ELECTRICAL DISTRIBUTION SYSTEM (AN OVERVIEW)

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ABSTRACT

The primary function of an electrical distribution system is to supply the customer's demands for energy after receiving the bulk electrical power from transmission or sub-transmission substation. The distribution substation is provided power at any required transmission or sub-transmission voltage level by the transmission or sub-transmission lines, which is forwarded to multiple distribution feeders originating in the substation. This paper presents a brief overview of electrical distribution system. It covers the classification and function of distribution network, feeder reconfiguration concept, service restoration, islanding, reliability issues, various load flow methods related to it, their advantages and limitations as well as few recent trends in electrical power distribution.

Keywords: *Distribution System, classification of distribution network, radial distribution system, load flow, reliability restoration*

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1. INTRODUCTION

Power system is a complicated interconnection of different electricity carrying utility system. The electricity utility system is usually divided into three subsystems, which are generation, transmission and distribution respectively. Further, the distribution system is commonly broken down into three components: distribution substations, primary and secondary distribution. At the substation level, the voltage is reduced and the power is distributed in smaller amounts to the customers. Consequently, one substation will supply many customers with power. Thus, the number of transmission lines in the distribution systems is many times that of the transmission systems. Furthermore, most customers are connected to only one of the three phases in the distribution system. Therefore, the power flow on each of the lines is different and the system is typically unbalanced. This characteristic needs to be counted for in load flow studies related to distribution networks. A distribution circuit uses primary or main feeders and lateral distributors. The main feeder originates from the substation and passes through the major load centers. The lateral distributors connect the individual load points to the main feeder with distribution transformers at their ends. Many distribution systems used in practice have a single circuit main feeder with wide range of resistance and reactance values. Thus, a radial configured distribution network has a main feeder and a number of laterals emanate from the nodes of the main feeder.

The present-day automated distribution systems are under continuous reformation. They are performing a number of jobs, like configuration management, continuous voltage control and routing of power through feeders by effective utilization of tie-switches and sectionalizing switches. [1-3]

Since the distribution networks are under continuous expansion program to meet the present demand of power, but unfortunately a less attention is paid towards to the optimum growth. As a result, the real power losses have become appreciable and voltage profile has become very poor. The load flow analysis is the solution, through which any network can be analyzed to improve its performance. [3]

2. OVERVIEW OF DISTRIBUTION NETWORK

The main objective of an electricity distribution system is to meet the customer's demands for energy after receiving the bulk electrical energy from transmission or sub-transmission substation. The distribution system can be subcategorized in three sub systems as: distribution substation, primary distribution system and secondary distribution system.

2.1 Distribution Substations

The distribution substation is provided power at any required transmission or sub-transmission voltage level by the transmission or sub-transmission lines, which is forwarded to multiple distribution feeders originating in the substation. This comprises of primary distribution system. Several feeders originate radially from the substation in order to supply the load. Functions of distribution substation can be given as follows:

(a) *Transmission of voltage:* Several transformers are located within the substation for stepping down voltage level as acceptable to the primary distribution voltage level. The configuration of these transformers would either be three phase or three single phase transformers connected as three phase banks. The primary distribution voltage standards are 4.16kV, 7.2kV, 12.47kV, 13.2kV, 14.4kV, 23.9kV and 34.5kV.

(b) *Protection and switching:* Various types of switchgear are located at the substation and can have the following components:

(i) *Switches:* These are those devices which connect or disconnect different parts of a network and also carry or obstruct normal load currents.

(ii) *Circuit breakers:* These devices work in a similar fashion to switches, in addition to which they can interrupt short circuit current. These devices are often paired with relays which can sense short circuit condition using potential transformers and current transformers.

(iii) *Re-closure:* These devices have the ability to reclose after opening, open again, and reclose again, repeating this cycle a predetermined number of times until they lockout. These are switches similar to circuit breakers.

(iv) *Fuses:* These devices have the capability of carrying a fixed load current without any hindrance and also obstruct a pre-defined fault current.

All of the above, but switches are protection devices. Switches are often used on high voltage side of the transformer, whereas the protection devices are used on the low voltage side. In case of substations supplying large amount of currents, the protection devices can be on both sides. Special substation designs to achieve high reliability may utilize multiple circuit breakers.

