# “Reliability Analysis of Bangladesh Power System.”

A report submitted to department of Electrical & Electronics Engineering, BRAC University in fulfillment of the requirements for thesis work for undergraduate program.

**BRAC University, Dhaka, Bangladesh**

# Declaration

We do hereby declare that our thesis on "Reliability Assessment of Bangladesh Power System" is submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the Bachelor of Science in Electrical and Electronics Engineering. This is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

Date: 13.12.12

Supervisor

Nahid Al Masood

___________________________

FARZANA YASMIN

___________________________

(Students Name)
Student ID: 09221160

SAZEED MOHAMMAD IBNE SAMAD

___________________________

(Students Name)
Student ID: 09221144

MD SAFAT SAMIR HAQUE

___________________________

(Students Name)
Student ID: 09221131

# Acknowledgement

We would like to thank our supervisor Mr. Nahid-Al-Masood, Assistant Professor, EEE, BUET. We are honored to have been under his guidance and he has helped us in every way a student can be helped. He arranged all the facilities and the necessary supports, which were indispensable for our work.

# Abstract

This paper presents reliability analysis techniques basically the "Recursive Technique" which are applied in distribution system planning studies and operation. Reliability of distribution systems is an important issue in power engineering for both utilities and customers. Reliability is a key issue in the design and operation of electric power distribution systems and load. Reliability analysis of distribution systems has been the subject of many recent papers and the modeling and evaluation techniques have improved considerably.

# TABLE OF CONTENTS

# Table List



# Figure List

# CHAPTER 01

## INTRODUCTION

## 1.1 Power System Reliability:

The primary function of a power system is to provide electrical energy to its customers as economically as possible with an acceptable degree of quality. Reliability of power supply is one of the features of power quality. The two constraints of economics and reliability are competitive because increased reliability of supply generally requires increased capital investment. These two constraints are balanced in many different ways in different countries and by different utilities, although generally they are all based on various sets of criteria.

A wide range of related measures or indicators can be determined using probability theory. A single all-purpose formula or technique does not exist. The approaches and their respective mathematical expressions depend on the defined problem and determined assumptions. Several assumptions must be made in practical applications of probability and statistical theory. The validity of the analysis is directly related to the validity of the model used to represent the system. Actual failure distributions rarely completely fit the analytical descriptions used in the analysis, and care must be taken to ensure that significant errors are not introduced through oversimplification of a problem.

The most important aspect of good modeling and analysis is to have a complete understanding of the engineering implications of the system. No amount of probability theory can circumvent this important engineering aspect.

There are two main categories of evaluation techniques: (i) analytical and (ii) simulation.

Analytical techniques represent the system by a mathematical model and evaluate the measures or indicators from this model using mathematical solutions. Simulation techniques estimate the measures or indicators by simulating the actual process and random behavior of the system.

Electric energy is produced and delivered practically on real time and there is no convenient method to readily store it. This makes necessary to maintain a continuous and almost instantaneous balance between production and consumption of electricity in power systems. A way to ensure energy balance is by keeping some margin of generation above the expected demand load, so the system can deal with unexpected mismatches between supply and demand leading to power shortages. Generation margins are attained by providing stand-by plant capacity and they represent reserves of generation capacity that can be rapidly utilized in case of a supply shortage. Utilities have traditionally determined reserve requirements using working rules and more recently probabilistic techniques. They estimate a reasonable amount of capacity to be reserved and kept available, so that credible contingencies will not cause a failure of supply. Nevertheless, even when analytical methods are used, a final decision regarding reserve levels depends on the operator's judgment of what is the acceptable risk of system failure. In fact, although it is not always made explicit, this decision is a trade-off between the additional reliability offered to customers and the cost of keeping the reserves available. The risk of shortages in generation can be reduced by increasing the investment in generation and the operating cost of keeping installed capacity available. However, overinvestment and high operating costs would be ultimately reflected in the bill paid by the customer. On the other hand, underinvestment and tight generation margins would lead to a low reliability offered to customers. In general, economic efficiency requires that the benefits of improvements in reliability be weighed against the costs of providing additional reliability. Accordingly, the main shortcoming of using quantity constrained methods to estimate reserve requirements is that economic criteria are not explicitly included in the decision-making process.

