Reliability Evaluation of EHT Sub-Stations
RELIABILITY EVALUATION OF EHV AC SUB-STATIONS

Now-a-day’s power system networks are more complex and integrated, the electrical power sub-stations are one of the strongest points, but they have significant weakest points in the operation. A reliable sub-station must have ultimate impact on the overall performance of the power system. The topology changes in various sub-station configuration models and enhance the power transfer capabilities. The reliability mainly depends on the equipment connectivity and their failure data. In this chapter the reliability evaluation of EHT sub-stations has computed by minimal cut set method and Monte Carlo Simulation technique with a realtime case study.

4.1 INTRODUCTION

In a traditional power system configuration, the generation, transmission and distribution are owned by a single entity called as ‘Vertically Integrated Utility’ (VIU) that supplies power to the customers. In deregulation environment, the performance of substations is key issue. Sub-stations and various switching stations play more significant role in the latest power system networks. Consumers demand is to be the highest priority and need to supply with smallest amount. In this business competitive environment, the utilities must sustain a high level of service continuity, and decide how to make economic measures for apt planning.

Sub-stations are more essential and significant segments of an electric power system networks and their reliability will affect significantly the continuity of the power supply to the consumer. The performance of sub-station mainly depends on the associated components such as bus bars, circuit breakers, isolators, transformers, instrument transformers (CT&PT’S), feeders and their controlling devices. EHT AC sub-station reliability assessment evaluates the effect of service continuity where the main power system components interconnect to the sub-station. Assessment of various configurations of sub-station reliability indices means that assessing how sufficiently these essential elements are able to achieve their anticipated operation. Present electrical sub-station layouts are getting ample attention is given for computation of performance [9].

The instantaneous effect of deprived sub-station design is the failure to enclose simple disturbances. Failure actions at sub-station can lead numerous outages with feasible cascading consequences and widespread loss of consumer load and place frustrate pressure
on the power grid. Providing power imbalance between generation and consumers is an clearly a luxurious solution. More directly that less costly, minimum interruption duration and sufficiently spares are the solutions for the enhancement of sub-stations for better reliability. The reliability of the sub-station is assessed by inspecting the effect of faults and outage of each every component within the sub-station is a matter of outmost important in operation.

Reliability of a sub-station mainly depends on the following parameters, i.e.

(a) The sub-station configuration (arrangement of circuit breakers).
(b) The reliability of the sub-station components.
(c) The reliability of the protective systems.

Economic aspects to be considered:

- Investment cost, operation and maintenance cost
- Interruption cost/outrage cost

Technical aspects to be considered as:

- Operation flexibility , service continuity, security, reliability
- Automation level
- Further extensions
- Maintenance
- Protective relaying, short circuit current limitations

To assess the sub-station reliability, decoupling it from the rest of the system will give improved results. This would allow better detail information to be given to the sub-station reliability while keeping the intricacy of the complete system evaluation down.

Most utilities have a variety of sub-station ages in their system. Some sub-stations may be very new with automation incorporated into their design and the latest technology. Other sub-stations may be relatively old without automated switching and electromechanical protective relays still are in operation in the power grid. These substations require crew to be dispatched for switching when failure occurs. Overall performance of the power system depends on this variety in sub-station designs for any utility.

The sub-station reliability indices are divided into two groups.

⇒ First group contains probability of outage and frequency outage for each set of outside relations. The mutually exclusive events outage sets are left behind the connections for must be in service if single set of the connections is in failed state.
The next group contains only outage rate, outage duration and the outage probability of every connection. These events are not mutually exclusive; the remaining connections can be in service or in an outage state.

The specific load point indices can be evaluated with a group of outage data (failure rate) in particular connection. Huge capital cost is needed while building new facilitates and limits the budget, however it is not a realistic solution to construct new infrastructure for EHVAC substation. The present infrastructure must be modified to progress its reliability and act. This group of composite generation and transmission system reliability evaluation of station reliability indices can be used. An outage event takes place can contribute 20 percent to 25 percent interruptions to customer very easily therefore one place where changes can be easily is substations.

(1) Power system reliability depends extremely on sub-station reliability.
(2) A failure in Sub-Station causes the continuity of supply to the number of customer.

Sub-station reliability assessment includes composite system reliability analysis that increases the complexity of the problem. Reliability of sub-station plays an import role for increasing the customers that are fed by the sub-station will have higher reliability. Therefore, sub-stations seem be a probable place to force a big number of customer’s dependability. These allow a better detail to be given to the sub-station reliability analysis while keeping the difficulty of the entire system valuation down.

