CHAPTER 1
INTRODUCTION

1.1 General

Reliability worth assessment is currently receiving considerable attention as it provides the opportunity to incorporate the costs or losses incurred by utility customers as a result of power failures in the overall analysis of system costs and benefits. A variety of approaches have been utilized to assess the cost of power interruptions. These include analytical methods, case studies and customer survey approaches. The survey approach can easily include the effect of many factors such as time of occurrence, duration and frequency of interruption and therefore provides a practical framework for detailed analysis. In recent years, power demand has increased with high information-oriented society. Since electric power systems play a major role in a modern society, professional engineers are responsible for the planning, design, and operation of power systems. A modern power system are desired to have high efficiency and high reliability. In this situation, new generation facilities and expansion of the transmission lines must be planed and constructed maintaining reliability of power systems and reducing loss of load in faults. However modern power systems are complex, highly integrated, and very large. It is difficult to determine the optimal set up point for that reason. Power system planning has been studied over decades. By formulation an optimization problem which has non-linearity with integer and continuous variables. The objective of this problem is maintenance of reliability and reducing loss of load. The exact optimal solution of this problem can be obtained by complete enumeration. However this method cannot be applied to realistic optimization problem due to its computation intensity.

Distribution system reliability has acquired significance in these days, because distribution system performance can directly have an effect on the customers. In today's electricity market, utilities are expected to give highly reliable power supplies at competitive prices. So every distribution company tries to supply a reliable power supply to the customers. But it is not simple to provide a reliable power supply as it is influenced by the faults in the power system, failure of generators and other power system components. Sudden raise in load demand and weather conditions may also lead to outages in the distribution system.

Reliability evaluation of distribution system accesses the capability of the load points in regard to provided that a suitable power supply to the consumers. Distribution systems normally consist of radial feeders, unlike transmission systems, which are looped. This is the main cause that a large number of consumers are affected by the failure of a single component. Now a days, modified radial system designs with usually open tie lines have become popular in order to reduce the reliability impact of radial design.

The best distribution reliability performance can be achieved by the companies that can give the best tree trimming schedules, the best maintenance schedule, the best design schemes (which can contain the charge of costly equipments such as circuit breakers, recloses) and the most effective team placement. Some of the basic indices are used to assess past performance for the area, subsystem and subsystem level are the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI), the customer average interruption duration index (CAIDI), the average service availability index (ASAI), the average service unavailability index (ASUI), the energy not supplied (ENS).

Predictive reliability evaluation of a distribution system is generally concerned with the system performance at the consumer load points. The basic indices usually used are load point failure rate, outage duration and annual unavailability. The basic indices are significant with respect to a particular load point, but they do not provide on overall appreciation of the area or the system performance. Additional indices can be calculated using these basic indices and the numbers of consumers/ load connected at each load point in the system. Reliability indices of a distribution system are function of component failures, repairs and restoration times, which are random by nature.

1.2 LITERATURE REVIEW

Warren [1] has given the idea of distribution system reliability, and mentioned some definitions regarding the distribution system reliability and also stated the factors affecting the distribution reliability. Some realistic ways to develop reliability such as effective tree-trimming, system improvements by providing reclosers, sectionalizers etc have also been mentioned. The distribution system reliability is measured in terms of reliability indices as per the IEEE and in this work all the related definitions and equations are taken form IEEE guide for electric power distribution reliability indices [2].

Billinton [3] declared that three load point indices mainly feeder failure rate, repair rate, unavailability of the system are to be considered while evaluating the distribution system reliability.The basic method to find the reliability index of the distribution system has been explained and analytical method has compared with the probabilistic simulation method.

Now a day's automation in distribution systems is increasing largely. Automated and remote controlled switches play important roles in automated distribution systems. Determination of the Optimum number and location of switches in distribution system automation is an important problem from the reliability and economical points of view. Moradi and Fotuhi- Firuzabad [5] have presented reliability worth based approach to determine optimum number of switches. The best locations of switches are determined by powerful heuristic algorithm Simulated Annealing.

Moradi and Fotuhi- Firuzabad [6] have given a novel three state approach encouraged form the discrete version of a powerful particle swarm optimization (PSO) to find out the optimum number and locations of two types of switches (sectionalizers and breakers) in radial distribution systems. The uniqueness of the proposed algorithm is to simultaneously consider both sectionalizer and breaker switches. The feasibility of the proposed algorithm is examined by application to two distribution systems. The proposed explanation approach gives a global optimal solution for the switch placement problem.

Member [7] states that automatic devices that locate and automatically sectionalize faulted branches in MV voltage power distribution systems restrict significantly the extent of distruption caused by long power interruptions when properly positioned. Some algorithms and automatic calculation procedures are proposed here for determining the optimum number and location of automatic sectionalizing switching devices. Using these algorithms, the optimal solutions have found out for both radial and meshed systems. The procedure is based on Bellmann's optimality principle which combined with thinning techniques yields finding the optimal solution in a very short time for real size problems.

Ying et al. [8] gave the importance of placing of sectionalizing devices in distribution systems. They have considered both the technical and the economic issues. On the technical issues, it describes how distribution automation affects the reliability indices using typical Swedish networks to express the impact of such operational features. On the economic issues, it demonstrates the impact of automation on the benefits of power supply in terms of consumer outage costs. Weixing et al. [18] have given the reliability evaluation of complex radial distribution system, considering voltage constraints. They developed an algorithm by classifying the load points during a fault into different groups for calculating the reliability indices of the distribution system.

Billinton [9] gave new formulation for sectionalizing device placement taking into consideration outage, maintenance and investments costs. The formulation of sectionalizing switches is a combinational constrained optimization problem with a non linear, non differentiable objective function. A solution methodology based on the optimization technique of simulated annealing, is proposed to determine (i) the number of sectionalizing switches and (ii) the locations of the switches. The proposed solution methodology can suggest a global optimal solution for the sectionalizing device placement problem which includes the reliability, investment and maintenance costs.

Ying et al. [10] have presented an approach for determining optimum allocation of automatic switching devices in distribution systems considering investment constraints and taking into account dynamic network configuration changes by using an in house developed computer program RADPOW [11, 13]. A number of application studies of the approach are performed to show the effect of network and investment constraints on the optimal allocation of such devices.

1.3 OBJECTIVE

Automatic switching devices like circuit breaker, recloser, sectionalizing switches etc are located in primary distribution systems for different purposes, e.g., to improve reliability, to isolate component failures and faults, and to reconfigure the network, etc. In general, determining optimum position and number of automatic switching devices is a complex process due to a large number of variables involved as well as the complicated task of the mathematical presentation of several requirements and limitations specified by systems configuration. The problem of finding the locations and the number of sectionalizing switches required in a distribution network which best meets the designated system criterion falls into a class of problems known as "combinatorial optimization problems". It is complicated to solve this type of problem by conventional optimization methods. This problem has received significant attention and a number of techniques and methods have been developed including:

- The alternative policy method, by which a few alternative policies are compared and the best one is selected.
- The linear programming and integer programming methods, which linearize constraint conditions.
- The method based on the Optimization technique of simulated annealing for solving non differentiable, combinatorial optimization problem.

These methods have different advantages and disadvantages. Especially in long range planning, a great number of variables are concerned, and thus there can be a number of possible alternative plans which make the selection of the optimum alternative a very complex task. The reliability indices deduced include load point indices and overall system indices. The load point indices are average failure rate λ (f/yr), average outage time r (h), average annual outage time U (h/yr), and average energy not supplied ENS (kWh/yr). From these load point indices the following system indices can be obtained:

- System Average Interruption Frequency Index (SAIFI) (int/yr.cust)
- System Average Interruption Duration Index (SAIDI) (h/yr.cust)
- Customer Average Interruption Duration Index (CAIDI) (h/int)
- Average Energy Not Supplied AENS (kWh/yr.cust)
- Total Annual Cost ($)

In this work, a reliability analysis is carried on a radial distribution network. The distribution system reliability indices are calculated and a study is carried to show the effect of placement of protective devices on distribution system reliability indices. Based on the reliability indices, we are able to analysis the distribution system reliability and the optimum allocation of automatic switching devices.

1.4 OVERVIEW OF THE THESIS REPORT

This thesis is ordered as follows:

Chapter-1: Gives brief introduction about Distribution System Reliability, Objective of this Thesis report and literature review.

Chapter-2: Gives definitions of various terms related distribution systems, Distribution system reliability and different types of Failures and interruptions.

Chapter-3: Provides the information regarding the Distribution System Reliability, System reliability performance, factors influencing the Distribution System Reliability.

Chapter-4: Describes the procedure for Distribution System Reliability evaluation.

Chapter-5: Describes the different techniques for distribution system reliability and optimal switch placement in radial distribution system.

Chapter-6: Discussion the results and concludes the overall thesis work.

CHAPTER-2

DEFINITIONS AND TERMINOLOGY

2.1 ELECTRICAL POWER DISTRIBUTION SYSTEM

2.1.1 Historical Back ground

Until the 1870s electricity was a matter only to engineers and researchers. Experiments were conducted to study more about electrical phenomena, and batteries were the main source of power. The Belgian researcher Zenobe Gramme invented the generator, which could supply greater electrical currents than the battery. Electricity feeders were then build from small and large power plants to supply light and run electricity machines for primary and secondary industries. The first incandescent lamp came into being around 1880, invented simultaneously by Thomas Alva Edison and the English man Joseph Swan. Electricity had finally reached its consumers providing the demand and rational for electricity power delivery systems.

2.1.2 Power Distribution Systems

Power delivery systems consist of transmission and distribution systems (T&D systems) for the transport of electrical power from the producers to consumers. These consists of thousands of overhead lines, substations and transformers and other equipment spread over large geographical areas, and the interconnected to deliver power on demand to consumers. The major design of a T&D system is based on two physical and economic constraints [14].

The first constraint being that is more economical to transport power at high voltages because of the reduction in losses, but higher voltages transmission requires equipment with greater capacity which is turn it more expensive.

The second constraint is that power is more economical to generate in large amounts, but it must be deliver in small quantities at low voltage levels (120-250 V). Although it should be acknowledged that with the reconstruction of electric power systems due to introduction of deregulation this in now only partially true. However the fundamental question is which part of the whole system is the Distribution System. Three types of distinctions between transmission and distribution systems are:

1. **<u>Voltage Level</u>:** Transmission ≥ 34.5k V and distribution ≤ 34.5k V.

2. **Function:** Distribution includes all utilization voltage equipment and all overhead lines that feed services transformers.
3. **Configuration:** Transmission includes a network, and distribution includes only the radial equipment in the system.

