties since they mostly depend upon RES. Due to the uncertainty, a number of problems such as frequency offset and voltage fluctuation can be posed. To deal with these challenges, the MC approach is used to calculate the reliability of the DS with DGs for failure state analysis, considering multiple accidents and islanding strategies.

C. Automatic Reclosing

Automatic reclosing is a very effective method for fault clearing in power grid systems. It plays an important role in the reliability of overhead networks and improving its supply quality. In [34], the MC approach is applied to assess the reliability of the smart power DN considering different case scenarios. The impact of the DGs and automatic reclosers on the system is considered. The time-sequential MC method is used by generating an artificial history using the random number generator. According to the first scenario, the installation of one automatic recloser or two automatic reclosers on the system can lead to a reduction in SAIDI, SAIFI, and EUE, reducing cost and energy consumption. In the second scenario, a 1MW distributed generator is connected to the system. The results show that the automatic reclosers are required when a distributed generator is installed to the system. Otherwise, no benefit can be obtained because a fault on the system has a higher possibility of blocking the connection of the distributed generator units during outages. In summary, DGs together with the installation of the automatic recloser will be appreciated during blackouts and major outages while enhancing the system indices considerably.

D. Maintenance

Maintenance is an activity to maintain a system or extend its life expectancy and to enhance the reliability and availability of the system [35]. Maintenance is crucial for power DSs because of its ability to maximize asset performance. The impact of the maintenance strategies on the reliability of the DN is significant [36]. The maintenance strategies can be separated into two types: corrective maintenance and preventive maintenance. Corrective maintenance is carried out after a failure occurs as a last resort, whereas preventive maintenance is carried out to reduce failure probabilities before a failure occurs.

TABLE III: RELIABILITY INDICES

Reliability indices	Definition	Mathematical computations
SAIFI	System Average Interruption Frequency Index	$\text{SAIFI} = \frac{\text{Total number of customer interruptions}}{\text{Total number of customer served}}$; $\text{SAIFI}=\frac{\sum \lambda_i N_i}{\sum N_i}$ where λ_i – the failure rate, N_i – the total number of customers at load point *i*
SAIDI	System Average Interruption Duration Index	$\text{SAIDI} = \frac{\text{Sum of customer interruption duration}}{\text{Total number of customer served}}$; $\text{SAIDI}=\frac{\sum U_i N_i}{\sum N_i}$ where U_i – the annual outage duration at load point *i*
CAIDI	Customer Average Interruption Duration Index	$\text{CAIDI} = \frac{\text{Sum of customer interruption durations}}{\text{Total number of customers interruptions}}$; $\text{CAIDI}=\frac{\text{SAIDI}}{\text{SAIFI}}$
ASAI	Average System Availability Index	$\text{ASAI} = \frac{\text{Customer hours of available service}}{\text{Customer hours demanded}}$; $\text{ASAI}=\frac{\sum N_i * 8760 - \sum N_i U_i}{\sum N_i * 8760}$
ASUI	Average System Unavailability Index	$\text{ASUI} = \frac{\text{Sum of customer interruption duration}}{\text{Customer hours demanded}}$; $\text{ASUI}=\frac{\sum N_i U_i}{\sum N_i * 8760}$
CAIFI	Customer Average Interruption Frequency Index	$\text{CAIFI} = \frac{\text{Total number of customer interruptions}}{\text{Number of distinct customers interrupted}}$; $\text{CAIFI}=\frac{\sum \lambda_i N_i}{\sum M_i}$ where M – the number of customers affected at load point *i*
AENS	Average Energy Not Supplied	$\text{AENS} = \frac{\text{Total energy not supplied}}{\text{Total number of customers served}}$; $\text{AENS}=\frac{\sum L_a(i) U_i}{\sum N_i}$ where $L_a(i)$ – the average connected load at load point *i*
EENS or EUE	Expected Energy Not Supplied or Expected Un-served Energy	$\text{EENS or EUE} = \sum L_a(i) U_i$
RSLI	Reticulation System Loss Index	$\text{RSLI} = \frac{\sum \text{kVA hours lost interruptions}}{\text{Total connected kVA served}}$

