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## RESEARCH ARTICLE

### RELIABILITY ANALYSIS OF POWER DISTRIBUTION NETWORK

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#### ABSTRACT

*Modern society is highly dependent on the efficient operation of electric power systems and has developed in such a way that even a small interruption in electric power supply has a significant effect. The knowledge of the reliability of distribution networks and systems is an important consideration in the system planning and operations for development and improvements of power distribution systems. To achieve the target of minimum interruptions as possible to customers, utilities must strive to improve the reliability but at the same time reduce cost. It is a known fact that most of customer interruptions are caused by the failure in distribution system. This paper presents the analysis of different case studies of distribution systems using Electrical Transient and Analysis Program (ETAP) software.*

**KEYWORDS:** Reliability, distribution system, ETAP®, reliability indices, radial system

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#### INTRODUCTION

Power distribution network system established mainly to provide adequate electricity supply to customers as economically as possible with reasonable assurance of reliability. Nowadays, the power distribution networks have grown exponentially in term of size and technology over the past few years. As a result, utility company must strive to ensure that the customer's reliability requirements are met with optimum strategic planning and lowest possible cost (Roystone, 2014). Reliability evaluation of power systems can have a significant effect on the design and asset management of the system (Roy, 1996). Being one of the most important parts of the power system, substations play a key role in the transmission and distribution of electricity, and will be the main subject studied in this paper.

Because the specific times at which initiating events that cause components to fail are unpredictable, the system must be operated at all times in such a way that the system will not be

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left in a dangerous condition should any credible initiating event occur. Since power system equipment is designed to be operated within certain limits, most pieces of equipment are protected by automatic devices that can cause equipment to be switched out of the system if these limits are violated. If any event occurs on a system that leaves it opening with limits violated, the event may be followed by a series of cascading failures continues, the entire system or large parts of it may completely collapse. This is usually referred to as a system blackout (Shahriar *et al.*, 2011).

From a power system perspective, the social and working habits of modern society have come to rely on and demand a continuous supply of electrical energy. In reality, continuous supply of electricity is not achievable due to random power system failures (Liisa et al, 2007). However, the impact these failures have on power system adequacy can be minimised with increased investment during planning, design and operating phases of a power system. As a result, an important aspect of modern power system design considers the relationship between the reliability of a particular design, and the economic feasibility of achieving such a design (Lokesh, 2009).

This paper presents the reliability analysis of power distribution network using ETAP software. The software simulation process is meant to create a better understanding of the various aspect of distribution system reliability analysis.

#### METHODS OF RELIABILITY ASSESSMENT

Power system reliability indices can be calculated using a variety of methods. The basic approaches. The two main approaches are; analytical and simulation.

Analytical techniques represent the system by a mathematical model and evaluate the reliability indices from this model using numerical solutions. They generally provide expectation indices in a relatively short computing time. Unfortunately, assumptions are frequently required in order to simplify the problem and produce an analytical model of the system.

Simulation methods estimate the reliability indices by simulating the actual process and random behaviour of the system. The method therefore treats the problem by a series of real experiments. The technique can theoretically take into account virtually all aspects and contingencies inherent in the planning, design, and operation of a power system. These include random events such as outages and repairs of elements represented by general probability distributions, dependent events and componet behavior, queing of failed components, load variations (Billinton et al, 1996).

#### FREQUENTLY USED TERMS RELATED TO RELIABILITY ANALYSIS

**Reliability** - is a measure of the ability of the power system to deliver electricity to all points of utilization within accepted standards and in the amount desired, for the period of time intended, under the operating conditions intended.

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Adequacy - relates to the existence of sufficient facilities within the system to satisfy the consumer load demand at all times; taking into account scheduled/ unscheduled outages.

Security - ability of the electric systems to respond to sudden disturbances arising within that system, such as electric short circuits.

Fig. 1: System Reliability Subdivision

Power systems security can be broken into two major functions that are carried out in an operations control center:

- System monitoring.
- Contingency analysis.

System monitoring provides the operators of the power system with related up-to-date information on the conditions on the power system. The second major security function is the contingency analysis. The results of this type of analysis allow systems to be operated defensively. Many of the problems that occur on a power system can cause serious trouble within such a quick time period that the operator could not take action fast enough. This is often the case with cascading failures.

