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Analysis on Reliability Evaluation in Power System

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Abstract— Assessment of reliability performance in each power systems has to be performed in a cost-benefit structure. The model, yet, a time-consuming task, particularly for the systems which includes a huge count of feasible configurations, so simpler modalities referred to the reliability indices evaluation are utilized. This paper makes a clear survey on fifteen reliability evaluation approaches. Three details like used methodology, performance measures, and best performance is categorized and reviewed under various forms like diagrammatic representation and tables.

Keywords—Reliability Evaluation; power System; performance Measure; Time-Consuming; Electic power
Nomenclature

Acronyms	Description
CVaR	Conditional value-at-risk
DR	Demand Response
VOLL	Values of Lost Load
PP	Polypropylene
MLPVI	Multilevel PV Inverter
SAPSs	Small Autonomous Power Systems
PWM	Pulse-Width Modulation
PLECS	Piecewise Linear Electrical Circuit Simulation
SHP	Small Hydro-Power
UGF	Universal Generating Function
DOOBNs	Dynamic Object-Oriented Bayesian networks
OOBNs	Object-Oriented Bayesian Networks
EDA	Enhanced Assessment of Distribution Algorithm
EPNS	Expected Power Not Supplied
OCC	Operating Capacity Credit

I. INTRODUCTION

Nowadays, the generation of ELECTRIC power is professed to be huge contributors of emissions of carbon dioxide, and the nations in the world are determined for obtaining the vital portions of the whole electric requirements from all the substitute sources that minimize the carbon dioxide footprints. Among all the resources, Wind power is observed as the most appropriate substitute for the huge generation of power, and it is being quickly produced all over the world. With the raising of wind power penetration, reliability is considered as rising strategy since because of the added unpredictability in wind power. Most importantly, the generation of wind power is overseen by the various atmospheric circumstances, and the system operator of electric could not dispatch or control the wind power in the similar manner as like the existing generator including hydro or thermal unit. The output power generated from wind farm is ordered through the arbitrary deviations related to the wind regime at the site.

The conventional unit's reliability in a little future time is defined through the rate of failure. If the traditional generating unit is represented as a two-state system, it dwells in the operable state as well as inoperable states on the short lead time along prospect defined particularly by the failure of unit that assumes that repair is not feasible in the short lead time like some hours. In order to push further investment in the generation of wind, certain distinct service operators have newly adopted some rules for providing the capacity credits for the generation of wind. In the market called restructured energy markets, those novel rules will allow the wind generation for competing on equivalent footing along traditional generation. Yet, the wind generation's intermittent nature done the reliable capacity analysis, which grants the grid more challenging. However, a wind generator has the value of capacity if they raise the system's generation reliability of power. Power system [21] [22] [23] reliability [18] [19] depends on the additional generation. Even though, the level to which the reliability [20] improving deviates with the penetration level of power generation form. The reliability impact [16] [17] of any power generation system should be examined at every core operation. This paper makes a view

on 15 reliability indices models, their performance measures and the best performance. All those details is clearly described by means of tables. The rest of the paper is organized as follows: Section II reviews the literature work. Section III explains the research gaps and challenges in reliability assessment. Section IV ends the paper.

II. ANALYTICAL PART ON STATE-OF-THE-ART RESEARCH WORKS

A. Related Works

In 2013, rade and Nikola [1] had performed an evaluation under the effect of DG continuously operation that has the output behavior (non-stochastic) on the supply reliability in industries. They have introduced a set of novel indices that represents the effect of DG under interruption's frequency, duration of interruption as well as the estimated energy that has not supplied to each single customer. Additionally, a novel composite index accumulating the DG effects on the whole supply reliability, with the inclusion of frequency of interruption, its duration along with the expected energy not supplied, was developed. Finally, the outcomes from various case studies via real time network were analyzed and discussed.

In 2013, Suman *et al.* [2] have stated that the wind power generation was considerably varied from all the existing thermal as well as hydropower generation, which means the wind power, was managed via the atmosphere and it could not be dispatched as the existing units done for responding the need of the system. Here, the existing system's operational reliability purely based on the committed unit failures along with the leading time of the consequent available unit. They have governed the wind turbine generators reliability contribution through the unpredictability of wind speed during wind site. Further, the short-term wind approach was introduced to the distinct lead time must be correctly joined with the existing committed units for power system's operational reliability with the appropriate significant penetration of wind. In the lead time, risk concept was evaluated on the reliability contribution, and also the hot reserve units were dedicated later. This was done for the incorporate of wind power in formulating the reliability of system. Finally, the proposed model was applied on IEEE-RTS for evaluating the operational system.

