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Reliability Based Power Distribution Systems Planning: A Review

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Abstract: **This paper reviews recent work on power distribution systems reliability areas and identifies challenges facing power distribution planning in adopting reliability assessment. By study we understand analysis performed on models that evaluate distribution system reliability for a simultaneous different factor affecting reliability. We review work the basic principles of which have been described by others, but implementation requires practical management decisions. Changes have implications for the relationship between the distributors of electricity and the Regulator. We also mention whether the work has been done at the strategic level, i.e. if it concerns the planning of power distribution system based on reliability and uncertainty.**

Keyword: **Power distribution system and reliability evaluation**

I. INTRODUCTION

The characteristics of today's competitive environment, such as the demand of reliable power with which system are designed, power distribution company need for higher reliable and lower operational costs, are forcing companies to continuously search for ways to improve their performance. Reliability models decision support systems and uncertainty analysis tools are examples of approaches taken by system in an attempt to improve their operational performance and remain competitive under the threat of increasing competition. Godfrey et al (1996) identified three major issues for the implementation of reliability planning. Reliability data Customer damage function data reliability analysis software to these have been added: Policy Business process Research Skills development. All of these aspects present challenges for distribution planners because of a history of no or only limited reliability assessments. Billinton et al (1984) and Ajodhia (2002) had been studied a lack of data on distribution system reliability and customer impact has forced planners to adopt deterministic approaches to system planning and, historically, redundancy-planning decisions have been based on simple rules. New requirements to assess the reliability constraints of reinforcement alternatives need quantitative reliability analysis as well as uncertainty to use the results for decision-making.

II. MONTE CARLO SIMULATION

Supriya et al (2014) had been study reliability assessment is an important tool for distribution system planning and operation. Distribution system reliability assessment is able to predict the interruption profile of a distribution system at the customer end based on system topology and component reliability data. The reliability indices can be evaluated using analytical method or Monte Carlo simulation method. The reliability analysis is to quantify, predict, and compare reliability indexes for various reliability improvement initiatives/network configurations. By understanding the distribution system reliability indices using analytical method, further implements a reliability models to evaluate the distribution system reliability using Monte-Carlo simulation method. General distribution system elements, operating models and radial configurations are considered in the program. Overall system and load point reliability indices and expected energy unserved are computed using these techniques. Reliability assessment estimates the performance at customer load points considering the stochastic nature of failure occurrences and outage duration. The basic indices associated with load points are: failure rate, average outage duration and annual unavailability. Furthermore, his models

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can predict other indices such as System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Frequency Index (CAIFI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability /Unavailability Index (ASAI), Energy Not Supplied (ENS) and Average Energy Not Supplied (AENS). This information helps utility engineers and managers at electric utility organizations to decide how to spend the money to improve reliability of the system by identifying the most effective actions/ reconfigurations. Li,et al (2008) presented fuzzy-probabilistic modeling techniques for system component outage parameters and load curves. The fuzzy membership functions of system component outage parameters are developed using statistical records, whereas the system load is modeled using a combined fuzzy and probabilistic representation. Based on the fuzzy-probabilistic models, a hybrid method of fuzzy set and Monte Carlo simulation for power system risk assessment was proposed to capture both randomness and fuzziness of loads and component outage parameters. He used an actual example using a regional system at the British Columbia Transmission Corpoation. He demonstrated the application of the presented fuzzy-probabilistic models for system parameters and new system risk evaluation method. Billinton et al(1999) presented an analytical techniques for distribution system reliability assessment can be effectively used to evaluate the mean values of a wide range of system reliability indices. This approach is usually used when teaching the basic concepts of distribution system reliability evaluation. The mean or expected value, however, does not provide any information on the inherent variability of an index. Appreciation of this inherent variability is an important parameter in comprehending the actual reliability experienced by a customer and should be recognized when teaching distribution system reliability evaluation. He presents a time sequential Monte Carlo simulation technique which can be used in complex distribution system evaluation, and describes a computer program developed to implement this technique. General distribution system elements, operating models and radial configurations are considered in the program. The results obtained using both analytical and simulation methods are compared. The mean values and the probability distributions for both load point and system indices are illustrated using a practical test system. Yu et al (2002) described a power system reliability evaluation including protection system failures. A modified protection system reliability model including two major protection failure modes is established. Protection system failure is the main cause of cascading outages. The mechanism and scheme of protection system have been analyzed on their contribution to the cascading outages after a fault occurs. Non-sequential Monte Carlo simulation approach was used to implement the stochastic properties of component contingency and protection system failure. The whole procedure is verified in the WSCC-9 bus system. BIP (Bus Isolation Probability), LOLP (Loss of Load Probability), and newly introduced EPL (Expected Power Loss) are calculated to demonstrate the vulnerability of a power system under cascading outages.

