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Review

A holistic analysis of distribution system reliability assessment methods with conventional and renewable energy sources

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Abstract: Reliable electrical distribution system is the primary requirement of smart grid. Further, with the integration of intermittent renewable energy sources (RESs), reliability assessment is very vital. Various deterministic and probabilistic methods are utilized to assess the reliability of distribution system. This review study is about distribution system reliability assessment (DSRA) with and without renewable energy generation technologies such as micro grid, distributed generation, solar and wind. For that purpose, DSRA methods such as Monte Carlo simulation (MCS) and other DSRA methods are discussed. The distribution system reliability is considered by using the renewable energy generation techniques. The stochastic features of the parameters in the designing process defined the type of MCS simulation technique. These techniques are utilized to provide reliability assessment of compact system due to huge computational time associated with them. It can be restricted by restricting number of lumped equipments for a given renewable energy source. Further, numerous states can also be used to describe the arbitrariness in the renewable energy generation, because of the stochastic behavior of the resources and the mechanical degradation of the system.

Keywords: distribution system reliability assessment; Monte Carlo simulation; Micro-grid; solar energy; wind energy

1. Introduction

The distribution network is considered to distribute electricity from the generation and transmission to the consumers. The goal of the reliability assessment of power system is to evaluate the continuity of the various facilities' output to fulfill the end users demand. During the past years renewable energy sources (RESs) are increasingly utilized into the power distribution network due to the growing prices of conventional energy supplies. Further, due to the increase public concerns on the environmental issue like global warming, also encourages the integration of RESs in to the main grid. The increasing cost effective renewable energy penetration is depends on the external natural resources like solar and wind. The intermittent behavior of the RESs is quite different as compare to conventional energy sources (CESs). This put additional burden on the need of the evaluation of distribution system reliability assessment (DSRA) with RESs. MCS is the conventional technique to compute the various reliability factors of different sub areas of an energy system such as the distribution network (DN). Analytical models are also used for the reliability assessment of DN.

Demand response (DR) is a method that incorporates consumers in demand side management (DSM) of electricity utilization, which depends on the energy pricing signal obtained from the utility. End users can be managed their total usage by creating awareness. DSM techniques are basically implemented for large consumers like industrial parks and commercial buildings. Further, DR techniques incorporated DSM techniques with load shifting, energy efficiency and conservation program. The main objective of DR techniques is to transfer the load from peak hours to off peak hours. It is performed by providing the consumers incentives so that critical peak demand will be minimized.

Therefore, this paper provides a detailed review of reliability assessment techniques of distribution system, under conventional (without RESs) and smart grid (with RESs) environment, as it is the critical issue in power system. The manuscript is ordered as follows: second section provides the general overview of distribution system reliability assessment problem. Different methods of distribution system reliability assessment problem are discussed in section three. Section four discussed the distribution system reliability assessment problem with various renewable energy sources followed by the conclusion.

2. General overview of DSRA problem

In October 1996, Brown et al. [1] introduced a novel analytical method for DSRA. It named Hierarchical Markov Modeling. It is incorporated the effects of isolation of faults, restoration of loads and multiple failure modes through generating Markov model. This model depends on the topology of system that is linked to prevent system and also protection components. In July 2015, López et al. [2], introduced the mixed integer programming based second order conic programming for reconfiguring the DN. It considered maximization of the reliability and minimization of instantaneous total real losses as the objective functions. There are various advantages of this model such as realistic, precise, flexible and efficient in computation. In 2014, Hajian-Hoseinabadi et al. [3] proposed the set of compound reliability assessment methods those incorporated the impacts of automation such as distribution automation structure, substation automation systems, automated primary DN, automated substations and integration among them. In 2014, Hashemi et al. [4], introduced the flux lock based superconducting current disturbance controllers with tap changer (TC-