In 2009, Pavlos and Yiannis [3] had stated that the formulation of reliability performance must be performed in cost-efficient model. The respective model, however, was very time consumption work, particularly for systems that include huge count of feasible configurations. Hence simpler approaches termed to the formulation of reliability indices were utilized. In the SAPSs, utilizes the deterministic criteria. The model, still, could not be practiced in SAPS, which includes only the renewable energy sources, because of the intermittent nature of the granted energy. This research work has implemented a complete reliability cost along with the analysis of worth. Further, it was joined with the formulation of certain fundamental probabilistic indices for discovering the performance. Then they have proposed the regularized energy reliability indices and unavailability's energy index could be utilized as the sufficient criteria of optimal performance of system. Finally, the model was evaluated via a huge count of sensitivity analysis studies, which were on the basis of various maximum annual loads as well as various load type mixes.

In 2005, Annunzio, and Santoso, [4] have stated that since the intermittent renewable generation was more vital in the power generation portfolio, it becomes largely vital in assessing the effects on power systems' generation reliability. Hence, it was the aim of this research work on evaluating the reliability effect of wind power penetration through the fundamental load probability loss and expectation process. In order to stop this, reliability effects of different wind power penetration levels were examined and were compared to existing fossil-based units. Finally, the outcomes have revealed that at wind penetration levels < 5%, the effect of reliability of wind farm was compared to conventional unit. Nevertheless, at penetration levels larger than 5%, the wind farm was minimal effective in minimizing the LOLE.

In 2006, Rajesh *et al.* [5] have stated that the renewable energy sources, particularly the wind turbine generators were concerned as the vital generation alternatives in the field of power systems as it was nonexhausted in nature and also has benign environmental impacts. In fact, the penetration of wind power requires developing further broadly applicable models for assessing the actual advantages of supplementing wind turbines to existing generating systems. Moreover, reliability formulation of generating systems including wind energy sources was a difficult progress. This needs an accurate wind speedy forecasting model for the wind farm site. The approach needs historical wind speed information that was gathered over number of years for the location of wind farm to determining the needed wind speed parameters. The assessment process must accurately model the power output's intermittent nature from the wind farm. More often, the sequential Monte Carlo simulation approach was used. This research work has presented a simplified approach for the formulation of power systems' reliability with wind power. The introduction of the usual wind speed approach that applicable for diverse wind farm locations was presented. The approach was further simplified through the determination of least multistate representation in reliability formulation. Finally, case studies have been applied to prove the superiority of proposed work.

In 2005, Rajesh and Po [6] had stated that the rapid raising of wind power contribution has provoked the requirement on developing more broadly accessible models on assessing the actual advantages of supplementing wind turbines to conventional systems. Here, the reliability as well as the cost assessment needs the simulation of huge wind speed information for particular farm sites. The major phases were the construction of wind speed simulation approach, which was introduced in this research work. It was more vital that the proposed approaches could maintain the vital wind farm locations' arithmetic characteristics. The Wind speed information from 2 wind sites was utilized for illustrating the approach. The authors have presented the outcomes of wind information simulation, power profile output, and power system risk formulation, which were compared via various wind model types at various wind farm sites. The aim was to gain a common and suitable approach for reliability assessment of power systems including wind sources.

In 2016, Egill *et al.* [7] have presented the enhanced way of concerned evaluating the capacity deficit risk of the composite power system. With the application of significance sampling of load states along with the generation as well as transmission states in the systematic mode, the developed approach was various orders of magnitude, which was more effective than the crude Monte Carlo simulation, which was significantly more effective than conventional algorithms (Cross-Entropy based), which has applied other manners of assessing the significance sampling distributions. They have applied the efficient system performance measure for finding the optimal significance sampling distributions while pre-simulation, which could vitally minimize the needed investigational effort. They have done the simulation work on IEEE bus system and has finalized the performance of developed approach.

In 2016, Mohammed *et al.* [8] have investigated the effects of transient instability on the reliability. Conventionally, the evaluation of composite system reliability was done, which was on the basis of steady-state assessment of load curtailments. Moreover, the system dynamics were because of the computational difficulty. The authors have proposed 3 stability indices (probabilistic transient) for the assessment of system robustness over dynamic contingencies. They have also used a direct method to evaluate the transient stability on the basis of formulating the system's energy margin under fault events. In order to do the update of probabilistic transient stability indices, they have used the energy margins. The reliability dependencies and stability indices on the time of fault clearing were formulated. Finally, the model was applied practically, and the outcomes were indicated the significance of impact of stability in reliability evaluation.