## 1.2 Necessity of Reliability Analysis:

**• Improving system reliability:**

In a developing country like Bangladesh, we are already facing huge amount of load shedding. There have been a number of reforms in the power sector in Bangladesh. But government reforms failed to bring desired improvements in the power sector. On the other hand, we are loosing transformers and generators for security violation or for some overload problem, or a bus voltage outside the limit. It means that if we aren't able to maintain our existing generator or network properly It might be a great loss of our valuable property. With the help of reliability analysis we will be able to know the ranking by which helps us to know the amount of losses for any fault in bus, generator, transformer and transmission line. So we must have to be aware to solve the problem before they arise.

**• For secured operation:**

As we can determine early by using this method that which components are risky and have probability to fail in near future so we can be more aware about those components and can take additional steps of maintenance to protect it. That means, we can operate components of the power system more safely and effectively utilizing this analysis.

**• For future planning and expansion:**

If fault occurs in any transmission line then the load flows through the rest of the lines in the system and this process will increase pressure on those lines. To avoid such problem we can run reliability analysis and design a parallel line and avoid this kind of problem. Thus reliability analysis helps us to expand transmission line and improve future power system.

## 1.3 Definition of Reliability:

Reliability is the probability of a device or system performing its purpose adequately for the period of time intended under the operating conditions encountered.

## 1.4 Four basic components of Reliability:

- Probability
- Adequate performance
- Time
- Operating condition

## 1.5 Definition of Probability:

Probability is the relative frequency with which an event occurs in a series of many trails or observations under constant conditions.

Probability, P, of any particular event occurring= lim (f/n)

Where f = number of occurrences of a particular outcome

And n = number of times an experiment is repeated.

## 1.6 Classification of Probability:

### 1.6.1 Independent probability:

If two events, *A* and *B* are **Independent** then the joint probability is

$$P(A \text{ and } B)=P(A \cap B)=P(A)P(B) \qquad (1)$$

for example, if two coins are flipped the chance of both being heads is P(1/2 and 1/2)=P(1/2) P(1/2)= ¼.

### 1.6.2 Mutually exclusive:

If either event *A* or event *B* or both events occur on a single performance of an experiment this is called the union of the events *A* and *B* denoted as P(A U b). If two events are **Mutually Exclusive** then the probability of either occurring is

$$P(A \text{ or } B) = P(A \cup B)=P(A)+P(B) \qquad (2)$$

For example, the chance of rolling a 1 or 2 on a six-sided die is
P(1 or 2)=P(1) +P(2)= 1/6.

### 1.6.3 Not mutually exclusive:

If the events are not mutually exclusive then
P(A or B)=P(A)+P(B)-P(A and B) (3)

For example, when drawing a single card at random from a regular deck of cards, the chance of getting a heart or a face card (J,Q,K) (or one that is both) isP(13/52or12/52)=P(13/52)+P(12/52)-P(3/52)=11/26, because of the 52 cards of a deck 13 are hearts, 12 are face cards, and 3 are both: here the possibilities included in the "3 that are both" are included in each of the "13 hearts" and the "12 face cards" but should only be counted once.

### 1.6.4 Conditional probability:

**Conditional probability** is the probability of some event *A*, given the occurrence of some other event *B*. Conditional probability is written P(A|B), and is read "the probability of *A*, given *B*". It is defined by

$$P(A|B)=P(A\cap B) / P(B) \qquad (4)$$

If P(B)=0then P(A|B)is formally undefined by this expression. However, it is possible to define a conditional probability for some zero-probability events using a σ algebra of such events (such as those arising from a continuous random variable).