#### BASIC CONCEPTS OF RELIABILITY CALCULATIONS

- Two-State Model

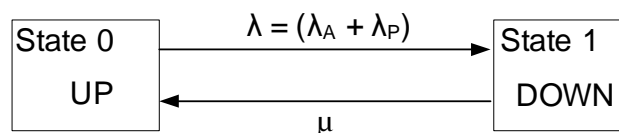


Fig. 2: A component two state space diagram

The probability of failure or repair for a fixed interval of time is constant in a continuous Markov process. Power system components can be represented by discrete system states with constant transition rates between these states. In Figure 2, “State 0” represents the healthy state of the component and the component is in an operating condition. The component when it cannot perform its intended function is in “State 1” or the failed state. Transitions occur between “State 0” and “State 1”. The transition rates between the states are the failure rate “ $\lambda$ ” and the repair rate “ $\mu$ ” and are shown in Figure 2. Figure 3 shows the two states in terms of the average residence time in each state.

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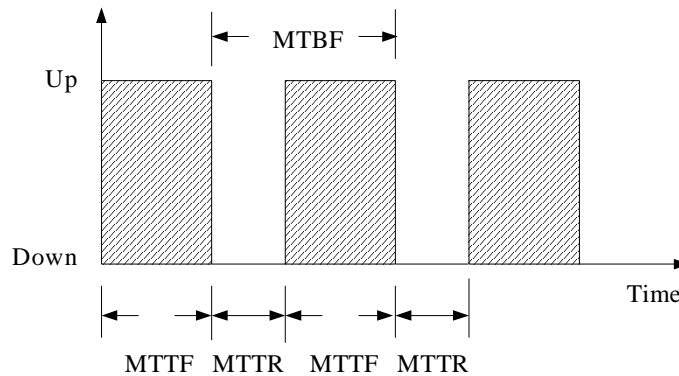


Fig. 3: Mean time diagram for a two state component

Where:  $\lambda$  = Failure Rate

$\lambda_A$  = Active Failure Rate

$\lambda_P$  = Passive Failure Rate

$\mu$  = Repair Rate

MTTR = Mean Time To Repair

MTTF = Mean Time To Fail

The summation of MTTF and MTTR is the mean time between failures (MTBF).

Equations 3.1 to 3.3 show the relationship between the transition rates and the transition times shown in Figures 3.1 and 3.2 respectively.

$$MTTF = 1/\lambda \tag{1.1}$$

$$MTTR = 1/\mu \tag{1.2}$$

$$MTBF = MTTF + MTTR = 1/\text{frequency} \tag{1.3}$$

- Two Components in Series

In the series structure both components must be intact for the system to function, "a chain is no stronger than its part" while in the parallel structure both must fail for the system to stop functioning. In this case, all the components are connected in series as shown in Figure 4 and the equations needed to evaluate the basic indices are as follows:



Fig. 4: Series Structure

Average failure rate of the system:

$$\lambda_{\text{sys}} = \lambda_1 + \lambda_2 \tag{1.4}$$



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Average failure duration of the system:

$$r_{sys} = \frac{\lambda_1 r_1 + \lambda_2 r_2 + (\lambda_1 r_1)(\lambda_2 r_2)}{\lambda_{sys}} \approx \frac{\lambda_1 r_1 + \lambda_2 r_2}{\lambda_{sys}} \quad (1.5)$$

Average Annual Outage time of the system:

$$U_{sys} = \lambda_{sys} \times r_{sys} \quad (1.6)$$

- Two Components in Parallel

In parallel system, the failure modes of the load point involve overlapping outages, i.e. two or more components must be on outage at the same time in order to interrupt a load point as shown in Fig. 5. It is assumed that the failures are independent and that restoration involves repair or replacement, the equations used to evaluate the indices of the overlapping outage are as shown below.