In 2018, Amjad *et al.* [9] have stated that the Uncertainties in renewable energy resources, as well as demand in electricity, have proposed some novel drawbacks to energy as well as microgrids reserve scheduling, especially in autonomous mode. The authors have developed a risk-constrained stochastic model for maximizing the predictable profit of microgrid operator on various facts like renewable resources uncertainties, demand load as well as electricity price. Here, the trade-off among maximizing the expected profit of operator and the threat of attaining low profits were modeled through the use of CvaR approach. The influence of participation of consumer in DR program and its respective emergency load shedding for various VOLL were examined on the predictable operator profit. Further, the effects of various VOLL, as well as risk aversion parameters, were demonstrated on the reliability of system. They have also presented the simulation outcomes for illustrating the risk aversion effect on issue in system security. Finally, the arithmetical outcomes have demonstrated the performance of proposed model over other methods.

In 2018, YAN *et al.* [10] have stated that the construction as well as the ultrahigh-voltage power grid process have resolved the issue of optimal energy resources allocation and have played a major role in advancing the social development. For analyzing the ultrahigh voltage AC/DC system reliability that was joined with quasi-Monte Carlo approach, the reliability approach of different components as well as systems were recognized and had enhanced the simulation speed with high accuracy rate. They have also designed the BPA-Matpower data interface for assuring the compatibility as well as the efficacy of software. Subsequently, they have proposed an index system to evaluate the reliability. On the basis of actual regional power grid, they have compared the proposed approach with conventional sequential Monte Carlo approach, and demonstrated the effectiveness of the proposed system.

In 2017, Yeonha *et al.* [11] have stated that the PP had the exceptional heat resistant and was the eco-friendly insulation material, which could be recycled when compared to polyethylene (cross-linked). In Europe, PP insulated high-voltage class cables were commercialized. Thus, the authors have proposed the PP insulated cables and have done the physical, thermal, as well as electrical tests. The vital process was the verification of design life of proposed cables. Moreover, the authors have proposed the long-term reliability formulation approach via frequency acceleration and have recognized the draft standard.

In 2017, Gatla *et al.* [12] have stated that recently, great process has been done in the progression of multilevel inverters (MLIs, as it has the benefits like minimized voltage stress with greater efficiency. As the MLPVI was the most serious part within the PV energy system's failures, it become more significant in predicting the lifetime of components and the MLPVI system. This research work has analyzed the five-level modular cascaded H-bridge MLI, which was on the basis of grid-connected application. Subsequently,

independent dc-link voltage controller was employed by considering the generated reference value from the utmost power point tracking algorithm of every PV module. They have investigated the loss as well as the thermal distributions of various power devices and has also demonstrated for different PWM controllers. The simulation work was done using MATLAB/Simulink and PLECS blockset, and has validated the theoretical analysis as well. They have formulated the MLPVI's reliability through parts stress mapproach, which has shown that the MLPVI has effective reliability by the use of phase shift PWM control technique.

In 2017, Lili *et al.* [13] have stated that the output of electric power from SHP generator was commonly defined by the water flow that slowly fluctuates in short term. Nevertheless, the water flow greatly deviates with seasonal alterations (for long-term mode). This uncertainty would take high effect on reliability of system, particularly for the systems with large penetration (hydro-power). This research work has presented an approach for evaluating the SHP generators' reliability. The process of producing as well as flow runoff conflux was investigated and has modeled the UGF approaches. The expected generated energy along with generation availability was utilized for evaluating the SHP generators' reliability. Finally, they have evaluated the performance of proposed model.

In 2018, Yuan *et al*. [14] have proposed a new reliability evaluation approach of complex systems by a DOOBNs. The proposed approach includes 2 major phases, termed, construction phases for OOBNs as well as for DOOBNs. In the Initial stage, the fragments of network along same structures as well as parameters were separated into classes; subsequently, those were then encapsulated. Then the OOBNs construction was completed as per the relationship between the encapsulated classes. Secondly, each fragment of dynamic Bayesian networks was developed by the initial stage phase, which was proclaimed by the class namely DOOBN. Finally, the accuracy of proposed model was formulated via all-voting, all-series, series-after-voting, voting-after-series, parallel-after-series, as well as series-after-parallel systems. Further, the model was minimizing the modeling complexity and could adopt the effective arithmetic reasoning algorithms.