SECTION BREAKUP

• 4.2 Sub-Station Reliability Assessment
• 4.3 Sub-station evaluation basics
• 4.4 Sub-station configurations
• 4.5 Sub-station reliability evaluation methods
• 4.6 Algorithm of Monte Carlo Simulation
• 4.7 Methodology and test case study
• 4.8 Real time Case Study of 220kVSub-Station at Nellore
• 4.9 results and discussions
• 4.10 summary of the chapter
4.2 SUB-STATION RELIABILITY ASSESSMENT (SRA)

SRA means evaluating the reliability of sub-station. The measure of sub-station reliability increases the power transfer capability of a sub-station by overcoming component failures. It is intended for use by designers, operators, planners and users of electric power substations or switching stations.

_SRA is particularly suitable for:_

- Comparing sub-station/network configuration alternatives,
- Evaluating the sensitivity of performance to outage statistics,
- Evaluate the sensitivity of sub-station performance to equipment rating,
- Evaluating the sensitivity of sub-station performance to load level
- Determining the impact of equipment maintenance on reliability.

*Electric Sub-Station Function for the Power Systems*

Electric sub-station mainly functions voltage change from one level to another level, switching purpose, voltage regulation, to compensate for system voltage changes with the help of compensating methods. Sub-station also provides an inter connection between electric transmission and distribution circuits of the system. In modern days the substations focus on protection, condition monitoring, and data measuring, state estimation with Phasor Measuring Units (PMU) installation. It also provides measurement various power flow parameters (P, Q, V, I etc.) and switching surges eliminated from electric system. Interconnection between the various public and private generating companies now-a-days makes more complex operational behavior.

EHT sub-station should be designated, constructed and operated to meet customers’ need at the lowest possible cost commensurate with the quality of service desired. Sub-station planning considers the location, size, voltage, services and ultimate function of the sub-station. Not only the operational complexity but also load component requires enough importance in deciding the bus configuration. Apart from forced outage data, the design of sub-station is to be load specific and design specific to a transmission line under expansion. A generalized view point i.e. load component that is empirical proposed for bus configuration selection in sub-station design by calculating ratio of the load to be fed by the new sub-station (or by an old sub-station under expansion) to the total district load. Sub-stations are one of the strongest points in a complex power system.
network and it is somewhat could be described as pathetic points or points of failure that would guide to loss of load. For the perceptive of how to compute the reliability of various sub-station arrangements; an engineer can use this information to facilitate better design a system with the finest overall reliability [10].

The determination of the reliability of a sub-station can also be significant for existing installation as it can assist to find weak points that may be cause overall system unreliability. This chapter will present an overview in determining sub-station reliability indices. The intention of the assessment should be clearly evident as this may affect the selection of which method is used to determine reliability. A technique may appear at how sub-station reliability affects the overall reliability, how the system reliability affects sub-station reliability. To estimate the reliability of the sub-station one requires the reliability indices. The reliability indices for the sub-station are:

(1) Annual Outage time (hrs/year)
(2) Annual outage duration
(3) Failure rate.

4.3 SUB-STATION EVALUATION BASICS

Assumptions
1. The actual system is represented by a network.
2. Two or more parallel branches connected between any pair of nodes are merged to form single branch.

There are five important steps to be carried out when estimating the sub-stations performance. The method used to carry out each of the five steps can differ depending on the selected reliability evaluation. The following steps are listed below:

(i) Physical System Description
(ii) Performance Criteria
(iii) Reliability Indices
(iv) Failure Mode and Effects Evaluation
(v) Accumulation of Failure Effects and Summary

4.3.1 Physical system description

It is a key step at the beginning and the sub-station reliability assessment is to find out the margins of the system that will be studied. The scheme of study would incorporate
not only the sub-station, but also the incoming and outgoing feeders as well as determining
the impact the sub-station has on the system and eventually consumer satisfaction. Once
the boundary is determined, then next step is to representation of all the components. The
simplest case, two state, up/down model can be used to represent all the components, or if
more details are required higher order models can be utilized. The detail needed will be
dependent on what type of failure modes being considered. Figure 4.1 shows Markov
component models of increasing complexity [10]. The three states are:

* State before the fault (U)
* State after the fault but before isolation (S)
* State after isolation but before repair (R)

![Component Models](image)

4.3.2 Performance criteria

If any system constraints are desired for the study, they must add this step. This
would incorporate objects such as transmission line carrying constraints, bus voltages and
overloads. The criteria particularly in this step will vary deeply upon what type of
reliability study is being carried out. A system study may include a large number of
operating constraints while an industrial sub-station study may include only a few.

4.3.3 Reliability indices

At this level of satisfactory performance must be developed. Some commonly used
sub-station reliability indices are listed below.