The part of the power system which distributes electrical power for local use is known as distribution system. In general, distribution system is the electrical system between the substation fed by the transmission system and the consumer's meters. It generally consists of feeders, distributors and service mains.

i. **Feeder:** A feeder is a conductor which connects the substation (or localized generating station) to the area where power to be distributed. Generally, no tapings are taken from the feeder so that current in it remains the same throughout. The main consideration in the design of the feeder is the current carrying capacity.

ii. **Distributor:** A distributor is a conductor from which tapings are taken for supply to the consumers. In fig 2.1 AB, BC, CD and DA are the distributors. The current through the distributor is not constant because tapings are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration.

iii. **Service mains:** A service main is usually a small cable which is used to connect the distributor to the consumer's terminals.

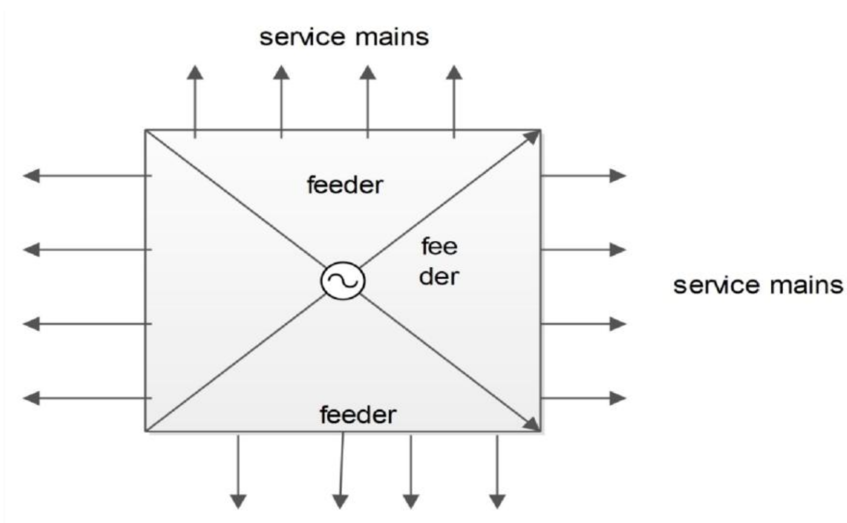


Fig. 2.1 Distribution system

2.1.3 Classification of Distribution System

A distribution system may be classified according to:

i. **Nature of Current:** According to nature of current, distribution system may be classified as (a) D.C distribution, (b) A.C distribution system. Now days, A.C system is universally adopted for distribution of electric power as it is simpler and more economical then direct current method.

ii. **Type of construction:** According to the type of construction, distribution system may be classified as (a) overhead system, (b) underground system. The over head system is normally employed for distribution as it is 5 to 10 times cheaper than the equipment underground system. In general, the underground system is used at places where overhead construction is unfeasible or prohibited by the local laws.

iii. **Scheme of Connection:** According to scheme of connection, the distribution system may be classified as (a) Radial System, (b) Ring main system, (c) Inter connected system.

2.2 RADIAL DISTRIBUTION SYSTEMS

In this system separate feeders give out from a single substation and feed the distributors at one end only. Fig. 2.2 shows a single line diagram of a radial distribution system where a feeder OC supplies a distributor AB at a point A. Obviously the distributor is fed at one end only i.e., point A in this case.

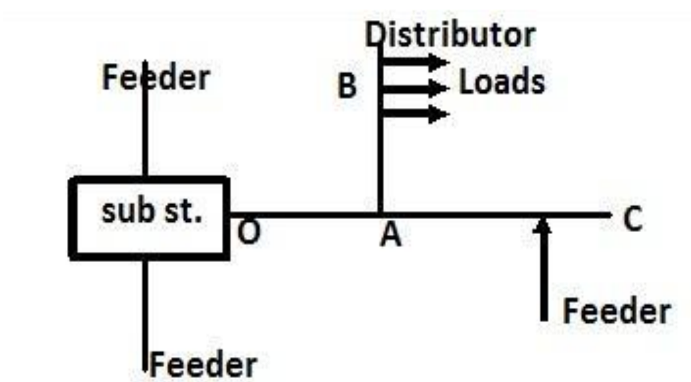


Fig. 2.2 Radial distribution system

This is the simplest distribution circuit and has the lowest initial cost. However it has following draw backs.

a) The end of the distributor nearest to the feeding point is heavily loaded.

b) The consumers are dependent on a single feeder and single distributor. So, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.

c) The consumers at the distant end of the distributor would be subjected to the serious voltage fluctuations when the load on the distributor changes.

2.3 Failures

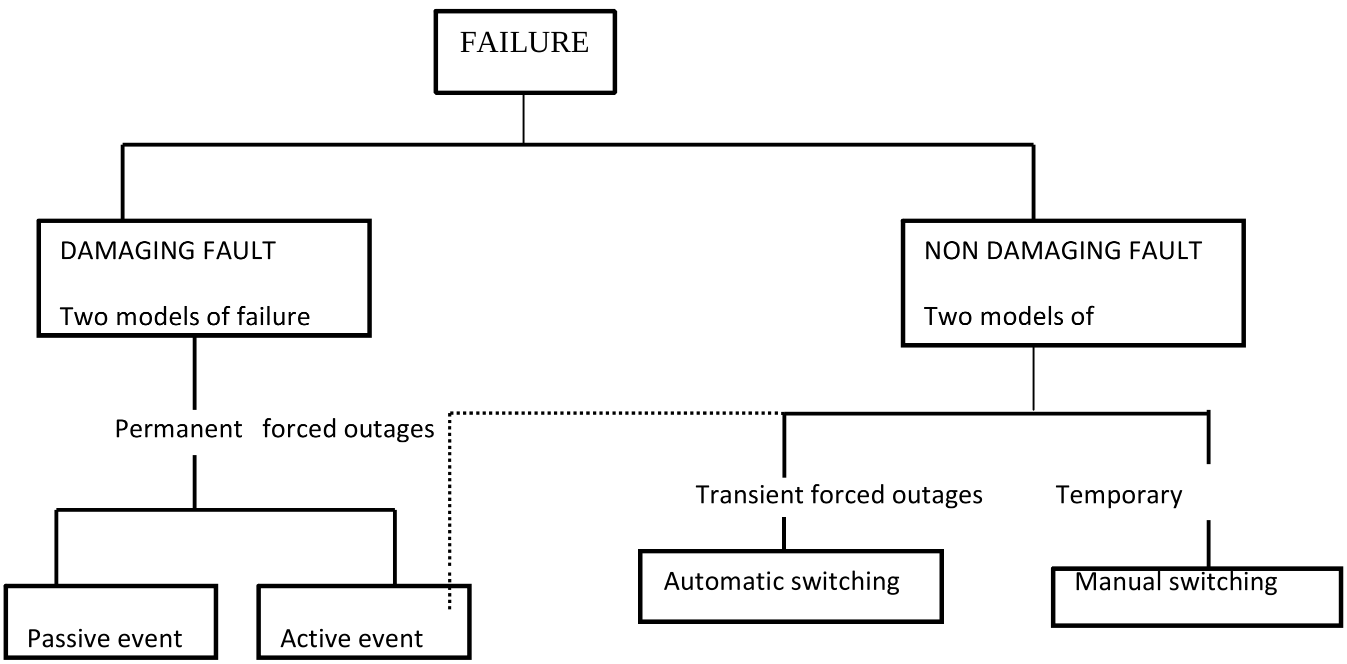


Fig. 2.3 Definitions of failure

Failures can be divided primarily into damaging faults and non- damaging faults. Outages caused by damaging faults are usually called permanent forced outages, while outages caused by non- damaging faults are categorized again after the action of restoration into:

(i) **Transient forced outages** when the system is restored by automatic switching and the outage caused by automatic switching and the outage time is negligible.

(ii) **Temporary forced outages** when the system is restored by manual switching or fuse replacement. Long interruptions are caused by damaging faults (permanent faults) and short interruptions are often caused by transient faults.

Damaging faults can be classified into two models of failure **passive** and **active** failure.

An **Active Failure** is a failure of an item which causes the operation of the protection devices around it and results in the opening of one or more fuses.

A **Passive Failure** is a failure that is not an active failure.

The failed component by an active failure is consequently isolated and protection barkers are re-closed. This leads to services restoration to some or all of the load points. However, for the passive failure service is restored by repairing or replacing the failed component.

The outage time of failure is made up of various items depending on the cause. Fig. 2.4 shows two different time sequences following active and passive failure. As can be seen in the figure, the active failure can be restored by either repair or replacement, or by switching. The dotted line in figure 2.3 and 2.4 indicates active failures that are restored by switching and not caused by a damaging fault. These are referred to as additional active failure. An **additional active failure** is a failure mode that occurs when a component fails actively and causes interrupted through its impact on other components.

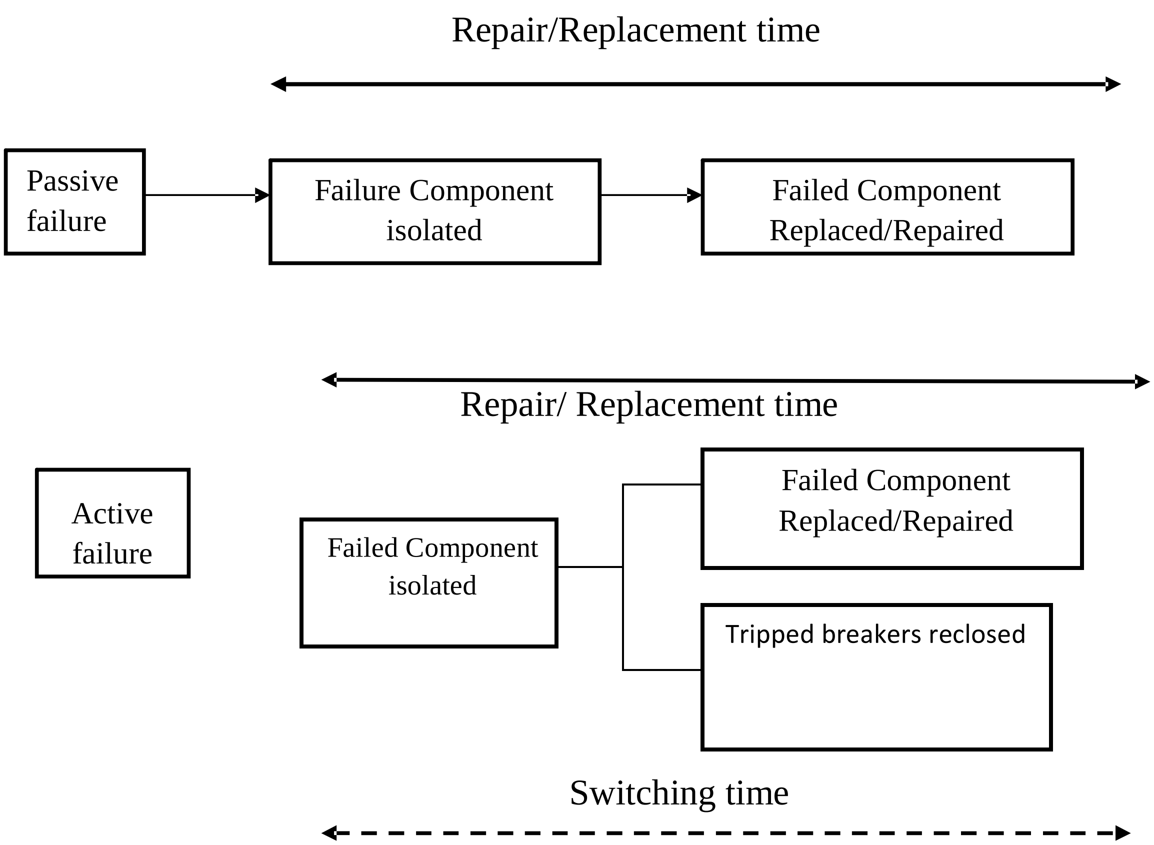


Fig. 2.4 Outage time sequence

The basic definition of distribution system reliability, factors affecting the distribution system reliability and definitions of distribution system reliability indicates will be discussed in the next chapter.

