CHAPTER TWO:

DISTRIBUTION SYSTEM RELIABILITY

2.1. Introduction:

Distribution systems hold a very significant position in the power system since it is the main point of link between generation and consumers. Effective planning of radial distribution network is required to meet the present growing domestic, industrial and commercial load day by day. Distribution networks have gained an overwhelming research interest in the academics as well as in the industries community nearly from last three decades. The examples of prominent distribution networks that effect domestic/residential users and industrial personals are water distribution networks, electricity distribution networks, data/voice communication networks, and road traffic networks etc. Electricity is an essential commodity and its absence for short-while creates annoyance and discomfort in everybody's life. In fact, it puts most of the modern household and office appliances to a total stop. Electrical power distribution is either three or four wires.

In any installation, service continuity in the event of an insulation fault is also directly related to the earthing system. An unearthed neutral permits service continuity during an insulation fault. Contrary to this, a directly earthed neutral or low impedance-earthed neutral, causes tripping as soon as the first insulation fault occurs. In order to meet these specifications, a properly designed and operated radial distribution network should possess the following characteristics:

I. The system should support energy supply at minimum operation and maintenance cost and should satisfy the social and engineering aspects.
II. It must satisfy the continuous changing of the load demand for active and reactive power.

III. Unlike other forms of energy, electricity is not easily stored and thus, adequate "spinning" reserve of active and reactive power should be maintained and controlled in an appropriate manner.

IV. The power supply must meet the following specific standards to maintain the quality of service offered:

a. Regulated voltage.

b. Well maintained constant frequency.

c. Level of reliability/security that guarantees consumers satisfaction.

2.2. Elements of the Distribution System:

In general, the distribution system is derived from electrical system which is Substationally fed by the consumers' premises and the transmission system. It generally consists of feeders, laterals (circuit-breakers) and the service mains. Figure2.1 shows the single line diagram of a typical low tension distribution system.

2.2.1. Distributed Feeders:

A feeder is a conductor, which connects the sub-station (or localized generating station) to the area where power is to be distributed.The main consideration in the design of a feeder is the current carrying capacity.

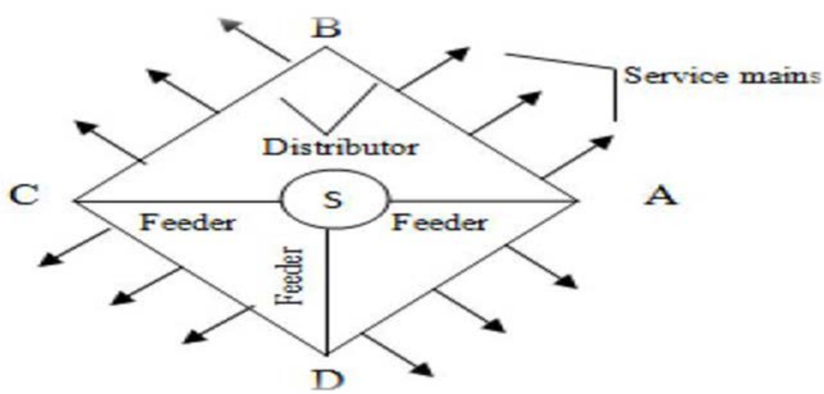

Figure 2.1: Elements of Distribution System

2.2.2. Distributor:

A distributor is a conductor from which tapping are taken for supply to the consumers. In Figure 2.1, AB, BC, CD, and DA are the distributors. The current through a distributor is not constant because tapping are taken at various places along its length.

2.2.3. Service mains:

A service mains is generally a small cable which connects the distributor to the consumer's terminals.

2.2.4. Requirements of a Distribution System:

It is mandatory to maintain the supply of electrical power within the requirements of many types of consumers. Following are the necessary requirements of a good distribution system:

I. **Availability of power demand:** Power should be made available to the consumers in large amount as per their requirement.

II. **Reliability***:* It can see that present day industry is now totally dependent on electrical power for its operation. So, there is an urgent need of a reliable service. Improvement in reliability can be made up to a considerable extent by:

   1. Reliable automatic control system.
   2. Providing additional reserve facilities.

III. **Proper voltage:** Furthermost requirement of a distribution system is that the voltage variations at the consumer terminals should be as low as possible.

IV. **Loading**: The transmission line should never be over loaded and under loaded.

V. **Efficiency**: The efficiency of transmission lines should be maximum say about 90%.

2.3. Faults:

Faults kill. Faults start fires. Faults force interruptions. Faults create voltage sags. Tree trimming, surge arresters, animal guards, and cable replacements: these tools reduce faults. It cannot eliminate all faults, but appropriate standards and maintenance practices help in the battle. When faults occur, we have ways to reduce their impacts. [4]

2.3.1. General Fault Characteristics:

There are many causes of faults on distribution circuits. A large EPRI study was done to characterize distribution faults in the 1980s at 13 utilities monitoring 50 feeders [4].