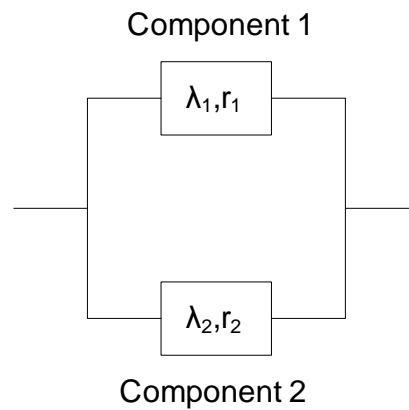


Fig. 5: Parallel Structure

$$\lambda_{sys} = \frac{\lambda_1 \lambda_2 (r_1 + r_2) / 8760}{1 + (\lambda_1 r_1 + \lambda_2 r_2) / 8760} \approx \lambda_1 \lambda_2 (r_1 + r_2) / 8760 \quad (1.7)$$

$$r_{sys} = \frac{r_1 r_2}{r_1 + r_2} \quad (1.8)$$

The three basic reliability parameters requires for analysis are:

Average failure rate:  $\lambda_{sys} = \sum_i \lambda_i \quad (1.9)$

Average annual outage time:  $U_{sys} = \sum_i \lambda_i r_i \quad (1.10)$

Average outage time:  $r_{sys} = \frac{U_s}{\lambda_s} = \frac{\sum_i \lambda_i r_i}{\sum_i \lambda_i} \quad (1.11)$

These are adequate for simple radial systems and more extended indices have to be used for general distribution systems (mixed radial and meshed systems).



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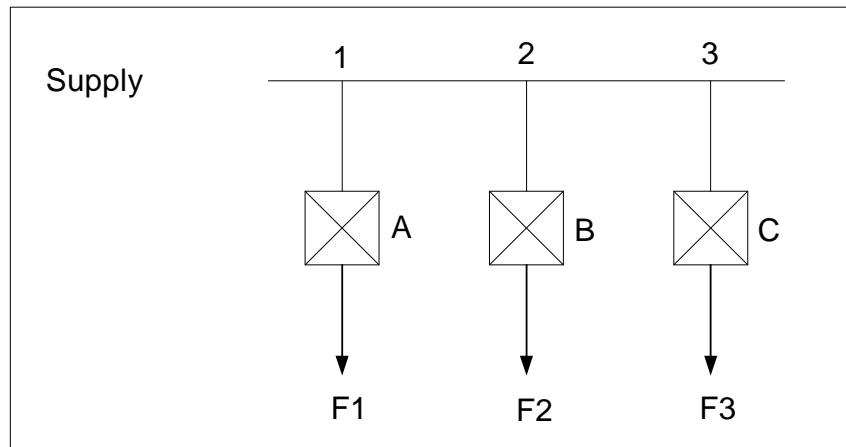


Fig. 6: Simple 3-load point radial system

A radial system consist of a set of series components, including lines, cables, disconnects (or isolator), bus bar, breaker, earth switch and etc (Lokesh, 2009). A customer or substation connected to any load point of such system requires all components between himself and the supply point to be operating. A simple radial system shown in Figure 6. The assume failure rates and repair times of each line A, B and C are shown in Table 1.1 and the load point reliability indices are shown in Table 1.2. Data shown is the typical and general feature of radial system. The assumption made is perfect isolation of faults on line element A, B and C by the circuit breaker.

Table 1.1: Component data for system in Figure 6

| Line | $\lambda$ (f/yr) | r (hours) |
|------|------------------|-----------|
| A    | 0.2              | 6.0       |
| B    | 0.10             | 5.0       |
| C    | 0.15             | 8.0       |

Table 1.2: Load Point reliability indices for the system of Figure 6

| Load Point | $\lambda$ (f/yr) | r (hours) | $U_L$ (hours/yr) | Number of customer | Average Load Demand (kW) |
|------------|------------------|-----------|------------------|--------------------|--------------------------|
| F1         | 0.2              | 6.0       | 1.2              | 200                | 1000kW                   |
| F2         | 0.10             | 5.0       | 1.7              | 150                | 700Kw                    |
| F3         | 0.15             | 8.0       | 2.9              | 100                | 400kW                    |

The customer and load oriented indices can now be evaluated as shown below:

$$SAIFI = \frac{(0.2 \times 200) + (0.3 \times 150) + (0.45 \times 100)}{200 + 150 + 100} = 0.289 \text{ interruption/year}$$

$$SAIDI = \frac{(1.2 \times 200) + (1.7 \times 150) + (2.9 \times 100)}{450} = 1.74 \text{ hours/customer year}$$

$$CAIDI = \frac{SAIDI}{SAIFI} = 6.02 \text{ hours/customer interruption}$$



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The above illustration is the basic evaluation technique for basic radial system. For the purpose of this study, further operating philosophy will be apply such as additional of isolation (disconnects), additional protection and automation, transferrable load and others system configuration that might affect the reliability indices. It shall be observe that, when the additional features applied on the evaluation, there will be changes and improvement in the reliability indices.

