Distribution System Reliability: An Overview

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Abstract— From the survey of previously published papers, it is found that most of work is done on the generation and transmission side reliability, whereas little work is done on distribution system reliability and Indices under deregulated environment. In reliability study of distribution system development of accurate and consistent models to represent system behavior is always a main concern to researchers. A computer program which provides system representation for the evaluation of substation and switching station reliability performance in terms of outage frequencies and duration is needed. It performs failure modes and effects analysis and provides a concise and orderly description of various combinations of occurrences within the system that could result in an interruption and is applied to practical systems. The effects of different component failure modes, normally open breakers or switches, unrealistic protective system etc. must include in reliability predictions. In this paper an overview is carried out for distribution system reliability for various substation configurations and assumptions those are covered in researchers symposium and transaction papers. This study is useful for researcher those are working with the similar problem formulated in their research work. Various reliability indices and reliability cost mentioned in literature are discussed in this paper.

Keywords: SAIFI, SAIDI, CAIDI, ASAI, CTADI, MAIFI.

I. INTRODUCTION

Reliability can be considered as a failure rate reduction of distribution feeder components. Enhancement of reliability is possible by means of capacitor placement. The conventional objective function which consists of cost of losses and cost of capacitor has two objectives. The one objective function considers only cost of reliability and second considers the cost of reliability and investment. However, in order to avoid excessive computational times for large feeders, the following measure can be considered to reduce the computational time. ECOST is calculated to determine the acceptable level of reliability for customers. Conventional objective function and reliability based objective function is evaluated separately. Failure rate is considered with linear relationship to the percentage of compensation, in real practice these failures is never in linear, so it is need to develop a method for nonlinear solution of such objective functions. Review of published research literature on distribution system reliability addresses the various aspects such as maintenance strategies as well as the use of capacitor. However, in recent years many researchers have focused on optimal placement of capacitors (OCP) for enhancement of reliability. Lot of research work is reported on OCP with the conventional objective function considering total cost of losses and investments.

Considering the growth of nonlinear load, while deciding optimal capacitor placement for enhancement of reliability with wider objective function, it is necessary to make sure that the configuration of capacitor will have minimum impact on harmonic distortion of the voltage and issues related with series and parallel resonances needs to be addressed. While studying the optimal capacitor configuration problem there is a need to consider a single phase as well as three phase loads with voltage unbalance conditions.

II. PROBLEM FORMULATION

Many of the researcher formulate the problem of reliability based on evaluation of reliability indices like system average interruption frequency index(SAIFI), system average interruption duration index(SAIDI), customer average interruption frequency index(CAIFI), customer average interruption duration index(CAIDI) and momentary average frequency index(MAIFI). Reliability cost(ECOST) is also one of the important parameter needs to be considered while formulating distribution system reliability. Reliability cost is the function of failure rate, customer composite damage function and average load.

III REVIEW OF EXISTING RELIABILITY SOLUTION APPROACHES

3.1. Distribution System Reliability Standards

3.1.1. 493-\IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems"

The fundamentals of reliability analysis as it applies to the planning and design of industrial and commercial electric power distribution systems are discussed in 493- "**Gold Book**". Reliability analysis based on probability

methods, fundamentals of power system reliability evaluation, economic evaluation of reliability, cost of power outage data, equipment reliability data, and examples of reliability analysis are discussed in detail. Emergency and standby power, electrical preventive maintenance, and evaluating and improving reliability of the existing plant are also addressed (IEEE Standard 493, 2007).

3.1.2. 1366-\IEEE Guide for Electric Power Distribution Reliability Indices"

Distribution reliability indices and factors that affect their calculations are defined in 1366 guide. The indices are intended to apply to distribution systems, substations, circuits, and defined regions as discussed in standard (IEEE Standard 1366, 2012).