CHAPTER-3

DISTRIBUTION SYSTEM RELIABILITY

3.1 GENERAL

Distribution Reliability as per the IEEE dictionary definition is the ability of the distribution system to perform its function under stated conditions for a stated period of time without failure [1]. Distribution reliability is mainly important in these competitive days because the distribution system feeds consumers directly. Generation and transmission events can cause interruption to consumers, but events on these systems are much liable to affect the consumers than the distribution system.

The distribution system is that portion of the electric power system which links the bulk power source to the customer facilities. Sub- transmission circuits, distribution substations, primary feeders, distribution transformers, secondary circuits and customer connections form different parts of the distribution system. Distribution system reliability evaluation therefore consists of assessing how effectively the different parts to execute their intended function.

The main function of a modern electric power system is to provide its consumers with electrical energy as economically as possible and with an acceptable degree of reliability. This degree of expectation requires electric power utilities to supply an uninterrupted power supply to their consumers. It is not possible to design a power system with 100% reliability. Power system managers and engineers therefore attempt to achieve the highest possible system reliability within their socio-economic constraints.

In the power system, reliability can be defined as concern regarding the system's ability to provide a sufficient supply of electrical energy. Many utilities review the past performance of their systems and employ the resultant indices in a broad range of managerial activities and decisions. All utilities try to know reliability implications in system planning, design and operation through a wide range of techniques.

3.2 FACTORS INFLUENCING POWER SYSTEM RELIABILITY

The factors influencing power system reliability can be divided into four categories. They are component reliability, environmental conditions, loading and system configuration.

3.2.1 Component statistics

A power system consists of various components, such as lines, cables, transformers, breakers, switches, reactors, and capacitors. Any single component outage causes a partial or even entire outage. The availability of component functionally is characterized by failure rates and repair or replacement times.

Failure rate

Component failures can be divided into aging failures and chance failures. Aging failure is a conditional failure that depends on the component's history. Fig 3.1 shows a bathtub curve of a component's failure rate change during its life time. An aging failure can happen suddenly after a component enters its Wear-out period. Fig 3.1 indicates that a component failure rate is not constant. Failure rate distributions are different form component type to component type. Some expensive components, like transformers, come with a set of reliability data provided by the manufacturer, including the component's life cycle statistical distribution. Now days, the infant mortality period of some expensive components is generally consumed by manufacturers so that when these components are put into service they are already in a reliable state. We notice from fig 3.1 that the failure rate in the normal operation period is a constant failure rate, and it does not depend on a component's age.

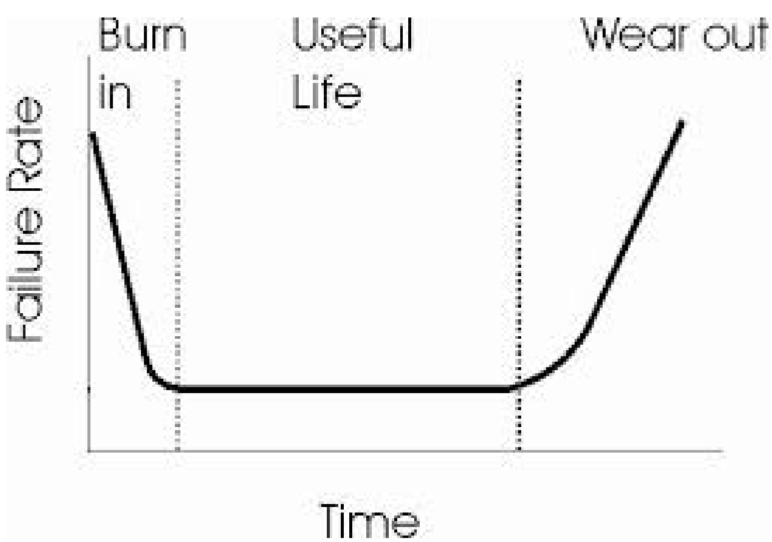


Figure 3.1 Bath-tub curve of a component's life

Therefore, change failure can be modeled as an exponential distribution. (Exponential distribution is the only distribution that has a constant failure rate). This statistic generally can be obtained under normal operating conditions form the manufacture. However, loading and environmental conditions often give to equivalent failures. Failure rates for operating under abnormal conditions are difficult for manufactures to provide.

Repair Time

There are no good models for repair time (or down time), since the repair time for failure equipment depends upon many things, such location, group dispatch policy, different failure parts in a type of component and so on. Historical data shows that the repair time is also affected by weather conditions. Stormy conditions usually prolong the process of customer down time.

3.2.2 System Configurations

System configurations include various issues, including topology, transportation capacity, protection/ coordination schemes and Switch placement. These factors all affect the reliability level of a system to some extent. Basically, assuming the protection and coordination scheme permits, more connectivity between feeders means more potential alternate feeds to the interconnected feeders, and whether the potential alternate feeds can actually provide alternate power during contingency situation is determined by the capacity of the feeders themselves.

3.2.3 Environmental Conditions

Power system components are exposed to various weather conditions and hazards. Animals, motor vehicle accidents, rain, ice and tree contact can all lead to faults and failures. Environmental dependent failures may be of short duration. During such events, the probability of failure of components is increased dramatically. Many utility companies have provided this increased attention, especially with weather dependent failures. It is difficult to develop an accurate model for the catastrophic environment since its probability of occurrence and the impact range can only be based on a rough estimate. Generally weather condition modeling is better designed than the other environment conditions since historical weather data is always available. For example, if we divide the weather conditions into two basic states: normal and adverse, and the failure rates and repair times of components for these two states are available, the system reliability can be evaluated separately for the two weather states and the resulting reliability indices can be weighted by the probability of the weather states.

3.3 BASIC DISTRIBUTION SYSTEM

A distribution circuit normally consists of primary or main feeders and lateral distributors. A main feeder originates from the substation and passes through the major load centers. The individual load points are connected to the main feeder by lateral distributors with distribution transformer at their ends [1]. A typical distribution feeder is shown in Fig. 3.2.

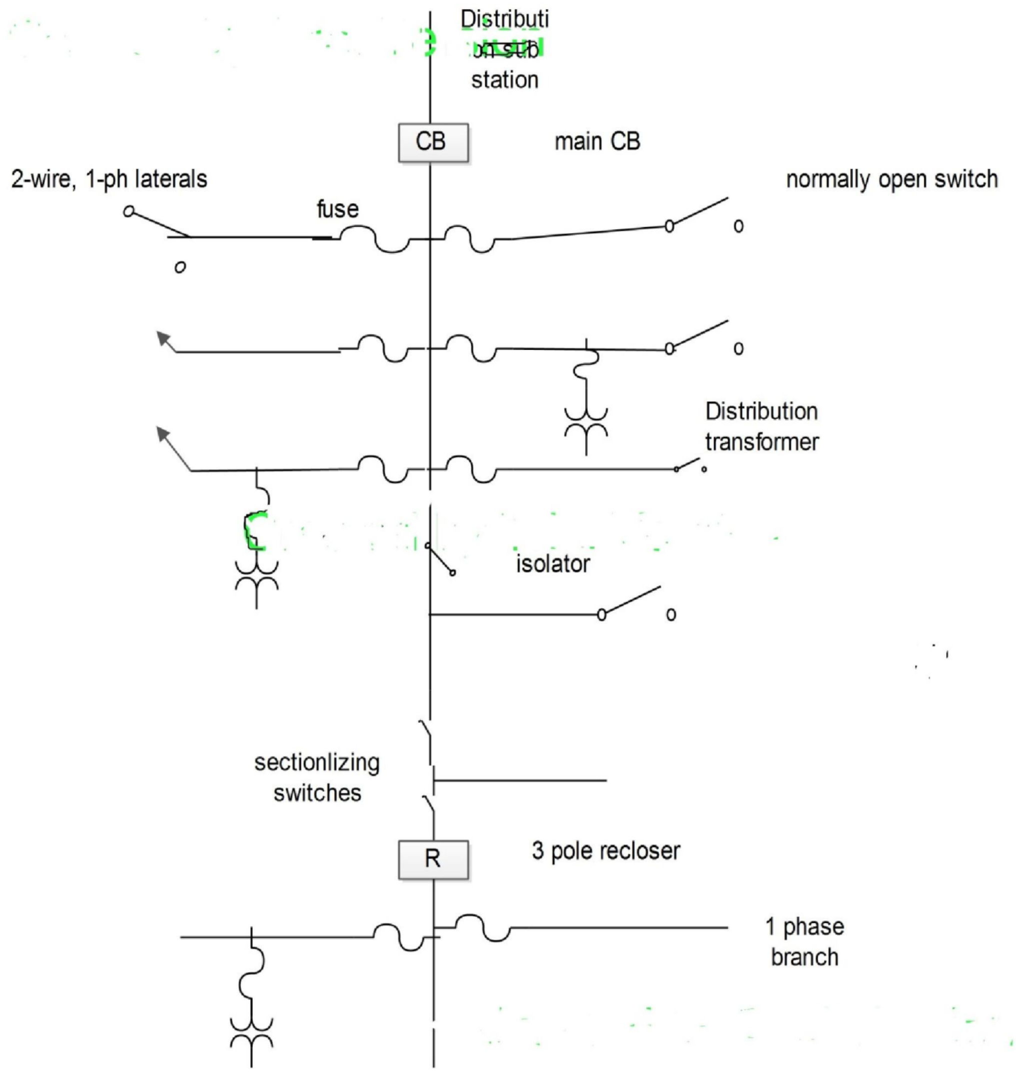


Fig. 3.2 basic distribution network

Many distribution systems have a single circuit main feeder and are defined as 'Radial Distribution System'. There are also many systems which although constructed using meshed circuits, are operated as radial systems using normally open switches in the meshed circuits. Radial systems are popular because of their simple design and usually low cost. There systems have a set of series components between the substation and the load points. The failure of any of these components causes outages of the load points. So providing a reliable power supply to the consumers is a difficult task.