Let's consider a simple radial system using ETAP software

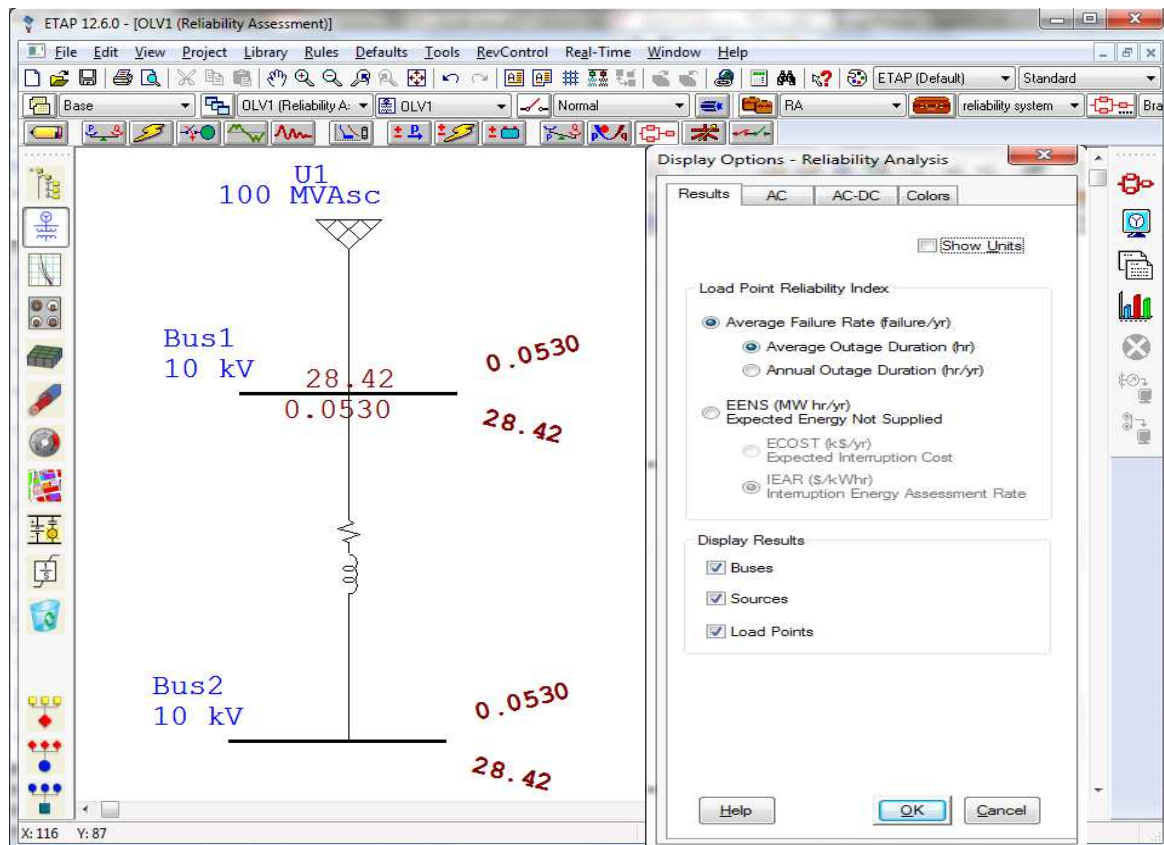


Fig. 7: System Average outage duration (hr)

$$\lambda = 3(\text{Bus 1, Bus2 and U1}) \times 0.001 \text{ (Failure/year)} + 0.05 \text{ (Failure/year)}$$