3.2. Distribution system Reliability Indices

The ability to determine the performance and the characteristic of a distribution system is an important requirement in any utility. Voltage and fault levels, load flow, protection co-ordination and reliability indices influences the design and operating characteristics are the distribution system and therefore largely determine the level of quality and continuity experienced by the customer. Reference (M. S. Grover et al., 1974) discusses about protective equipment located in a network to protect equipment and to isolate equipment failures and faults, the type of protective equation used can have a direct bearing on the frequency and duration of outages experienced by customer. The inclusion of fault recognition and isolating characteristics of protecting equipment in reliability calculation can have a significant effect on reliability indices in (D. O. Koval et al., 1979). The approach presented can be used in manual calculations or included in a digital computer program. This helps to quantitatively evaluate the effect of proposed protection co-ordination scheme on the customer reliability levels and assist in the development of the most suitable configuration. The concept of protective zone branches is based on various assumptions such as all faults are permanent faults, the protective equipments perfectly isolates all permanent faults simultaneously protective equipment is perfectly coordinated, the protective equipment does not fails in actual system. The above mentioned assumptions are not applicable in practical distribution system. Reference (R. Billinton et al., 1985), discusses the results of a series of simulations studying the distributional variation associated with indices for simple distribution systems. Distributions for the Load Point Failure Rate, Load Point Outage Duration, Load Point Annual Interruption Time, SAIDI, SAIFI, and CAIDI are presented. When the frequency of failures at a load point is predicted, only the average value of that quantity is typically calculated. The probability that the load point will suffer a specified number of failures in a year is not normally calculated. Similarly, the expected values of the duration indices are determined but the probabilities of various durations are not calculated. The mean values are extremely useful and are the primary indices of load point adequacy. The financial losses associated with the supply reliability will vary from one industry to the other. The tariff made applicable to industrial customer is TOD tariff. It is necessary to evaluate the reliability indices and probability of interruption for each TOD zone. Means of improvement of distribution system reliability is not addressed. Cost of each interruption will vary from customer to customer which will governed by the extent of automation and process integration. While evaluation of cost of each interruption, it is not adequate to consider the cost function as linear with the duration of interruption. Financial losses associated with duration of interruption will vary from customer to customer. The work only focuses on evaluation of CAIDI and SAIFI indices.

The data used in distribution system reliability evaluation includes system configuration, load data and component outage data. During reliability prediction and evaluation of reliability indices lot of man hours are required on collecting and organization of enormous amount of data. The application of microcomputer based DBMS to manipulate the large amount of data required in the evaluation of distribution system reliability is reported (Y. Y. Hsu et al., 1990). It is found that though the use of distributed DBMS in the outage report system component outage data and the other data can be gathered and complied in more efficient way, the work is not extended for computation of cost, voltage drop and losses. In reference (R. E. Brown et al., 1998), the method proposed does not consider major events when common mode is causing many failures and assumes that each sustained interruption impacts the system in same way regardless of the frequency. The proposed model is adequate only for completely controllable system with reclosers. When there are no reclosers used on system, no momentary interruptions can occur and MAFFI is not controllable. To handle the situation there is need to do more work on proposed equations to only consider SAIFI. Improvement of Distribution System

Reliability does not mean more expense and capital investment. Reclosers, sectionalizers, fuses, relay, breakers can be used to improve the reliability. However, these additional components may also increase in failure rate, which affects to degrade the distribution system reliability. So it becomes necessary to identify areas in the distribution system, where more problems can occur and require improvements to better serve to the customer. From the historical performance of customer, evaluation of SAIFI, CAIDI, SAIDI and MAIFI is possible whereas energy based indices such as EUE (Expected unsupplied energy in KWH per year) is also used in (R. Boateng et al., 2003), for selecting the best option from various alternatives, which requires minimum requirement of additional equipment.

Using component data, network data, switching data and outage data analysis of load point indices can be primarily computed, through program which is already discussed in [1-8]. Using which reliability indices including EUE are evaluated combinely for substation and distribution feeder by predictive reliability assessment. However, authors neglected the points related to cost optimization which may possible in such combined automation of substation and feeder. The indices are calculated using the default outage data and do not represents the true performance of system reliability. It will be more realistic to examine area reliability by including all feeders and substations that serve the area. In the planning of the distribution system it is of considerable interest to have an efficient algorithm to obtain the reliability of the system and be able to compare an alternative solution. The various parameters required to be considered for evaluation are average permanent outages frequency, outage duration, load not supplied and energy not supplied. To provide good estimate of the system reliability indexes operation characteristics should be modeled as realistically as possible. To improve modeling it is necessary to include component fault rate, to be correlated with system loading and time dependent reserve capacity in each point of the system.