1. Failure rate \( \lambda \) (/yr)
2. Duration (min/yr)
3. Repair time \( r \) (hrs)
4. Availability (%)

4.3.4 Failure Mode and Effects Evaluation

For each failure mode, the effects of the failure and what action must be taken to
correct the failure needs to be determined. The effect of each failure can then be listed
according to the likelihood of the event. The following steps can provide a framework for gathering the needed information from each failure mode.

1. Protection system status and resulting breaker action.
2. Have breaker actions caused load interruption
3. Have any performance criteria violations occurred
4. Record all the effects by terminal affected, along with the probability of the event and its duration.

Failure modes are categorized into four basic groups

- Passive failure events
- Active failure events
- Stuck-condition of breakers
- Overlapping failure events

**Passive failure:** Passive failure events are referred to as all the component faults which do not cause operation of protection breakers. Examples are undetected open-circuits and inadvertent operations of circuit breakers.

**Active failure:** Active failure events are all the component faults which cause the operation of the primary protection zone (breakers) around the failed component. An example is a short-circuit fault.

**Stuck-condition of breakers:** Stuck-condition of breakers arises when circuit breakers in the primary zone fail to operate following an active failure event. Back-up protection must then respond and a larger section of the sub-station may become isolated.

**Overlapping failure:** Overlapping failure events arise when sub-station components fail during the restoration time associated with a previously failed sub-station component. The overlapping failure events usually considered are those involving only two station components. The probability of higher-order outages is normally negligible

### 4.3.5 Accumulation of Failure Effects

The final step is to list all system failures by the probability of occurrence. This will provide a clear picture of scenarios that will cause the most problems. To find the system reliability (or in this case, sub-station reliability), combine the system failure probabilities and frequencies are contained.
4.4 SUB-STATION CONFIGURATIONS

Some of the major sub-station configurations are considered in this segment. Certain configurations may be more appropriate to an explicit task and the components in each category of sub-station may be different. But with the exception of switching stations, they normally incorporate a power transformer, CB, isolator and LA etc. In this section, a brief preamble to five commonly used sub-station bus configurations is discussed followed by a number of advantages/disadvantages [55].

- DESIGN – A: Dual supply single bus configuration (back to back radial)
- DESIGN – B: Dual supply with Sectionalized Bus (Tie breaker)
- DESIGN – C: Breaker-and-a-Half configuration
- DESIGN – D: Ring Bus configuration
- DESIGN – E: Double Breaker-Double Bus configuration

4.5 SUB-STATION RELIABILITY EVALUATION METHODS

Many methods were developed by earlier researchers for evaluation of sub-station reliability. The methodologies can be categorized into network reduction, markov modeling, minimum cut-set and Monte-Carlo Simulation approaches [1, 10]. The following are briefly explains the sub-station reliability evaluations and configurations techniques.

4.5.1 Network reduction

This method uses an equivalent sub-station model to simplify the original sub-station, but excludes all feeder breakers. Equations are derived to calculate the equipment failure rates and durations. However, this method ignores the impact of maintenance, and is therefore not appropriate for reliability modeling of substations with aging infrastructure and maintenance.

4.5.2 Markov Modeling

This technique is based on a Markov model in which each state of the sub-station is a combination of particular states which are utilized in equipment Markov models. The reliability indices can then be calculated through solving Markov equations. This method is straightforward and has several applications, especially in small scale sub-station with limited components. However, the increased number of equipment or states in equipment models will greatly increase the complexity in sub-station Markov models.
4.5.3 Minimum Cut-Set

Minimum cut-set method is an alternative network reduction method. A cut-set is a group of components that when fails causes the system to be unavailable. A minimum cut-set is the smallest set of components such that if they fail, the system fails. An $n^{th}$ order minimum cut-set is identified a set consisting of $n$ components. The minimum cut-set method has many advantages viz. easy implementation, handles complex networks that cannot be characterized by either serial or parallel connections, gives insight into critical component dependencies. This dissertation implements a minimum cut-set method for sub-station reliability assessment. This method is completely discussed in section 1.9.2 of chapter-I

4.5.4 Monte Carlo simulation

Simulation method is widely applied in system level reliability assessment, including sub-stations. Sequential or non-sequential Monte-Carlo simulation techniques are used to sample the durations of events or the states of equipment, and the system reliability is calculated through the simulated event history. Again, the increased number states in modeling equipment reliability by Markov process will increase calculation burden and the simulation programs may experience long execution time, before converging to a satisfied value. One possible solution to decrease the executing time is using parallel computing techniques, in order to efficiently utilize the capacities of multi-processors and large memory resources [10, 37, and 56].

Monte Carlo simulation is a significant computational tool to deal the stochastic point process. If primarily focuses on the modeling aspects involved in these kinds of studies and suggest a technique based on Monte Carlo Simulation (MCS). There are two main techniques present to evaluate the power system reliability estimate by analytical and simulation methods. Analytical techniques symbolize the system by analytical models and estimate the reliability indices by numerical solutions.