$$= 0.053 \text{ (Failure/year)}$$

$$U = 3 \times 0.001 \times 2(\text{hr}) + 0.05 \times 30(\text{hr})$$

$$= 1.506 \text{ hr/year}$$

$$r = U/\lambda = 28.42 \text{ (hr/Failure)}$$



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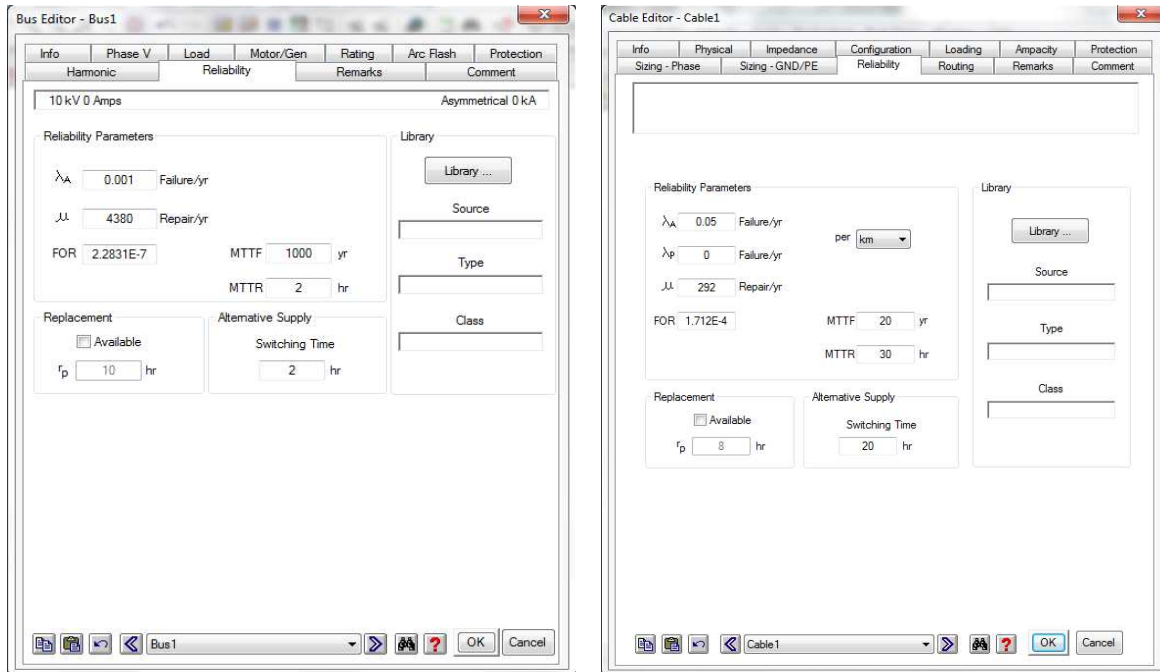


Fig. 8: System components reliability indices (MTTR, Failure/year, etc)

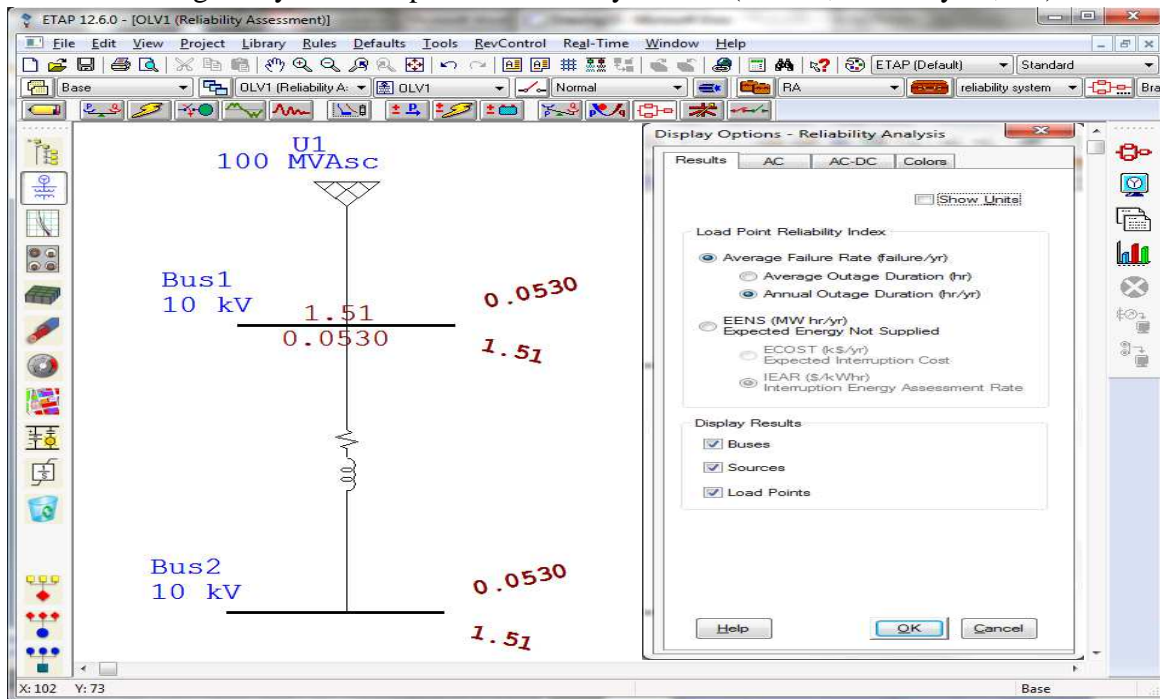


Fig. 9: System Annual outage duration (hr/yr)

It can be observed from figure 7 and 9, that Bus1 and Bus2 have the same failure rate.