III. DISTRIBUTION GENERATION AND RELIABILITY

Atwa et al (2009) found the development and utilization of wind-based distributed generations (DGs) had been observed worldwide for several reasons. Among those is controlling the emission of environmentally harmful substances, limiting the growth in energy costs associated with the use of conventional energy sources and encouraging the independent power producers for participation in the electricity market system. He presented a probabilistic technique to evaluate the distribution system reliability utilizing segmentation concept and a novel constrained Grey predictor technique for wind speed profile estimation. Su Bae et al (2007) illustrated an analytical technique for evaluating the reliability of a distribution system, including distributed generation. Unlike the large-scale generation of the transmission system, distributed generation (DG) creates difficulties in evaluating reliability indices due to the complexity of the operation status. Explicit expressions for analyzing the reliability of distributed generation were proposed. The technique was proposed includes the characteristics of DG, such as operation mode to mix peaking and standby modes and the failure of starting and DG itself. Bae et al (2008) presented an analytical technique to evaluate the reliability of customers in a microgrid including distributed generations (DGs). Operators of the microgrid are responsible for a reliable energy supply to their customers. Due to the strategy of the priority on their customers, the restoration process of DGs should be reordered when system outage happens. The previous study has proposed the analytical technique to evaluate the reliability of customers in the distribution system that one operator owns all DGs. They proposed method includes photovoltaic (PV) systems and fuses, and the impact factor is modified to obtain the interruption cost. Also, equations are generalized to consider more than one component in a section. Case studied in RBTS Bus 4 verify that the accuracy of the proposed technique is comparable to that of MCS, and the configuration of system divided into several microgrids changes the reliability of customers in the microgrids. Biju et al (2013) illustrated assessment of customer power supply reliability is an important part of distribution system operation and planning. Distribution system reliability assessment is able to predict the interruption profile of a distribution system based on system topology and component reliability data. They had been developed for reliability enhancement of radial distribution system having distributed generation (DG) and also determining the optimum values of failure rates/repair times, reliability of the distribution system has been optimized subjected to constraints on customer and energy based indices i.e. SAIFI, SAIDI, CAIDI, AENS, and ASAI. The objective function includes (i) cost of modification for failure rates/repair times (ii) additional cost of expected energy supplied by DG. A recently developed Bacterial foraging algorithm was employed to solve the optimization problem. The technique had been implemented on an eight node distribution network. The results shows were compared with PSO, CAPSO and DE algorithms.

Gil et al (2012) discussed possible benefits of coordinated deployment of renewable-based micro-generation (MG) systems and energy storage schemes on reliability performance of distribution networks. Particular attention was given to continuity of supply of low voltage residential customers and potential scenarios to improve service quality by reducing the frequency and duration of customer long interruptions. Detailed network representations and improved models of aggregate loads and distributed generation/storage systems ware used to assess the variable behaviour of domestic power demands and renewable energy resources. The conventional Monte Carlo Simulation (MCS) analysis is extended with an empirical probabilistic model of network faults, in order to estimate both system and customer-related reliability indices in the most realistic manner.

IV. OPTIMIZATION TECHNIQUES

Arya et al (2011) described a methodology for reliability enhancement of radial distribution system by determining optimal values of repair times and failure rates of each section. Penalty cost functions had been constructed as function of failure rates and repair times. Constraints on customer and energy based indices i.e. SAIFI, SAIDI, CAIDI and AENS had been considered. The problem has been decomposed in two stages. First stage determined the optimum failure rates and second stage optimized repair times satisfying constraints. A differential evolution (DE) had been used as optimization technique. The algorithm had been implemented on a sample test system. They compared the results with those obtainedusing particle swarm optimization and coordinated aggregation based particle swarm optimization techniques.

