Journal Européen des Systèmes Automatisés
Vol. 57, No. 1, February, 2024, pp. 303-309
Journal homepage: http://iieta.org/journals/jesa

Identifying Key Reliability Factors in Micro-Grid Systems Using Principal Component Analysis

Amuta O. Elizabeth[1*], Ongbali S. Oyaka[2], Hope Orovwode[1], Abel E. Airoboman[3], Sobola Gabriel[1], Dike H. Nwenenda[4]

[1] Department of EIE, Covenant University, Ota 112104, Nigeria
[2] Department of Mechanical, Covenant University, Ota 112104, Nigeria
[3] Department of Electrical Engineering, Nigeria Defence Academy, Kaduna 800281, Nigeria
[4] Department of Petroleum Engineering, Covenant University, Ota 112104, Nigeria

Corresponding Author Email: elizabethamuta@covenantuniversity.edu.ng

https://doi.org/10.18280/jesa.570130

Received: 8 September 2023
Revised: 17 January 2024
Accepted: 30 January 2024
Available online: 29 February 2024

Keywords:
micro-grid, PCA, reliability, StatistiXL, variable

ABSTRACT

One way to solve the shortage in power supply and the rapid load growth is by operating power systems that could improve power supply reliability. The study aims to carry out a holistic evaluation by identifying the several reliability variables that could influence the micro-grid power system's reliability which is vital in electricity generation. Thirty-three reliability variable factors that are commonly observed to influence power systems reliability were chosen for the micro-grid power systems study and examined using the principal component analysis (PCA). The system reliability key variables were evaluated using the StatistiXL software. A structured questionnaire was crafted considering thirty-three reliability variables, harvested from literature, and administered to respondents in the micro-grid power system industry. The respondent size was determined at a level of confidence of 95% and an error margin of 5% was deployed to corroborate an adequate population size representation which validated the study data. StatistiXL software was deployed to analyze the (mxn) data matrix, collated from the respondents' scores. The matrix was used as the input variable for the model deployed for the factor analysis. Nine factors with eigenvalues (λ>1) were mined and labeled for the analysis, but all the trivial variables were discarded. The PCA result holistically pinpointed the key reliability variables that influence the micro-grid reliability, revealing that system availability represented by factor 1 (F_1) loaded 24% of the total variables studied, with reliability cluster including Mean Time Between Failures (MTBF) = - 0.844, Mean Time to Repair (MTTR) = - 0.737, Demand Response (DR) technique = 0.752, Failure Rate = 0.647 among others. The failure rate and the frequency of outages in F_1, were an indication that system availability would be influenced, thereby affecting the micro-grid performance. The study also extracted some weak factor loading, F_8 and F_9 indicting them as reliability variables whose influences do not impact negatively on the micro-grid reliability but should not be discarded in the study of the reliability of micro-grid power systems. Hence an attempt to improve the system's reliability, concentrating on the key variables factors, the weak variables should not be neglected.

1. INTRODUCTION

The electric power system is a very complex infrastructure that is usually operated as a large-scale network. The energy infrastructure's reliability indicates the whole infrastructure's capacity to meet the customers' demand for energy [1]. All human activities depend on it; hence the power system network should be reliable. Reliability assessment is vital in micro-grids to ensure satisfying electricity needs sustainably. The study aims to examine the reliability of the micro-grid power system by determining the principal reliability variable factors that affect the micro-grid network performance using PCA. The study focused on the adequacy aspect of reliability that is associated with the system's ability to satisfy power supply demand [2]. The reliability studies involve assessing the systems' performance in terms of 'adequate' reliability indices to design systems that meet regulatory standards [3]. The electric power reliability measures the overall system's ability to satisfy electrical energy demand [4, 5]. The reliability of the power network is expected to function satisfactorily under stated planned actions and make electrical energy supply adequately available to customers for a specific period [6, 7].