MCS estimate the reliability indices by simulating the real process with random behaviour of the system. Therefore, the method treats the trouble as a succession of experiments. Analytical technique is typically restricted to the estimate of expected values and to a restricted choice of system parameters. There is a need of frequently knowing the range of the reliability indices to substations. Monte Carlo simulation is a practice that involves the use of arbitrary numbers and the possibility to answer the problem.
Workstation simulation has to do with using computer models to imitate real life or make predictions. This type of model is usually deterministic; we get the identical results no stuff how many times we re-calculate. The crucial constraint in the time sequential simulation is to fabricate reasonable artificial operating/restoration histories of the appropriate elements. These simulated histories depend on the system operating/restoration modes and the reliability parameters of the elements.

Basic transmission equipment such as transmission lines and transformers, and protection elements such as disconnect switches, fuses, breakers and alternate supplies. The time during which the element remains in the up state is called the Time to Failure (TTF) or Failure Time (FT) are shown in Figure 4.2. The time during which the element is in the down state is called restoration time that can be either the Time to Repair (TTR) or the time to replace. Transition from up state to a down state can be caused by the failure of an element or by the removal of elements for maintenance purpose only. The only simulated element is operating/ restoration history of a component.

![Figure 4.2 Element Operating/Repair History](image)

The parameters TTF, TTR are accidental variables and may have different probability distributions according to Billiton et al. [10]. In this thesis exponential distribution is used for evaluation of reliability. Several studies specify the time to failure is reasonably described by an exponential distribution. Safeguard elements are used repeatedly to isolate the failed elements or failed areas from healthy areas when one or more failures occur in system. The uniform distribution can be generated directly by a uniform random number. The arbitrary variables from other distributions are converted from the generated uniform random number. Random numbers are generated and converted Time to Switching (TTS) using equation (3.3).

\[
\begin{align*}
TTF &= \frac{1}{\lambda_t} \ln(U) & (4.1) \\
TTR &= \frac{1}{\mu} \ln(U) & (4.2) \\
TTS &= \frac{1}{\lambda_a} \ln(U) & (4.3)
\end{align*}
\]
Where, U is uniformly distributed parameter,

$\lambda_t$ is total failure rate, $\mu$ is outage duration and

$\lambda_a$ is the active failure rate.

From the time sequential diagram, the up time ($T_{up}$) is equal to time to failure and it can be defined as $T_{up}=\text{TTF}$. Similarly, the down time ($T_{down}$) is equal to time to repair and time to switching and it is defined as $T_{down}=\text{TTR}$. Circuit breakers include the switching actions, so time to switching is used for calculating the active failures of the circuit breaker. The overall transmission system failure and repair rates can be calculated using the formulae.

$$\lambda = \frac{N}{T_{up}} \quad (4.4)$$

$$r = \frac{T_{down}}{N} \quad (4.5)$$

Here $\lambda$ = average failure

$r$=repair rates and

$N$= number of interruptions

### 4.6 ALGORITHM OF MONTE CARLO SIMULATION

Step 1: Random number generator

Step 2: Translate number into a value such as up time using a conversion technique on the suitable time to failure of the distribution component.

Step 3: Once again generate the new random number.

Step 4: Translate this number into a value of repair time using conversion method on the suitable time to repair distribution component.

Step 5: From 1-4 is repeated for a desired simulation period. In order to obtain distributions for a period of time this is able to arrest the outage actions to be considered.

Step 6: Step 1-5 again repeated for each component in the system and in case of breaker include not only its own failures, but also those actions due to other related active failures.

Step 7: Step 1-6 is repeated for the desired number of simulated periods.

Step 8: First consider the simulated period lasting n years.

Step 9: First consider the component (Bus Bar).

Step 10: Calculate the number of times this component fails during this period is N. The failure rate ($\lambda$) is approximately equal to $N/\text{TTF}$. 
Step 11: Evaluate the total down time of the load point. This will be equal to the total down time (repair time) of the component. Then the average repair time is $\text{TTR}/N$ a similar manner calculated the switching time is $\text{TTS}/N$. The total down time is the summation of the switching time and the repair time.

Step 12: The annual unavailability ($U$) is given by product $\lambda r$. By this, the artificial history of each component in the station is obtained.

Step 13: Separate the component first order, second order and third order events.

Step 14: Calculate the reliability indices such as outage rate, average outage duration, failure rate, repair rate.

4.7 METHODOLOGY AND TEST CASE STUDY

Minimal cut-set method is used mainly to estimate the sub-station reliability based on the principle of continuity of service. A minimal cut-set is a set of sub-station components which, when all fail, results in loss of continuity of service for the sub-station but when any one component of the set has not failed, does not cause sub-station failure. The failure modes of mechanism can be separated into passive and active failures. The sequence of active and passive failures is shown in below Figure 4.3.