V. UNCERTAINTY IN SYSTEMS

Feng et al (2008) studied failure probability of system components may vary with the changes of weather, environment and other operation conditions. The time-varying or condition-based failure probability can be represented using a fuzzy model. Based on credibility theory, he presented a novel operation risk assessment method to handle the two-fold uncertainty combining randomness and fuzziness in power system operations. A random fuzzy model is developed to accommodate impacts due to various operation conditions and other factors on the failure probability of system components. The WECC nine-bus system, IEEE 14-bus system and an actual power system in Northeast China were used to demonstrate feasibility and applicability of the presented method. The operation risk assessment module using the method has been embedded in the EMS system in a district control center of a power company to perform real-time operation risk assessment. Barbosa et al (2013) studied the uncertainty assessment in reliability indices is usually performed by the propagation of uncertainties in input data reliability (failure rates and repair times) for the estimated reliability indices using mathematical models, such as fuzzy sets. They found that analysis cannot be directly applied in distribution networks when there are significant errors between historical and predicted indices. In his studied the propagation of uncertainty in power distribution network must take an opposite direction that means: to use historical reliability indices to determine the uncertainties associated with reliability input data. They used to determine the confidence intervals associated with reliability data of power distribution equipments based on available historical indices. These intervals are determined by combining the bootstrap technique with calibration models. The tests with a Brazilian distribution networks demonstrate that the proposed method can estimate the upper and lower bounds for the reliability data in a specified significance level. Rocco et al (1998) proposed a reliability evaluation is considered a very useful tool in the planning of a distribution system because one can evaluate the performance of several configurations based on their reliability indices. These values were obtained both from analytical or simulation models, using system components data such as component failures, repairs and restoration times. One difficult problem therein is the quantification of the model parameters. If they are available, e.g., from measurement, they are not accurate and are subject to uncertainty. The studied of a system with parameters over a possible range of variations (due to uncertainty) can be approached by evaluating the effects of such variations. There are two classical ways of dealing with uncertainty parameters: Sensitivity Analysis, Repeated Simulations (Trial and error or Monte Carlo). They were proposed the use of Interval Arithmetic to evaluate reliability uncertainty in Distribution Systems. Interval Arithmetic takes into consideration the uncertainty of all of the parameters and is able to provide strict bounds for indices, with only one evaluation. The final interval will contain all possible solutions due to the variations in input parameters. It is also shown that it is possible to perform sensitivity analysis by using Interval Arithmetic.

VI. DISTRIBUTION SYSTEM PLANNING

Khator et al (1997) developed a power distribution planning is a complex task in which planners must ensure that there is adequate substation capacity (transformer capacity) and feeder capacity (distribution capacity) to meet the load demands. Decisions such as allocation of power flow, installation of feeders and substations, and procurement of transformers are costly ones which must be evaluated carefully. The review of research problems as well as models related to the planning of substations and/or distribution feeders. Following a general discussion, we review existing research work under two major groups: planning under normal conditions, and planning for emergency. A discussion on relevant research opportunities was included.

Sagar et al (2013) described the concept and characteristics of smart grid distribution systems, basic difference between conventional and smart grid distribution systems, functional management and reliability evaluation of smart grid distribution systems. In smart grid distribution system, remotely controlled high rated power electronic switches were used in the place of normal disconnecting switches on feeder. In normal operation of distribution system, these act as normally closed switches. Whereas, in faulted conditions, the computer system at the control center will sense the fault location through the sensors, digital controls, G.I.S and will turn off the power electronic switches to isolate the fault section and as well as operate other protective devices to restore the loads under the un-faulted in less than one cycle period to maintain high reliability of the distribution systems. The reliability indices of a radial distribution system for (i) conventional (non-automated), (ii) automated and (iii) smart grid configurations are calculated and the results are compared. Firuzabad et al (2009) presented a preventive maintenance application-based study and modeling of failure rates in breakers of electrical distribution systems. This is a critical issue in the reliability assessment of a system. The impacts of failure rate variations caused by a preventive maintenance are examined. This was considered as a part of a Reliability Centered Maintenance (RCM) application program. A number of load point reliability indices were derived using the mathematical model of the failure rate, which is established using the observed data in a distribution system. Lantharthong et al (2012) developed a reliability evaluation technique which was applied in distribution system planning studies and operation. Reliability of distribution systems is an important issue in power engineering for both utilities and customers. Reliability is a key issue in the design and operation of electric power distribution systems and load. Reliability evaluation of distribution systems has been the subject of many recent papers and the modeling and evaluation techniques had been improved considerably.