The current reliability evaluation methods neglect the effect of preventive maintenance. However, preventive maintenance is an effective measure to enhance the reliability of DN in comparison with corrective maintenance. Although preventive maintenance cannot avoid element failures, the probability of equipment failure can be effectively reduced by implementing preventive maintenance as it can maintain the reliability of equipment at a high level. A new method, which consists of two maintenance ways in preventive strategy: preventive maintenance and corrective maintenance, to evaluate the reliability of DN is proposed in [35]. The method is tested based on the IEEE RBTS BUS6 system that includes one 10kV bus and four feeders. According to the simulation and result analysis, SAIDI and CAIDI reliability indices along with preventive maintenance show better results than those with corrective maintenance. To conclude, the overall cost of maintenance decreases and the total number of maintenance grows steadily. However, a deterioration can be seen in SAIFI index.

E. A Combination of Renewable DERs with ESSs

In [37], three smart solutions such as a dynamic network restoration scheme, integration of wind generation and installation of a composite system are considered to improve the DN reliability. The implementation of the dynamic network reconfiguration scheme can bring dramatic reliability improvements in terms of EENS, SAIFI, and SAIDI with the exception of ASAI. All the load point indices such as load point interruption frequency and duration for the system with the dynamic network configuration perform better than those of without the dynamic network reconfiguration. When wind turbines are integrated, the EENS and SAIDI indices decrease steadily. However, there is no any significant improvement in the ASAI index because of its high initial value. The wind turbine system has a slight and substantial influence on the interruption frequency and the interruption duration of the load points respectively. A composite system consists of the integration of the on-site storage with a wind turbine system. The system reliability indices are enhanced when the composite system rating is increased. Accordingly, after implementing all smart solutions altogether, there can be observed a noticeable improvement in the system reliability.

F. Demand Response and ICT

Demand response refers to a change in energy usage by consumers from their normal consumption patterns at times of high market prices and high network loading [38]. It can improve the power system reliability, lower peak demand and reduce overall plant and capital cost investments, leading to tangible benefits for both the customers and the utility.

ICT can also fail, impacting on communication imperfections in the smart grid reliability [39]. Therefore, the reliability assessments are required not only for the physical electricity network but also the communication network to obtain more realistic reliability results.

G. Other Factors

The adverse weather conditions like a storm are regarded as the decisive factor which will make a contribution to the bad performance of the DN [40]. An optimal automation level problem of DNs is one of the main issues which can be mitigated by minimizing reliability indices, cost and benefit ratio and maximizing network benefit [41]. Embedded failures like cold load pickup are not usually considered in calculating reliability indices, causing less reflection of the actual system behavior. The paper [42] analyses the reliability of the distribution power system considering cold load pickup events and lightening search algorithm optimization method to provide a robust solution.

According to Table IV, in which, reliability assessment of DNs is tabulated, the most common approaches to evaluate the reliability are the MC method (stochastic) and the analytical method. MC approach provides better results for analyzing complex systems reliability than analytical approaches, due to its accuracy. ETAP and DIgSILENT software programs are found useful to provide engineering services to simulate, monitor, control, optimize and analyze electrical power systems for transmission, distribution, generation and industrial plants. In terms of reliability indices, SAIDI and SAIFI are the most commonly used to measure DS reliability. Renewable DGs including ESSs have a positive influence on the DNs to address reliability issues.

