Reliability Analysis of 20 KV Electric Power Distribution System

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Abstract. The reliability of the distribution system is the ability of a system to supply electrical energy continuously without causing failure to consumers. The reliability of the distribution system can be analyzed based on the SAIDI (System Average Interruption Duration Index), SAIFI (System Average Interruption Frequency Index), and CAIDI (Customer Average Interruption Duration Index) indices. The SAIFI, SAIDI and CAIDI values are determined by simulating using ETAP 12.0.6 software, which is by running reliability assessment analysis. The simulation process was carried out on an IEEE 9 bus network distribution system. The simulation results show a SAIFI value of 1.113 frequency/customer.yr, a SAIDI value of 17.306 hours/customer.yr and a CAIDI value of 15,549 hours/customer interruption. For normal operating conditions, the total demand for loads supplied from secondary substations to the 20 KV distribution network is 12,955 MW and 5,234 MVAR, with losses of 8.06%

Keywords: Reliability, distribution, SAIDI, SAIFI, CAIDI

1. Introduction
Electricity supply for customers requires various components including generating systems, transmission systems and distribution systems. These components are interrelated to one another that forms an electric power system. Electric power system is a collection of electricity centers and substations (load centers) which are connected to one another by a transmission network so that it is an interconnection system.

The distribution system is the part of the power system component that has the most disruptions, so the main problem in operating the distribution system is to overcome interference. Disturbances can occur in the generator system, transmission system and distribution system so that it will have a blackout on the customer [1].

The reliability of an electric distribution system can be calculated by knowing the amount and length of outages experienced by each load. The reliability of the distribution system is defined as the ability of the distribution system to carry out its functions for a specified period of time without failing. To be able to determine the level of reliability of a system, an examination must be made through calculation and analysis of the success rate of performance or operation of the system that is reviewed at a certain period, then compare it with the standards set.
To find out the reliability of a feeder, a reliability index is established, which is the amount to compare the appearance of a distribution system. Reliability indices that are often used in a distribution system are SAIFI (System Average Interruption Frequency Index), SAIDI (System Average Interruption duration Index). The reliability index is a number or parameter that indicates the level of service or the level of reliability of a consumer electricity supply [4] [5].

This paper will analyze the reliability of the system on a 20 KV primary distribution network. In an electric power system, reliability is the level of service to consumers so that electricity supply can be carried out continuously. The reliability index calculation is done using ETAP software which will be tested on the IEEE-9 bus network distribution system. Network configuration is a radial distribution system that is supplied from one side of the supply end (secondary substation bus).

2. Distribution system modelling

2.1. Primary distribution system configuration

The configuration of the primary distribution system consists of a radial feeder, parallel feeder and ring feeder or loop feeder [2] [3]. A feeder radial is the simplest and commonly used one. It is used the extensively to supply small and medium residential, commercial, industrial and non-critical loads. It derives its name from the fact that the feeder radiates from the secondary substation and branches into sub-feeders and laterals which extend into all parts of the area served. The feeders and sub-feeders are three-phase three-wire (or four wire) circuits. The customers may be of three-phase or single phase. The distribution transformers are connected to the primary feeders, sub-feeders and customers, usually through fused cutouts. The radial feeder is the most economical but the least reliable of the various types since a fault in the feeder means disruption of supply. Figure 1 shows a radial primary feeder.

![Radial feeder](image1)

Figure 1. Radial feeder

A system of two or more radial feeders originating from the same or different secondary substations and separately routed through the load areas is known as loop feeder system. If the ends of the two feeders are tied together through normally open switching devices, the resulting arrangement is known as open loop system. If the ends are tied together by means of normally closed switching devices, the result is a ring loop or simply ring feeder. The loop feeder provides a good continuity of service. The feeder and loop component must have sufficient delivery capacity to service loads that might be transferred under emergency condition. This system is the most practical for providing reasonable reliability with nearly full utilization of facilities. Figure 2 shows a loop feeder.
2.2. Reliability of electric power system
Reliability is the probability of a device performing its function adequately for the intended period of
time under specified operating condition [2]. The reliability of an electric power system is the ability of
an electric power system to carry out its functions continuously without experiencing interference
continuously without experiencing interference.