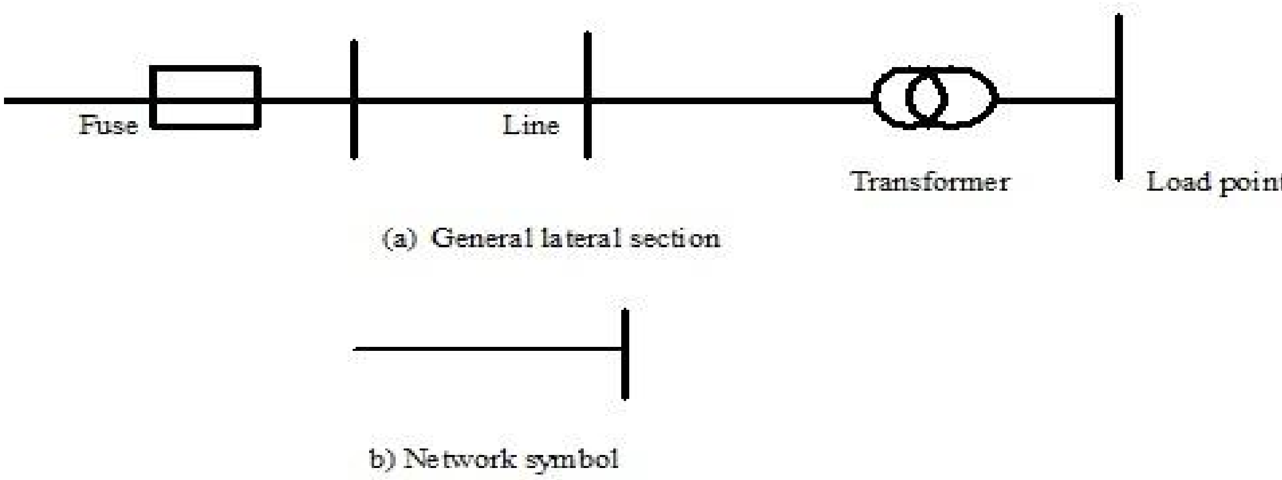
The outage duration and number of customers affected due to a components failure are reduced by using extensive protection and sectionalizing schemes. The sectionalizing equipment provides a convenient means of isolating the faulted section. The supply can be restored to the healthy sections, maintaining the service to some of the load points, while the faulted component is under repair. In some systems there is a provision for an alternative supply in case of failure of main distribution system. This alternate source is used to supply that section of the main feeder which becomes disconnected from the main supply after the faulted section has been isolated.

3.4 General Segments and Components of a Distribution System

It is complicated to directly use FMEA to build up a general program because of the possible complexity of system configuration and the large number of component and their operating models. A more common approach utilizing reliability equivalents can be used to make a flexible program to calculate the reliability indices [4]. In this approach, the general branches and element of a distribution system are defined as follows:

3.4.1 General Lateral Section

Lateral distributors are basic segment in a distribution system. There are a variety of feasible lateral distributors depending upon their configuration and component operating models. Almost all of them can be represented by the general lateral section shown in fig. 3.3 which contains the basic elements, a transformer, transmission line and fuse, which appear in a lateral section [4].



b) Network symbol

Fig. 3.3 General lateral section

3.4.2 General Main Section

The general main section shown in fig. 3.4 is used to characterize a main segment in a primary feeder. A general main section consists of disconnects and a transmission line.

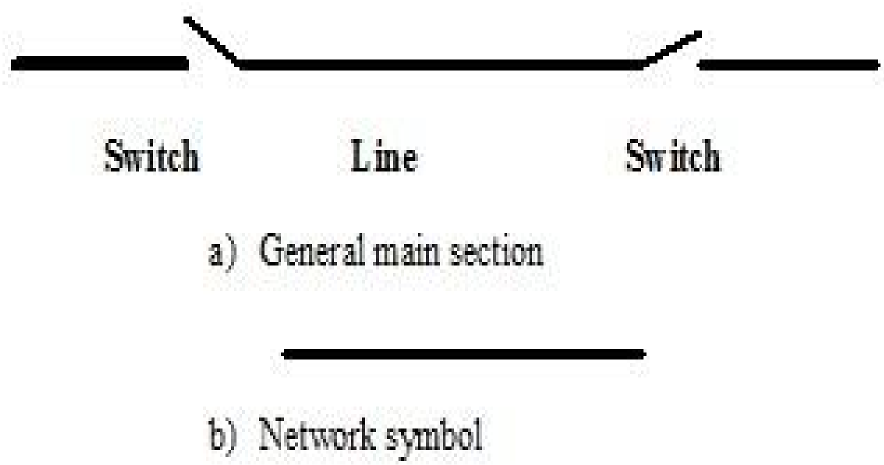
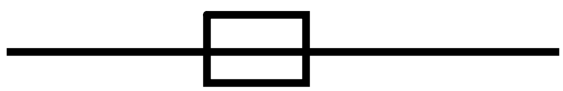


Fig. 3.4 General main section

3.4.3 General Series Element

A general series element consists of a corresponding series component assumed for the reason of easy calculation and a step down transformer as shown in fig. 3.5.

a) General series component



b) Network symbol

Fig. 3.5 General series component

Three types of parameters are used to explain the configuration, reliability and operating features of a general segment. These are topological parameters that show the location of the element in the system, reliability parameters which give the component failure rate and restoration times and component model parameters that explain the operating models for fuses or disconnects when a failure occurs.

CHAPTER-4

DISTRIBUTION SYSTEM RELIABILITY EVALUATION

4.1 RELIABILITY

The term reliability is broad in meaning. In general, reliability designates the ability of a system to achieve its assigned work where past experience helps to form advance estimates of future performance. It is defined as :

Reliability is the probability of a device or system performing its function effectively, for the period of time intended, under the operating conditions intended.

Reliability can be calculated throughout the mathematical concept of probability by identifying the probability of successful performance with the degree of reliability. Usually, a device is said to perform satisfactorily if it does not fail during the time of service. On the other hand, a large number of devices are expected to suffer failures, be repaired and then returned to service during their complete useful life. In this case a definition of reliability is the availability of the device, which is defined as follows:

The ***availability*** of a repairable device is the ratio of time, during the proposed time of service, that the device is in, or ready for service.

The indices used in reliability evaluation are probabilistic and, therefore, they do not give exact predictions. They declare averages of past events and chances of future ones by resources of most common values and long-run averages. This information has to be complemented with other economic and strategy considerations for decision building in planning, design and operation.

4.2 DISTRIBUTION SYSTEMS RELIABILITY

The function of an electric distribution system is to supply electricity to its consumers efficiently and with a reasonable guarantee of continuity and quality . The assignment of achieving economic effectiveness is assigned to system operators or competitive markets, depending on the type of industry structure adopted. The quality of the service is evaluated by the degree to which the supply of electricity is available to the consumers. The reliability of power supply is related to the probability of providing consumers with continuous supply and with a voltage and frequency within prescribed ranges. Nevertheless, the following remarks are important when assessing the reliability of the entire power system:

- The actual degree of reliability experienced by a consumer will vary from location to location. Different functional areas may propose different degrees of reliability.
- There should be equality between the reliability of different parts of the system. It is useless to strongly support a part if weaker areas exist on the supply chain.
- In deregulated systems, efficient pricing mechanisms for transmission and distribution must regard as a reliability component.

4.3 EVALUATION TECHNIQUES

A radial distribution system consists of lines, cables, disconnects (or isolators), etc. A consumer connected to any load point requires all components between himself and the supply point to be operating. Consider a general feeder containing main sections, general lateral sections and some series components as shown in fig. 4.1[4]

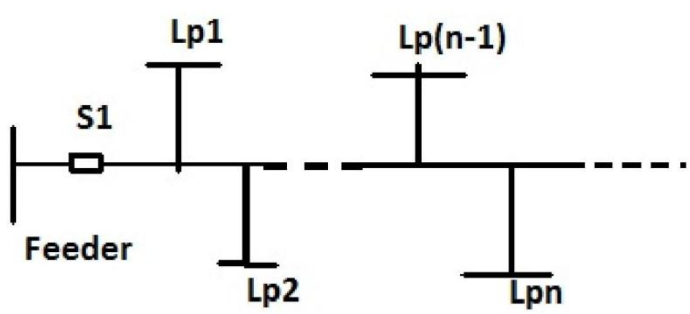


Fig. 4.1 General Feeder

The General equations for calculating the three basic load point indices (load point failure rate, average outage time and average annual outage time) for kth load point are given below:

$$\lambda_k = \sum_{i\sim=S} \lambda_s + \sum_{i\sim=k} \lambda_i + \sum_{i\sim=j} q_j \lambda_j \tag{4.1}$$

$$U_k = \sum_{i\sim=s} \lambda * r_s + \sum_{i\sim=k} \lambda_i * r_i + \sum_{i\sim=j} q_j * \lambda_j * r_j \tag{4.2}$$

$$r_k = \frac{U_K}{\lambda_K} \tag{4.3}$$

Where λ_k is the failure rate due to the element in series for the kth load point.

λ_i is the failure rate of laterals other than kth lateral which can isolate the faulty section.

Normally = 0, if ith section contains a circuit breaker or a fuse.

λ_j is the failure rate of the sections having fuse as a protective device, with a failure probability of ' ' .

= 0; if fuse is 100 % reliable.

r_i, r_j, r_s are the failure durations, having values according to the network configuration.

If the distribution system has no alternate supply, then r_s is the appropriate repair time and r_i is the switching time for the load points that can be isolated by disconnection from the failure section and restored by the main supply. r_j is the restoration time when a fused lateral is subjected to fault. The value of r_j will be equal to the isolation time (r_{iso}) if an isolator is present in between k^{th} load point and j^{th} section, otherwise it will be repair time (r_r) of the section j, if no protection device is present between the load point and fused lateral.