TABLE IV: RELIABILITY ASSESSMENT OF DNS

Ref	Approach	Simulation tool and/or test model	Considered reliability indices	The way to achieve an objectivity	Notes: pros and cons
[32]	Random and Sequential MC	Matlab, radian distribution network	SAIDI, SAIFI, CAIDI	MC simulation and Poisson's process are used to estimate load points reliability indices in islanding and non-islanding modes	The positive influence on reliability, it can be standard in practice; technical issues are neither addressed nor suggestions to improve upon them are provided
[33]	Non-sequential MC	C++; IEEE RBTS-Bus 6	EENS, ASAI	The introduction of DGs considering multi accidents under islanding schemes	The reliability improvement brought by DGs and islanding schemes; further research of multiple accidents is required, inaccurate frequency indexes due to the non-sequential MC method, every aspect cannot be covered in the practical use
[34]	Time-sequential MC	Matlab; IEEE 34 node test system	SAIFI, SAIDI, CAIDI, EUE	Simulate the IEEE 34 node test feeder; applying the ARs and DG units in the feeder	Reduction in the amount of energy, improved reliability indices; no new results or methods suggested
[35]	Sequential MC	IEEE RBTS-Bus 6	SAIDI, SAIFI, CAIDI	The proposed reliability assessment method to the DN considering preventive maintenance and its impact on element failure rates	Reduction in the overall maintenance cost and SAIDI, CAIDI improvement with the preventive maintenance strategy but a deterioration in SAIFI index
[36]	Reliability Centered Maintenance methodology	DIgSILENT PowerFactory 15.1; Phontong substation	SAIDI, SAIFI	Applying the appropriate maintenance activities to enhance the system reliability and reduce the failure as well as the interruption by the Reliability Centered Maintenance methodology	A reduction in the number of outages under budget maintenance cost and maintenance frequency, providing a better quality of service for the consumer; a challenging task to prevent power outages caused by animals, power interruption reduced by 76.97% is not considered very high

[37]	Sequential MC	IEEE RBTS-Bus 4	EENS, SAIDI, SAIFI, ASAI	The consideration of three smart solutions such as a dynamic network restoration scheme, integration of wind generation and installation of a composite system which consists of a wind turbine and an on-site storage system	A remarkable improvement in the reliability indices after applying all smart solutions together, the available capacity margin can have a significant impact on the restoration results; customer outages caused by a failure on the lateral branch cannot be restored by network reconfiguration scheme
[40]	Analytical approach	DIgSILENT to simulate failure rates, NEPS software; model of Johannesburg town	SAIDI, SAIFI, RSLI	The assessment and evaluation of the distribution performance in Soweto, South Africa through reliability based methodology by assessing the worst contributing events	A considerable impact on South Africa's economy and society and a continuous power supply; faults cannot be 100% eliminated due to the uncontrollable weather conditions
[41]	Analytical technique based on failure mode effect analysis	ETAP software; medium voltage (11kV) DN	EENS, SAIDI, SAIFI, CAIDI	The proposed methodology to determine the optimal level of medium voltage DNs which is based on a heuristic combinatorial search technique and implementation of a substation-centralized based advanced distribution automation system	A decrease in system indices such as SAIDI and EENS by applying the proposed advanced DS, leading to reliability improvement, increasing customer satisfaction and reducing system interruption cost; but no any reduction in SAIFI index
[42]	Sequential MC and Lightening Search Algorithm feedback	Radial power distribution system	SAIDI, SAIFI, CAIDI, ENS	The proposed Sequential MC simulation coupled with Lightening Search Algorithm to find the optimal sequence of the restoration of the point of outages considering cold load pickup events	Lightening Search Algorithm is highly efficient than the genetic algorithm, the system performance can enhance for short intervals; failures might happen and the system equipment might be subjected to stresses because of blind restoration
[43]	Analytical method based on a systematic generalized approach	Medium-voltage network	SAIDI, SAIFI	Telecontrolled switches and microgrids are taken into account	Telecontrolled sectionalizers greatly enhance SAIDI, while worsening SAIFI

V. Conclusion and Discussion

In this paper, the reliability has been discussed in detail with its major concepts, methods, and indices. It is observed that a considerable improvement on the reliability can be noticed when renewable DGs with ESSs are applied to the system.

The utility companies should encourage the integration of RESs into their DSs as an alternative way to enhance the system reliability. However, RESs are intermittent by nature and have a number of uncertainties. An accurate prediction of the amount of power to be produced by RESs is an open issue in integrating RESs into the electricity grid. Therefore, modeling, simulation, analysis techniques should be developed in terms of operational reliability and efficiency of the power grid. Current studies mostly focus on solar and wind energy, causing insufficient research in other alternative energy sources. Hence, future research should also consider and include other alternative energy sources when considering future electrical systems.