The objective of a reliable power system network is to ensure the network's load requirements are satisfied at any point in time by the power system [8, 9]. Studies of the micro-grid system's reliability are carried out to assess the system's capability to meet the electricity demands of connected customers. Among other reliability analysis methods such as analytical analysis, and fault tree analysis, PCA was chosen for this study because PCA is the only method that could bring out the key reliability factors needed to achieve the aim of the paper. Various factors affect power system reliability and influence its performance, however, the challenge has been identifying key variables factors among the numerous factors in the literature, hence, this study considered some reliability variable factors of micro-grid power systems. Most researchers in micro-grid power system reliability assessment focused on cost using different models to measure the system's reliability without considering various factors that could influence micro-grid reliability, thereby affecting power supply sustainability. Akinyele et al. [10] assessed the solar photovoltaic micro-grid technology's performance for evaluating the output power. The studies [11, 12] proposed that micro-grid reliability can be measured by modelling the total life-cycle costs. Vedachalam and Atmanand [13] carried out an assessed energy storage technology for the Indian electricity sector and noted that the Indian power sector needs a cumulative energy capacity of a battery of 270GW by 2047 for the achievement of better grid reliability and energy quality. The findings noted that battery storage is vital in determining the electricity transformation to realize a reliable power system in India [14]. Jafari et al. [15] proposed a practical energy market strategy to reduce energy not supplied and increase the reliability of the micro-grid. Also, Ibrahim et al. [16] evaluated the reliability of a micro-grid prioritizing loads, applying a hybrid analytical simulation method. It is seen that previous research did not scientifically pinpoint the key variables that affect the micro-grid reliability. Hence, this study focused on these reliability variable factors that will help in pinpointing the principal factors that majorly affect micro-grid power systems. These reliability factors could affect a reliable continuous power supply, which is the gap that has been addressed in this study. Variable factors affecting micro-grid reliability were formerly fragmented in literature.

Micro-grid concept

Micro-grid definition is still not standardized, as there are many definitions of the micro-grid. Micro-grid power system is an assembly of electric power generation, backup batteries, and various kinds of loads that could operate either connected to the traditional grid [17]. Micro-grid can also be explained as integrating various energy generating sources to handle all loads within its locality [18]. Micro-grids can make electricity supply potent and economical [19]. Micro-grid can operate seamlessly and independently when the energy sources are properly selected and controlled, thereby resulting in a high reliability system [20, 21]. Electric power system, availability, and reliability are critical to satisfying the power consumption needs more reliably.

The micro-grid overall performance can be enhanced by improving on the micro-grid reliability, hence there is a need to holistically identify these reliability variable factors and analyse these factors. Table 1 presents references to reliability variable factors. From the literature reviewed, studies show that although reliability variable factors have been studied, there is still the under-explored issue that few studies are focusing on the comprehensive evaluation of the various reliability factors that can affect micro-grid performance.

Table 1. References of reliability variables factors of micro-grid power system

S/N	Variables Affecting Micro-Grid Reliability	Reference
1	Protection device	[22]
2	Number of interruptions on the system	[23]
3	Energy storage technologies	[24]
4	Emissions	[25]
5	Cost of energy	[25]
6	Load	[26]
7	Expected Energy not Supplied (ENNS)	[27]
8	Loss of power supply probability LPSP	[28]
9	Loss of load probability	[28]
10	Generating sources	[29]
11	Failure rate	[30]
12	Demand Response (DR) techniques	[2]
13	Average outage duration	[30]
14	Average annual unavailability or average annual outage time	[30]
15	System Average Interruption Duration Index (SAIDI)	[31]
16	System Average Interruption Frequency Index (SAIFI)	[30]
17	Customer Average Inter-ruption Duration Index (CAIDI)	[32]
18	Average annual power outage frequency λ (time/year)	[33]
19	System brake down	[15]
20	Interruption COST (ECOST) indices	[29]
21	Repairate (r)	[32]
22	Availability (A)	[26]
23	Mean Time To Repair (MTTR)	[34]
24	Mean Time Between Failures (MTBF)	[34]
25	Number of affected consumers	[35]
26	Outage duration	[31]
27	Unavailability	[23]
28	ASAI	[36]
29	Frequency of outages	[34]
30	Total operating time	[31]
31	Mean TIME To Failure (MTTF)	[34]
32	Diesel fuel price fluctuations	[25]
33	Total Number of Interruptions (TNI)	[36]

2. RESEARCH METHODOLOGY

2.1 Principal component analysis

From literature, it was noted that reliability variables could influence micro-grid reliability. PCA was chosen for the study because it is a type of variable reduction tool that helps to concentrate variables. PCA helps to know the variable to focus on, which is critical based on the factor loadings of the various variable factors [37].

2.2 Eigenvalues theoretical framework

Eigenvalues helped to retain principal component during varimax rotation in the PCA technique that was deployed for the study. The variance in the data and the decision-making process for the number of retained principal component of the reliability variable factors were measured using the eigenvalues in the PCA [38]. In the principal component analysis, the eigenvalues helped to determine only the number of principal component to be retained. Eq. (1) was applied to solve the unit matric:

$$Ax = \lambda x \tag{1}$$

$A = unknown\ vector, \lambda = unknown\ scalar$

The study used $x \neq 0$ = non-trivial solution, for any value of λ.