A radial distribution system which is usually in series, its basic reliability parameters average failure rate, λ_s, average outage time, r_s, and average annual outage time, U_s, are given by

$$\lambda_s = \sum_i \lambda_i \tag{4.4}$$

$$U_S = \sum_i \lambda_i * r_i \tag{4.5}$$

$$r_s = \frac{U_s}{\lambda_s} \tag{4.6}$$

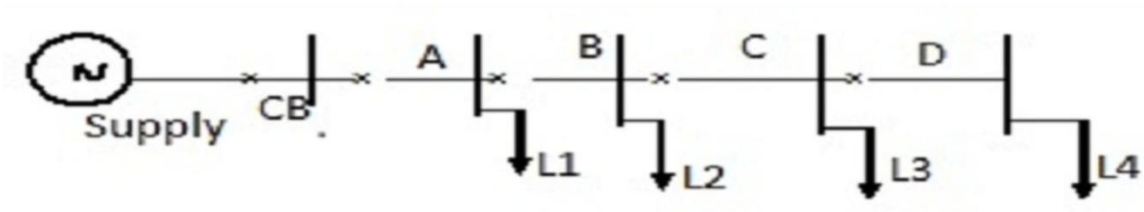


Fig. 4.2 simple 4-load point radial system

Consider the simple radial distribution system shown in fig. 4.2. The assumed failure rates and repair rate of each line A, B, C and D are shown in table 4.1 and corresponding load-point reliability indices are shown in table 4.2. Table 4.2 shows the typical accepted feature of a radial distribution system that the consumers connected to the outermost from the supply tend to undergo the greatest number of outages and greatest unavailability. Here it is assumed that the failure of any line element does not affect other lines.

Table 4.1 line element data for the system of fig 4.2

Line	λ (fl/yr)	r (hrs)
A	0.15	5
B	0.20	6
C	0.10	8
D	0.20	6

Table 4.2 Load-point reliability indices for the system of fig. 4.2

Load point	λ_L (fl/yr)	r (hrs)	U_L (hrs/yr)
L_1	0.15	5.0	0.75
L_2	0.35	5.6	1.96
L_3	0.45	6.1	2.75
L_4	0.65	6.1	4.0

The reliability indices that have been calculated by classical concepts are the three primary ones of average failure rate, average outage time and average annual unavailability.

Although these indices are basically important, but they do not always provide an entire representation of the system performance and response. In order to reflect the significance of a system outage, additional reliability indices can be calculated. The additional indices are most commonly used are defined in the following section.

4.4 CUSTOMER-ORIENTATED INDICES

The performance of the distribution system is defined in terms of distribution system reliability indices. These definitions are based on the work done by the IEEE PES distribution committee, working group on system design and task group on Distribution reliability Indices [2]. Most indices are calculated from the Customer Information System (CIS).

The following basic factors specify the data needed to calculate the indices.

i – Load point

r_i – Repair time for load point i.

N_i – Number of customers of load point i.

$L_{a(i)}$ –average load connected to load point i.

n —Total number of load point.

λ_i – Failure rate (failures/ circuit-mile/year) of load point i.

U_i – Annual outage time of load point i.

Some of the reliability indices most commonly used [2] are:

- System Average interruption Frequency Index (Sustained interruptions), **SAIFI**

  This index is calculated to give information about the average frequency of sustained interruptions per customer over a predefined area. It is defined as:

$$\text{SAIFI} = \frac{\text{Total number of customer interruptions}}{\text{Total number of customer served}}$$

Mathematically

$$SAIFI = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1} N_i} \quad \text{Failure/ customer/ year} \qquad (4.7)$$

- System Average Interruption Duration Index, **SAIDI**

  This index is commonly referred to as customer hours of interruptions, and is considered to give information about the average time the consumers are interrupted. It is defined as:

$$SAIDI = \frac{\text{Sum of customer interruption duration}}{\text{Total number of customers served}}$$

$$SAIDI = \frac{\sum_{i=1} U_i N_i}{\sum_{i=1} N_i} \quad \text{Hours/customer/ year} \qquad (4.8)$$

- Customer Average Interruption Duration Index, **CAIDI**

  This refers the average time required to restore service to the average customer per sustained interruption.

$$CAIDI = \frac{\text{Sum of customer interruption duration}}{\text{Total numbers of customers interruptions}}$$

$$CAIDI = \frac{\sum_{i=1} U_i N_i}{\sum_{i=1} \lambda_i N_i} \quad \text{Hours/interruption} \qquad (4.9)$$

- Average Service Unavailability Index, **ASUI**

$$ASUI = \frac{\text{customers hours of unavailable services}}{\text{Customers hours demanded}}$$

$$ASUI = \frac{\sum_{i=1}^{n} U_i N_i}{8760 * \sum_{i=1} N_i} \qquad (4.10)$$

There are 8760 hours in a regular year, 8784 in a leap year.

- Average Service Availability Index, ASAI

  This is given by the following equation:

  ASAI = (1- ASUI) (4.11)

4.5 LOAD AND ENERGY-ORIENTATED INDICES

- Energy Not Served, **ENS**

  This index provides the energy not served by the distribution system during interruption.

$$ENS = \sum_{i=1}^{n} U_i L_{a(i)} \quad \text{MWH/year} \qquad (4.12)$$

- Average Energy Not Served, **AENS**

  This index provides the average amount of energy not served by distribution system.

$$AENS = \frac{ENS}{\sum N_i} \quad \text{MWH/ customer/ year} \qquad (4.13)$$

The customer and load-orientated indices are very helpful for assessing the severity of system failures in future reliability investigation. Assessment of system performance is a important procedure for three main reasons:

(a) It establishes the sequential changes in system performance and therefore helps to identify weak areas to need for back up.

(b) It establishes existing indices which provide as a guide for suitable values in future reliability assessments.

(c) It enables prior predictions to be compared with actual operating experience.

4.6 APPLICATION TO RADIAL SYSTEMS

Many distribution systems are designed as single radial feeder systems. There are many systems which are constructed as meshed systems, are operated as single radial feeder systems by using normally open switches in the mesh. The reason of these normally open switches are to decrease the quantity of equipment exposed to failure on any single feeder circuit and to make sure that, in the event of a system failure or during scheduled maintenance periods, the normally open switch can be closed and another opened in order to reduce the total load that is disconnected.

4.6.1 Effect of CB on radial system

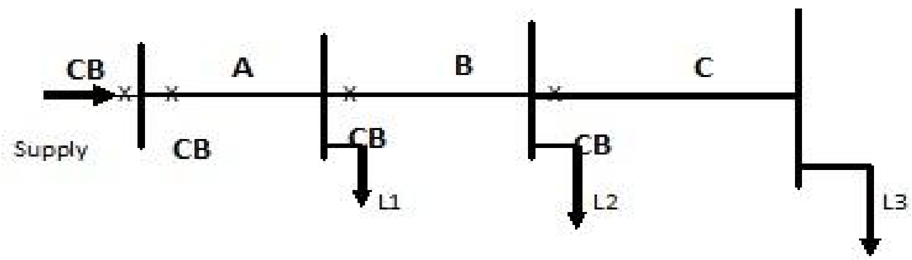


Fig. 4.3 radial distribution network all branches contain CB

Consider now the system shown in Fig. 4.3. This is a single line representation of the system and it is assumed that any fault, single-phase or otherwise, will trip all phases. It is usually found that lines and cables have a failure rate which is approximately proportional to their length. For above network let the main feeder A, B, and D have a failure rate of 0.1 f/km yr. Using these basic data and the line lengths given in Table 4.3 gives the reliability indices also shown in Table 4.4.

If any component failure occurs then each failure will cause the circuit breaker to operate in corresponding section. If fault occurs in segment A then all loads are disconnected and we are able to supply again when fault is repaired. When fault occurs in segment B then load L2 and L3 are disconnected and we can supply only load L1. When fault is repaired then we resume the supply to all load points. If there are no points at which the system can be isolated then each failure must be repaired before the breaker can be reclosed. On the basis of this operating method, the reliability indices of each load point (A, B. C) can be calculated using the principle of series systems as shown in Table 4.4.

Table 4.3 reliability parameter for system of fig. 4.3

branch	Length(km)	λ (fl/yr)	r ,Repair rate(hrs)
A	3	0.3	4
B	2	0.2	4
C	4	0.4	5

Table 4.4 reliability indices for the system of fig. 4.3

load pt	L1			L2			L3		
Branch	λ (fl/yr)	r (hrs)	U (hrs/yr)	λ	r	U	λ	r	U
A	0.3	4	1.2	0.3	4	1.2	0.3	4	1.2
B	0	0	0	0.2	4	0.8	0.2	4	0.8
C	0	0	0	0	0	0	0.4	5	2.0
Total	0.3	4	1.2	0.5	8	2.0	0.9	13	4.0

In ideal case each branch is provided a C.B. but cost becomes high. Such case is known as maximum protection case.

4.6.2 Effect of fuse in lateral distributor

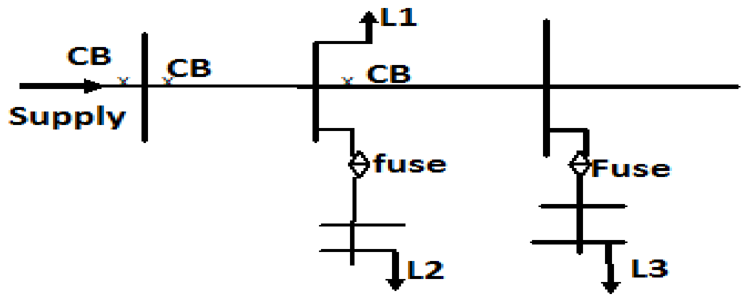


Fig. 4.4 radial distribution network with lateral

Additional protection is provided in practical radial systems. Fig 4.4 shows a radial system with lateral is connected by a fuse. In this case a fault on a lateral distributor causes its fuse to blow; because of this disconnection of its load point until the fault is repaired but does not influence any other load point. The system reliability indices are modified and shown in table 4.5. In this case the reliability indices are enhanced for all load points.

Let main feeder has a failure rate 0.1 fl/km/yr and lateral distributors (L1, L2) have a failure rate 0.2 fl/km/yr. using this data and line lengths given in table 4.5, we can calculate reliability parameters and indices.

Table 4.5 reliability parameters for fig 4.4

segment	length	λ (fl/yr)	r (hrs)
Main feeder			
L1	2	0.2	4
Distributor			
L2	2	0.4	3
L3	3	0.6	3

Table 4.6 reliability indices for system of fig. 4.4

load pt	L1			L2			L3		
Branch	λ	r	U	λ	r	U	Λ	r	U
1	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
2	0	0	0	0.4	3	1.2	0	0	0
3	0	0	0	0	0	0	0.6	3	1.8

CHAPTER-5

DIFFERENT TECHNIQUES FOR DISTRIBUTION SYSTEM RELIABILITY

5.1 GENERAL

A Distribution system is relatively cheap and outages have a much localized effect. Therefore less effort has been committed to quantitative evaluation of the capability of various alternative designs and reinforcements. The analysis of the consumer failure statistics of most utilities shows that the distribution system makes the greatest individual involvement to the unavailability of supply to a consumer. These reinforcements need to be concerned with the reliability estimation of distribution systems.