In 2017, Liu *et al*. [15] have stated that for improving the computational effectiveness of Simulation (Monte Carlo) in reliability assessment of composite power systems, this examination has presented a model, which was on the basis of enhanced assessment of distribution algorithm (EDA) as well as double cross-linked list. While comparing to the conventional models, the proposed model was comprehensively enhanced in the phases of sampling and state assessment. Here, in the sampling phase, they have developed the learning algorithms based on the population. Similarly, they have introduced the mutation strategy for the probabilities of elements in normal state. This has enhanced the brilliant population characteristics. In the next stage, the state search, as well as match progression, was speed up through the utility of intelligent storage technology that was on the basis of double across linked list. At last, through the evaluation, it was proven that the proposed strategy was better in terms of reliable and effective.

*B. **Algorithmic Analysis***

Fig 1 shows the diagrammatic representation of used methodologies from the reviewed fifteen papers. It is observed that the authors in [1] have used the Expanded Reliability model. Then the short term wind model is used in [2]. Normalized energy reliability indices are adopted in [3]. The approach of loss of Load probability is developed in [4]. The model like WTG power generation model is used in [5]. In [6], the wind speed simulation model is used. The cross entropy model is adopted in [7], and the probabilistic transient stability indices are developed in [8]. The method like CVaR method is in [9]. In [10], the authors have developed the model of long-term reliability evaluation method. Five-level modular cascaded H-bridge MLI is used in [11]. The theory named Flow runoff theory is used in [13], DOOBNs [14] is developed in [15]. The improved EDA is the method that used in [16].

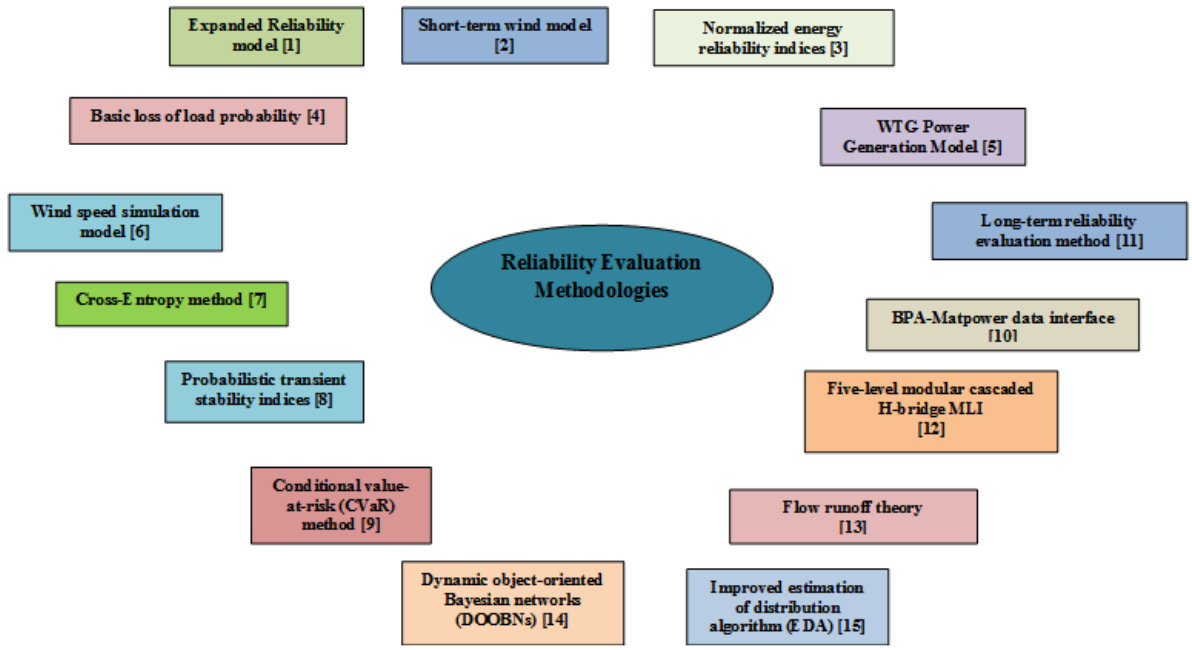

Fig. 1: Diagram of Adopted Methodologies

C. Used Performance Measures

Table I summarizes the used performance measures from the reviewed papers. Various measures have been used, and particularly, EENS is a measure that is used by [1] [9] and [10], which is the 20% of the contribution. Then the power output is used as the measure in [5] and [6], which is the 13.33% of contribution. EPNS is the most important measure, which has been used by 26.66% of total contribution. 46.66% of total contributions have been used the LOLO measure. Only 6.66% of contribution has used the total failure rate. Similarly, 6.66% of contribution has used the OCC measure to measure the performance of proposed model. 6.66% of contributions have measured the total cost and turbine efficiency as well. 66.66% of total contributions have used other measures like Failure rate, Reliability measure, and probability, and so on.