The utilization of the renewable based DG has a great impact on improving the reliability of the smart grid system. The detailed analysis of different published approaches leads to the conclusion that while assessing power system reliability in the presence of renewable DGs, the solution to deal with the problem of location and sizing units of DG, power quality issues and DG models considering different uncertain factors needs to be further investigated.

Renewable DG resources are not only the solution toenhance the grid reliability due to uncertainties of RESs, thus the combination of ESSs together with renewable DGs plays an important role in improving system reliability, stability, and power quality. However, most of the energy storage technologies are still very expensive, thereby the development of energy storage technology requires policy support from the government in order to expand in the energy market and develop the large-scale manufacturing facilities for storage devices. Further developments of energy storage technologies are needed to improve the performance of a DN considering ESS placement, sizing, capacity, storage planning and modeling, stochastic optimization, environmental and geographic constraints, and analysis of the reliability of a DN with ESSs through the verification of reliability indices.

Analytical methods for reliability assessment of DNs have been explored, promoted by their reduced computational time in comparison with simulation. However, the MC method is typically used to model and analyze the uncertainties and complexities of DNs accurately. Researchers can also work to find out new modeling work in the analytical approaches taking into account the uncertainties as well as complexities of DNs accurately and the assumptions. By reviewing a number of research papers, it is found that the research work has been generally concentrated on DG, whilst some relevant studies have been proposed for energy storage.

Islanding operation of DG is one of the technical solutions for reliability improvement, however, in islanding condition, further research is required to confront the issues of instability in voltage and frequency. The smart grid applications will have to be equipped with new sophisticated automatic reclosing devices to isolate the faulty part from the rest of the system, thus, the implementation of auto reclosing in existing DN with high penetration of DGs will also need further investigation. In the future, more research work is required to study not only the corrective maintenance strategies, but also the influence of preventive strategies on the reliability evaluation. Severe weather conditions should be also considered in the grid's current and planning performance and reliability since adverse weather events are happening more often than ever before, having serious impacts on the power system.

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REFERENCES

[1] M. L. Tuballa and M. L. Abundo, "A review of the development of smart grid technologies," *Renewable and Sustainable Energy Reviews*, vol. 59, no. Supplement C, pp. 710-25, 2016.

[2] N. S. Nafi, K. Ahmed, M. A. Gregory, and M. Datta, "A survey of smart grid architectures, applications, benefits and standardization," *Journal of Network and Computer Applications*, vol. 76, no. Supplement C, pp. 23–36, 2016.

[3] N. Shaukat, S. Ali, C. Mehmood, B. Khan, M. Jawad, U. Farid, Z. Ullah, S. Anwar, and M. Majid, "A survey on consumers empowerment, communication technologies, and renewable generation penetration within smart grid," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 1453–1475, 2018.

[4] W. L. Chin, W. Li, and H. H. Chen, "Energy big data security
threats in IoT-based smart grid communications," *IEEE Communications Magazine*, vol. 55, no. 10, pp. 70–75, October 2017.

[5] M. Masera, E. F. Bompard, F. Profumo, and N. Hadjsaid, "Smart (electricity) grids for smart cities: Assessing roles and societal impacts," *Proceedings of the IEEE*, vol. 106, no. 4, pp. 613–625, April 2018.

[6] N. Hadjsaid and J. Sabonnadiere, *Smart Grids*, ser. ISTE. Wiley, 2013.

[7] H. Kuang, S. Li, and Z. Wu, "Discussion on advantages and disadvantages of distributed generation connected to the grid," in *Proc. International Conference on Electrical and Control Engineering*, Sept. 2011, pp. 170–173.

[8] C. K. Das, O. Bass, G. Kothapalli, T. S. Mahmoud, and D. Habibi, "Overview of energy storage systems in distribution networks: Placement, sizing, operation, and power quality," *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 1205–1230, 2018.

[9] B. Sultana, M. Mustafa, U. Sultana, and A. R. Bhatti, "Review on reliability improvement and power loss reduction in distribution system via network reconfiguration," *Renewable and Sustainable Energy Reviews*, vol. 66, pp. 297–310, 2016.

[10] A. K. Aliyu, B. Modu, and C. W. Tan, "A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 2502–2518, 2018.