Some other aspects must also be considered to calculate the reliability of distribution systems. Firstly, through a given reinforcements method may be somewhat economical, large sum of money are spent collectively on such systems. Secondly, it is essential to ensure a sound balance in the reliability of the various element of a power system, i.e., generation, transmission and distribution. Thirdly, several alternatives are available to the distribution engineer to achieve suitable consumer reliability, as well as alternative reinforcement schemes, allocation of spares, improvements in maintenance plan, alternative operating policies.

5.2 EXAMPLES FOR RELIABILITY CALCULATION:

Several distribution systems are designed and constructed as single radial feeder systems. There are many other systems which are constructed as meshed systems, are operated as a single radial feeder by using normally open switches in mesh. The purpose of these normally open switches is to decrease the amount of equipment exposed to failure on any single feeder circuit and to make sure that, in the event of a system failure or during scheduled maintenance periods, the normally open point can be closed and another opened in order to reduce the total load that is severed [19].

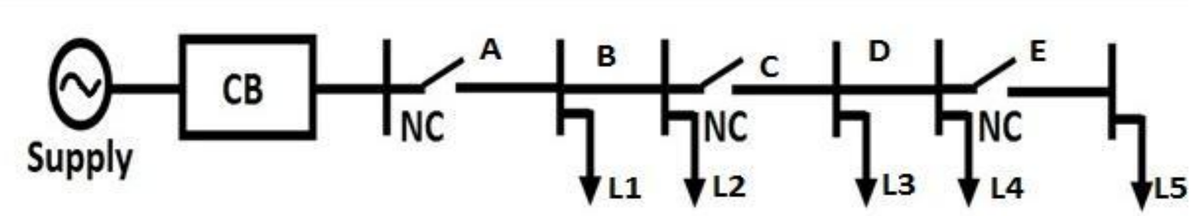


Fig. 5.1 A radial system with isolator

The flow of power is always from the substation transformer downstream to the individual consumers for the typical radial feeder. For a fault anywhere on the feeder, only one recloser operates, which is the closet to the fault, to minimize the number of affected consumers. As an example, 6-bus radial feeder with a substation breaker, three reclosers is shown in Fig. 5.1. Assuming there are no distributed generators, the first recloser upstream the fault will operate in the occurrence of a fault anywhere on the line. Then the consumers positioned downstream the recloser will lose supply. However, if fault occurs between bus2 and bus 3 then substation breaker will trip first after that recloser 2 will operate allowing the portion of the feeder downstream from it to operate as an island so that we can continue supply up to bus 2.

Here customers at the end of radial feeder have lower reliability. Now on the basis of method explained in chapter 4 we find a matrix between load point and branch. This matrix is helpful to calculate the reliability indices of the system. When fault occur in load point 1 then C.B. will trip first and all the load point will interrupted till load point 1 is not repaired. Hence the failure rate of all load point is same as $_1$ and repair rate is $r_{1.}$ When fault occur in branch 2 then C.B. will trip at the source end and the failure rate of all load point will be same as $_2$. Now isolator 2 will operate so we can resume supply up to branch 1 within riso time but the repair rate of branch 2 and 3 will be same $r_{2,}$ similarly for branch 3 and 4 and so on. Here is failure rate and r is repair rate. It is found that lines and cables have a failure rate which is proportional to their length.

riso= Additional time required to locate the fault and open the recloser of faulted segment and reclose the circuit breaker to resume the supply is known as riso.

Let feeders (A, B, C, D, and E) have a failure rate 0.1 fl/km/yr. Using these basic data and their line lengths given in table 5.1 we find the reliability parameters also shown in table 5.1.

Table 5.1 Reliability parameters for given system of fig 5.1

Branch	Length(km)	λ (fl/yr)	r (hrs)	riso (hr)
A	2	0.2	4	0.5
B	1	0.1	4	0
C	3	0.3	5	0.5
D	2	0.2	4	0
E	1	0.1	4	0.5

The load data for above network is also given in table 5.2.

Table 5.2 load data for 6-bus system

Load point	No of customers	Average load connected(kw)
L1	1000	4000
L2	700	3000
L3	900	3500
L4	1000	4200
L5	800	2500

Now to calculate the reliability indices and customer oriented indices we need to find out the equivalent failure rate, repair rate and unavailability corresponding to each load point. As procedure explained earlier, using the same procedure we find a matrix between load point and segment which is given below in table 5.3.

Table 5.3 reliability indices of fig. 5.1

Load pt	Load pt L1			Load pt L2			Load pt L3		
Branch	λ	r	U	λ	r	U	λ	r	U
A	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
B	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4
C	0.3	0.5	0.15	0.3	0.5	0.15	0.3	5	1.5
D	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
E	0.1	0.5	0.05	0.1	0.5	0.05	0.1	0.5	0.05
Total	0.9	13	2.2	0.9	13	2.2	0.9	17.5	3.55

Similarly for load point L4 and L5, we get the reliability indices. Now using reliability indices and load data we evaluate other indices using equation in previous chapter. From the table 5.3 we can say that as switch location varies then indices also changes. So we have to find the optimum location of isolators in a radial distribution network to minimize the customer oriented indices and also maximize the profit.

5.3 PROBLEM FORMULATION

As explain above this problem is an optimization problem so need to define an objective function and some constraints.

The objective function for this problem is as follows:

$$\text{Min } SAIDI = \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i} \qquad (5.1)$$

Subject to,

Switch position>=1;

Switch position<= n—1;

Where N_i is the number of customer connected at load point i.

U_i is the unavailability at load point i.

n is the number of bus in a radial distribution system

After calculating the indices we get the idea about ENS without switch and with switch using these data we calculate the profit as:

Profit= (ENSwsw-ENSws)*tariff —Ns*switch cost (5.2)

Where

ENSwsw = ENS without any switch in radial distribution system

ENSsw = ENS considering switches in system

Ns= number of switches placed in system

5.4 OPTIMIZATION TECHNIQUES USED

There are many methods available to solve the above optimization problem. The method which is used to solve the above problem is described below.

5.4.1 Genetic Algorithms

Biological evolution is used by Genetic algorithms to develop a series of search space points toward an optimal solution. This method involves coding of the parameter set before working with the parameters themselves. GAs work by selecting a population of the coded parameters with the maximum fitness levels and performing a combination of mating, crossover, and mutation operations on them to produce a superior set of coded parameters. Genetic algorithms are easy to apply and are able of locating the global optimal solution.

GA is an iterative process which begins with a arbitrarily generated set of solutions known as initial population. Objective function and fitness are calculated for each solution in the set. Pool of selected population is created by selection operators on the basis of these fitness functions; the solution in this pool has improved average fitness than that of initial population. The crossover and mutation operator are used to create novel solutions with the help of solution in the pool. The procedure is repeated iteratively while keep fixed number of solutions in pool of selected population, as the iteration progress, the solution improves and optimal solution is obtained.

For producing offspring, good solutions are selected from the initial generated population during the selection process of the GA. Using a mechanism good solutions are selected arbitrarily from the initial generated population which favours the more fit individuals. Good individuals will possibly be selected many times in a generation but poor solutions will not be selected at all.

Crossover is the second GA operator. In the crossover two parents are selected at random from the pool of obtained population with the selection process. Crossover generates two offspring which has some fundamental properties of the parents. The mutation operator creates an offspring using an arbitrary solution from pool.

Each new solution is evaluated i.e. objective function and fitness values are calculated. These newly generated offsprings and the populations are combined. The selection operator uses combined population for selection.

The standard procedure of GA is depicted in Flowchart as shown in Fig 5.2

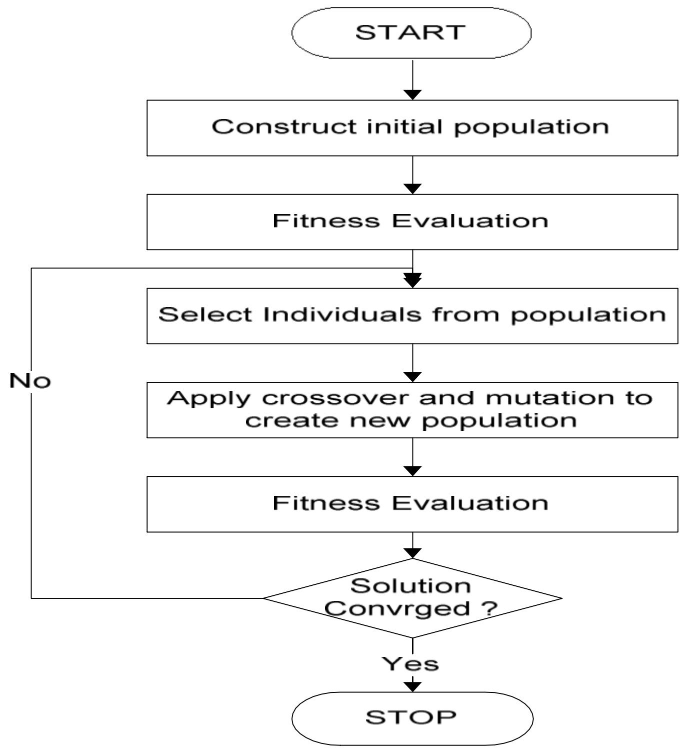


Fig. 5.2 Flowchart for reliability calculation by GA

The main stages of GA are:

- Coding: representing the problem at hand by strings;
- Initialisation: initialising the strings;
- Crossover: exchanging information between two mates;
- Mutation: introducing random information;
- Fitness evaluation: determining which strings are fit;
- Selection: deciding who mates;

The disadvantage of GA is the high processing time required [1]. This is due to their evolutionary concept, based on arbitrary processes that make algorithm quite slow. However different methods for reducing processing time have been proposed.