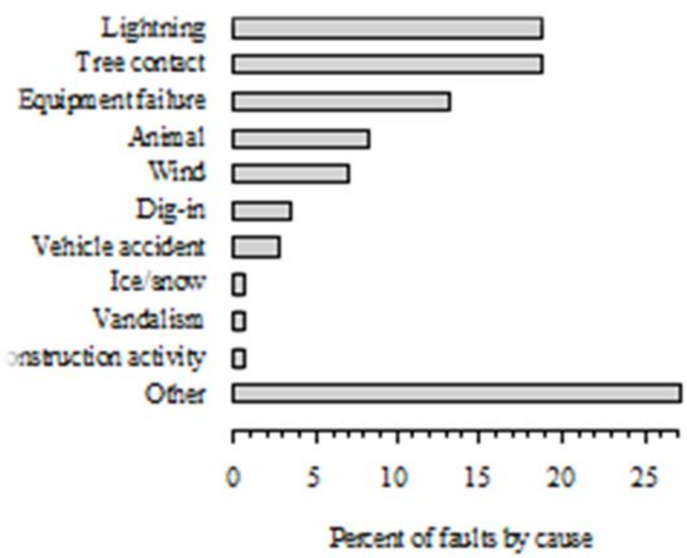

Figure 2.2: Fault causes measured in the EPRI fault study.

The distribution of permanent fault causes found in the EPRI study is shown in Figure 2.2. Approximately 40% of faults in this study occurred during periods of adverse weather which included rain, snow and ice. Distribution faults occur on one phase, on two phases, or on all three phases. Single-phase faults are the most common. Almost 80% of the faults measured involved only one phase either in contact with the neutral or with ground as shown in table 2.1. As another data point, measurements on 34.5-KV feeders found that 75% of faults involved ground (also 54% were phase to ground, and 15% were phase to phase) [4].

Table 2.1: Number of Phases Involved in Each Fault

Fault	**Percentage**
One phase to neutral	63%
Phase to phase	11%
Two phases to neutral	2%
Three phase	2%
One phase on the ground	15%
Two phases on the ground	2%
Three phases on the ground	1%
Other	4%

The actual fault rates are higher than this because many temporary faults are cleared by reclosing circuit breakers or reclosers. Faults are either *Temporary* or *permanent.* A permanent fault is one where permanent damage is done to the system. This includes insulator failures, broken wires, or failed equipment such as transformers or capacitors. Permanent faults on distribution circuits usually cause sustained interruptions for some customers. To clear the fault, a fuse, recloser, or circuit breaker must operate to interrupt the circuit. The most critical location is the three-phase mains, since a fault on the main feeder will cause an interruption to all customers on the circuit. Permanent faults may cause momentary interruptions for a customer. A temporary fault does not permanently damage any system equipment. If the circuit is interrupted and then reclosed after a delay, the system operates normally. Temporary (non-damage) faults make up 50 to 90% of faults on overhead distribution systems. The causes of temporary faults include lightning, conductors slapping together in the wind, tree branches that fall across conductors and then fall or burn off, animals that cause faults and fall off, and insulator flashovers caused by pollution. Temporary faults are the main reason that reclosing is used almost universally on distribution circuit breakers and reclosers (on overhead circuits) [4].

Determining the percentage of faults that are temporary versus permanent is complicated. For faults that operate fuses, it is easy. If it can be successfully re-fused without any repair, the fault is temporary:

$$\text{Percent permanent} = \frac{\text{Fuses replaced after repair}}{\text{Total number of fuse operations}}\ \text{X } 100\% \cdots\cdots\cdots\cdots (2.1)$$

Circuit breaker or recloser operations are difficult. If fuse blowing is used, where tap fuses always operate before the circuit breaker or recloser, the percentage of temporary faults cleared by circuit breakers and reclosers is:

$$\text{Percent permanent} = \frac{\text{Number of lockouts}}{\text{Number of lockouts+Number of successful reclose sequences}}\text{X } 100\% \cdots (2.2)$$

A SCADA system produces these numbers, but if this information is not available, the percentage can be approximated using circuit breaker count numbers:

$$\text{Percent permanent} = \frac{l}{n - r.l}\ \text{X } 100\% \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2.3)$$

Where:

n =total number of circuit breaker (or recloser) operations.
r =number of reclose attempts before lockout (there are r+1 circuit breaker operations during a lockout cycle).
l =number of lockouts.

If fuse *saving* is used, where the circuit breaker operates before lateral fuses, then it is more difficult to estimate the number of temporary faults. For the whole circuit (it is not possible to separate the faults on the mains from the faults on the taps), we can estimate the percentage as follows:

$$\text{Percent permanent} = \frac{l + f}{l + s + f2} \text{ X } 100\% \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2.4)$$

Where:

s =number of successful reclose sequences

f =number of fuses replaced following repair .

f2=number of fuse operations that are not coincident with circuit breaker trips

*f*2 should be close to zero, since the circuit breaker should operate for all faults. Assuming *f*2 is zero (which may have to be done, since this is a difficult number to obtain) implies no nuisance fuse operations without a circuit breaker operation. It is difficult for an outage data management system to properly determine the number of temporary faults. [4]

2.3.2. Targeted Reduction of Faults

Since faults are the root cause of interruptions and voltage sags, obviously, if faults are reduced, the incidence of interruptions and sags will be reduced. This cans be done in several ways including:

- Tree trimming.
- Animal guards.
- Arrester protection.
- Tree wire (covered wire).
- Aerial or underground cable.
- Identifying and replacing poorly performing hardware.