(c) *Regulation of voltage*: The feeder will cause a voltage drop IZ volts per unit length, owing to the current I flowing from source to load along the feeder length and finite impedance Z per unit length. Thus, load connected over the length of the bus will see varying voltage levels with the farthest load seeing the lowest voltage of all.

(d) *Metering:* Several substations have some sort of metering device that record, minimum existing current and current peaks and falls that have occurred in the last time period. Digital recording which is capable of recording a large amount of substation operational information is also heavily employed.

2.2. Primary Distribution

The primary distribution system includes feeders coming out from the substation and supplying power to several secondary distribution systems. Such feeders are generally three phase circuits. Feeders are usually radial from substation to loads. In densely populated cities, particularly commercial and business areas, where reliability is indispensable, feeders may be mashed in topology. The prices to pay for such a reliable system are as follows:

- The cost incurred is huge because in case of a fault the system requires at least two protective devices operating simultaneously. Further, in order to guarantee the reliability, multiple switching devices should operate along the feeder.

- The fault currents tend to be lower, closes to normal load currents, and hence there is less margin between breaker trip current and normal load current.
- Voltage control is very difficult since there are two control points.

One way to obtain the reliability benefit of a looped configuration while avoiding some of the above difficulties is to operate a looped configuration in open loop, i.e., employs a normally open switch mid-way in the loop. When the loop is faulted the normally open switch can be closed while a switch just downstream of the fault can be opened, and all of the de-energized loop up to the downstream switch can be supplied. The standard primary distribution voltage levels include 4.16kV, 7.2kV, 12.47kV, 13.2kV, 14.4kV, 23.9kV and 34.5kV. However, equipment is specified in terms of voltage class. Equipment of one voltage class may be utilized in any operating voltage assigned to that class. For example, an insulator of voltage class 15kV may be utilized in a 12.47kV, 13.2kV and 13.8kV system. There are four major distribution level voltage classes; 5kV, 15kV, 25kV and 35kV. The 15kV voltage class is the most prevalent.

2.3. Secondary Distribution

Branching from main feeder are laterals, also referred to in the industry as taps or branches. The laterals may be three phase, two phase (two phase of the three phase feeder with a neutral), or single phase (one phase from the single phase feeder and a neutral) the laterals are usually protected with fuses so that faulted laterals do not cause interruption at the feeder level. Standard secondary voltage levels are:

- ⇨ 120/240V single phase
- ⇨ 120/208V three phase
- ⇨ 277/480V three phase

2.3. Types of Distribution System

On the basis of scheme of operation, the following three types of distribution circuits are generally used in distribution system.

2.3.1. Radial distribution system

In radial distribution system (RDS), primary feeders take power from the distribution substation to the load areas by way of sub feeders and lateral-branch circuits. This is the most common system used because it is the simplest and least expensive to build. It is widely used in sparsely populated areas [4]. A radial system has only one power source for a group of customers. Radial feeders are characterized by having only one path for the power to flow from the source (distribution substation) to each customer. If the distributor is connected to the supply system on one end only, that system is called radial distribution system. The radial system is employed when the power is generated at low voltage and the substation is located at the centre of the load. The consumers at the end of the

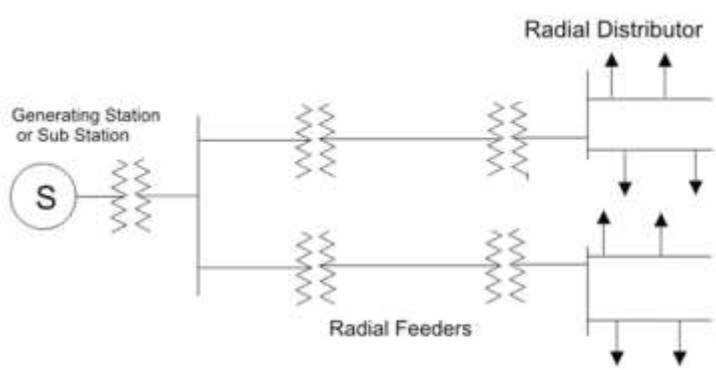

Fig.2.1. A schematic example of radial distribution system

distributor would be subjected to serious voltage fluctuations when the load on distribution changes. The advantages of radial system are its simplicity, and low cost, the amount of switching equipment required is small and protective relaying is simple. [5] The major disadvantage of radial system is its lack of security of supply. It is not the most reliable system, because a fault or short circuit in a main feeder may result in a power outage to all the users served by the system. Service on this type of system can be improved by installing automatic circuit breakers that will reclose the service at predetermined intervals. If the fault continues after a predetermined number of closures, the breaker will be locked out until the fault is cleared and service is restored. A schematic example of radial distribution system is shown in Fig.2.1.