$x = 0$ is a trivial solution λ because the factor does not contribute to explaining the variance. But, the interesting study is searching for "non-trivial" solutions in a way that x is not equal to 0 for any value of λ, which is also the eigenvalue of A. Eq. (1) was expressed as Eq. (2).

$$Ax - \lambda x = 0 \quad (2)$$

Multiplying λx by I, Eq. (2) gives Eq. (3).

$$(A - \lambda I)x = 0 \quad (3)$$

Since I is an identity matrix, then Eq. (3) is expressed as Eq. (4).

$$|A - \lambda I| = \left| \begin{matrix} (a_{11} - \lambda) & a_{12} & \dots\dots\dots\dots\dots\dots a_{1n} \\ a_{21} & (a_{22} \ -\lambda) & \dots\dots\dots\dots\dots a_{2n} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ a_{In}. & a_{In} & (a_{In} - \lambda) \end{matrix} \right| = 0 \quad (4)$$

The determinant of $A = |A - \lambda I|$ while the characteristic equation is $|A - \lambda I| = 0$. Hence expanding the determinant generates a polynomial degree of eigenvalues while the eigenvalues are given by the characteristic equation which also equals values. A structured questionnaire was created with 33 variables identified and used for the study. Renish Likert's 5-point attitudinal scale with dimensions including strongly disagree, disagree, agree, strongly disagree, and undecided, were used. The questionnaires were administered to the respondents in the powersystems. Eq. (5) was deployed to determine the respresentative population size of the power system population, selected for the research and that justified an adequate population size for the paper [38]. The sample size is vital and directly impacts on the accuracy to which a study generalizes findings to the larger poputaltion. Hence the sample size of considering 33 variables was taken to be large enough and adequate for the PCA study, to ensure that the sample covaraince matrix is a good approximate of the population covaraince matrix [38].

$$\text{Sample Size} = \frac{\frac{Z_{(1-\alpha)^2}}{2} \times P(1-p)}{d^2} \quad (5)$$

where,

$\frac{Z_{(1-\alpha)^2}}{2}$=Standard normal variate at 5% error

Z=Standard normal distribution

α=Significant level

p=Expected proportion in the population and

d=Absolute error or precision [39]

StatistiXL software was used to solve Eq. (4) for the eigenvalues. The reliability factors that are vital to the research were determined from eigenvalues.

2.3 Representative population size for the study

The respresentative population size used for the study was obtained after the sample size was determined using using Eq. (5) by choosing a confidence level of 95% and an error margin of 5% to corroborate adequate population size representation which validates the study data that was used. PCA technique was deployed beause the reliability data contains vast number of variables that are really correlated with each other, and of which PCA can simply reduce the dataset and also identify the key system of the data.

Confidence level of 95% and an error margin of 5% were chosen for the PCA study as seen in Eq. (5), because these are the values commonly used in statistical studies, to accurately determine results. The 95% condidence level was chosen to show that the survey result will accuraltely represent the studied population.

2.4 Data collected

Data used for the study was collected based on the retrieval and collation of the administered questionnaires to the respondents population in the Micro-grid power system. StatistiXL software was deployed to analyse the (mxn) data matrix, collated from the respondents' scores. The matrix was used as the input variable for the model deployed for the factor analysis done in the study. Figure 1 presents the various steps applied to the PCA analysis study.