![Fig.4.3 Sequences for Representing Active and Passive Failures](Image)

A component failure mode that does not cause the tripping of the circuit breakers, and therefore, does not have an impact on the remaining healthy components is classified as a passive failure. In contrast, a component failure mode that causes the tripping of the main protection breakers and therefore requires the removal of other healthy components is defined as an active failure. There are two major components present in the most of the
sub-station preparations. Direct outage of a particular feeder in the sub-station is the type one and other type of section can basis an indirect failure to an exacting feeder.

The component typically requires that an additional component fails prior to cause a direct outage of an exacting feeder. Analytical reliability models range from extremely simple to exceptionally complex models in the sub-station arrangement. The sub-station models are not as rationally attractive as composite models, but have key reward including smaller quantity of data requirements, more rapidly data entry and quicker execution time.

Uncomplicated models, but they do not offer as much as comprehensive information and can be a smaller amount than complete models. Due to this cause complete sub-station reliability modeling is obtainable in this paper. In this paper more assessment has been performed taking into account of faults and components failures. The various failure modes of the basic and non-basic minimal cut-sets considered here are given below.

1) First order entirety failure (Including both inactive and active failure)
2) First order active failure;
3) First order active failure with stuck condition of CB
4) Second order overlapping failure event involving two sub-station components.

4.7.1 Methodology implementation to Single bus configuration test case study

The previously anticipated approach was applied to three different sub-station configurations given in section 4.4 are computed with minimal cut set method and its MCS technique. The components modelled in the example will be transformers, bus bars and breakers. Two lines, either of which supplies the total load and the need of the reliability of each arrangement will be evaluated using the minimal cut-set method and MCS technique based on the continuity of service. From the single bus sub-station configuration is represented in terms of RBD shown in Figure 4.4 [31].

To model how a cut-set method would work for the single bus arrangement pattern has to be redrawn in below Figure 4.4, then the first order active failure modes are B₁, B₂, B₃, and B₄. To demonstrate this let us consider a fault occurs on L₁ and breaker B₁ fails to open, breaker B₂ will operate, thus breaking station continuity. Every minimal cut-set can be represented as a parallel collection of components and the different type of cut-sets jointly can be represents as a series arrangement shown in Figure 4.5.
Similarly, the same operation as that of B₂-B₄ is also for active failure modes. The component reliability data is shown in Table 4.1. The first order total failure of the system is that the failure of either bus i.e. is the high voltage bus and the low voltage bus. The failure of any one bus interrupts the continuity of the service. Therefore, the first order active failure plus stuck breakers (p=1) conditions are T₁+B₃ stuck and T₂+B₄ stuck.

\[ \lambda_s = 0.015 + 0.015 = 0.030 \]
\[ \lambda_t = 0.001 + 0.001 = 0.002. \]

B₁+B₂, B₃+B₄, B₃+T₂, B₄+T₁ and T₁+T₂ are the overlapping failures as shown in Figure 4.10. Parallel components represented as a combination of components failures and the failure rate can be each of paralleled group found by the below empirical equation as follow:

\[ \lambda_{pp} = \frac{\lambda_1 e^{-\lambda_1 t} + \lambda_2 e^{-\lambda_2 t} - (\lambda_1 + \lambda_2) e^{-\lambda_1 t - \lambda_2 t}}{e^{-\lambda_1 t} + e^{-\lambda_2 t} - e^{-(\lambda_1 + \lambda_2) t}} \]  \hspace{1cm} (4.6)

\[ \lambda_{B1+B2} = \lambda_{B3+B4} = 7.1357 \times 10^{-5} \]
\[ \lambda_{B3+T2} = \lambda_{B4+T1} = 1.772 \times 10^{-4} \]
\[ \lambda_{T1+T2} = 4.401 \times 10^{-4} \]

The sums of paralleled failure rates are equal to total failure rate of the system

\[ \lambda_o = 2 \times (1.772 \times 10^{-4}) + 2 \times (7.1357 \times 10^{-5}) + 4.401 \times 10^{-4} \]
\[ = 9.372 \times 10^{-4} \text{ f/yr} \]

Therefore the overall sub-station failure rate is the sum of all individual failure modes.
i.e calculated as follows as.

\[ \lambda = \lambda_t + \lambda_a + \lambda_s + \lambda_o = 0.0489 \text{ f/yr} \]

Similarly the annual outage time for the sub-station is

\[ U = U_t + U_a + U_s + U_o = 3.53 \text{ min} \]

\[ r = \frac{U}{\lambda} = 72.147 \text{ min/yr} \]