FLSFCL) to improve the reliability and minimize the current disturbance of the DN, integrated with distributed generation (DG). For this purpose optimal placement of TC-FLSFCL is performed along with the correction of the tap changer. In 2014, Ray et al. [5], proposed the difference search (DS) technique for solving the DSRA problem as an optimization problem. For improving the reliability of the DN, optimal number of remote control switches (RCS) are placed at the most critical positions. A multi objective optimization problem is formed for improving the reliability at the cooperated charge. In 2015, Saboori et al. [6], developed the practical method to place and size the energy storage system in DN. The mixed integer non liner programming is utilized to develop the problem while particle swarm optimization (PSO) is used to find the optimal solution. In 2015, Timashev et al. [7], proposed the designated process for the degradation and simultaneous growing of many oxidization defects as well as reduction of residual strong point in the pipeline with the help of Markov processes, which incorporated clean birth and pure death type, respectively. By this, the set of faults, which are energetically growing can be considered collectively like distribution system. This will minimize the limitations of the classical approach. In general, the designated procedure offers continuous and fair mathematical treatment to solve the key problems, associated with reliability and security of the pipeline design, operation and predictive maintenance. In 2015, Yssaad et al. [8], proposed reliability centered maintenance method (RCM) used for maintenance optimization that is based on the analysis of failure modes effects (FMEA). After determining the criticality of the system, a sufficient maintenance plan is adopted. The main recommendation that used is the re-integration of this maintenance policy, including an optimal and rational employment of the RCM approach. In 2014, Ajenikoko et al. [9], expanded the failure rate model to assess the different levels of reliability in Ibadan DN. The selection of the feeder is utilized to assess the reliability. Statistical analysis is utilized to calculate mean and standard deviation of the system reliability indices. The input parameters for the proposed model are the calculated reliability indices. In 2015, Bourezg et al. [10], introduced the Disjoint Sum of Product (DSOP) technique based computerized implemented method, which is developed and realized to the reliability assessment of the substation. The main aim of this implementation is to calculate reliability factors and various arrangements cost of the substation. In February 2005, Bertling et al. [11], proposed a technique to equate the impact of various maintenance methodologies on the reliability and cost of the system. This method incorporated the knowledge obtained from the statistics and practical experience of the maintenance solutions and module outages, to discuss reliability theory. In January 2002, Wang et al. [12], discussed the method for reliability cost and worth evaluation that is based on the time sequential simulation. It incorporated the effects of weather states and restoration resources. For symbolizing the impacts of weather and restoration resources on the module outage rates and restoration times, time varying weight factors (TVWF) are introduced. In 2001, Brown [13], proposed the novel method for enhancing the reliability by providing the optimal placement of normally-open points in DN. Various practical DNs with diverse characteristics are utilized to test the developed method. Results obtained from the different case studies presented that the proposed method provides the improved reliability in each case by reconfiguring the normally open points. By reconfiguring the feeders, reliability can be increased for little or no extra capital costs. In August 2002, Wang et al. [14] introduced the novel method for reliability assessment of the common DN configurations. The method can simply put up the possessions of burden separation and end user restoration by presenting reliability topologies of two different types. All the system components are separated essentially into three groups, according to the possibility for them to find energy source from various directions.

A brief summarization of important methods is presented in Table 1.

Table 1. DSRA using different techniques.

Research paper	Method utilized	Advantages	Applications
Brown et al. [1]	hierarchical Markov modeling	Incorporated impacts of multiple failure modes, fault isolation, and load restoration	Executed on Windows-based software application named DS-RADS
Camilo López et al. [2]	Mixed-integer second order conic programming (MISOCP) model	Flexible, realistic, and precise optimization approach with efficient computational nature	For minimization of the overall active power losses and the enhancement of the reliability indices
Ray et al. [5]	Difference search (DS) algorithm	Increase reliability at the cooperated cost	Optimum number and location of the remote control switch (RCS)
Yssaad et al. [8]	Reliability Centered Maintenance method	Re-development of maintenance policy	Used for maintenance optimization
Ajenikoko et al. [9]	Generalized failure rate model	Improve reliability of practical system (Ibadan DN)	Utilized mean and standard deviation of the system reliability indices
Bourezg et al. [10]	Disjoint Sum of Product (DSOP) algorithm	Computerized algorithm	Determined reliability indices and costs of different substation arrangements
Wang et al. [12]	Time-sequential simulation technique	Incorporated the effects of weather conditions and restoration of resources	Time-varying weight factors (TVWF) are introduced