2.3.2. Ring Main System

The loop (or ring) distribution system is one that starts at a distribution substation, runs through or around an area serving one or more distribution transformers or load centres, and returns to the same substation. The ring main system is more expensive to build than the radial type, but it is more reliable and may be justified in areas where continuity of service is required- at medical centre. In the loop system, circuit breakers sectionalize the loop on both sides of each distribution transformer connected to the loop. A fault in the primary loop is cleared by the breakers in the loop nearest the fault, and power is supplied

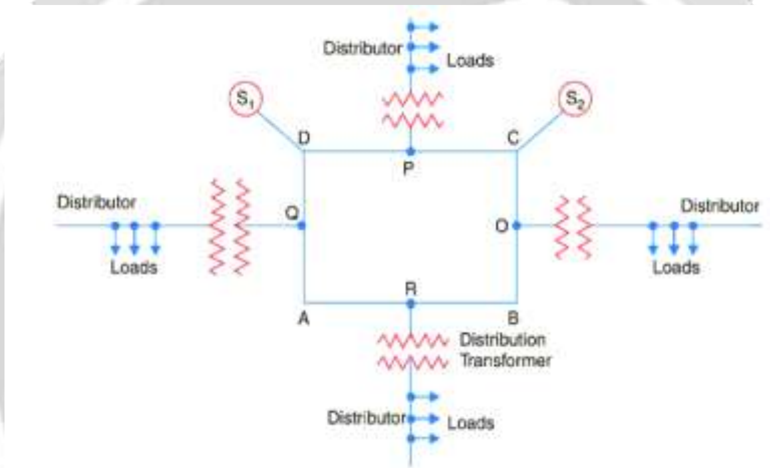

Fig.2.2. A schematic example of radial distribution system

the other way around the loop without interruption to most of the connected loads. If a fault occurs in a section adjacent to the distribution substation, the entire load can be fed from one direction over one side of the loop until repairs are made. A schematic example of ring main distribution system is shown in Fig.2.2. The ring main system has the following advantages:

(a) There are very less voltage fluctuations at consumer's terminals.
(b) The system is very reliable as each distributor is fed with two feeders.

2.3.3. Interconnected system

The network system shown in Fig 2.3 is the most flexible type of primary feeder system. It provides the best service reliability to the distribution transformers or load centres, particularly when the system is supplied from two or more distribution substations. Power can flow from any substation to any distribution transformer or load centre in the network system. The network system is more flexible about load growth than the radial or loop system. Service can readily be extended to additional points of usage with relatively small amounts of new construction. The network system, however, requires large quantities of equipment and is, therefore, more expensive than the radial system. For this reason, it is usually used only in congested, high load density municipal or downtown areas. When the feeder ring is energized by two or more than two generating stations or sub stations, it is called interconnected system.

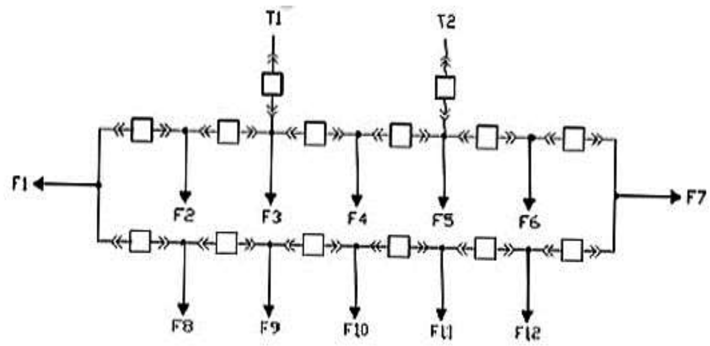

Fig.2.3. A schematic example of interconnected system

2.4. Reconfiguration, Service Restoration, Islanding and Reliability Restoration in RDS

There are some issues in radial feeder in radial feeder reconfiguration which are to be addressed carefully for the optimized power distribution of the feeder system. These are reconfiguration, service restoration, islanding and customer reliability maintenance. These are illustrated bellow.