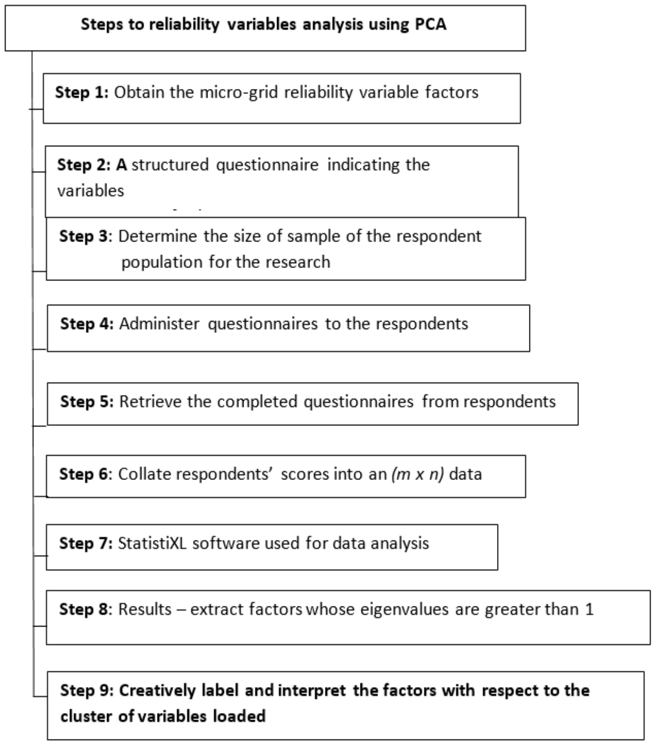

Figure 1. Micro-grid reliability variable analysis method

3. RESULTS AND DISCUSSION

The $(m \times n)$ data matrix generated was employed as an input variable into the PCA model and the matrix was assessed using the StatistiXL software.

The justification for selecting the nine factors with Eigenvalues greater than 1 was because the factors contributed to the variance of the variables studied based on their factor loadings. Among the 33 variables affecting the micro-grid power system reliability that were studied, 29 of the variables affect the micro-grid reliability performance according to the values of their respective factor loadings. However, the remaining four variables do not contribute reasonably to the explanation of the performance of the micro-grid, on account of their respective factor loading, which is between 0.00-0.045. The scree plot depicted in Figure 2 represents the variable factors that were selected, which indicates some key factors obtained from the PCA and were given interpretation.

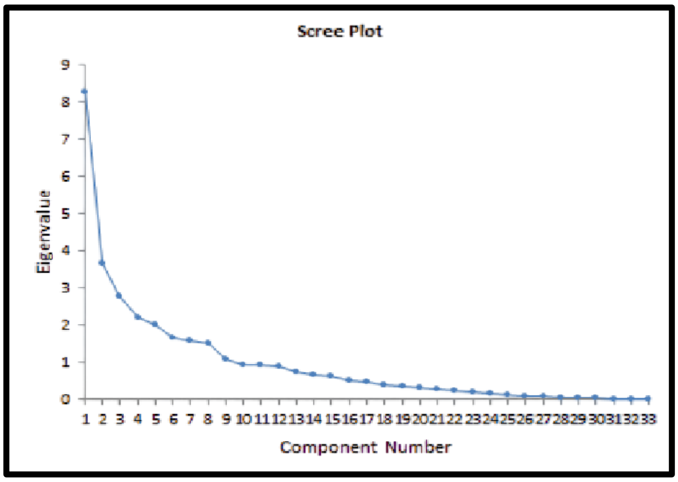

Figure 2. Reliability variable scree plot

The twenty-nine factors extraced from the PCA, loaded the nine clusters of the factor variables with their respective factor loadings, which were creatively labeled and explained as follows: All the nine cluster variables had the same impact on the microgrid reliability power system and so share a common correlation. Table 2 depicts the system availability factor representing $F_1(7)$, which is the principal factor and loaded 24% of the reliability variable factor studied. In this cluster MTBF wielded the highest factor loadings of 0.884 followed by Demand Response (DR) with a value of 0.752. Failure rate and availability had factor loadings of 0.64 and 0.638 respectively showing their relative significance in system availability. However, all reliability variables under the factor loadings significantly contribute to the performance of the micro-grid power system. All other variables in each factor loading group affect the performance of the micro-grid power system to a degree indicated by the magnitude of their factor loadings.

Table 2. System availability factor

$F_1(7)$	Reliability Variables Affecting MG Power System	Factor Loading
11	Failure rate	0.647
12	Demand Response (DR) techniques	0.752
19	System Components Brake down	0.558
22	Availability	0.638
23	Mean Time to Repair (MTTR)	0.737
24	Mean Time Between Failures (MTBF)	0.844
29	Frequency of outages	0.657

Table 3. System interruption factor

$F_2(5)$	Reliability Variables Affecting MG Power System	Factor Loading
20	Outage cost (OC)	0.514
21	Repair rate	0.616
25	Number of affected consumers	0.624
26	Outage duration	0.700
33	Total number of interruptions	0.899

Table 3 shows system interruption, loading a cluster of five variables. The total number of interruptions and outage duration gave high factor loadings of 0.899 and 0.700, respectively. In contrast, the remaining variable in that same cluster indicated various degrees of factor loading relating to the microgrid reliability performance.