3. Distribution System Reliability Assessment (DSRA)

3.1. DSRA method based on evaluation techniques

In 2012, Lantharthong et al. [15], introduced the DSRA methods, which are utilized in various planning and operational studies of DN. For utility and customers both, DN reliability is a vital criterion. By using adequate planning, monitoring and controlling of the system actions, cost associated with the low reliability such as operation and maintenance costs can be minimized. In March 1998, Billinton et al. [16], developed a practical method for complex radial DN reliability assessment. Based on the basic feeder theory, a set of general equations is developed. The basic calculations are utilized to govern the specific load side indices. DSRA of the number of practical test systems presented by this method is better than the traditional FMEA technique. In August 2011, Anbalagan et al. [17], developed an enhanced distributed model for reliability evaluation of power DN. As DSRA is an important factor in the designing and planning, it should perform in economic manner along with the minimum interruption to the customers load. The reliability services in power system are planned to improve the interoperability, which depends on standards like Xtensible Markup Language (XML), Simple Object Access Protocol (SOAP), etc. In 2012, Al-Muhaini et al. [18], defined the reliability evaluation of the future networked DN. The concept of Petri nets are utilized by the proposed method for the purpose of identification of the circuit minimum tile set. For the categorization of remaining type of sets such as tie sets, cut sets or minimal cut sets, prime number encoding and exceptional prime factorization techniques are utilized. Further, for the calculation of the availability and the failure rate of the network, Markov chain model is utilized. In 2015, Li et al. [19], studied the reliability assessment of the active DNs by incorporating customer accomplishment. The uniqueness of active DN is comes from the active management i.e., operation optimization of the system. This work adopted the two customer accomplishment indices i.e., electricity cost index and electricity consumption index as constraints condition in the form of accomplishment lower limits. Furthermore, the reliability assessment framework for active DN is also presented that incorporated operation optimization with reliability assessment, which is based on sequential Monte Carlo simulation (MCS). In 2015, Miloca et al. [20], recommended the procedure in two phases for the problem of extension planning in DNs in addition to the reliability criteria. The results presented the configuration for a network assembly demand growth in the considered time period along with the reliability criteria. The charts created by the application of the system average interruption duration index (SAIDI), which identified the severe areas based on the value of SAIDI. In 2015, Salman et al. [21] developed a framework to evaluate efficiency of adopted hardening solutions for DNs exposed to hurricanes. The results obtained from the study presented the significance of the reliability assessment, component importance along with the selected hardening of DNs. Further in some cases, the hardening elements, which have larger effect on reliability can also, be cost effective. In May 2003, Tsao et al. [22], developed the group of composite DSRA methods, which can implement on non-radial DN. For this purpose reliability factors at system side and load point are calculated. Five different types of DNs such as primary, closed loop, link arranged, general redial and open loop are utilized to calculate the degree of the reliability levels. The difficulty of each type of network decides the flexibility of the reliability levels. In 2010, Ren et al. [23], developed a mixed integer liner programming (MILP) based method for the integration and evaluation of distributed energy sources (DER). The method minimized the total cost of energy for an adopted year by selecting the DERs to install along with calculating their schedules of operation. The input data for the method are local weather data, energy loads at the selected site, utility tariff, information about selected DERs and their configurations.