Total reliability indices for the three sub-station configurations with 100 percent reliable transmission lines are listed in Table 4.2 (Ignoring Line Failure)

### Table 4.1 Sub-Station Component Reliability Data

<table>
<thead>
<tr>
<th>Component</th>
<th>( \lambda_t ) (/yr)</th>
<th>( \lambda_a ) (/yr)</th>
<th>( \lambda_m ) (/yr)</th>
<th>MTTR (hrs)</th>
<th>MTTM (hrs)</th>
<th>( P_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td>0.046</td>
<td>0.046</td>
<td>0.5</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Transformer</td>
<td>0.015</td>
<td>0.015</td>
<td>1.0</td>
<td>15</td>
<td>120</td>
<td>0.05</td>
</tr>
<tr>
<td>Breaker</td>
<td>0.006</td>
<td>0.004</td>
<td>1.0</td>
<td>4</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>Bus bar</td>
<td>0.001</td>
<td>0.001</td>
<td>0.5</td>
<td>2</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.2: Sub-Station Reliability Indices

<table>
<thead>
<tr>
<th>Arrangement</th>
<th>Minimal Cut Set Method</th>
<th>( \lambda ) (f/yr)</th>
<th>r (min)</th>
<th>U(min/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single bus configuration</td>
<td></td>
<td>0.0489</td>
<td>72.147</td>
<td>3.530</td>
</tr>
<tr>
<td>Sectionalized bus configuration</td>
<td></td>
<td>0.04462</td>
<td>71.721</td>
<td>3.159</td>
</tr>
<tr>
<td>One and half breaker</td>
<td></td>
<td>0.00301</td>
<td>185.82</td>
<td>0.559</td>
</tr>
</tbody>
</table>

It shows that the results obtained in Table 4.2 also improve the sub-station reliability and reduce the annual outage for three configurations. The one and half breaker scheme has more reliable scheme than the single bus configuration is remains the worst.

The MCS results for line, Transformer, breaker and Bus bar are shown in Table 4.3 and the derived results are shown in Table 4.4. The comparative performance of sub-station using Minimal cut-set and MCS technique is shown in Table 4.5.

### 4.7.2 Methodology implementation for MCS

#### Table 4.3 Monte Carlo Simulation Input Data

<table>
<thead>
<tr>
<th>Component</th>
<th>Total failure rate ( \lambda_t ) (/yr)</th>
<th>Active failure rate ( \lambda_a ) (/yr)</th>
<th>MTTR (hrs)</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td>0.0475</td>
<td>0.0475</td>
<td>7.7457</td>
<td>138</td>
</tr>
<tr>
<td>Transformer</td>
<td>0.0141</td>
<td>0.0141</td>
<td>15.9147</td>
<td>300</td>
</tr>
<tr>
<td>Breaker</td>
<td>0.0059</td>
<td>0.004</td>
<td>4.0484</td>
<td>1700</td>
</tr>
<tr>
<td>Bus bar</td>
<td>0.0011</td>
<td>0.0011</td>
<td>1.7791</td>
<td>10000</td>
</tr>
</tbody>
</table>
Table 4.4 Monte Carlo Simulation Output Data

<table>
<thead>
<tr>
<th>Configuration</th>
<th>$\lambda_t$ (/yr)</th>
<th>$r$ (min)</th>
<th>$U$ (min/Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single bus</td>
<td>0.04719</td>
<td>71.8504</td>
<td>3.39</td>
</tr>
<tr>
<td>Sectionalized bus configuration</td>
<td>0.042235</td>
<td>71.5629</td>
<td>3.022</td>
</tr>
<tr>
<td>One and half breaker</td>
<td>0.00339</td>
<td>157.8098</td>
<td>0.535</td>
</tr>
</tbody>
</table>

Table 4.5 Comparison of Analytical and Monte Carlo Simulation

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Analytical Method</th>
<th>Monte Carlo Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failure rate (f/yr)</td>
<td>$r$ (min)</td>
</tr>
<tr>
<td>Single bus configuration</td>
<td>0.0489</td>
<td>72.147</td>
</tr>
<tr>
<td>Sectionalized bus configuration</td>
<td>0.04462</td>
<td>71.72</td>
</tr>
<tr>
<td>One and half breaker</td>
<td>0.00301</td>
<td>185.8</td>
</tr>
</tbody>
</table>

### 4.8 REALTIME CASE STUDY OF 220kV SUB-STATION AT NELLORE

The 220kV/132kV/33kV sub-station is located in Nellore-Podalakur road in a vast area of about 63 acres of land and is 7kms from Nellore town centre. It is capable of delivering 300MW of power requirement of Nellore district. It consists of 3 Nos. of 220 kV/ 132kV power transformers of capacity of each 100 MVA, 6 Nos. of 220 kV feeders, 2 Nos. of 132 kV / 33 kV power transformers of 50 MVA, 7 Nos. of 132 kV feeders and 8 Nos. of 33 kV feeders to meet the above load catered over the district.