The reliability of the electric power system is the continuity of supplying electrical energy to
customers, for customers who have large capacities such as industries need a better level of service and
continuity. If the distribution of electrical energy is interrupted, the production process from the industry
will be disrupted.

2.3. Reliability index
To find out the reliability of an electric power system, it is based on a reliability index that is a quantity
that describes the performance of an electric power system, the indexes are SAIFI (System Average
 Interruption Frequency Index), SAIDI (System Average Interruption Duration Index). and CAIDI
(Customer Average Interruption Duration Index) [6] [7].

2.3.1. SAIFI (System Average Interruption Frequency Index).
SAIFI describes the average frequency of blackouts for each customer within a year in an area that is
evaluated.

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

\[
SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} \text{ f./cust.yr}
\]

\(\lambda_i\): failure rate
\(N_i\): number of customers at the point of load \(i\)
2.3.2. **SAIDI (System Average Interruption Duration Index)**

SAIDI describes the average duration of blackout for each consumer within a year in an area that is evaluated,

\[
SAIDI = \frac{\text{Sum of customer interruption duration}}{\text{Total number of customer served}}
\]

\[
SAIDI = \frac{\sum U_i N_i}{\sum N_i} \quad \text{(hr./cust. yr)}
\]  

(2)

2.3.3. **CAIDI (Customer Average Interruption Duration Index).**

CAIDI describes the average amount of time (duration) of each outage

\[
CAIDI = \frac{\text{Sum of customer interruption durations}}{\text{Total number of customer interruption}}
\]

\[
CAIDI = \frac{\sum U_i N_i}{\sum N_i A_i} \quad \text{(hr./cust. intr)}
\]

(3)

2.4. **Research step**

Data processing method is to compute with ETAP 12.0 software can be described as follows:

1) Describe the network configuration to be studied
2) Enter the network parameter values (R and X values).
3) Entering the voltage value on each bus.
4) Entering power values (P and Q) in the generator
5) Enter the load values (P and Q).
6) Perform computational processes with ETAP software by running load flow analysis to calculate demand for system load requirements for normal operating conditions.
7) Perform reliability assessments to determine system reliability
8) Determine the reliability index.

3. **Test performed on system**

The system test is carried out on the IEEE-9 bus system research object [8], the research data can be shown in table 1 and table 2:
Table 1. Load data IEEE-9 bus system

| V (KV) | P (KW) | Q (KVAR) | Pd (KW) | Qd (KVAR) |
|--------|--------|----------|---------|-----------|
| 20     | 1840   | 460      | 0       | 0         |
| 20     | 980    | 340      | 0       | 0         |
| 20     | 1790   | 446      | 0       | 0         |
| 20     | 1598   | 1840     | 0       | 0         |
| 20     | 1610   | 600      | 0       | 0         |
| 20     | 780    | 110      | 0       | 0         |
| 20     | 1150   | 60       | 0       | 0         |
| 20     | 980    | 130      | 0       | 0         |
| 20     | 1640   | 20       | 0       | 0         |

Table 2. Line/cable data IEEE-9 bus system

| From bus | to bus | R (Ω/KM) | X (Ω/KM) |
|----------|--------|----------|----------|
| 0        | 1      | 0.1233   | 0.4127   |
| 1        | 2      | 0.0140   | 0.6050   |
| 2        | 3      | 0.7463   | 1.2050   |
| 3        | 4      | 0.6984   | 0.6084   |
| 4        | 5      | 1.9831   | 1.7276   |
| 5        | 6      | 0.9053   | 0.7886   |
| 6        | 7      | 2.0552   | 1.1640   |
| 7        | 8      | 4.7953   | 2.7160   |
| 8        | 9      | 5.3430   | 3.0264   |

The configuration of the IEEE-9 bus system distribution network can be seen in Figure 3.