[11] R. Singh, "Energy sufficiency aspirations of India and the role of renewable resources: Scenarios for future," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 2783–2795, 2018.

[12] M. Mohammadi, R. Ghasempour, F. R. Astaraei, E. Ahmadi, A. Aligholian, and A. Toopshekan, "Optimal planning of renewable energy resource for a residential house considering economic and reliability criteria," *International Journal of Electrical Power and Energy Systems*, vol. 96, pp. 261–273, 2018.

[13] E. Park, "Potentiality of renewable resources: Economic feasibility perspectives in South Korea," *Renewable and Sustainable Energy Reviews*, vol. 79, pp. 61–70, 2017.

[14] M. T. I. Khan, Q. Ali, and M. Ashfaq, "The nexus between greenhouse gas emission, electricity production, renewable energy and agriculture in Pakistan," *Renewable Energy*, vol. 118, pp. 437–451, 2018.

[15] Z. Popovi, S. Knezevi, and B. Brbakli, "Optimal reliability improvement strategy in radial distribution networks with island operation of distributed generation," *IET Generation, Transmission Distribution*, vol. 12, no. 1, pp. 78–87, 2018.

[16] R. A. Hincapie, M. Granada, and R. A. Gallego, "Optimal planning of secondary distribution systems considering distributed generation andnetwork reliability," in *Proc. IEEE ANDESCON*, Oct. 2016, pp. 1–4.

[17] B. Banerjee and S. M. Islam, "Reliability based optimum location of distributed generation," *International Journal of Electrical Power and Energy Systems*, vol. 33, no. 8, pp. 1470–1478, 2011.

[18] G. H. Reddy, P. Chakrapani, A. K. Goswami, and N. B. D. Choudhury, "Optimal distributed generation placement in distribution system to improve reliability and critical loads pick up after natural disasters," *Engineering Science and Technology, an International Journal*, vol. 20, no. 3, pp. 825–832, 2017.

[19] R. Zhang, L. Z. Zhang, Y. Li, and L. Lv, "Distribution network reliability considering weather and distribution

generation," in *Proc. Asia-Pacific Power and Energy Engineering Conference*, March 2012, pp. 1–6.

[20] M. S. Guney and Y. Tepe, "Classification and assessment of energy storage systems," *Renewable and Sustainable Energy Reviews*, vol. 75, pp. 1187–1197, 2017.

[21] S. O. Amrouche, D. Rekioua, T. Rekioua, and S. Bacha, "Overview of energy storage in renewable energy systems," *International Journal of Hydrogen Energy*, vol. 41, no. 45, pp. 20914–20927, 2016.

[22] S. Mandelli, C. Brivio, M. Leonardi, E. Colombo, M. Molinas, E. Park, and M. Merlo, "The role of electrical energy storage in Sub-saharan Africa," *Journal of Energy Storage*, vol. 8, pp. 287–299, 2016.

[23] B. Shyam and P. Kanakasabapathy, "Large scale electrical energy storage systems in India current status and future prospects," *Journal of Energy Storage*, vol. 18, pp. 112–120, 2018.

[24] Z. Tan, Q. Tan, and Y. Wang, "A critical-analysis on the development of energy storage industry in China," *Journal of Energy Storage*, vol. 18, pp. 538–548, 2018.

[25] F. Cebulla, J. Haas, J. Eichman, W. Nowak, and P. Mancarella, "How much electrical energy storage do we need? a synthesis for the U.S., Europe, and Germany," *Journal of Cleaner Production*, vol. 181, pp. 449–459, 2018.

[26] G. Xu, W. Yu, D. Griffith, N. Golmie, and P. Moulema, "Toward integrating distributed energy resources and storage devices in smart grid," *IEEE Internet of Things Journal*, vol. 4, no. 1, pp. 192–204, Feb 2017.

[27] U. Oh, J. Choi, and H. Hyeon Kim, "Reliability contribution function considering wind turbine generators and battery energy storage system in power system," in *Proc. iFAC Workshop on Control of Transmission and Distribution Smart Grids CTDSG*, 2016, vol. 49, no. 27, pp. 301–306.