The Nellore sub-station receive power from the 220 kV Podili sub-station through 220 kV Nellore-Podili circuit I & II double circuit line and one single circuit line from 220 kV Ongole sub-station. The sub-station also connected to 440 kV Manubolu sub-station through 3 no’s 220 kV feeders namely 220 kV Manubolu 1, 2 and 3. The sub-station is also connected through 132 kV Nellore–NTS feeder and through 132 kV Nellore-Manubolu feeder to 400 kV Manubolu sub-station to meet the load demand in Nellore district. The following are the 220 kV feeders available at Nellore sub-station.

The following are the 220kV feeders available in 220kV Nellore sub-station.
- 220kV Podili-Nellore circuit no. I from Podili sub-station.
- 220kV Podili –Nellore circuit no. II from Podili sub-station
- 220kV Ongole-Nellore single circuit from Ongole sub-station.
- 220kV Nellore-Maubolu circuit –I from 400kv sub-station Manubolu.
- 220kV Nellore-Manubolu circuit-II from 400kv sub-station Manubolu
- 220kV Nellore-Manubolu circuit-III from 400kv sub-station Manubolu

Figure 4.6 220kV/132kV/33kV sub-station is located in Nellore

We are considering the two input lines of Podili-I and Podili-II and the bus configuration used in this sub-station is single bus configuration with three breakers. The input data of this Nellore sub-station is collected (appended in Appendix-IV) from the APTRANs Co. available records and consolidated into Table 4.6 shown below. This data being applied to various configurations as discussed earlier in the test system for reliability indices evaluation. The switching time for the breaker is considered as 1 hour and there is no auto reclosing of breaker in this sub-station and the probability of stuck breaker condition is considered as $P_c=0.0045$. The model calculation for line is given below.
4.8.1 Model calculations

The model calculation of the Podili line-II is shown below:

The Maintenance duration of Podili line-II = 31.900 hrs
Number of Maintenance actions = 14
The interruption duration for two years = 20.54993 hrs
Number of failures for two years = 20
The operating time for two years = 17520 - 20.54993 = 17500.46 hrs

\[ MTTR = \frac{no.\ of\ failures}{Total\ interruption\ time} \]
\[ r = \frac{20.54993}{20} = 1.01\ hrs \]
\[ \mu = \frac{1}{r} = 1.0 \]

\[ MTTF = \frac{sum\ of\ operating\ time}{no.\ of\ failures} \]
\[ m = \frac{17500.46}{20} = 437.22 \]
\[ \lambda = \frac{1}{m} = \frac{1}{437.22} = 1.14 \times 10^{-3}\ f/yr \]

\[ MTTM = \frac{Maintenance\ time}{No.\ of\ maintenance\ actions} + MTTR \]
\[ MTTM = \frac{31.9}{14} + 1 \]
\[ = 3.0525\ hrs \]

The model calculation of the Podili line - I is shown below

The Maintenance duration of Podili line – I = 38.76 hrs
Number of Maintenance actions = 13
The interruption duration for two years = 21.53367 hrs
Number of failures for two years = 14
The operating time for two years = 17520 - 21.53667 = 17498.4633 hrs
\[ m = \frac{17498.4633}{14} = 1249.89 \]
\[ \lambda = \frac{1}{m} = \frac{1}{1249.89} = 8.0007 \times 10^{-4}\ f/yr \]

\[ MTTM = \frac{38.76}{13} + 1.538 = 4.5195\ hrs \]

Table 4.6 Input Data of 220KV Sub-Station Using Minimal Cut Set Method

<table>
<thead>
<tr>
<th>Component</th>
<th>Total failure rate (λt/yr)</th>
<th>Active failure rate (λa/yr)</th>
<th>MTTR (hrs)</th>
<th>Maintenance failure rate (λm/years)</th>
<th>MTTM (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td>0.00114</td>
<td>0.00114</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Transformer</td>
<td>0.00022</td>
<td>0.00022</td>
<td>5.6</td>
<td>0.5</td>
<td>17.511</td>
</tr>
<tr>
<td>Breaker</td>
<td>0.00022</td>
<td>0.00014</td>
<td>1</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>Bus bar</td>
<td>0.0001</td>
<td>0.0001</td>
<td>2</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>
4.8.2 Results Obtained Using Minimal Cut Set Method for Nellore sub-station