3.2. DSRA method based on Monte Carlo simulations

In June 2006, Silva et al. [24], developed a novel procedure that depends on chronological MCS to estimate the probability concentration functions of the reliability distribution factors and, as a result, the penalties due to the new factor called maximum continuous interruption duration per customer (MCID). Furthermore, the DN is sufficiently decomposed and the latest computational approaches can be utilized to model and program. In 2014, Ge et al. [25], presented the active DSRA problem of low and high distributed generation dispersion level by utilizing MCS technique. This problem consists of two sub problems i.e., low dispersion problem and high dispersion problem. In 2014, Conti et al. [26], proposed a generalized systematic technique, which is helpful for isolating the outages impacts on the load buses reliability by incorporating intentional islanding. This is performed either using sequential or random MCS, for assessing DSRA in smart grids. Further, a basic random MCS based yearly subdivision disturbance probability is also calculated that is linked with the branch fault frequency. In May 1999, Billinton et al. [27], proposed that DSRA problem can be improved by incorporating the annual dispersion associated with reliability factors. This is performed with the help of sequential MCS. For evaluating the reliability of complex radial DN, a time sequential MCS is utilized. The proposed approach is implemented on the practical DNs by using both simulation and analytical method. In 2014, Martinez-Velasco et al. [28], introduced the modified MCS technique for DSRA by utilizing parallel computation. In this approach embedded generation is excluded from the calculation. A three phase system model is utilized in this approach, which required power simulator, running in the time driven mode. For large systems, thousand of cores are required to run in both parallel and sequential manner to perform simultaneous simulations. In 2006, Zapata et al. [29], performed the DSRA problem of the unbalanced system by using sequential MCS technique. Single and double phase faults are considered for this purpose as these are more frequent in the system. The sequential MCS is adopted in this work because it can easily incorporate both operative and productive unbalance.

3.3. DR based techniques

Hussain et al. [30] developed a particle swarm optimization (PSO) based scheduling technique for DR. It is utilized for residential customers in which six shift-able appliances load are considered for 24 hour duration. Meng et al. [31] proposed a pricing scheme, which is based on the real time basis for DR, for that purpose Stackelberg Game and Genetic Algorithm (GA) method are utilized. Talha et al. [32] compared the performance of two meta-heuristic techniques namely GA and artificial fish swarm method for DSM. Logenthiran et al. [33] proposed a DSM technique for future smart grid with large devices. This technique is based on the shifting of loads. Further evolutionary algorithm is utilized to find the optimal results. Rahim et al. [34] proposed a DSM based optimization method, which combined tariff and block rates. For developing the optimization model, multiple knapsacks are utilized. Further, ant colony optimization is utilized to optimize the problem.

Table 2 provides summarization of the various distribution system reliability assessments methods discussed in section 3.

Table 2. DSRA using different techniques in section 3.

Techniques	Research paper	Model utilized	Advantages	Applications
Reliability evaluation techniques	Lantharthong et al. [15]	Load Point Reliability indices	Operation and maintenance costs are minimized	Utilized in distribution system planning studies and operation
	Billinton et al. [16]	Load Point Reliability indices	Suitable for practical distribution systems and superior from FMEA approach	General feeder concept is utilized for reliability evaluation
	Miloca et al. [20]	System average interruption duration index (SAIDI)	Reliability criteria is incorporated for expansion planning	Utilized for expansion of distribution networks
Monte Carlo simulations	Silva et al. [24]	Chronological MCS	Modern computational methods can be easily implemented as the system is sufficiently decomposed	Evaluate the probability concentration functions of the reliability distribution indices and the penalties
	Conti et al. [26]	Random and sequential MCS	Assessed the distribution system reliability in smart grid	For isolating the outages impacts on load buses reliability, incorporating intentional islanding
	Zapata et al. [29]	Sequential MCS technique	Incorporate both operative and productive unbalance	Utilized for DSRA problem of unbalanced system
DR based Techniques	Hussain et al. [30]	Particle swarm optimization (PSO)	Optimal scheduler is developed for load appliances	Utilized for residential customers
	Logenthiran et al. [33]	Evolutionary algorithm	Shifting of peak loads is performed	DSM technique for future smart grid
	Rahim et al. [34]	Multiple knapsacks are utilized with ant colony optimization	Combined tariff and block rates	DSM based optimization method