[28] Y. Xu and C. Singh, "Power system reliability impact of energy storage integration with intelligent operation strategy," *IEEE Transactions on Smart Grid*, vol. 5, no. 2, pp. 1129–1137, March 2014.

[29] A. Azizivahed, E. Naderi, H. Narimani, M. Fathi, and M. R. Narimani, "A new bi-objective approach to energy management in distribution networks with energy storage systems," *IEEE Transactions on Sustainable Energy*, vol. 9, no. 1, pp. 56–64, Jan 2018.

[30] T. P. Kumar, N. Subrahmanyam, and M. Sydulu, "Cmbsnn for power flow management of the hybrid renewable energy storage system-based distribution generation," *IETE Technical Review*, pp. 1–12, 2018.

[31] Y. Chen, Y. Zheng, F. Luo, J. Wen, and Z. Xu, "Reliability evaluation of distribution systems with mobile energy storage systems," *IET Renewable Power Generation*, vol. 10, no. 10, pp. 1562–1569, 2016.

[32] S. Conti and S. A. Rizzo, "Monte Carlo simulation by using a systematic approach to assess distribution system reliability considering intentional islanding," *IEEE Transactions on Power Delivery*, vol. 30, no. 1, pp. 64–73, Feb. 2015.

[33] X. Zhang, Z. Bie, and G. Li, "Reliability assessment of distribution networks with distributed generations using Monte Carlo method," in *Proc. International Conference on Smart Grid and Clean Energy Technologies*, 2011, vol. 12, pp. 278–286.

[34] T. Aljohani and M. Beshir, "Matlab code to assess the reliability of the smart power distribution system using Monte Carlo simulation," *Journal of Power and Energy Engineering*, vol. 5, pp. 30–44, 01 2017.

[35] H. S. Zhao, H. Y. Liu, S. Chen, Y. Y. Wang, and H. Y. Zhao, "Reliability assessment of distribution network considering preventive maintenance," in *Proc. IEEE Power and Energy Society General Meeting (PESGM)*, July 2016, pp. 1–5.

[36] O. Vilayphonh, S. Premrudeepreechacharn, and K. Ngamsanroaj, "Reliability centered maintenance for electrical distribution system of phontong substation in Vientiane capital," in *Proc. 6th International Youth Conference on Energy (IYCE)*, June 2017, pp. 1–6.

[37] H. Guo, V. Levi, and M. Buhari, "Reliability assessment of smart distribution networks," in *Proc. IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA)*, Nov. 2015, pp. 1–6.

[38] N. Good, K. A. Ellis, and P. Mancarella, "Review and classification of barriers and enablers of demand response in the smart grid," *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 57–72, 2017.

[39] R. S. de Carvalho and S. Mohagheghi, "Analyzing impact of communication network topologies on reconfiguration of networked microgrids, impact of communication system on smart grid reliability, security and operation," in *Proc. North American Power Symposium (NAPS)*, Sept. 2016, pp. 1–6.

[40] T. R. M. Khumalo and J. H. C. Pretorius, "Distribution network reliability enhancement through reliability based methodology: A case study in Soweto Eskom distribution," in *Proc. Australasian Universities Power Engineering Conference (AUPEC)*, Nov. 2017, pp. 1–6.

[41] M. R. Elkadeem, M. A. Alaam, and A. M. Azmy, "Optimal automation level for reliability improvement and self-healing mv distribution networks," in *Proc. Eighteenth International Middle East Power Systems Conference (MEPCON)*, Dec 2016, pp. 206–213.

[42] A. Al-Nujaimi, M. A. Abido, and M. Al-Muhaini, "Distribution power system reliability assessment considering cold load pickup events," *IEEE Transactions on Power Systems*, vol. 33, no. 4, pp. 4197–4206, July 2018.

[43] S. Conti, S. A. Rizzo, E. F. El-Saadany, M. Essam, and Y. M. Atwa, "Reliability assessment of distribution systems considering telecontrolled switches and microgrids," *IEEE Transactions on Power Systems*, vol. 29, no. 2, pp. 598–607, March 2014.

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