Table 4 shows factor loading depicts power supply probability which loaded a cluster of four variables. The cluster outlined the Customer Average Interruption Duration Index (CAIDI) and Loss of power supply probability (LPSP) to have high loading factor loadings of 0.863 and 0.735, respectively.

Factor F_4, given in Table 5, also depicts system load variability as a bipolar factor, with three positive and negative factor loadings in the cluster. The System interruption variable displayed a higher loading factor of 0.796, while load =0561. System interruption could result in breakdowns of some sensitive equipment such as protection devices and loss of consumers, hence it should be treated with utmost concern in the reliability performance of micro-grid power systems. Factor F_4, als has one negative factor loadings of -0.653, indicating how negatively the variables affect the reliability of the micro-grid power system. The Factor loading of -0.653, in the model demonstrates that variable cost of components is a critical variable.

Table 4. Power supply probability factor

$F_3(4)$	Reliability Variables Affecting MG Power System	Factor Loading
8	Loss of power supply probability LPSP	0.735
10	Generating sources	0.590
16	System Average Interruption Frequency Index (SAIFI)	0.631
17	Customer Average Interruption Duration Index	0.863

Table 5. System load variability factor

$F_4(3)$	Reliability Variables Affecting MG Power System	Factor Loading
2	System interruption	0.796
6	Load	0.561
13	Variable cost of components	-0.653

The Mean time to failure in reliability is essential, and it is presented in Table 6. The maintenance index estimates the average time a non-repairable component or system can function before it fails. MTTF invariably gives the lifespan of the equipment. The factor loading of 0.737 denotes an immense variance of MTTF and its importance in the power system. Hence, if MTTF is not checked, it can affect the reliability of a system, thereby affecting power supply sustainability, especially in isolated communities.

Factor F_6 is a duplex factor indicating that the system operation time of a micro-grid is of paramount importance by the laudable factor loading of 0.825, as seen in Table 7**.** The variable factors range from 0.676 to 0.825. The unavailability variable wields 0.676 factor loading indicating that unavailability issues in micro-grid reliability must be considered at all times to ensure a reliable power supply in micro-grid power systems.

Factor loading F_7 is also a duplex factor with energy storage technology and diesel fuel price fluctuations, as given in Table 8. The factor has a factor loading ranging from 0.668 to 0.761, depicting that diesel fuel price influences reliability. Fluctuation and constant changes in the price rate of diesel can have significant effects on micro-grid reliability. The energy storage component had a factor loading of 0.668, indicating that this component could affect the system's reliability.

The system unavailability time factor is a bipolar factor, with positive and negative factor loadings in the cluster, depicting protection devices and average annual outage time, as shown in Table 9. The average annual outage time wielding a factor loading of 0.795 and the protective device indicates an average factor loading of -0.538. This factor suggests that the protection devices must be considered for a micro-grid to run smoothly. Hence the system unavailability time factor must be of utmost concern in micro-grid reliability management.

Factor (F_9) is also a duplex factor and consists of Emissions and Expected Energy Not Supplied (EENS), with loading factors of -0.645 and 0.810, respectively, as shown in Table 10. EENS factor loading indicates that it is a reliability variable that must be considered in micro-grid power systems so that the reliability performance can be improved. The emssion variable had -0.645 factor loading also making that factor loading to be critical facor that must not ne neglected.

Table 6. Mean Time to Failure factor

F_5(1)	Reliability Variables Affecting MG Power System	Factor Loading
31	Mean time to failure(MTTF)	0.736

Table 7. System operation time factor

F_6(2)	Reliability Variables Affecting MG Power System	Factor Loading
27	Unavailability	0.676
30	Total operating time	0.825

Table 8. Energy storage capability factor

F_7(2)	Variables Affecting MG Power System	Factor Loading
3	Energy storage technology	0.668
32	Diesel fuel price fluctuations	0.761

Table 9. System unavailability time factor

F_8(2)	Reliability Variables Affecting MG Power System	Factor Loading
1	Protection devices	-0.538
14	Average annual unavailability	0.795

Table 10. Unmet demand factor

F_9(2)	Reliability Variables Affecting MG Power System	Factor Loading
4	Emissions	-0.645
7	Expected Energy not Supplied (EENS)	0.810

Extensive researchers in the field of reliability of power system issues have focused on using some reliability methods such as the analytical method [40], without considering reliability variable factors that would influence the reliability performance of a micro-grid system.

Also, Amaral et al. [41] deployed a simulation method but still did not holistically consider reliability variables that could impact power system reliability, hence this study focused on identifying the fragmented reliability variable in literature and analyzing them.