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**Considering a parallel system**, the reliability of the system is therefore governed by two lines (Components1 and Components2) and the two transformers (T1 and T2). For simplicity the failure rate for the circuit breakers connecting the transformers to the buses are set to zero. It could be noticed that for double contingency analysis, the indices at main bus are the same but a lot higher at bus2. This due to the consideration of both transformers T1 and T2 fail at the same time.

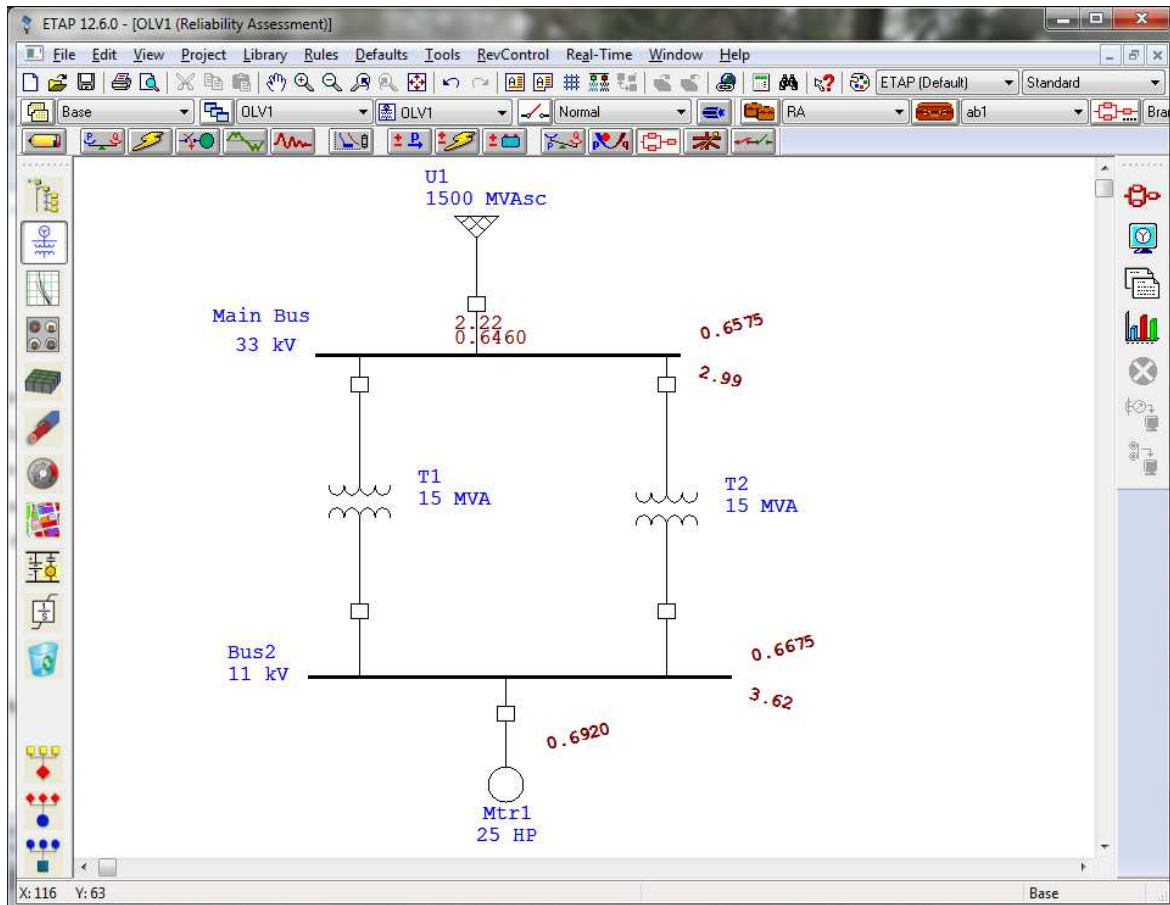


Fig. 10: System Average outage duration (hr) (double contingency)