TABLE I. ADOPTED PERFORMANCE MEASURES IN REVIEWED PAPERS

Citation	EENS	Power Output	EPNS	LOLE	Total Failure rate	OCC	Total cost	Turbine efficiency	Others
[1]	✓								✓
[2]						✓			✓
[3]									✓
[4]				✓					✓
[5]		✓		✓					
[6]		✓		✓					✓
[7]			✓	✓					
[8]			✓	✓					✓
[9]	✓		✓				✓		
[10]	✓			✓					✓
[11]									
[12]					✓				✓
[13]								✓	
[14]									✓
[15]			✓	✓					

D. ***Attained Maximum Performance***

Table II summarizes the best performance measure attained from the reviewed papers. Here, the annual availability is 99.98, which is measured in [1] and [14]. The least EENS is 61.57. The UCR value of [2] is 2703. The best OCC is attained in [2] as 49%. The EIU of [3] is 0.48%. The COE of [3] is 0.393%. The best power output is 27MW, which is evident from [5]. The least LOLP of the contribution is 2.096. The best EPNS is 22.53. Then the best EENS of the whole contribution is 11232.948.

TABLE II. ATTAINED BEST PERFORMANCE MEASURE

Measure	Best Performance value	Citation
Annual availability	99.98829	[1] [14]
EENS	61.57	[1]
UCR	2703	[2]
OCC	49%	[2]
EIU	0.48%,	[3]
COE	0.393%	[3]
Power Output	27	[5]
Probability	0.0112	[5]
LOLP	2:096	[7] [8] [10] [15]
EPNS	22.53193	[7] [8] [10] [15]
EENS	11232.948	[1] [9] [10]
Total failure of switch	14.96	[12]

E. ***Types of Load***

Table III summarizes the different load types that used in reviewed contributions. From this, it is evident that the model in [1] has used the non-motor loads. In [2], Forecast load is used. Annual loads are used in [3]. In [4], Daily peak load is considered. In [7], Gaussian load is used. Base load is considered in [9]. Then the reactive load is used in [10]. Finally, in [13], Electricity load is considered.

TABLE III. TYPES OF LOAD

Citation	Loads
[1]	Non-motor loads
[2]	Forecast load
[3]	Annual loads
[4]	Daily peak load
[7]	Gaussian load
[9]	Base load
[10]	Reactive load
[13]	Electricity load

III. RESEARCH GAPS AND CHALLENGES

Even though, the tracing can conclusively grant the particular basis of evolving the real-time transmission system state space selection criterion in the aspect of reliability examination in power system; it encompasses the well-being model in the deregulated environment. Nevertheless, the deep examination is warranted to obtain the quantitative indices of restructured power systems via the joining of network equivalents as well as tracing. Further, several issues under load curtailment must be addressed at the time of contingency simulations. The policies that to be developed for the generation of re-dispatch must require to have effective attended. The issue of reserve management should be invariably figured in taking decisions. Then, the adaptability of network equivalents on creating a modeling paradigm to have well-being analysis must be made feasible through the implications embracement of power flow tracing. In future, a wider framework on the research perspectives for holistically addressing the vital issues that can profoundly effect the reliability examinations in the liberalized environs has to be developed.

In live assessment, if the statistics-related distributions are substituted with the condition-related distributions that are attained by PHM, the assessment of reliability as well as uncertainty bands are not fixed under priori, however, makes the alteration under the dependability of PHM predictive power. Due to the failures frequency, the unavailability of equipment, the human error probability as well as the probability of failure recovering alters because of aging impacts and some other factors of environmental as well as operational, which is the major challenging concern. This proclaims that the assessment should be done under time-dependently based on prognostics results and prior assessment using the prognostics data.

IV. CONCLUSION

This paper has reviewed the 15 contributions under reliability evaluation. All the works are viewed on three aspects: Used or developed methodology, the used performance measures, best performance measure. In this, the adopted methodologies were diagrammatically represented, and the other aspects were summarized in tables. More importantly, the challenges and future directions of reliability evaluation were clearly described in the paper.

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