4. CONCLUSIONS

The study holistically pinpointed the key reliability variables affecting micro-grid reliability which were not annexed in research. The result showed that the system availability reliability factor, represented by factor 1 (F_1) loaded 24% of the studied variables thereby serving as the principal reliability factor. System availability reliability clusters include Mean Time Between Failures (MTBF) =-0.884, Mean Time To Repair (MTTR) =-0.737, Demand Response (DR) technique =0.752, and Failure Rate =0.647 among others. All other variables in each factor group (F_2 to F_9) also affect the performance of the micro-grid power system to a degree indicated by the magnitude of their factor loadings. The PCA study also sharpens focus on the micro-grid reliability variables to improve micro-grid power system performance based on the respective factor loadings of the variables investigated. The system availability reliability factor influences the micro-grid reliability performance among other variables factors studied. Hence an attempt to improve the system reliability, more attention needs to be on the system availability cluster variables. The factors studies can be optimized by including micro-energy storage into the power system to als enhace the reliability. The findings from the study will assist engineers, researchers, and investors in designing a reliable microgrid for any location, especially in developing countries. Based on the findings, future ivestigation could be done on a biohybrid robots as emerging technologies that could enhance micro-grid reliability.

However, PCA has a limitaion that, the technique can lead to information loss if the right number of principal components that would explain disparity in the dataset is not selected.

ACKNOWLEDGMENT

The authors will like to thank the Covenant University Centre for Research Innovation and Discovery for their support for this research work.

REFERENCES

[1] Adefarati, T., Bansal, R.C. (2017). Reliability and economic assessment of a microgrid power system with the integration of renewable energy resources. Applied Energy, 206: 911-933. https://doi.org/10.1016/j.apenergy.2017.08.228

[2] Khan, B., Alhelou, H.H., Mebrahtu, F. (2019). A holistic analysis of distribution system reliability assessment methods with conventional and renewable energy sources. AIMS Energy, 7(4): 413-429. https://doi.org/10.3934/energy.2019.4.413

[3] Xiang, Y., Wang, L., Zhang, Y. (2018). Adequacy evaluation of electric power grids considering substation cyber vulnerabilities. International Journal of Electrical Power & Energy Systems, 96: 368-379. https://doi.org/10.1016/j.ijepes.2017.10.004