An algorithm is presented in (M. Vega et al., 2003), to evaluate the distribution system reliability which takes into account load switching to another alternative source of feeding with reserve capacity in normally open points considering the feeders that operate in radial form. In proposed evaluation authors has considered the load curve or supply point and cost of energy not supplied. The proposed work focuses only on permanent outages with the assumptions that an un-faulted tree keeps its topology and only un-faulted nodes can be added as a consequence of a fault, to feed back its load through normally open points and outage duration distribution is considered equal for all elements in the system. According to authors the difference in the results obtained when these assumptions were included is significant when the algorithm was applied to simple system. It is required to apply the proposed algorithm for more complex system with a high peak demands for evaluation of adequacy and accuracy of the proposed algorithm. The reliability indices before and after the implementation of proposed algorithm are not presented. The financial losses due to interruptions varies widely among various kinds of customers hence required the reliability level also differ accordingly. Any reliability improvement or reinforcement project of distribution system configuration must involve reliability cost/worth assessment.

The reliability cost is the capital cost of utility invested to improve the reliability of customers service, whereas the reliability worth is the benefits received by customers associated with better reliability. The total cost of reliability is summation of ability cost and customer interruption cost. Previous published most of research work quantifies the value of service reliability in terms of customer interruption cost. Notable optimization methods such as genetic algorithm or simulated annealing are employed by some researchers for optimal designing of distribution system based on total cost of reliability. Differential evolution (DE) based approach for optimal distribution system reliability planning taking both customer interruption cost and utility cost into consideration is discussed (T. F. Tsao et al., 2005).

The main objective of the proposed work is to locate main feeder sectionalizing switches and lateral fuses so as to minimize total cost for different conditions and configuration. The optimum location of sectionalizing switches in the main feeder and fuses in the lateral distribution systems, such that total cost in minimized is a combinational optimization problem. It is difficult to solve the location problem by conventional nonlinear optimization problem. Hence, differential evolution technique is used. According to authors optimum allocation of sectionalizing switches is strongly influenced by the inclusion or not of load transfer. Fuses because of their low cost and high effectiveness are recommended for installation at every lateral. Sector customer damage function $/ KWH is considered as function of customer class and duration. The proposed work needs to be extended considering the sector customer damage function $/KW considering the various reliability indices not on average value for calculation of interruption cost /reliability worth but on knowledge of probability distributions associated with indices because interruption cost often varies nonlinearity with duration.

Demand side management, distribution cost planning, network transformer placement, study in many other distribution system analysis need rigorous operational type analysis rather than planning oriented analysis. The difference between these two type analysis should be properly emphasized otherwise misuse of the planning type method to analyze the operational behaviour of the system will distort the explanation of the calculated results and lead to incorrect conclusions. A computer program that meets the requirements of rigorous operational type analysis, to perform power flow, system loss and contingency analysis on a large scale distribution system, combining primary and secondary network is presented (T. H. Chen et al., 1991). However, the computational analysis proposed program does not take into account the effect of reactive power compensation on loss reduction. To improve the security and reliability of distribution system as much power as must go through a transmission line which can be achieved by using shunt capacitor as a reactive power to improve the load carrying capability of the line. Consequently the capacitor existence can not be ignored in evolution system reliability (A. A. Sallam et al., 1994).

The state space method is used for calculation of reliability indices for compensated and uncompensated systems with different success criteria. The importance of using shunt capacitor to improve the level of distribution system reliability is illustrated in addition to their original function as reactive power controller based on Markov process and use of shunt capacitor indicated improvement in system reliability. However, the proposed work does not address the reliability enhancement using optimal capacitor placement for determination of capacitor sizes and locations. The total cost of losses and investment is also not considered. Use of shunt capacitor for distribution system reliability enhancement involves various issues such as optimal location, size and minimum investment involved for optimal level of reliability. The problem of optimally locating and sizing of capacitor bank is not addressed in this proposed work. Reference L. Goel et al. (1991) illustrate how the concept of previously developed for generation system and for composite generation and transmission system can be extended to the area of distribution system to evaluate IEAR index. The reliability data in terms of failure rate, MTTF and MTTR is used. Expected Energy not supplied EENS is also addressed using approximate method. Evaluation is carried out for the existing system. However enhancement of reliability indices is not mentioned properly in this paper.