2.4.1. Distribution Feeder Reconfiguration

The objective of "Distribution Feeder Reconfiguration" can be a part of distribution automation. The configuration management is done at the time of service maintenance or service testing. The configuration of this radial distribution system can be changed by changing the status of switches. The normally close sectionalizing switches are opened and same numbers of normally open tie-switches are closed. This is called reconfiguration. In new topological structure, the tree shape of radial distribution is maintained. The procedure can be said as the part of "Distribution Management". Generally, reconfiguration is done to obtain minimum loss path for the loss feeding. So, other purposes of reconfiguration of distribution networks are to minimize power loss and to improve voltage profile and reliability of the system [6].

2.4.2. Service Restoration in Distribution System

Service restoration is a process of restoring power flow immediately after any kind of disturbance in the power system. This disturbance may be due to the fault in the distribution system and in this case some portion of the distribution system may run out of power. To establish this connection, some tie-switches have to be closed maintaining the radial structure. Service restoration happens in the same procedure like feeder reconfiguration. For a complex distribution feeder system, it is quite cumbersome to restore ample amount of power from a distant control centre. There are varieties of loads in distribution system such as industrial, commercial and residential loads. If there is less power available at the feeding point, the control centre restores the service depending upon the priority of the customers.

2.4.3. Islanding

Power system islanding is closely related to the micro-grid islanding. It means isolation of one or more than one node at the time of power distribution due to faulty power controlling operation. As power flow is totally dependent on the status of the existing switches in the tree structure, bad controlling or an invalid sectionalizing and tie switches combination can lead to islanding of the whole or a single region. Islanding hampers the reliability of power system and therefore it should be eliminated quickly after any outage.

2.4.4. Customer feeding and reliability Restoration

On the basis of priority, the electrical system is chosen to supply at the time of outage to the residential, commercial and industrial customers. In industrial hub, outage of electricity for one hour may cause serious loss of raw assists. In general, if a load point in feeder section is heavily loaded then there will be chance of voltage dipping. As stated earlier, reconfiguring the structure, the heavily loaded portion of the feeder can be transferred to lightly loaded feeder portion. By doing this, some nodes in the feeder system may lead towards the verge of voltage collapsing situation. Overloading can reduce the capacity of feeder line and life span of distribution transformers connected to the system. Apart from this if configuration is changed by altering more number of switches in the system, the power system can suffer from the ill effect of the switching surge.

2.5. Optimization, Feasibility and Constraints

The main objective of power system is to supply the electricity to the consumer as economically as possible maintaining the reliability of the service. In this process the system operator or planner must look into the transmission loss, voltage profile and other power quality issues. So, the power system must be run at optimum level of all factors. In some aspects the optimization means a way of selecting the best one from a set of alternatives. In other aspect, it means a set of techniques to design a system with respect to specific parameters. The parameters are called constraints, which any result to its desired value. Optimization means to utilize the resources wishfully. [6]

Feasibility is the term which is closely related to the real life use of any problem. For any optimized system to find out its strength and weakness is called feasibility. Any new technology or strategy in power system comes after some cost conveying. Installation of new unit in power station involves cost and time in the whole process. If new installed system does not come with fruitful result, it cannot be feasible at all. So an optimized system may not be feasible all the time.

In case of power generation, the constraints are coal or water availability, number of running units, liquid assets to preserve raw material, number of technicians available, etc. In case of power transmission and distribution, the practical constraints are conductor capability to carry current, transformer overload, loading conditions, voltage level, frequency, etc. [6]. So, any process cannot yield suitable result without considering all the constraints of the system.

2.6. Load flow Analysis of Distribution Systems

Power flow analysis is a very important and basic tool for the analysis of any power system as it is used in the planning and design stages as well as during the operational stages. Some applications, especially in the fields of optimization of power system and distribution automation, need repeated fast power flow solutions. In these applications, it is imperative that the power flow analysis is solved as efficiently as possible.