[4] Esan, A.B., Agbetuyi, A.F., Oghorada, O., Ogbeide, K., Awelewa, A.A., Afolabi, A.E. (2019). Reliability assessments of an islanded hybrid PV-diesel-battery system for a typical rural community in Nigeria. Heliyon, 5(5). https://doi.org/10.1016/j.heliyon.2019.e01632
[5] Ohijeagbon, O.D., Oluseyi, A., Waheed, O., Adekojo, M., Salawu, E.Y., Oyawale, F.A. (2019). Design of optimal hybrid renewable energy system for sustainable power supply to isolated-grid communities in North Central, Nigeria. Procedia Manufacturing, 35: 278-284. https://doi.org/10.1016/j.promfg.2019.05.040
[6] Tezer, T., Yaman, R., Yaman, G. (2017). Evaluation of approaches used for optimization of stand-alone hybrid renewable energy systems. Renewable and Sustainable Energy Reviews, 73: 840-853. https://doi.org/10.1016/j.rser.2017.01.118
[7] Heylen, E., Deconinck, G., Van Hertem, D. (2018). Review and classification of reliability indicators for power systems with a high share of renewable energy sources. Renewable and Sustainable Energy Reviews, 97: 554-568. https://doi.org/10.1016/j.rser.2018.08.032
[8] Lopez-Prado, J.L., Vélez, J.I., Garcia-Llinas, G.A. (2020). Reliability evaluation in distribution networks with microgrids: Review and classification of the literature. Energies, 13(23): 6189. https://doi.org/10.3390/en13236189
[9] Soyemi, A.O., Samuel, I.A., Adesanya, A., Akinmeji, A., Adenugba, F. (2021). A robust energy policy review of selected African countries: An impetus for energy sustainability in Nigeria. In Journal of Physics: Conference Series, IOP Publishing, 1734(1): 012028. https://doi.org/10.1088/1742-6596/1734/1/012028
[10] Akinyele, D.O., Rayudu, R.K., Nair, N.K.C. (2015). Global progress in photovoltaic technologies and the scenario of development of solar panel plant and module performance estimation-application in Nigeria. Renewable and Sustainable Energy Reviews, 48: 112-139. https://doi.org/10.1016/j.rser.2015.03.021
[11] Júnior, E.D.F.M., Rüther, R. (2020). The influence of the solar radiation database and the photovoltaic simulator on the sizing and economics of photovoltaic-diesel generators. Energy Conversion and Management, 210: 112737. https://doi.org/10.1016/j.enconman.2020.112737
[12] Mohseni, S., Brent, A.C. (2020). Economic viability assessment of sustainable hydrogen production, storage, and utilisation technologies integrated into on-and off-grid micro-grids: A performance comparison of different meta-heuristics. International Journal of Hydrogen Energy, 45(59): 34412-34436. https://doi.org/10.1016/j.ijhydene.2019.11.079
[13] Vedachalam, N., Atmanand, M.A. (2018). An assessment of energy storage requirements in the strategic Indian electricity sector. The Electricity Journal, 31(7): 26-32. https://doi.org/10.1016/j.tej.2018.08.003
[14] Bai, H., Miao, S., Zhang, P., Bai, Z. (2015). Reliability evaluation of a distribution network with microgrid based on a combined power generation system. Energies, 8(2): 1216-1241. https://doi.org/10.3390/en8021216
[15] Jafari, A., Ganjehlou, H.G., Khalili, T., Bidram, A. (2020). A fair electricity market strategy for energy management and reliability enhancement of islanded multi-microgrids. Applied Energy, 270: 115170. https://doi.org/10.1016/j.apenergy.2020.115170
[16] Ibrahim, M., Khair, A., Ansari, S. (2015). A review of hybrid renewable energy systems for electric power generation. International Journal of Engineering Research and Applications, 5(8): 42-48.
[17] Poudel, B., Parton, K., Morrison, M. (2022). The drivers of the sustainable performance of renewable energy-based mini-grids. Renewable Energy, 189: 1206-1217. https://doi.org/10.1016/j.renene.2022.03.006
[18] Garmabdari, R., Moghimi, M., Yang, F., Gray, E., Lu, J. (2020). Multi-objective energy storage capacity optimisation considering microgrid generation uncertainties. International Journal of Electrical Power & Energy Systems, 119: 105908. https://doi.org/10.1016/j.ijepes.2020.105908
[19] Sufyan, M., Abd Rahim, N., Tan, C., Muhammad, M.A., Sheikh Raihan, S.R. (2019). Optimal sizing and energy scheduling of isolated microgrid considering the battery lifetime degradation. PloS One, 14(2): e0211642. https://doi.org/10.1371/journal.pone.0211642
[20] Ge, S., Sun, H., Liu, H., Li, J., Zhang, X., Cao, Y. (2019). Reliability evaluation of multi-energy microgrids: Energy storage devices effects analysis. Energy Procedia, 158: 4453-4458. https://doi.org/10.1016/j.egypro.2019.01.769
[21] John, T.M., Wara, S.T. (2018). A tutorial on the development of a smart calculator to determine the installed solar requirements for households and small businesses. In 2018 IEEE PES/IAS PowerAfrica, Cape Town, South Africa, pp. 319-323. https://doi.org/10.1109/PowerAfrica.2018.8521000
[22] Cagnano, A., De Tuglie, E., Mancarella, P. (2020). Microgrids: Overview and guidelines for practical implementations and operation. Applied Energy, 258: 114039. https://doi.org/10.1016/j.apenergy.2019.114039
[23] Escalera, A., Hayes, B., Prodanović, M. (2018). A survey of reliability assessment techniques for modern distribution networks. Renewable and Sustainable Energy Reviews, 91: 344-357. https://doi.org/10.1016/j.rser.2018.02.031
[24] Faisal, M., Hannan, M.A., Ker, P.J., Hussain, A., Mansor, M.B., Blaabjerg, F. (2018). Review of energy storage system technologies in microgrid applications: Issues and challenges. IEEE Access, 6: 35143-35164. https://doi.org/10.1109/ACCESS.2018.2841407
[25] Adefarati, T., Bansal, R.C. (2019). Reliability, economic and environmental analysis of a microgrid system in the presence of renewable energy resources. Applied Energy, 236: 1089-1114. https://doi.org/10.1016/j.apenergy.2018.12.050
[26] Okozi, S.O., Chukwudi, P.C., Olubiwe, M., Obute, K.C. (2018). Reliability assessment of nigerian power systems case study of 330kv transmission lines in benin sub-region. International Journal of Engineering Research & Technology, 7(03): 399-405. https://doi.org/10.17577/ijertv7is030181
[27] Fattahi, A., Nahavandi, A., Jokarzadeh, M. (2018). A comprehensive reserve allocation method in a micro-grid considering renewable generation intermittency and demand side participation. Energy, 155: 678-689. https://doi.org/10.1016/j.energy.2018.05.029
[28] Dawoud, S.M., Lin, X., Okba, M.I. (2018). Hybrid renewable microgrid optimization techniques: A review.