Ying et al (2011) studied the safety-critical nature of new complex cyber-physical systems mandates a thorough analysis to fully understand and quantify failure mechanisms and their impact on system design. They introduced a system-level reliability analysis method for assessing the dependability of alternative conceptual design architectures. The method enables the analysis of criticality and sensitivity of components to the system-level requirements, based on component connections and their failure probability. The analysis performed at this earliest stage of design facilitates the development of more robust and reliable system architectures. Application of the presented method to the design of a representative aerospace electrical power system (EPS) demonstrates these capabilities. J. Ramírez et al (2004) were presented a new possibilistic (fuzzy) model for the multiobjective optimal planning of power distribution networks that finds out the nondominated multiobjective solutions corresponding to the simultaneous optimization of the fuzzy economic cost, level of fuzzy reliability, and exposure (optimization of robustness) of such networks, using an original and powerful meta-heuristic algorithm based on Tabu Search. He determines the optimal location and size of the future feeders and substations in distribution networks with dimensions significantly larger than the ones usually presented. The model also allows determining the optimal reserve feeders that provided the best distribution network reliability at the lowest cost for a given level of robustness (exposure). The model had been intensively tested in real distribution networks, which proves their practical application to large power distribution systems. Billinton et al (2006) illustrated weather environment can severely impact the performance of an overhead distribution system and an electric utility's operational ability. The likelihood of system failure increases due to enhanced line failure rates during bad weather periods. Reliability appraisals without incorporating weather conditions can be quite optimistic and affect planning and design decisions. Recognition of various weather contributions to the total system performance indices help to pinpoint situations where investment may provide maximum reliability improvement. An approach was presented to assess distribution system reliability in different weather conditions such as normal, adverse and extreme and illustrated using a practical distribution system. Reliability indices are evaluated in three different weather states and a series of sensitivity studies were presented. The effects of repair time and the frequency of major storm occurrences were illustrated.

Brown et al (1998) illustrated distribution system reliability assessment is able to predict the interruption profile of a distribution system based on system topology and component reliability data. Unfortunately, many utilities do not have enough historical component reliability data to perform such an assessment, and are not confident that other sources of data are representative of their particular system. These utilities do not incorporate distribution system reliability assessment into their design process and forego its significant advantages. He presented a way of gaining confidence in a reliability model by developing a validation method. This method automatically determines appropriate default component reliability data so that predicted reliability indices match historical values. The result was a validated base case from which incremental design improvements can be explored.

Gupta et al (2014) studied distribution systems form an important link between the bulk energy sources and consumers. About 80% of the interruptions that the consumers experience occur due to failures in distribution systems. This is due to radial nature of these links and scarcity of protection devices. Therefore, reliability assessment is essential to identify weaker areas needing reinforcements and understand, how changes made in one part of system affects performance in the remainder part of the system. The study had been conducted on the existing distribution system of Indian Institute of Technology, Roorkee as it is a miniature form of our modern day distribution systems, which represents different kind of loads existing simultaneously and where continuity of supply needs to be maintained at all times. The reliability indices for this system are evaluated by analytical method using the concept of failure modes and effect analysis for radial distribution systems. The results shows determine unreliable sections in the distribution system which are required to be upgraded.