5.4.2 Particle Swarm Optimization (PSO)

The PSO technique is one of the techniques under the wide category of Swarm Intelligence methods for solving optimization problems. It is a population-based search algorithm where each individual is known as a particle and represents a candidate solution. Each particle in the PSO flies throughout the search space with an adjustable velocity that is modified according to its own flying experience and that of the other particles. In PSO, each particle tries to progress itself by imitating the behaviour of its successful peers. Now, each particle has a memory thus is capable of detecting the best position in the search space it visited. The position consequent to the best fitness is called as *pbest*, and the best one among all particles in the population is known as *gbest*. The features of the searching procedure can be summarized as follows:

- ❖ The initial positions of *pbest* and *gbest* are different. By using the different direction of *pbest* and *gbest*, all agents progressively depict close to the global optimum.
- ❖ The modified value of the agent position is continuous, so the technique can be applied to the continuous problem. But, the technique can also be useful to the discrete problem using grids for the XY position and velocity.
- ❖ There are no changes in searching processes even if continuous and discrete state variables are used with continuous axes and grids for the XY positions and velocities. i.e., the method can be applied to mixed-integer nonlinear optimization problems with continuous and discrete state variables.
- ❖ The above idea is explained using only the XY axis (two-dimensional space). But, the method can simply be applied to the n dimensional problem. The modified velocity and position of each particle can be calculated using following formulas.

$$v_{j,g}^{(t+1)} = w * v_{j,g}^{(t)} + c_1 * r_1() * (pbest_{j,g} - x_{j,g}^{(t)}) + c_2 * r_2() * (gbest_g - x_{j,g}^{(t)})$$

$$x_{j,g}^{(t+1)} = x_{j,g}^{(t)} + v_{j,g}^{(t+1)} \qquad (5.3)$$

With j = *1,2,...,n* and *g = 1,2,...,m*

Where,

n= number of particle in a group

m = number of members in a particle

t = number of iterations (generations)

$v_{j,g}^{(t)}$ = velocity of particle j at iteration t,

$$v_g^{\min} \leq v_{j,g}^{t} \leq v_g^{\max}$$

w = inertia weight factor

c_1, c_2 = cognitive and social acceleration factors, respectively

r_1, r_2 = random numbers uniformly distributed in the range (0, 1)

$x_{j,g}^{(t)}$ = current position of particle j at iteration t

pbest=pbest of particle j

gbest=gbest of the group

Since above problem is discrete integer problem, which is known as mixed integer particle swarm optimization (MIPSO) problem. There is some modification is required in the procedure which is given below.

In discrete binary PSO , the related variables are interpreted in terms of changes of probabilities. A particle flies in a search space limited to zero and one in each direction and each v_{id} represents the probability of member x_{id} taking value 1. The update rule governing the particle flight speed can be modified consequently by introducing a logistic sigmoid transformation function:

$$S(v_{id}) = 1/(1 - \exp(-v_{id})) \quad (8)$$

The velocity can be updated according to this rule:

If rand() < $S(v_{id})$, then $x_{id} = 1$; or else $x_{id} = 0$.

The maximum allowable velocity V_{max} is wanted to limit the probability that member x_{id} will take a one or zero value. The smaller the V_{max} is, the higher the chance of mutation is for the new individual.

CHAPTER-6

RESULTS AND CONCLUSIONS

In this thesis work, to find out the reliability indices, customer-oriented indices and optimal location of switches to calculate the profit for 6, 13 and 22 bus radial distribution network has been considered. The reliability data and load date for all the systems is given in appendix. Different optimization technique has been applied to evaluate the problem in order to compare the result.

In this thesis work we have considered (5.1) as objective function and (5.2) to calculate the profit. These techniques provide us optimal location of switches in radial distribution system to find the reliability of distribution system and profit. Also, we have considered ENS as a cost function to compare the result with switch cost.

The total cost due ENS is given as:

Cost= tariff x ENS

Switch cost= 25000.00 per switch

Switch cost= 25000.00 x number of switches used in radial feeder.

- **Result for 6-bus system:**

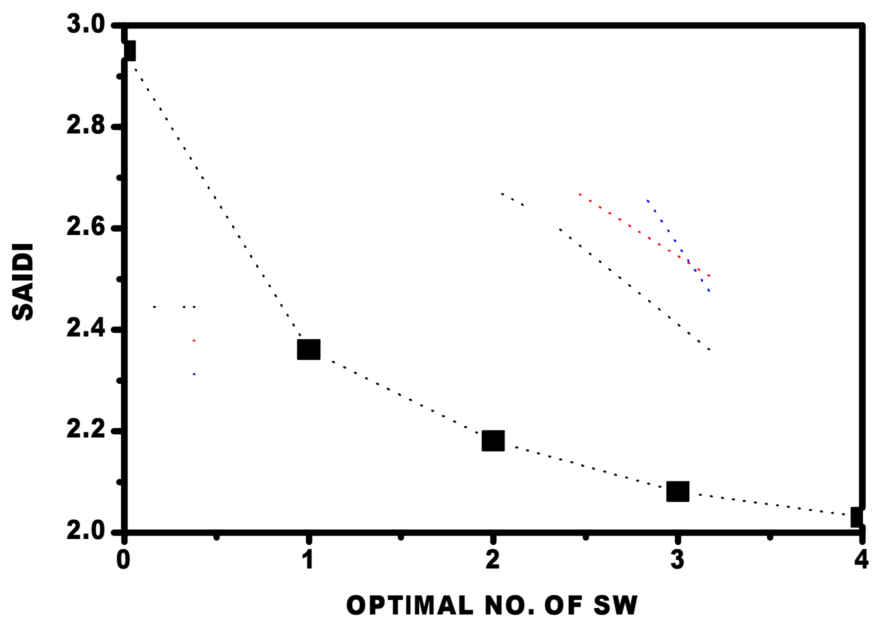


Fig. 6.1Variation of SAIDI with optimal no of switches

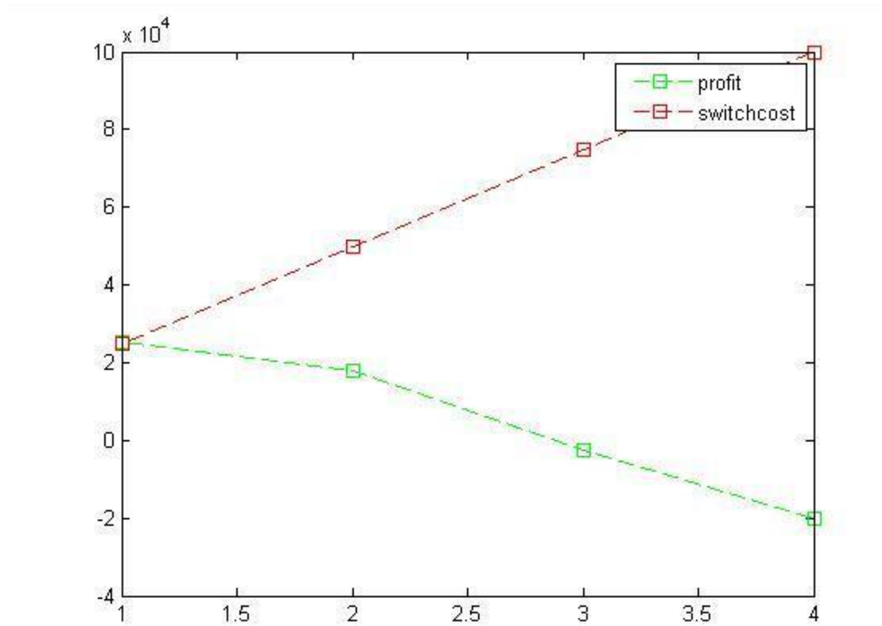
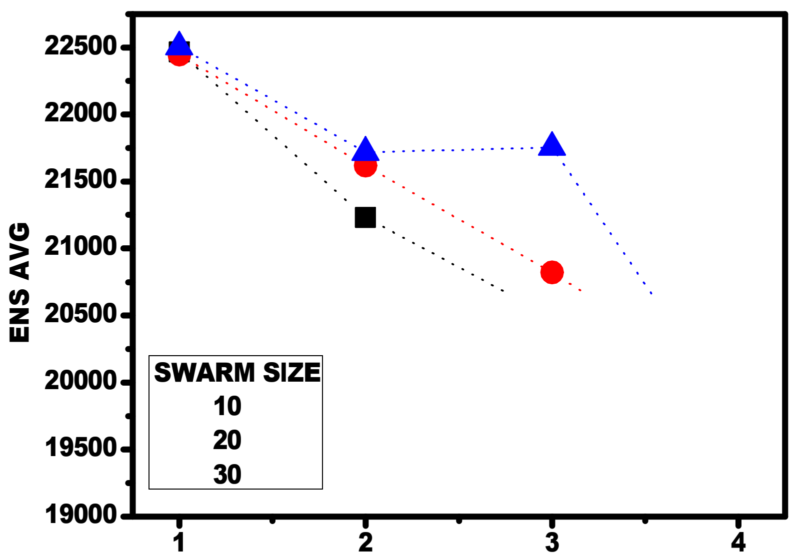


Fig. 6.2 variation of profit, switch cost with switches



From above fig. It is clear that for 6 bus system we can use maximum two switches to get optimum profit and minimum SAIDI. Fig. 6.3 shows as swarm varies ENS also varies which affects the profit for utilities.

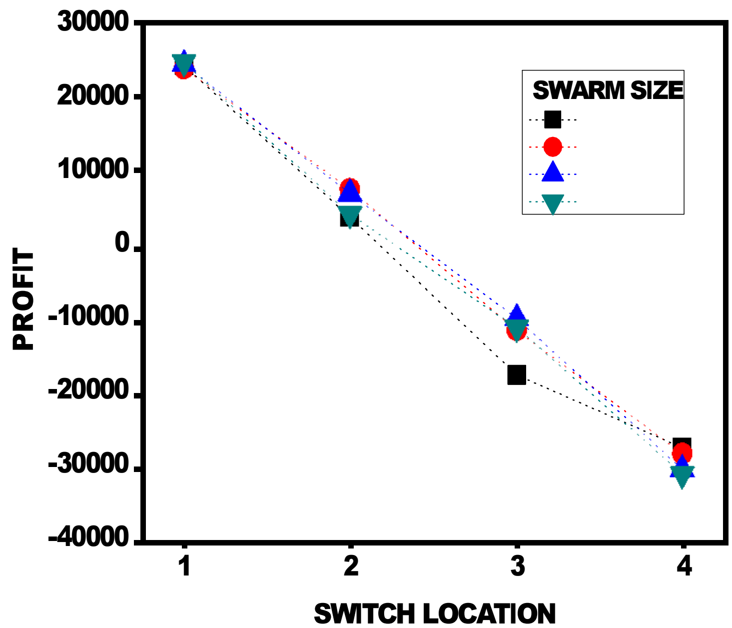


Fig. 6.4 variation of profit with swarm

Table 6.1 result for 6-bus system

No of SW	ENS	SAIDI	Switch location	Profit(GA) INR	Profit(PSO) INR
0	29500	2.95	0	0	0
1	22325	2.3642	4	25225	24245
2	**19825**	**2.1857**	**2,4**	**17725**	**7365**
3	19125	2.0857	2, 4, 5	-2375	-1776.5
4	18075	2.0357	2, 3, 4, 5	-20025	-27678

Table 6.1 shows variation of ENS, SAIDI with switch location. This table also give the idea about profit. Optimal result is shown in table by bold numbers.