Figure 3. Network configuration of the IEEE 9 bus system
4. Results and Discussion

System testing conducted in this paper is on the IEEE 9 bus system with a base value of 30 MVA with a voltage of 20 KV and 50 Hz. Network configuration is in the form of a radial distribution system that is supplied from the sending side (secondary substation). The simulation process is carried out using ETAP software, for normal operating conditions the 20 KV radial distribution system is simulated with load flow analysis, which shows the condition of the system at peak load. The system will be analyzed on each bus, with bus 1 (secondary substation bus) considered a slack bus or reference bus. This load flow calculation is done to find out the amount of power supply to the system, the voltage drop and losses in the network. The value of the power demand is 12.955 MW and 5.234 MVAR supplied from the substation, with the largest voltage drop occurring on cable 5 which is 3.37%. The amount of total losses in the IEEE 9 bus system is 1045.1 KW and 1326.5 KVAR.

Then a simulation is performed to calculate the reliability of the system by running a reliability assessment of the ETAP software. The simulation results show the reliability value can be shown in the table 3.

| Bus number | Average interruption rate (f/yr) | Average outage duration (hour) | Annual outage duration (hr/yr) |
|------------|----------------------------------|--------------------------------|-------------------------------|
| BUS 1      | 1.033                            | 14.82                          | 15.306                        |
| BUS 2      | 1.053                            | 15.01                          | 15.806                        |
| BUS 3      | 1.073                            | 15.2                           | 16.306                        |
| BUS 4      | 1.093                            | 15.38                          | 16.806                        |
| BUS 5      | 1.113                            | 15.55                          | 17.306                        |
| BUS 6      | 1.133                            | 15.72                          | 17.806                        |
| BUS 7      | 1.153                            | 15.88                          | 18.306                        |
| BUS 8      | 1.173                            | 16.03                          | 18.806                        |
| BUS 9      | 1.193                            | 16.18                          | 19.306                        |

Table 3 shows the reliability of the system which consists of the average number of interruptions and duration of outages of each bus. The average value of the duration of the interruption has increased for the bus farthest away from the power supply side that is bus 9, while the bus closest to the power supply side, the average duration of interruption is very small, namely on bus 1. while buses are on the power supply side, the average duration of disturbance is very small, namely on bus 1.

The duration of outages of each bus has increased for the most distant buses from power supply, the most experienced blackouts are bus 8 and bus 9. The reliability values from table 3 can be made in graphical form, which shows the average amount of interruption and duration of outage as shown in figures 4 and 5.
Figure 4. Characteristic of average interruption rate for the IEEE 9 bus system

Figure 5. Characteristic of outage duration for the IEEE 9 bus system

The results of the SAIFI, SAIDI and CAIDI reliability index calculations for the IEEE 9 bus system distribution network with ETAP software can be shown in table 4.

Table 4  Reliability index value for the IEEE 9 bus system.

| Type   | Index value         |
|--------|---------------------|
| SAIFI  | 1.130 f/cust        |
| SAIDI  | 17.306 hr/cust.yr   |
| CAIDI  | 15.549 hr/cust.intr |

The results of table 4 show that the SAIFI index value of 1.130 f / cust is still below the IEEE standard std1366-2000 which is 1.45 f / cust [9]. The SAIDI and CAIDI index values from table 4 are 17,306 hr / cust.yr and 15,549 hr / cust.intr respectively, these values exceed the IEEE standard std1366-2000, respectively 2.3 hr / cust.yr and 1.58 hr / cust.intr.

5. Conclusion
From the results of the reliability analysis for the IEEE 9 bus system, the following conclusions can be drawn:

1) Total power demand supplied from substations to the 20 KV distribution network is 12.955 MW and 5.234 MVAR, with losses of 8.06%.
2) The average duration of disturbance has increased for the bus farthest away from the power supply side (bus 9) that is 1.193 times / year.

3) The duration of outages that often appear is on bus 8 and bus 9 respectively 16.03 hours and 16.18 hours.

4) Reliability index value: SAIFI of 1.113 frequency / customer.yr, SAIDI value is 17.306 hours / customer.yr, and CAIDI value is 15.549 hours / customer interruption

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