4. DSRA methods with renewable energy sources

4.1. Micro grid

In 2009, Costa et al. [35], recognized the situations in which the availability of micro grid can minimize the outage rate and time period and therefore, enhance the value of reliability factors of

DN. The presence of the micro-grid is an advantageous situation for distribution operator as it transmits the results of penalties reduction paid directly to consumers, penalty avoidance according to the total energy non supplied, and minimization in the not distributed energy. In 2014, Allahnoori et al. [36], performed DSRA in the presence of micro-grids by incorporating uncertainty in generation and load. Micro-grids have the ability to improve the reliability of DNs that depends on the ratio of their generations and loads. In January 2012, Conti et al. [37], proposed an advanced generalized concept that has been accessible along with the associated analytical formulation, for DSRA in a multi micro-grid smart DN. Furthermore, a novel technique is proposed to compute the adequacy of micro-grid integrated conventional and renewable DGs by considering load shedding. In 2012, Khodayar et al. [38], utilized the high reliability distribution system (HRDS) for the economic operation of the micro-grid. HRDS is implemented to loop DNs due to its higher reliability and lesser outages. Micro-grid, which is utilized in this work, consists of DGs, manageable demands with energy storages. In January 2014, Ahmed et al. [39], performed the DSRA during the grid connected and islanded modes of micro-grid. The Roy Billinton Test System (RBTS) bus 2 is utilized to show the improvement in reliability with the help of MCS. The adopted micro-grid consists of solar photovoltaic (PV), wind turbine (WT), and diesel generator. In 2015, Tuffaha et al. [40], studied the impact of addition of PV and energy storage into the micro-grid integrated DN. For modeling of energy source and storage along with overall reliability calculation, Markov model is utilized. RBTS is utilized for assessing the different system and load reliability factors. In 2013, Wang et al. [41], performed the DSRA with micro-grids and find out the best impact of micro-grid on DN interruptions along with the best micro-grid configuration. This comprehensive information is helpful for decision making in micro-grid planning. Further, for facilitating the economic and reliability analysis of micro-grid system, novel matrices with different economic and reliability factors are also developed. In March 2014, Conti et al. [42], assessed the distribution system reliability by considering Tele-controlled switches and micro-grids. For that propose, a new analytical technique is developed for assessing the impacts of Tele-controlled switches and micro-grids' disconnection on the DN reliability along with their combined impacts as well. The outcome of the method showed that utilization of Tele-controlled switches strongly improved the system average interruption duration index (SAIDI) while little improvement is made in the system average interruption frequency index (SAIFI). In 2012, Pretea et al. [43], assessed the reliability and sustainability of the micro-grids in the context of regional electricity market. Results showed that electricity market with fossil fuelled micro-grids with CO_2 emission cost achieved the maximum composite sustainability. From the economic point of view, the sustainability of the micro-grids are largely depends on the mix of generation techniques utilized for micro-grids. A large portion of the expensive techniques such as fuel cells can make these configurations less attractive from the economic point of view.