- **Result for 13- bus system:**

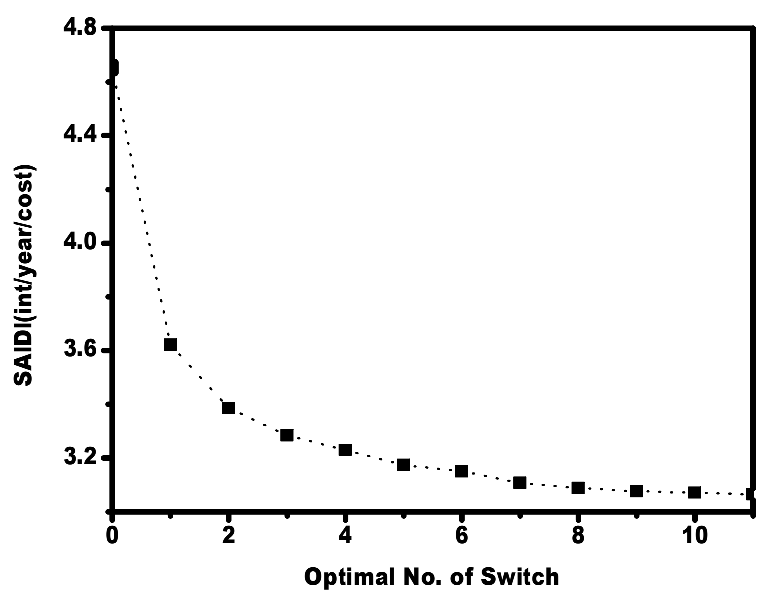


Fig. 6.6 variation of SAIDI with switches

Fig. 6.6 shows that as switches is increased in radial distribution system then SAIDI decreases.

Table 6.2 result for 13-bus system

No of switch	ENS	SAIDI	Profit(GA)	Profit(PSO)
0	122400	4.6525	0	0
1	91875	3.6213	218600	209878
2	87150	3.3852	238225	209994
3	85500	3.2838	245162	218568
4	83500	3.2283	230663	222731
5	81250	3.1727	224562	198637
6	80875	3.1271	202450	186882
7	**79775**	**3.1065**	**181300**	**164123**
8	79437.5	3.0871	163650	150528
9	79087.5	3.0815	140750	1272220
10	78637.5	3.0760	117850	99721
11	78337.5	3.0704	94950	82761

From table 6.2, it is clear that 7 numbers of switches is the optimal solution.

- **Result for 22-bus system:**

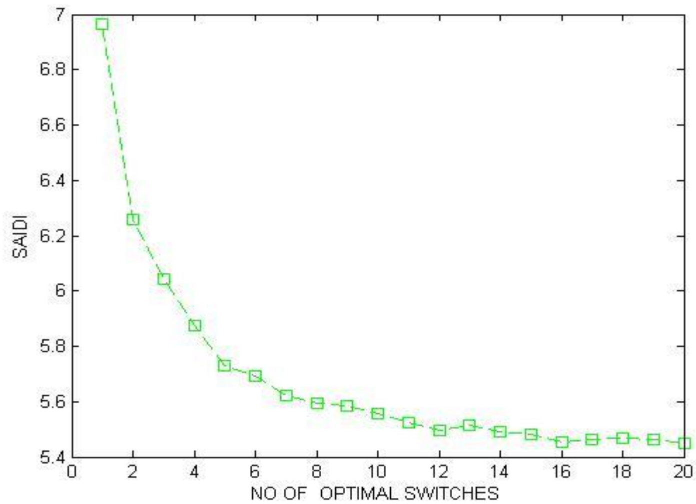
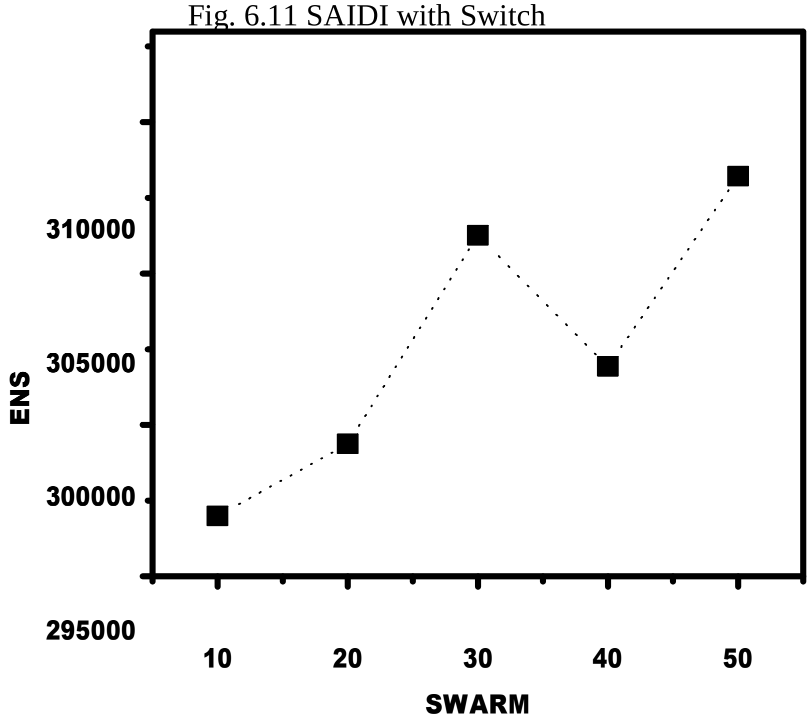
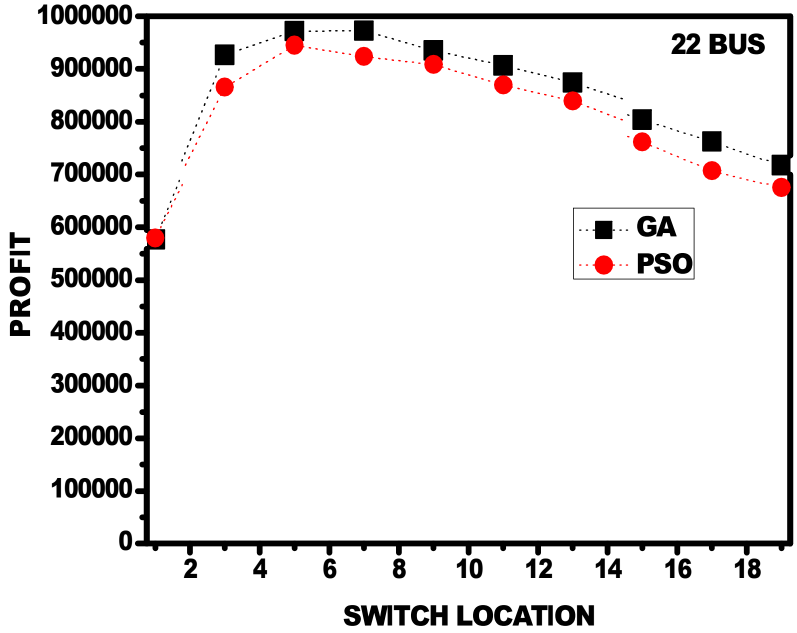


Fig. 6.11 SAIDI with Switch





From fig. 6.10, it is clear that as switch increases SAIDI decreases and after 12 switches the variation in SAIDI is very less. So for this system optimal number of switch is 12 which provide optimal profit and minimum SAIDI.

CONCLUSION AND FUTURE WORK

From the results, it is clear that with the inclusion of protective devices such as isolators; sectionalizing switches the reliability of the distribution system is improved. Based on the reliability indices, the optimal number as well as location was found to improve reliability and profit for utilities. The SAIDI is minimum at optimal locations for all scenarios. The number of optimal switches was found by calculating the SAIDI minimum.

GA and PSO optimization techniques are used to determine the optimal number of isolators and maximum profit

FUTURE WORK

The following points may be taken into account for future work:

- Reliability analysis of different loads (e.g. domestic load, commercial load, government load, etc.)
- The impact of distributed generation on the optimum location of isolators to be evaluated.
- Provision of manual devices along with automatic sectionalizing devices is made to improve system reliability.
- Location of multiple isolators to be considered.

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APPENDIX DATA FOR 6-BUS SYSTEM

Table A.1 fail data for 6 bus system

branch	λ	r	riso	switch
1	0.1	4	0.5	1
2	0.2	5	0.5	0
3	0.1	4	0.5	1
4	0.15	5	0.5	1
5	0.1	4	0.5	0

Table A.2 load data for 6 bus system

Load point	Customers connected	Demand
1	100	2000
2	100	3000
3	200	2000
4	200	2000
5	100	1000

DATA FOR 13-BUS SYSTEM

Table A3 failure data for 13 bus system

branch	λ	r	riso	switch
1	0.1	2	0.5	0
2	0.15	2.5	0.5	0
3	0.2	3	0.5	0
4	0.2	3	0.5	0
5	0.15	2.25	0.5	1
6	0.1	2	0.5	1
7	0.1	2	0.5	0
8	0.15	2.35	0.5	0
9	0.2	3.25	0.5	1
10	0.2	3	0.5	1
11	0.15	2.25	0.5	0
12	0.1	2	0.5	1

Table A.4 load data for 13-bus system

Load pt	Customer connected	demand
2	100	1000
3	200	2000
4	300	3000
5	200	4000
6	300	5000
7	100	2000
8	400	3000
9	100	1000
10	200	4000
11	300	1000
12	100	2000
13	400	1000

DATA FOR 22-BUS SYSTEM

Table A.5 failure data for 22-bus system

branch	λ	r	riso	switch
1	0.1	2	0.5	0
2	0.15	2.5	0.5	1
3	0.2	3	0.5	0
4	0.25	3.5	0.5	1
5	0.15	2.25	0.5	0
6	0.1	2	0.5	0
7	0.1	2	0.5	1
8	0.15	2.25	0.5	0
9	0.2	2.75	0.5	1
10	0.25	3.25	0.5	0
11	0.15	2.35	0.5	1
12	0.1	2	0.5	0
13	0.1	2	0.5	1
14	0.15	2.25	0.5	1
15	0.2	3.25	0.5	0
16	0.25	3.35	0.5	1
17	0.15	2	0.5	0
18	0.1	2	0.5	0
19	0.1	2	0.5	1
20	0.15	2.25	0.5	0
21	0.2	3	0.5	0

Table A.6 load data for 22-bus system

Load pt	Customer connected	Demand
2	100	1000
3	200	2000
4	300	3000
5	200	4000
6	300	5000
7	100	2000
8	400	3000
9	100	1000
10	200	4000
11	300	1000
12	100	2000
13	400	1000
14	100	1000
15	200	2000
16	300	3000
17	200	4000
18	300	5000
19	100	2000
20	400	3000
21	100	1000
22	200	4000