With the invention and widespread use of digital computers in 1950s, many methods for solving the power flow problem have been developed such as indirect Gauss-Seidel (bus admittance matrix), direct Gauss-Seidel [7] (bus impedance matrix), Newton-Raphson [8] and its decoupled versions. However, these algorithms have been designed for transmission systems, and therefore their application to the distribution systems usually does not provide good results and very often, the solution diverges. One of the reasons why these methods are unsuitable for distribution systems is that they are mostly based on the general meshed topology of a typical transmission system whereas most distribution systems have a radial or tree structure. Another reason is due to the high R/X ratio of distribution systems. This is a factor which causes the distribution systems to be ill-conditioned for conventional power flow methods, especially the fast-decoupled Newton method [9], which diverges in most cases. Lastly, the active and reactive loads of a distribution system are dependent on the bus voltage. However, most of the conventional power flow methods for both transmission and distribution systems, consider power demands as specified constant values. The constant power load model is highly questionable and it is so especially for a distribution system because the bus voltages are not controlled. Therefore, there is a need for a power flow method that takes this aspect into consideration to obtain better and more accurate results. Though considerable efforts has been directed to the development of solution algorithm for power flow analysis of transmission systems with great success, in contrast, comparatively fewer solution algorithms have been developed for power flow analysis of distribution systems. Therefore, the growing need of distribution companies for more complete studies and the increase in system automation have motivated the development [8] of a specialized algorithm for distribution systems that consider all their particular characteristics.

The solution procedure and formulations can be precise or approximate, with values adjusted or unadjusted, intended for either on-line or off-line application, and designed for either single case or multi-case applications, but it should meet the following requirements.

- They should have high speed and low storage requirements, especially for real time large system applications, as well as multiple case and interactive applications.
- They should be highly reliable, especially for ill conditioned problem, outage studies, and real time applications.
- They should attain accepted versatility and simplicity.

2.6.1. Load Flow Methods for Distribution Networks

Several methods are available for load flow analysis of radial distribution networks. Some of them are discussed as under:

(a) Gauss-Seidel load (GS) flow method:

This is most primitive method of load flow study. A recursive expression for bus voltage V_p is developed from the load current flowing I_p through the bus 'p' and the power S_p injected to the bus. The iteration process begins with a flat voltage profile assumption to all the buses except the slack bus. The bus injected powers and the series branch admittance parameters are known and hence the bus voltages are updated using the eqn. A convergence check is made on these updated voltages and the iteration process is continued till the tolerance value is reached. [7]

This method gives very slow rates of convergence as compared to other methods, but involves very small amount of memory and does not necessarily involve, solving of matrices.

(b) Newton-Raphson method:

This method load flow study is a land mark in the load flow solution methods. Several methods are based on this technique. The convergence rate is appreciably fast. The recursive power flow equations for real and reactive powers (Pi, Qi) are used as core equations. If the rectangular form of voltage vector is used, the load flow method is called rectangular coordinate method and if the polar form of voltage vector is used, the load flow method is called rectangular polar coordinate method. [8]

(c) Fast Decoupled load flow method:

It is observed from the Newton-Raphson method that the changes in real power are very much influenced by the changes in load angle only and get negligibly affected due to the change in voltage magnitude. Similarly, the changes in reactive power (Q) are very much influenced by the changes in voltage magnitudes and no changes takes place due to the load angle changes. [9] This formed the basis for the Fast-decoupled load flow method and this method is called Approximate Newton method. The iteration procedure is same as the NR method and the memory and storage requirements are reduced considerably, the solution is a converged with the decoupling condition that the series branch conductance should be smaller than the series branch susceptance.

(d) Backward/Forward Sweep Method:

Kirchhoff's Current Law and Kirchhoff's voltage Law are used during the backward flow to calculate the bus voltage from last node of each line or a transformer branch. Then, the linear proportional principle is used to find out the ratios of the real and imaginary parts of the specified voltage to the calculated voltages at the substation bus. During the forward sweep, the voltages at the buses starting from first nodes towards the last nodes are updated by the real and imaginary parts of the calculated bus voltage multiplying with the corresponding ratio. The entire process stops after the mismatch of the calculated and the specified voltage at the substation and when the convergence rate is less than the tolerate limit. [10]

(e) BIBC/BCBV Method:

In this method two developed matrices, bus injection to bus current (BIBC) and branch current to bus voltage (BCBV), and a simple matrix multiplication (DLF) are used to obtain load flow solutions. This solution converges very early on; therefore, execution time is very small. [11]

2.6.2. Limitations of the Classical load Flow methods

The main limitation of the NR method is the large storage & large solution time. It is due to the repeated Formation and triangularization of Jacobean matrix. Then by making certain approximations in the Jacobean elements, an approximate network method, called Fast Decoupled Load Flow (FDLF) method, came into existence. It has been observed that the computational efficiency and reliability of FDLF method is higher than NR method and has been used as a main mathematical tool to compute load flow of transmission networks of power industry. The negative aspect of the FDLF method has been observed that the method failed to give converged solution for a network having high (R/X) ratios.