$$\lambda = 2(\text{Main Bus, Bus2}) \times 0.001 \text{ (Failure/year)} + (U1) \times 0.643 \text{ (Failure/year)} + 4(\text{CB2, CB3, CB4, CB5}) \times 0.003 \text{ (Failure/year)}$$

$$= 0.657 \text{ (Failure/year)}$$

$$U = 2 \times 0.001 \times 2 \text{ (hr)} + 0.643 \times 2 \text{ (hr)} + 4 \times 0.003 \times 50 \text{ (hr)}$$

$$= 1.89 \text{ hr/year}$$

$$r = U/\lambda = 2.9 \text{ (hr/Failure)}$$



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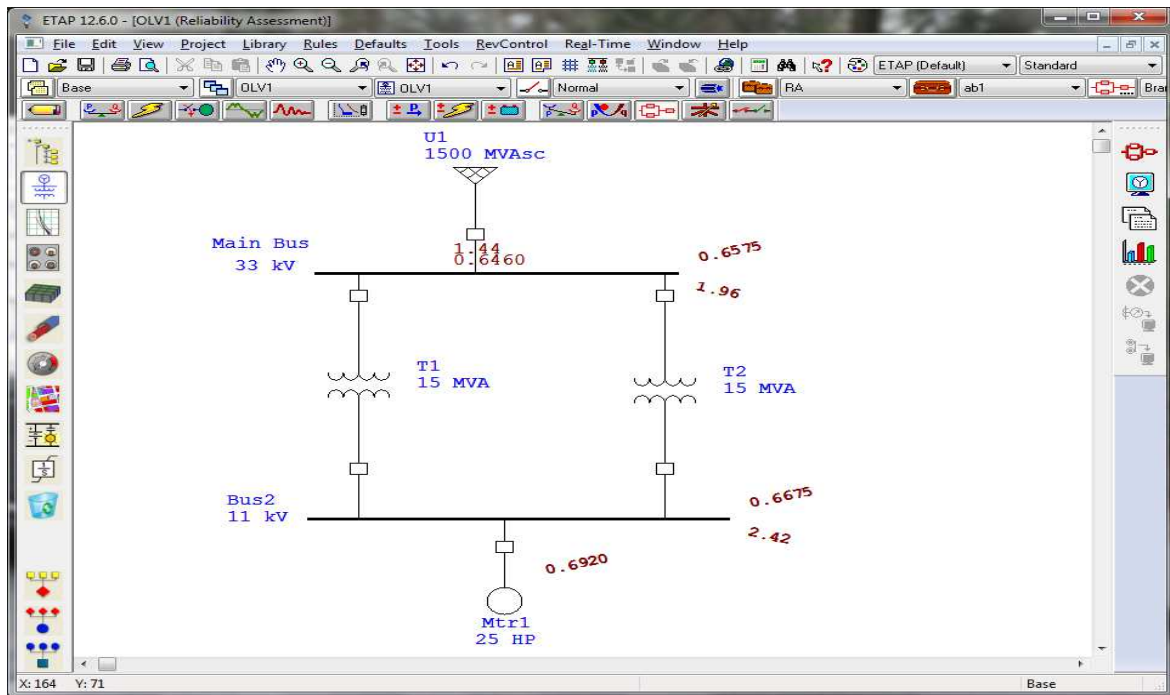


Fig. 11: System Annual outage duration (hr/yr)

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**Load Point Output Report**