- Line patrols including infrared thermography.

The most important sections are not necessarily the locations with the most faults per mile. The number of customers on a circuit and the type of customers on a circuit are important considerations. On-site investigations can help reduce faults. Faults tend to repeat at the same locations and follow patterns.

Faults are not evenly distributed along lines. Faults are not inevitable. Not all faults are "acts of God." Most are from specific deficiencies at specific structures. On overhead circuits, most faults result from inadequate clearances, inadequate insulation, old equipment, or from trees or branches extending into a line. Consider faults as preventable and then go look for them. Crews can be trained to spot pole structures where faults might be likely. During restoration, crews can identify several common causes of faults including:

- Poor jumper clearances.
- Old equipment (such as expulsion arresters).
- Bushings or cable terminations unprotected against animals.
- Poor clearances with polymer arresters.
- Damaged insulators.
- Damaged covered wire.
- Bad cutout placement.
- Danger trees/branches present [4].

2.4. Reliability:

Distribution reliability primarily relates to equipment outages and customer interruptions. In normal operating conditions, all equipment (except standby) is energized and all customers are energized. Scheduled and unscheduled events disrupt normal operating conditions and can lead to outages and interruptions [5].

2.5. Reliability Indices:

Reliability indices are statistical aggregations of reliability data for a well defined set of loads, components, or customers. Most reliability indices are average values of a particular reliability characteristic for an entire system, operating region, substation service territory, or feeder [5].

The most widely used reliability indices are averages that weight each customer equally. Customer-based indices are popular with regulating authorities since a small residential customer has just as much importance as a large industrial customer. They have limitations, but are generally considered good aggregate measures of reliability and are often used as reliability benchmarks and improvement targets. Formulae for customer-based indices include (unless otherwise specified, interruptions refer to sustained interruptions):

$$1.\ \mathrm{SAIFI} = \frac{\text{total number of customer interruption}}{\text{total number of customer served}}\ /\mathrm{yr} \cdots\cdots\cdots\cdots\cdots\cdots (2.5)$$

$$2.\ \mathrm{SAIDI} = \frac{\Sigma \text{customer interruption duration}}{\text{total number of customer served}}\quad \mathrm{hr/yr} \cdots\cdots\cdots\ \cdots\cdots\cdots (2.6)$$

$$3.\ \mathrm{CAIDI} = \frac{\Sigma\ \text{customer interruption duration}}{\text{total number of custmer interruption}}\quad \mathrm{hr} \cdots\cdots\cdots\cdots\cdots\cdots (2.7)$$

$$4.\ \mathrm{ASAI} = \frac{\text{Customer Hours Service Availability}}{\text{custemer hours service demand}}\quad \mathrm{pu} \cdots\cdots\cdots\cdots\cdots\cdots (2.8)$$

CAIFI and CTAIDI are based upon the number of customers that have experienced one or more interruptions in the relevant year. Formulae for these indices are:

$$5.\ \mathrm{CAIFI} = \frac{\text{total number of customer interruption}}{\text{Customers Experiencing 1 or more Interruptions}}\ /\mathrm{yr} \cdots\cdots (2.9)$$

$$6. \text{CTAIDI} = \frac{\Sigma \text{ Customer Interruption Durations}}{\text{Customers Experiencing 1 or more Interruptions}} \quad \text{hr/yr} \cdots\cdots (2.10)$$

$$7. \text{MAIFI} \quad = \frac{\text{Total Number of Customer Momentary Interruptions}}{\text{Total Number of Customers Served}} \quad \text{/yr} \cdots\cdots (2.11)$$

$$8. \text{MAIFI}_{\text{E}} = \frac{\text{Total Number of Customer Momentary Events}}{\text{Total Number of Customers Served}} \quad \text{/yr} \cdots\cdots\cdots (2.12)$$

MAIFI is attractive to utilities because it can be easily computed from breaker and recloser counters. MAIFI_{E} is a better measure of customer satisfaction since multiple closely spaced momentary interruptions have much less impact than the same number of momentary interruptions spaced days or weeks apart [5].

2.6. System Optimization:

Several different categories of reliability improvement projects were explored, corresponding to consequences of the expert system rules. The Basic categories of reliability improvement options examined include:

- ***Transfer Path Upgrades****:* A transfer path is an alternate path to serve load after a fault occurs.
- ***New Tie Points:*** Adding new tie points increases the number of possible transfer paths and may be a cost-effective way to improve reliability on feeders with low transfer capability**.**
- ***Increased Line Sectionalizing****:* Adding fault interrupting devices (reclosers and fuses) improves reliability by reducing the number of customers interrupted by downstream faults.
- ***Feeder Automation:*** the automated feeders allow post-fault system reconfiguration to occur much more quickly than with manual switches, allowing certain customers to experience a momentary interruption rather than a sustained interruption [5].