4.2. Distributed generation

In 1996, Hegazy et al. [44], presented a general assessment of the impact of DG on the DN reliability. The state duration test group technique and MCS are applied for evaluating the different reliability indices for a radial DN with DG units running in equivalent with the system. In 2012, Abdullah et al. [45], developed a novel method for assessing the impact of DG on DN reliability. DG plants generated the energy at consumer's location or at the local distribution substation and therefore can be directly supplied to the customer. DG techniques have greater impacts on high reliability application, as a source of emergency generation. DG can be served to the end user during the electricity outage to keep the system more reliable. In October 2013, Al-Muhaini et al. [46], assessed the impacts of traditional and renewable DGs on the reliability of future DN, even though they are not purely radial. The intermittency of renewable energy generation sources such as wind and solar is also incorporated in the computation. By calculating the adequacy transition rate, the stochastic behavior of the renewable energy sources and their effects on system reliability are presented. In May 2009, Atwa et al. [47], evaluated the reliability of the DN, at the time of islanded mode of operation of wind energy based DGs. A new Grey predictor technique with constraints is used for assessing the profile of wind speed. A probabilistic method is utilized for comparing the probabilistic nature of the DGs generation and demand to calculate the generation probability for satisfying the demand at the islanded period. Therefore, both islanded mode and system reliabilities are improved. In September 2015, Conti et al. [48], proposed a technique for DSRA in the presence of DGs. Two automatic and general processes are considered with analytical and MCS techniques for assessing the DNs reliability with consideration of DGs islanding. The major advantages of these processes are fast computation of the system reliability and base development for software implementation. In 2006, Duttagupta et al. [49], introduced a novel technique, which simulated the working of DN with DG and calculated the level of load and reliability of such DNs. This reliability assessment can be utilized for primary planning studies along with quantitative reliability assessment of DNs. In April 2008, Wang et al. [50], utilized the concept of depth-first search algorithm for the separation of the system into several small units for increasing the traversing speed. MCS simulation approach is utilized to model the running status of the DN. Along with that probability model of various components is also developed for quantitatively evaluating the system reliability. In December 2008, Jahangiri et al. [51], developed an analytical method for assessing the impacts of DGs on DN reliability factors. For that purpose, DG units are considered as back up generation units and their availability and unavailability are utilized. Presence of DG units in the DN affected the restoration time of load points. In February 2005, Li et al. [52], utilized distributed processing method for DN reliability index assessment. Moreover, the balanced task divider concept is utilized to enhance the efficiency of the process. In the next step, for reliability based DN reconfiguration, distributed processing of reliability index assessment is applied. Further, the reconfiguration problem is combined with local search and simulated annealing to optimize the system reliability. In 2012, Borges [53], concluded that by combining the renewable energy generation integrated reliability models with various evaluation methods enhanced the reliability of DN, mostly when islanded mode of renewable energy sources is considered. Though, the benefits will be reduced or negligible if the variable renewable energy sources are not adequately planned. In 2005, Fotuhi-Firuzabad et al. [54], developed an analytical method for assessing the impacts of DG on DN reliability factors. This techniques incorporated inherent powers of both DG and DN, i.e., change in the DG resources, outage of the DG elements and variation in the demands. In 2003, Chowdhury et al. [55], discussed ideas and implementations of probabilistic reliability methods to calculate DG equivalence for DN in the deregulated utility structure. DN reliability planning for local area is an important tool for the selection of area capacity improvement solutions. In 2012, Arya et al. [56], developed an analytical technique for the reliability assessment and improvement of DN integrated with DG. For that purpose, backup mode of operation of DG is calculated. For reliability improvement, an optimization problem is developed with respect to failure rate and repair time for each section of DN. The developed problem is subject to the constraint conditions such as failure rate/repair rate and system and energy based reliability factors. In December 2012, Brown et al. [57], developed the optimization problem of the feeder addition in an isolated DN, which is integrated with DGs. The objective function of optimization problem consist of two objectives i.e. cost and reliability, which are calculated by using slack bus-based definition of energy not supplied (ENS) reliability factor. To improve the energy outcome of the DGs, a mathematical formulation is developed by using the outcomes of the survey of smart distribution along with integrating the capacity factor of renewable energy-based DGs. In 2015, Li et al. [58], proposed a novel method based on hierarchical classification for characterizing the operating states of the DN with DGs. It is helpful in studied the characteristics of DN with DGs. For incorporating the different operation states of DN, various important attributes are considered such as stability, reliability, integrity and economy. In August 2012, Issicaba et al. [59], evaluated the security and adequacy of DNs with DG. For performance evaluation of DN, security and adequacy aspects are considered and the real impact of DG integration is computed. A combined discrete-continuous model of simulation is developed by utilizing the steady state and dynamic analysis for assessing the DN operation. In 2014, Yang et al. [60], developed an analytical method for evaluating the reliability of DN consisting DG. Based on the number and position of the disconnectors, feeder segments are classified into various hierarchical levels. These developed hierarchical levels are utilized to form the directed relation-graph (DRG), which is implemented directly for evaluating the reliability of system and load points. In 2016, Arya [61], developed an algorithm to decide the preferences in maintenance tasks for feeder sections of DNs. The method is utilized to compute the recently developed weighted cumulative diagnostic importance factor (WCDIF) for each feeder segment. It symbolized the relative quantitatively importance of prioritization of maintenance tasks. In 2012, Georgilakis et al. [62], solved the problem of optimal DG placement in DNs. The combination of DG units is also provided. The main goal of the optimal placement problem of DG is to find the optimal locations and capacities of DGs for optimizing the DN operation and planning under the constraint conditions of DGs capacities. The general optimal DG placement problem consists of characteristics such as multiple DGs installation, design variable for placement and size and the total system loss minimization. In 2015, Liu et al. [63], examined the assessment of static voltage stability of DNs by utilizing the two-point approximation method and continuance power flow technique. The probabilistic behavior of DG units is also considered. The developed method can also be utilized for online voltage stability assessment as it is fast in calculation. In 2015, Paleti et al. [64], developed the small autonomous hybrid power system consists of WT, PV and Pico-hydro generation for evaluation of system reliability. These resources don't have the same operational characteristics. Markov model is utilized to evaluate the availability of developed hybrid system. The reliability assessment of DN is performed under the cases of with and without the developed hybrid power system for various load points.