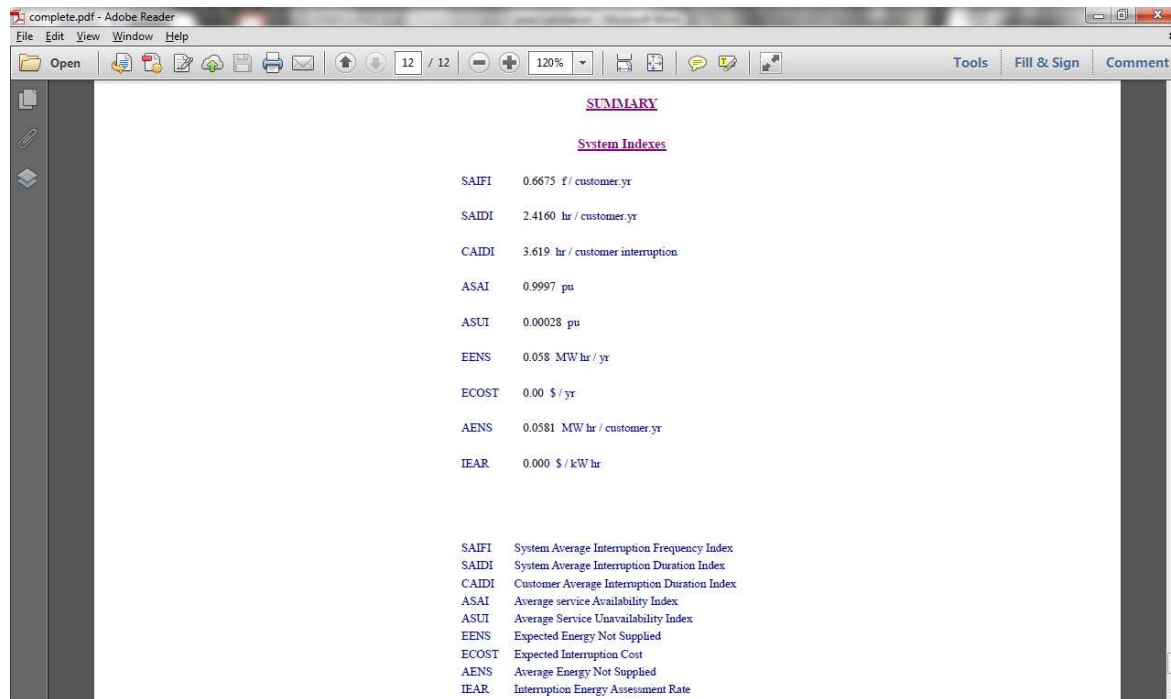
| Bus      |             |                  | Average Interruption Rate | Average Outage Duration | Annual Outage Duration | EENS     | ECOST | IEAR     |
|----------|-------------|------------------|---------------------------|-------------------------|------------------------|----------|-------|----------|
| ID       | Load Sector | Connected Bus ID | f/yr                      | hour                    | hr/yr                  | MW hr/yr | \$/yr | \$/kW hr |
| Bus2     | N/A         |                  | 0.6675                    | 3.62                    | 2.4160                 | 0.0581   | 0.00  | 0.000    |
| Main Bus | N/A         |                  | 0.6575                    | 2.99                    | 1.9630                 | 0.0000   | 0.00  | 0.000    |
| Mtr1     | None        | Bus2             | 0.6920                    | 5.26                    | 3.6410                 | 0.0875   | 0.00  | 0.000    |
| U1       | None        | Main Bus         | 0.6460                    | 2.22                    | 1.4360                 | 0.0000   | 0.00  | 0.000    |

Fig. 12: Load point output report



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SUMMARY

System Indexes

|       |         |                            |
|-------|---------|----------------------------|
| SAIFI | 0.6675  | f / customer.yr            |
| SAIDI | 2.4160  | hr / customer.yr           |
| CAIDI | 3.619   | hr / customer interruption |
| ASAI  | 0.9997  | pu                         |
| ASUI  | 0.00028 | pu                         |
| EENS  | 0.058   | MW hr / yr                 |
| ECOST | 0.00    | \$ / yr                    |
| AENS  | 0.0581  | MW hr / customer.yr        |
| IEAR  | 0.000   | \$ / kW hr                 |

|       |                                              |
|-------|----------------------------------------------|
| SAIFI | System Average Interruption Frequency Index  |
| SAIDI | System Average Interruption Duration Index   |
| CAIDI | Customer Average Interruption Duration Index |
| ASAI  | Average service Availability Index           |
| ASUI  | Average Service Unavailability Index         |
| EENS  | Expected Energy Not Supplied                 |
| ECOST | Expected Interruption Cost                   |
| AENS  | Average Energy Not Supplied                  |
| IEAR  | Interruption Energy Assessment Rate          |

Fig. 12: System indexes

## CONCLUSION

The results obtained from reliability studies, provide an appropriate benchmark for assessing the system performance and identifying the weak point of the system. Verifying the weak point of the system may make the planners to increase the investment at a certain load point during the planning phase and consequently reduce the further costs due to supply interruption in operation stage.

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