For example, in a bag of 2 red balls and 2 blue balls (4 balls in total), the probability of taking a red ball is 1/2; however, when taking a second ball, the probability of it being either a red ball or a blue ball depends on the ball previously taken, such as, if a red ball was taken, the probability of picking a red ball again would be 1/3since only 1 red and 2 blue balls would have been remaining.

## 1.7 Summary of probabilities:

| Event | Probability |
|---|---|
| A not A | P(A)€[0,1] |
| A or B | $P(A^c)=1-P(A)$ |
| | $P(AUB)=P(A)+P(B)-P(A\cap B)$ |
| | $P(AUB)=P(A)+P(B)$ if A & B are mutually exclusive |
| A and B | $P(A\cap B)=P(A\|B)P(B)+P(B\|A)P(A)$ |
| | $P(A\cap B)+P(A)P(B)$ if A&B are independent |
| A given B | $P(A\|B)=P(A\cap B)/P(B)$ |

## 1.8 Quantification of LOSS due to forms of INTERRUPTION:

Interruption cost components are:

**Table 1.1**

| Residential Consumers | Industrial Consumers | Commercial Consumers |
|---|---|---|
| Damage of electrical appliances | Damage of electrical appliances | Damage of electrical appliances |
| Cost of alternative electrical sources | Cost of alternative electrical sources | Cost of alternative electrical sources |
| Damage of perishable goods | Damage of raw materials | Damage of perishable goods |
| Loss due to inconvenience | Additional wages | Additional wages |
| | | Loss due to inconvenience |

# CHAPTER 02

## NETWORK MODELING & BASIC TERMINOLOGY

**2.1 Series system:** The components in a set are said to be in series from the reliability point of view if they all must work for system success or only one need to fail for system failure.

Consider a system where two independent components A & B are in series,

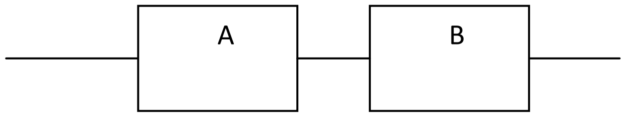


**Figure 2.1**:series system

Let, $R_A$=reliability of component A or probability of successful operation of A

$R_{B=}$ reliability of B or probability of successful operation of B

$Q_A$=unreliability of component A or probability of failure operation of A

$Q_B$= unreliability of component B or probability of failure operation of B

$R_A + Q_A = 1$ (5)

$R_B + Q_B = 1$ (6)

Let, series system reliability =$R_S$

Since, A& B must be successful simultaneously for system success,

$R_S = R_A . R_B$ (7)

System unreliability $Q_S = 1 - R_S$

$= 1. R_A . R_B$

$=1-(1- Q_A).(1- Q_B)$

$= Q_A + Q_B - Q_A . Q_B$ (8)

If 'n' number of components are in series system reliability,

$R_S=R_1,R_2,R_3….Rn$

$R_S = \prod Ri$ (9)

System unreliability $Qs = 1 - Rs = 1 - \prod Ri$ (10)

**2.2 Parallel system:** The components in a set are said to be in parallel from the reliability point of view if only one need to be successful for system success or all must fail for system failure.

Consider a system where two independent components A & B are in parallel,

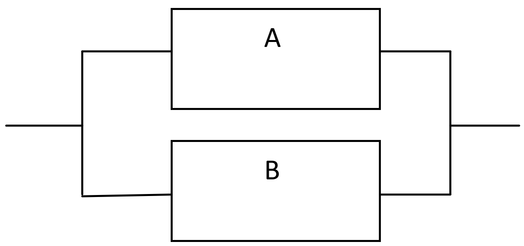


**Figure 2.2**: parallel system

Let, $R_A$=reliability of component A or probability of successful operation of A

$R_{B=}$ reliability of B or probability of successful operation of B

$Q_A$=unreliability of component A or probability of failure operation of A

$Q_B$= unreliability of component B or probability of failure operation of B

Let, parallel system reliability =$R_p$

Since, A& B must be faill simultaneously for system failure,

System unreliability $Q_p = Q_A.Q_B$ (6)