3.3. Distribution system Evaluations and Cost Functions

Reference (Abdollah Kavousi Ford et al., 2014) formulate the multi objective function for capacitor placement consisting system average interruption frequency index, system average interruption duration index and average energy not supplied index in addition to active power loss and capacitor cost. The author focussed on minimizing line current and hence faults in the line. The main objective function consist cost of capacitor and active power loss cost. Firefly algorithm is used to simulate objective function. However the method of failure rate modification method used is old one and compensation of reactive current is based on assumption. Utilities increasingly are assessing system reliability from a cost/ benefit point of view. The costs of interruption are visually calculated to determine the benefit or worth of reliability. The potential problem for the distribution system application as well as the generation and composite system application is that conventionally only the average value of indices are determined and considered. Interruption costs often vary non linearly with duration. Use of the index average value to calculate interruption cost/ reliability worth can result in large errors.

Knowledge of the probability distributions associated with indices can be used to more occur accurately estimate user interruption cost, to estimate the error inherent in using average index value and to more useful apply the interruption cost estimates. Investigation of the effect of the interruption duration distribution and cost curve shapes. On interruption cost estimate and more specifically a cost error resulting from utilizing average interruption duration rather than the entire duration distribution is presented and discussed in reference (E. Wojczynski et al., 1985). According to authors the $/KWHR form can result in significant errors due to the cost function nonlinearity. The duration specific $/KW form is demand more appropriate for interruption costing especially in distribution system studies. The methods to improve the reliability and reduce the interruption duration are not discussed.

Most of the distribution companies adopt its own load curtailment policy and strategy, considering the parameters like minimum interruption cost, distribution reliability indices, duration and frequency of interruption load compatibility etc., authors presented a new method to assess the reliability performance represented by LOLC loss of Load cost. The objective of proposed work in (A. M. L. D'Silva et al., 2001), is development of an along algorithm capable of identifying the automotives that provides the rawest interruption cost, maintaining the reliability of the system within these levels allowed by these legislation.

A new methodology to assess the reliability performance of the distribution system considering different load shedding properties among feeders, the adopted strategy consider the minimum interruption cost, represented by LOLC loss of Load cost) Index and traditional distribution indices equation SAIFI, SAIDI. Different strategy result in a great variation in the reliability indices including the interruption cost. In selecting the policy to be adopted taking into consideration only. The minimization of interruption cost, the criteria established for other reliability indices may be violated. Policy which may be presents the lowest interruption cost may not be the most adequate option. The analysis was carried out taking into consideration the system as a whole and the load points individually. For optimization of the load shedding strategy in the distribution system, the specific network distribution legislation imposed by the regulatory council also is included in the evaluation process. While evaluation of distribution system reliability where there is a gap between demand and supply.

It is necessary to consider optimum load shedding strategies and the other system hardware issues governing reliability of a distribution system to improve the overall reliability. In recent years the percentage of sensitive load is increasing at faster rates these equipment operations gets affected by momentary and short duration interruption. Large use of such sensitive electronic equipments has greatly increased the impact that short and momentary interruptions have great impact on customers, hence IEEE introduced MAIFI index (W. Li et al., 2002). It is necessary to develop an algorithm to evaluate the reliability of distribution system with MAIFI. A new reliability evaluation algorithm for a complex radial distribution system which contains a subroutine of improved distribution load flow dynamically responding the change of restoration network topology induced by system reconfiguration to examine the network constraint after network reconfiguration is proposed in (W. Li et al., 2002).