Allan et al (1991) had been described an electrical distribution system for use in teaching power system reliability evaluation. It includes the entire main element found in practical system. However, it was sufficiently small that studied can analyses it using hand calculations and hence fully understand reliability models and evaluation techniques. The data needed to perform basic reliability analyses. It also contains the basic results for a range of case studied and alternative design/operating configurations. Nahman et al (2003) studied effects of uncertain input data on the performance evaluation of a distribution system are analyzed. A criterion was introduced for assessing the grade of uncertainty of the results obtained in the calculation of maximum loads, voltage drops, energy losses, and characteristic reliability indices of a network if some input parameters are only guesses based on limited experience, measurements, and/or statistical data. Reasonable outputs bounds are determined based upon the shape of the function measuring the uncertainty. High uncertainty of a result obtained indicates that a re-examination of relevant uncertain input data would be recommendable for a more precise quantification. The method proposed was applied to a real life example for illustration.

Chaudonneret et al (2012) presented the development and application of a Monte Carlo based simulation approach for the evaluation of the reliability of an electrical distribution system, taking account of the presence of supporting Information and Communications Technologies (ICT). Starting from an examination of the nature of electrical distribution system reliability, a functional representation of the associated ICT was proposed in order to incorporate the impact of ICT dysfunction on the reliability of the electrical distribution system. Integrating this ICT representation into a Monte Carlo based simulation approach to electrical distribution reliability has allowed the dependence of the electrical network on ICT to be examined numerically. Results show the important existing, nonhomogeneous dependence between reliability of the electrical network and the behaviour of different elements of the supporting ICT. At the same time, the results highlight the need for further refinements in the representation of the ICT, a process which can be aided by the use of the developed numerical approach.

VII. OTHER FACTO

Ilie et al (2012) were presented a simple methodology for the formulation of accurate reliability equivalent models of LV and MV parts of larger power supply systems. Calculated failure rates and mean repair times of the equivalent part of the network are assigned to the corresponding bulk load supply point so that the original power supply system can be correctly represented by a reduced model during the conventional reliability analysis. The accuracy and effectiveness of the equivalenting methodology were demonstrated through a number of different scenarios applied to a test system, representing the typical UK distribution network configurations. Bhargavaet al (April 2013) presented a two-stage restoration technique incorporating weather effect considerations in reliability cost/worth evaluation of distribution systems. The weather conditions play a significant role on the reliability of a given power system leading to frequent incidence of failures to overhead system and their effectiveness. The physical stresses exerted by adverse weather increase the failure rates of transmission or distribution lines resulting in increased coincident failures of multiple circuits. Especially adverse weather can cause tremendous system damages and significantly strikes the reliability. Therefore, it is high time to address the issue by devising appropriate technique considering weather conditions. The briefly demonstrates the conventional two weather state models which ware used for predictive reliability assessment incorporating normal and adverse weather conditions. He presented an approach to identify weather specific contributions to system reliability indices and illustrates the technique by utilizing a RBTS distribution system. Zhang et al (2010) shows a boundary analysis method for reliability and economic assessment in distribution systems. The main purpose was to deal with uncertainties of input data, especially when statistical information is unavailable or insufficient. The presented method was uses interval numbers to enclose variability and incertitude in reliability and economic parameters, and provides the estimates on upper and lower bounds of reliability and economic indices. The proposed method had been applied to real-life distribution reinforcement projects. Case studies demonstrated effectiveness and efficiency of the method.