System relaibility $Rp = 1. Qp$

$=1- Q_A.Q_B$

$=1-(1- R_A).(1- R_B)$

$$= R_A + R_B - R_A . R_B \qquad (11)$$

If ‘n’ number of components are in parallel system reliability

System unreliability $Qs = \prod Qi$ (12)

System unreliability $Rp = 1 - Qp = 1 - \prod Qi$ (13)

## 2.3 SERIES-PARALLEL SYSTEM

Principle used to reduce sequentially the complicated configuration by combining appropriate series and parallel branches until a single equivalent element remains or formed.

This equivalent element then represents the reliability or unreliability of the original configuration.

As for an example,

1. If a system of components 1, 2, 3 and 4 are in series with each other and in parallel to a series set of components of 5, 6, 7 and 8...

Steps:

i. Combine the series components 1,2,3 and 4 to form an equivalent component 9.

   R(9) = R(1).R(2).R(3).R(4)

ii. Combine components 5,6,7 and 8 to form equivalent component 10.

   R(10) = R(5).R(6).R(7).R(8)

iii. Combine parallel equivalent components 9 and 10 to form component 11.

   R(11) = 1- Q(9).Q(10)

   = 1- (1-R(9)). (1-R(10))

   = R(9)+R(10)-R(9).R(10)

2. A system of parallel components 3 and 4 are in series with a series system of 1 and 2. This entire setup is then in parallel to a component 5...

Steps:

i. Combine component 3 and 4 to form the equivalent component 6.

$$Q(6) = Q(3).\, Q(4)$$

ii. Combine component 1 and 2 with the equivalent component 6 to form a new equivalent of component 7.

$$Q(7) = 1- (1-Q(1)).(1-Q(2)).(1-Q(6))$$

$$= Q(1)+Q(2)+Q(6)-Q(1).Q(2)-Q(6).Q(1)+Q(1).Q(2).Q(6)$$

iii. Combine component 5 and 7 to form another equivalent component of 8

$$Q(8) = Q(5).Q(7)$$

## 2.4 REDUNDANT SYSTEM

A system consisting of more than one components and the operation of only one component causes the success of the system is called a Redundant System.

A parallel system is an example of a redundant system and a series system is an example of non-redundant system. A system may be partially redundant or fully redundant.

### 2.5 PARTIALLY REDUNDANT SYSTEM

If for the success of a system, the operation of N number of components are required and the system has M number of components where N<M<2N, then the system is called Partially Redundant System.