4.3. Renewable energy resources

4.3.1. Solar energy

In 2016, Chaouachi et al. [65], proposed the framework for assessing the electric vehicle (EV) and PV synergies in emerging DNs. Energy penetration from the renewable energy sources (RESs) and EVs is continuously increasing. Therefore, to match this ever increasing penetration, an emerging DN framework is required with the aim to make DN more capable and reliable. In 2007, Conti et al. [66], performed the load flow analysis of DN integrated with PV. A probabilistic load flow analysis for radial DN integrated with grid connected PV is developed by using MCS. For that purpose, hypothetical models, their representation and applications are also presented. For implementing the proposed method, software is also developed that permits to compute the impact of integrating PV units on the DN. In 2014, Hung et al. [67], integrated the PV and battery energy storage (BES) system to minimize power losses and enhance the voltage stability of the commercial DN. By combining the PV with BES, each non-dispatchable PV is converted into the dispatchable energy source. For analyzing the capacity and the power factor of the PV-BES combination, a novel multi objective index based analytical method is developed. In 2015, Shah et al. [68], assessed quantitatively the security of DN associated with flexible generation, electrical vehicle and system loads, by chronological based risk assessment method. The proposed method is the extension of the chronological simulation based power system analysis method. For risk assessment with appropriate base values, the linear unbroken severity functions are utilized. In 2013, Mostafa et al. [69], discussed the problem of phase unbalance state with respect to three phase DN due to extensive integration of single phase PV generator with micro feed in tariffs. The adopted problem is more complex due to the extensive utilization of single phase load. Further, energy losses are significantly important with micro feed in tariffs. In 2013, Alam et al. [70], mitigated the PV impacts, which are due to high penetration of PV into the low voltage DN, by effectively utilizing the distributed energy storage systems. For efficiently utilizing the available capacity of energy storage, a charging/discharging strategy is also developed by incorporating the state of charge of energy storage and the intended length of changing/ discharging duration. In November 2011, Atwa et al. [71], evaluated the adequacy of DN integrated with wind and solar DGs under various modes of operating conditions. MCS and analytical methods are utilized along with novel lack of confusion index probability distribution function to simulate the solar irradiance. In July 2009, Yazdani et al. [72], developed a control scheme for three phase PV system integrated with DN. An inner current control loop and an outer DC link voltage control loop are adopted by the developed control scheme. For PV, the inner current control scheme provide the protection against outside faults while outer DC link voltage control scheme enabled the control and/or increase of the active power generation of PV.