Table 4.7 Output Data of 220KV Sub-Station Using Minimal Cut Set Method

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Failure rate $\lambda$ (/yr)</th>
<th>$r$ (min)</th>
<th>$U$ (min/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single bus</td>
<td>1.2004 x10-3</td>
<td>69.998</td>
<td>8.403 x 10-2</td>
</tr>
<tr>
<td>Sectionalized bus</td>
<td>9.607678 x10-4</td>
<td>66.246</td>
<td>6.36 x 10-2</td>
</tr>
<tr>
<td>One and half breaker</td>
<td>1.0217 x 10-4</td>
<td>118.7975</td>
<td>1.21 x 10-2</td>
</tr>
<tr>
<td>Single bus with 3 breakers</td>
<td>1.703 x 10-3</td>
<td>67.0588</td>
<td>1.14 x 10-1</td>
</tr>
</tbody>
</table>

4.8.3 Results Obtained Using Monte Carlo Simulation

Table 4.8 Input Data of Monte Carlo Simulation

<table>
<thead>
<tr>
<th>Component</th>
<th>Total failure rate $\lambda$ (/yr)</th>
<th>Active failure rate $\lambda_a$ (/yr)</th>
<th>MTTR (hrs)</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.9580</td>
<td>8000</td>
</tr>
<tr>
<td>Transformer</td>
<td>0.0002119</td>
<td>0.0002119</td>
<td>5.8117</td>
<td>60000</td>
</tr>
<tr>
<td>Breaker</td>
<td>0.0002119</td>
<td>0.0001349</td>
<td>1.0378</td>
<td>60000</td>
</tr>
<tr>
<td>Busbar</td>
<td>0.00010439</td>
<td>0.00010439</td>
<td>1.9159</td>
<td>100000</td>
</tr>
</tbody>
</table>

Table 4.9 Output Data of Monte Carlo Simulation

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Failure rate $\lambda$ (/yr)</th>
<th>$r$ (min)</th>
<th>$U$ (min/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single bus</td>
<td>1.172 x 10^{-3}</td>
<td>69.78</td>
<td>8.18 x 10^{-2}</td>
</tr>
<tr>
<td>Sectionalized bus</td>
<td>9.3379 x 10^{-4}</td>
<td>66.1462</td>
<td>6.176 x 10^{-2}</td>
</tr>
<tr>
<td>One and half breaker</td>
<td>1.065 x 10^{-4}</td>
<td>113.8549</td>
<td>1.213 x 10^{-2}</td>
</tr>
<tr>
<td>Single bus with 3 breakers</td>
<td>1.65414 x 10^{-3}</td>
<td>66.9367</td>
<td>1.107 x 10^{-1}</td>
</tr>
</tbody>
</table>

Table 4.10 Comparison of Cut-set Method and Monte Carlo Simulation

<table>
<thead>
<tr>
<th>S. No</th>
<th>Configuration</th>
<th>Cut Set Method</th>
<th>Monte Carlo Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\lambda$ (f/yr)</td>
<td>$r$ (min)</td>
<td>$U$ (min/yr)</td>
</tr>
<tr>
<td>1</td>
<td>Single bus configuration</td>
<td>1.20x10^{-3}</td>
<td>69.99</td>
</tr>
<tr>
<td>2</td>
<td>Sectionalized bus</td>
<td>9.60x10^{-4}</td>
<td>66.24</td>
</tr>
<tr>
<td>3</td>
<td>One and half breaker</td>
<td>1.02x10^{-4}</td>
<td>118.79</td>
</tr>
<tr>
<td>4</td>
<td>Single bus with 3 breakers</td>
<td>1.70x10^{-3}</td>
<td>67.05</td>
</tr>
</tbody>
</table>

4.9 RESULTS AND DISCUSSIONS

Sequential method (Monte Carlo simulation) is used to assess sub-station reliability. The results are compared with the results obtained from analytical method.
Both the techniques provide converging information to design sub-station. The analytical approach evaluates the indices by a set of mathematical equations where the procedure is simple. The simulation technique evaluates the reliability indices by series of trials and therefore the procedure is more complicated and requires a longer computational time. A MATLAB program is developed to find the sub-station indices for various configurations. From the Tables 4.5 and Table 4.10, results concludes that the single bus configuration has the higher unavailability than the one and half breaker configuration are also shown in Figure 4.7.

![Bar Chart Comparision of Sub-stations Configurations](image)

**Figure 4.7 Pictorial Representations of Sub-Stations Configurations**

### 4.10 SUMMARY OF THIS CHAPTER

In this chapter, brief theoretical backdrop of various sub-station configuration and their merits and demerits are presented. Also presents the arithmetical, graphical and simulation methods of assessing the sub-stations described. A Matlab based programme is developed for the computation of reliability indices for various configuration of sub-station is performed. The results are compared with Monte Carlo simulation technique for test case and a real time case study.

The next chapter describes the distribution system reliability assessment for both the rural and urban real time feeder considering the diversity factor and load factor.