Gu et al (2012) studied a tool for network operators to recover network investment costs from network users as well as to provided forward looking economic signals, distribution network pricing models are also expected to identify and recover investment costs related to maintaining network security. The existing models reflect network security by determining the maximum allowed contingency flow along each component through implemented deterministic contingency analysis. They fail to consider two reliability cost drivers: 1) reliability levels of network components, and 2) interruption tolerance levels at different nodes. A novel distribution network pricing model to reflect two key reliability cost drivers: 1) the nodal unreliability tolerance mandated by security standards, which is linked to the customer size at the node, and 2) the stochastic nature of component reliability that reflects differing failure rates of network components. By combining the two factors, the new reliability-based pricing model was able to recognize the impact on network investment from network components' reliability in addition to their distance and the degree of utilization. The concept was demonstrated on three small networks: a single circuit system, a parallel-circuit system, and a meshed system. The applicability of the new pricing approach to practical systems was then illustrated on a practical distribution network in the U.K. system. Brown et al (2005) studied a majority of states has taken steps to regulate the reliability of electricity service, and there is a current regulatory trend focusing on worst-performing feeders (WPFs). He performed a comprehensive assessment of worst-performing feeders at Midwest Energy by examining nine years of historical interruption data and validating statistical results with predictive modeling. The result shows that historical data are able to reflect expected performance but are less able to reflect the risk of worse-than-expected performance. These results raise serious questions as to the usefulness of WPF lists in their present incarnation, and provided recommendations on how utilities can better identify and manage poor-performing feeders. Liu et al (2011) studied long-term reliability evaluation is implemented in power systems for applications such as planning. Short-term or operational reliability evaluation is gaining attention due to some emerging applications, e.g. electricity markets, impact of extreme weather, and integration of intermittent renewable energy sources. Some methods, analytical as well as simulation, had been proposed in the past to evaluate the short-term reliability of power systems. They proposed a simple analytical methodology to evaluate the reliability performance of composite power systems during a short period of time. In the proposed approach minimal cut-set method was used to calculate the time-specific reliability indices of composite power systems. Both system and nodal indices are calculated, and the common-cause failures (CCF) of system components were also considered. The proposed methodology was applied to the modified IEEE Reliability Test System (RTS) to investigate the impact of hurricanes on the reliability of composite power systems. The implementation demonstrates that the proposed methodology is effective, efficient and is flexible in its applications.

Prakash et al (2014) illustrated reliability of distribution side is assessed using ETAP software with various scenarios viz. consideration of lateral distributor protection and passive failure rate of components and large impact of distributed generations. The improvement in reliability in various cases has been evaluated on the basis of various reliability indices such as load point indices and system indices. The variation of indices had been followed with various different cases. The analysis is performed on Roy Billinton Test System (RBTS) using Electrical Transient Analyzer Program (ETAP). Arya et al (2011) developed fault avoidance and corrective maintenance are important measures for reliability improvement of a radial distribution system. The two measures decrease system down time and increases mean up time of the system. These happen due to the fact that failure rate and average repair time of the components are reduced. A methodology had been developed in this paper for failure rate and repair time allocation to each component of radial distribution system. A sensitivity based approach has been proposed. Penalty cost function has been introduced. The components having least sensitivity of penalty cost function with respect to system interruption time and failure rate had been selected for the improvement in failure rate and repair time. The algorithm had been implemented on a sample radial distribution system. Chowdhury et al (2004) illustrated an achieving high distribution reliability levels and concurrently minimizing capital costs optimization. Assuming given outage rates and repair times, distribution system design is the remaining factor in determining customer reliability. Including customer value of reliability in an economic analysis allows for optimization of the major components of distribution system design. Using mathematical models and simulations, a comparison of design concepts can he performed to compute the optimal feeder section length, feeder loading lwei and distribution substation transformer loading level. The number of feeder ties and feeder tie placement were also optimized through the models. The outcome of analysis was capital costs were directed towards system improvements that will be most cost-effective in improving system reliability. They presented a value-based probabilistic approach to designing urban distribution systems. The value based reliability methodology was illustrated using a practical urban distribution system of MidAmerican Energy Company.

Carvalho et al (2005) illustrated growing demand for improved quality of system service increases the importance of network automation, namely the investment in remote-controlled switch (RCS) devices. These allow improving the fault isolation and reconfiguration time and therefore increasing the system quality of service. The investment in switch devices comes at a cost and thus must be optimized. The problem of determining the optimal number of devices and their optimal location was a difficult problem: the solution space is combinatorial and the objective function is nonanalytical. They proposed to address a problem in a two-stage decomposition approach. Results were presented to i) divide the solution space into independent subspaces, and then ii) solve the optimization problems in each subspace. The solution approach is illustrated for a real distribution network problem.

VIII. DISCUSSION

Earlier very few were work done in reliability evaluation in distribution system and its planning. But with recent advents in technology, efficient utilization of resources is now a need for secure and reliable electrical power distribution system. For the concern of both customers and power utilities, reliability is a major issue for power distribution system. However lot of work is required to be done in uncertainty consideration of distribution system. Uncertainty of a result obtained reliability that a re-examination of relevant uncertain input data would be recommendable for a more precise quantification.

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