4.3.2. Wind energy

In February 2010, Atwa et al. [73], assessed the adequacy of DN integrated with wind turbine based DG under different modes of operating conditions. For assessing the adequacy, MCS and analytical methods are utilized under different mode of operation. The impacts of DG on the system adequacy are computed in terms of reliability factors such as loss of load expectation and loss of energy expectation. In 2014, Abdelsamad et al. [74], assessed the impacts of wind turbine based DG on DN, which is integrated with plug in electric vehicles. For incorporating the uncertainties related to the wind speed variation and charging of plug in electric vehicles, MCS technique is utilized. This work computed the excess in active/reactive power, energy exceeding normalization (EEN), un-served energy (UE) and energy losses. The outcome of the study presented that the maximum power production and plug in electric vehicle peak demand didn't occur at the same time. In August 2008, Vallée et al. [75], presented a novel technique for equivalent wind capacity computations. The equivalent two state wind models is used to calculate the wind equivalent capacities in order to utilized them into load covering predictive models. The global yearly wind energy distribution is recognized by convolution of the constitutive wind parks for attaining the equivalent wind capacities. In 2016, Wu et al. [76], evaluated the reliability of wind turbine generator integrated DN by switch section partitioning method. The grouping of the Weibull distribution and Markov chain models are utilized to establish the reliability models of wind turbine generators. The supply power sets of the first level load zone nodes with each wind turbine generator by describing the first-level load zone nodes. The dynamic separation strategy of island operation is developed based on the supply sets. In 2011, Aghaebrahimi et al. [77], proposed the novel method for reliability assessment of wind-diesel based islanded grids. MCS technique is utilized to find the impacts of islanded operation on the reliability factors. From the results, it is concluded that the developed islanding method improved the reliability of DN.

4.3.3. Impact of renewable energy sources on the distribution system reliability

As from the different literatures seen in the section 4, renewable energy resources in the different form such as micro-grid, distributed generation and individual solar PV and wind turbine are increased the reliability of distribution system. In the case of any outages in the utility grid supply, these renewable energy sources locally provided the continuous power supply. For adequately utilizing these energy sources, the problem of placement and sizing should be optimally discussed, so that the reliability of DN will greatly increase. Further, the intermittent nature of these renewable energy sources affects the generation output as well as the reliability of DN greatly. Therefore, various measures such as battery energy storage system, fly wheel mechanism etc. must be utilized to minimize the variation in the generation of these resources and enhance the utilization of these energy resources, so that the reliability will improve.

5. Conclusion

This review paper studied the distribution system reliability assessment with renewable energy generators, which include micro-grid, distributed generation, solar and wind and without renewable energy resource by different methods such as Monte Carlo simulations and other DSRA methods depend on evaluation techniques. Demand response (DR) and demand side management (DSM) techniques are incorporated to show their impacts on distribution system reliability. Different analytical models are discussed for the reliability studies of a distribution system with renewable energy sources. Sub-models are built for each element in the distribution network, including solar PV and wind turbine. This paper also reviewed features of reliability assessment researches in the distribution systems by including approaches of reliability assessment in DN, reliability factors calculation and the ability of micro-grids for improving the reliability of power DNs. The energy generated by renewable energy sources based micro-grids normally depends on the environmental condition. Therefore, this paper will helpful for researchers to find an appropriate renewable energy generation method to enhance the distribution system reliability. The futuristic enhancement of the current work may be to develop more detailed review, which incorporate more renewable energy sources and their impact of distribution system reliability.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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