Renewable and Sustainable Energy Reviews, 82: 2039-2052. https://doi.org/10.1016/j.rser.2017.08.007

[29] Adefarati, T., Bansal, R.C. (2017). Reliability assessment of distribution system with the integration of renewable distributed generation. Applied Energy, 185: 158-171. https://doi.org/10.1016/j.apenergy.2016.10.087

[30] Bullich-Massagué, E., Díaz-González, F., Aragüés-Peñalba, M., Girbau-Llistuella, F., Olivella-Rosell, P., Sumper, A. (2018). Microgrid clustering architectures. Applied Energy, 212: 340-361. https://doi.org/10.1016/j.apenergy.2017.12.048

[31] Nweke, J.N., Gusau, A.G., Isah, L.M. (2020). Reliability and protection in distribution power system considering customer-based indices. Nigerian Journal of Technology, 39(4): 1198-1205. https://doi.org/10.4314/njt.v39i4.28

[32] Al-Nujaimi, A., Abido, M.A., Al-Muhaini, M. (2018). Distribution power system reliability assessment considering cold load pickup events. IEEE Transactions on Power Systems, 33(4): 4197-4206. https://doi.org/10.1109/TPWRS.2018.2791807

[33] Guo, J., Liu, W., Syed, F.R., Zhang, J. (2019). Reliability assessment of a cyber physical microgrid system in island mode. CSEE Journal of Power and Energy Systems, 5(1): 46-55. https://doi.org/10.17775/CSEEJPES.2017.00770

[34] Abdulgalil, M.A., Alharbi, H.S., Khalid, M., Almuhaini, M.M. (2018). Reliability assessment of microgrids with multiple distributed generations and hybrid energy storage. In 2018 IEEE 27th International Symposium on Industrial Electronics (ISIE), Cairns, QLD, Australia, pp. 868-873. https://doi.org/10.1109/ISIE.2018.8433614

[35] Ma, W., Xue, X., Liu, G., Zhou, R. (2018). Techno-economic evaluation of a community-based hybrid renewable energy system considering site-specific nature. Energy Conversion and Management, 171: 1737-1748. https://doi.org/10.1016/j.enconman.2018.06.109

[36] Tur, M.R. (2020). Reliability assessment of distribution power system when considering energy storage configuration technique. IEEE Access, 8: 77962-77971. https://doi.org/10.1109/ACCESS.2020.2990345

[37] Schwenk-Nebbe, L.J., Vind, J.E., Backhaus, A.J., Victoria, M., Greiner, M. (2022). Principal spatiotemporal mismatch and electricity price patterns in a highly decarbonized networked European power system. iScience, 25(6). https://doi.org/10.1016/j.isci.2022.104380

[38] Ongbali, S.O., Afolalu, S.A., Oyedepo, S.A., Aworinde, A.K., Fajobi, M.A. (2021). A study on the factors causing bottleneck problems in the manufacturing industry using principal component analysis. Heliyon, 7(5). https://doi.org/10.1016/j.heliyon.2021.e07020

[39] Gao, F., Chen, T., Chen, K., Zhang, R., Wang, L., Liu, J., Hua, D., Stanič, S. (2021). A novel retrieval algorithm of multi-longitudinal-mode high-spectral-resolution lidar based on complex degree of coherence and the analyses of absolute errors. Journal of Quantitative Spectroscopy and Radiative Transfer, 272: 107829. https://doi.org/10.1016/j.jqsrt.2021.107829

[40] Patowary, M., Panda, G., Deka, B.C. (2019). Reliability modeling of microgrid system using hybrid methods in hot standby mode. IEEE Systems Journal, 13(3): 3111-3119. https://doi.org/10.1109/JSYST.2019.2925453

[41] Amaral, T.S., Gomes Jr, S., Borges, C.L. (2021). Reliability evaluation of bulk power systems with wind generation using small signal stability analysis. International Journal of Electrical Power & Energy Systems, 129: 106840. https://doi.org/10.1016/j.ijepes.2021.106840