A parent search technique is used to determine the affected area after a permanent fault occurs and breadth. First search technique is used to classify the affected area into three sub areas. The algorithm effectively considers the automated characteristics of distribution systems whereby considers only momentary interruptions. As per todays scenario and the requirement to remain in the deregulated global electricity market it is need to go through condition monitoring for preventive maintenance. Most of the distribution systems consist of a transformer. Transformer incipient fault are developed slowly and often in the form of deterioration of insulation which may lead towards breakdown, which are initially not measurable by other protective equipments like fuse, relay, and reclosers. Various incipient fault detection techniques such as dissolved gas analysis, partial discharge analysis have been successfully applied, but their techniques have high cost and are off-line (L. Karen et al., 2003). Authors suggested a low cost, on-line incipient fault detection technique for distribution transformer using terminal measurement and based on advanced signal analysis, which is a time domain and time frequency domain analysis using discrete wavelet transfer DWT. Analysis is carried out by ANSOFTs Maxwell software. Analysis model developed with ageing part and arcing part. Portable data acquisition system is used to monitor the appropriate signals. National Instruments provides interface box for comparison of signals. However, proposed work focuses only on single phase transformer.

It is always necessary to select a proper type of distribution system to satisfy the requirements of reliability of particular load area or customer. Quantitative reliability assessment models are of considerable importance for the various types of distribution systems. Reliability evaluation models for five commodity used distribution systems are developed and presented according to their distribution system configuration, the operating characteristics of protectors and component reliability parameters (T. Fa et al., 2003). Developed system reliability evaluation model reflects the effect of distribution substation, primary distribution system and intersection between them. Most common system reliability indices such as SAIFI, SAIDI are calculated using load point indices. For evaluation of distribution substation reliability minimal cut set method based on criteria of continuity of service is used. The various failure modes of the minimal cut sets considered are first order total failure, first order active failure, first order active failure with stack condition of circuit breakers, second order overlapping failure event involving two substation components. According to authors the system reliability indices are dominantly affected by primary distribution system more than distribution substation. In present scenario the financial losses incurred by customers are more related to momentary interruptions. The work is restricted to evaluation of SAIFI, SAIDI only.

IV NEED OF RELIABILITY EVALUATION FOR DISTRIBUTION SYSTEMS

Reliability can be classified into two components: security and adequacy. Adequacy is the static evaluation of a systems ability to supply the load. Security refers to the systems capability to experience contingencies (outages) and maintain service to all customers and respect all equipment limits. Traditionally these have been analyzed as separate issues and it is quite possible to have a reliable but insecure system and vice versa. In general adequacy is focused on planning while security is focused on operations. In the traditional distribution system, the security problem is not meaningful, any outage will result into customers interruptions, and thus, by the traditional definitions, insecure. Considering the change of industrial process automation, integration of conventional approach resulted into need of highest supply Reliability. Todays requirement of supply system reliability at developed countries has gone up to 99.9999999 due to process requirements. The process has become more integrated and interconnected. Even a short duration interruption causes high financial losses to various industrial customers. The reliability of overall supply system is governed by reliability of generation system, transmission system and Distribution system. In addition to reliability of generation system and Transmission system, reliability of distribution system is important in deregulated electricity market.

The performance and the cost of electricity supply of various distribution companies is going to be governed by quality and reliability of supply as electricity is considered as commodity. Optimal capacitor configuration in distribution system has a number of advantages such as reducing losses, improving voltage profile, improving power factor and so on. Since capacitor supply reactive load locally they improve the load carrying capability of the lines and therefore plays the same role as redundant lines and optimum capacitor configuration can also improve reliability indices of the distribution system. Since the capacitor bank is added in discrete steps the objective function is not differentiable and the capacitor placement problem is a mixed integer nonlinear program. However, most of the conventional algorithms proposed so for are unable to generate optimal solution for this type of problem. Optimal capacitor problem has been the topic of many research works in the past five decades. Capacitor banks are inadequate in discrete sizes and only fixed capacitors are used in distribution system calculations of optimal capacitor configuration needs to take into multiple objective functions.

V. CONCLUSION

In India reliability issues are linked with gap between demand and supply, transmission and distribution system reliability. However, the availability of electric supply to industrial customer is maintained except staggering holidays. In todays distribution network the growth of non linear load is taking place at faster rate considering the energy crises and the automation in industries while deciding the optimal capacitor configuration for enhancement of reliability in case of nonlinear load voltage distortion constraint in addition to voltage profile is needs consideration. The Distribution System Reliability is quite complex. Researchers have used a wide variety of methods including intelligent methods to solve the problem of reliability. This paper presents an overview of useful methods including benefits and drawbacks of suggested methods. It is necessary to address proper design and control in simulating reliability indices in proper direction.

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