2.6.3. Ill Conditions in a Distribution System

The distribution systems usually fall into the category of ill-conditioned power systems for conventional load flow methods with its special features, such as:

- *Radial or weakly meshed topologies:* Most of the distribution systems are radial or weakly meshed types. The increase in requirements for reliability and outgoing distribution generation has made the structure of distribution systems more complex. Therefore, the power flow analysis in such distribution systems has become more difficult.
- *High R/X ratio of the distribution lines:* Transmission networks are composed mainly of overhead lines thus, the ratio is usually lower than 0.5. In distribution networks where both overhead lines and cables are used, the R/X ratio is high ranging from 0.5 to as high as 7, where high ratio values are typically for low-voltage networks.
- *Unbalanced operation:* Three-phase unbalanced orientation greatly increases the complexity of the network model, since phase quantities have to be considered including mutual couplings.
- *Loading conditions:* Most of the load flow methods were developed assuming a static load model. But, a practical load model is required for getting reliable results.
- *Dispersed generation:* Distributed generation is being increasingly used to meet the fast load increase in the deregulation era. The utilities have to analyses the operating conditions of the radial-type systems with distributed sources.
- *Non-linear load models:* Widespread use of non-linear loads such as, rectifiers in distribution system distorts the current drawn from the source. Usually the commercial SCADA/DMS systems treat these distribution systems as independent parts, i.e., HVAC (High Voltage AC) loop and MVAC (Medium Voltage AC) or LVAC (Low Voltage AC) radial systems. Such rough equivalence will cause inaccuracies in the power flow solutions. [11]

2.6.4. Recent Developments in Load Flow Studies in Radial Distribution Systems

It is well known that the efficient load flow method is one of the most important and highly demanded software in the power industry, through which any network can be analyzed. The analysis of a distribution network has become an important area of activity for present day power system engineer.

The conservation of power principle [5] at a node level was the main principle used in the load flow methods. The principle says that, at any node the power fed into the node is equal to the sum of the power dissipated in the series branch connected to that node". The distribution network is considered in two configurations namely distribution network with main feeder only and the other is distribution network with main feeder and laterals. Kersting and Mendive [12] and Kersting [13] developed techniques for solving the load flow problem in radial distribution networks based on ladder-network theory in the iterative routine. This solution is complicated and having many assumptions for a typical distribution system, which is rarely a „pure" ladder network. In other words, the method is not designed to efficiently solve for meshed networks. Also, Stevens et al [14] demonstrated that the ladder –based technique is very fast but does not guarantee convergence.

A method based on Kirchhoff‟s voltage and current laws, also has been proposed for solving radial distribution networks. This method is known as Backward/Forward Sweep Method. In this method, a branch-numbering scheme was employed to enhance the computations. The method was then extended to apply to weakly meshed networks. In this method, they first break the interconnected grid at a number of points (breakpoint) in order to convert it into one simple loop. The radial network is solved by direct application of Kirchhoff‟ lows. They then account for the flows at the break point by injecting currents at their two end nodes. The numerical efficiency of this method however diminishes as the number of break point required to convert the meshed network to radial configuration increases. This restricts the practical application of the method to weakly mashed networks. [11]

Baran and Wu [15] obtained the load flow solution in a distribution system using iterative solution of three fundamental equations representing real and reactive power and voltage magnitude. These three equations are useful because they can be used in real system rather than in other classical known forms. If convergence is not met, a new equivalent network is determined with the new parameters and the process is continued till the convergence is achieved. Then the node voltages and branch power losses are computed. The main advantage of this method is the efficiency is achieved by avoiding repeated computations of node voltage magnitudes. Here they computed the system Jacobean matrix using a chain rule. The mismatch and the Jacobean matrix involve only evaluating simple algebraic equations and trigonometric functions. The formulation and evaluation of Jacobean are time consuming and requires large computer memory storage.

Goswami and Basu [16] presented a direct method for solving radial and mashed distribution networks. The method has the advantage that there is no convergence problem and an accurate solution is guaranteed for any realistic distribution system, and the ease with which composite load can be represented. The disadvantage is the difficulty in numbering the node and the branches, and the limitation that no node in the network is the junction of more than three branches.

Another method has been proposed by Das et al [17] for radial distribution network based on evaluating the total real and reactive power fed through any node. They created a unique node, branch and lateral numbering scheme to enhance the evaluation of real and reactive load fed through any node and receiving end voltages. This method has the advantage that all the data can be stored in vector forms, thus saving an enormous amount of computer memory.

Ghosh and Das [18] also presented a simple method for solving radial distribution networks by evaluating only a simple algebraic expression of receiving end voltage. In this method they assumed an initial flat voltage for all nodes. Then by numbering the nodes beyond each branch, they calculated the loads and charging current then the branch currents. The modified nodal voltages are recalculated and also the losses. Evaluating the difference between new and previous voltage values and then comparing it with an accepted tolerance verified the convergence of this method. This method is simple and has good and fast convergence, and can be used for composite load modeling, if the composition of the load is known. In the case of distribution network main feeder and laterals a proper bus and branch numbering scheme is used to read and retrieve the branch parameters and load values. In this configuration each lateral is treated as a main feeder of distribution network and the iteration process is continued for each lateral. Since the iteration process is carried in the forward direction of the power flow, the method is named as “Forward Sweeping Method”.

3. RELIABILITY CONSIDERATION

Reliability consideration becomes an integral part of the planning and operation of a modern-day power distribution system. Consequently, in recent years, there has been significant amount of effort devoted by the researchers on addressing the reliability issues while reconfiguring the distribution networks. The maximization of the reliability of the supplied power is being considered as the objective of the distribution system reconfiguration problem, as an alternative to, or in addition to the objectives such as the minimization of the real power loss, equipment cost or the voltage sag. [29]

Two approaches to reliability evaluation of power system distribution systems are frequently used, namely, historical assessment and predictive assessment. Historical reliability assessment involves the collection and analysis of an electric system's outage and interruption data. [30] It is essential for electric utilities to measure actual distribution system reliability levels and define performance indicators in order to assess their basic functions of providing a cost-effective and reliable power supply to all sectors of society.

The distribution system is an important part of the total electrical supply system, as it provides the final link between a utility's bulk transmission system and its customers [31]. Almost 80% of all customer interruptions occur due to failures in the distribution systems. Historical assessment generally analyzes discrete interruption events occurring at specific locations over specific time periods, whereas predictive assessment determines the long-term behavior of systems by combining component failure rates and the duration of repair, restoration, switching, and isolation activities that describe the central tendency of an entire utility's distribution system of the possible values for given network configurations. Accurate component outage data is, therefore, the key to distribution system predictive performance analysis. In addition to the physical configuration of the distribution network, the reliability characteristics of system components, the operation of protection equipment, and the availability of alternative supplies with adequate capacity also have a significant impact on service reliability. In practice, the determination of acceptable levels of service continuity is generally achieved by comparing the actual interruption frequency and duration indexes with arbitrary targets. These targets are based on the perception of customer tolerance levels for service interruptions. However, it has long been recognized that rules of thumb and implicit criteria cannot be used in a consistent manner when a very large number of capital investments and operating decisions are routinely being made [31]. Consequently, there is a growing interest in economic optimization approaches to distribution planning and expansion. The basic concepts involved in utilizing customer interruption costs in association with customer reliability indexes in distribution system planning are illustrated in [6] and [32].

Reliability evaluation in distribution network includes all the segments of an electric power system in an overall assessment of actual consumer load point reliability. The primary reliability indices used in distribution system reliability evaluation are the expected failure rate λ, the average duration of failure r, and the annual unavailability U, at the customer load points. Individual customer indices can also be aggregated with the number of customers at each load point to obtain the system reliability indices. These indices are the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI), the customer average interruption duration index (CAIDI) and the average service availability index (ASAI). The customer load point indices, SAIFI, SAIDI, CAIDI, AENS and ASAI are performance parameters obtained from historical event reporting. Many electric power utilities throughout the world compile these statistics on individual feeders, segments of the system, and on the entire system. [33]

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