## 2.5 <u>BASIC TERMINOLOGY</u>:

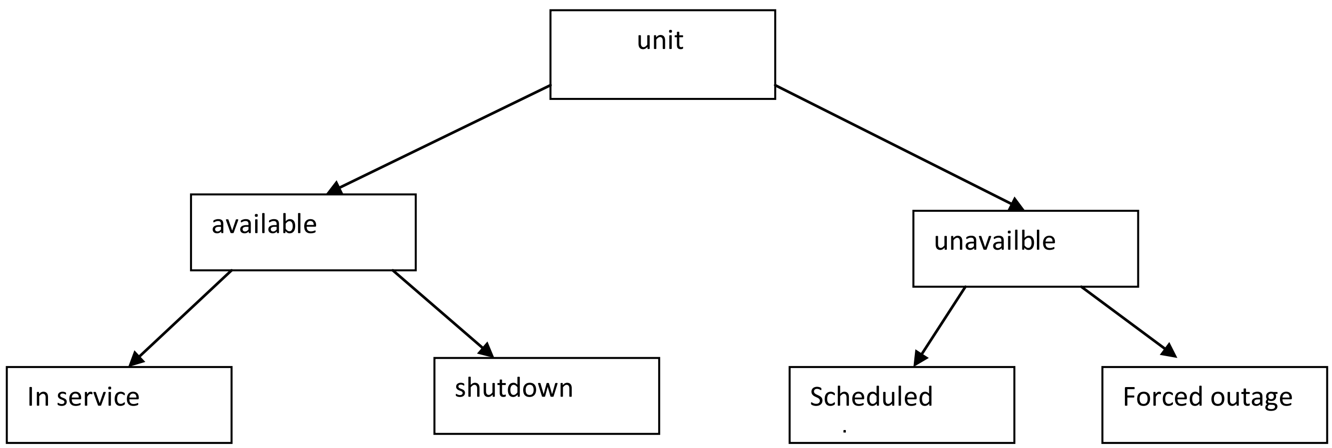


**Figure2.3: Basic Terminology Flow Chart**

**2.5.1 Outage**: the state of a component when it is not available to perform its intended function. A component outage may or may not cause on interruption of service to custom depending on system configuration.

**2.5.2 Load Factor:** It is the ratio of the average load over a period over the peak load occurring in that period.

Load factor = (average load over a period)/(peak load occurring in that period)

**2.5.3 Capacity Factor:** It is the ratio of the average load on a generating unit for a period of time over the capacity of the unit.

Capacity factor = (average load on a generating unit for a period of time)/(capacity of unit)

= (total energy produced by the unit)/(perfect output with 100% load factor)

**2.5.4 Planned or scheduled outage:** A loss of electric power when a component is deliberate ly taken out of service for preventive maintenance or repair.

**2.5.5 Forced Outage**: An outage that results from a component taken out of service automatically or manually because of improper operation of the equipment or human error.

FOR = (Forced Outage Hours) / (In Service Hours+ Forced Outage Hours)

**2.5.6 Outage Rate**: The mean number of outage per unit exposure time per component.

**2.5.7 Available capacity:** it is the resultant capacity or the remains of the actually capacity after the losses due to forced outage capacity and scheduled outage capacity.

AC=IC-FOC-SC (14)

Where

AC= available capacity

IC = installed capacity = $\sum_i Ci$

FOC= forced outage capacity

SC= scheduled outage capacity

# CHAPTER 03

## RELIABILITY ASSESSMENT

## 3.1. Power systems reliability adequacy assessment

Reliability assessment of real size electrical power systems is a complex problem. The historical reasons for this complexity are the enormous number of components that this type of systems possesses, the distinctive ways that these components may fail, and the singularity of the system operation. As a matter of fact there are several ways to produce electricity, each one with its own characteristics. Moreover in some of these generators there is an uncertainty associated to the availability of the primary source of energy. Combined to these facts, the power flow through the electric network obeys to the 1st and 2nd Kirchhoff laws, unlike the common transportation problem, which has only to verify the 1st Kirchhoff law, and, to maintain the stability, the system power production must always sequel the losses in the electric grid plus the randomness of the customer demand. Therefore understanding how the electric power systems works is essential to assess its reliability. Taking into account the previous mentioned facts, it is usual to divide the electric power systems in their main functional zones. These are:

• Generation;

• Composite generation/transmission;

• Distribution.

This division was first proposed in introducing the concept of hierarchical levels. The hierarchical level one, HLI, refers to generation facilities and their ability to supply the system demand; the hierarchical level two, HLII, refers to the composite generation/transmission systems and its capacity to deliver energy to the bulk supply points; the hierarchical level three, HLIII, refers to the complete system including distribution and its aptitude to assure the power and the energy demand of the individual consumers.

This partition allowed the development of specific techniques to quantify the reliability ,according to the zone characteristics and the reliability study in question. For instance, one of the traditional reliability studies is the adequacy of the generation capacity. In this particular study it is frequent to ignore the influence of the network and to aggregate all of the system demand in one single bus powered by all system plants. These simplifications allow to assess the reliability of the power system generation subset and to draw conclusions on whether is necessary the construction of new power plants to enhance the security of supply. However, if the transmission system is not properly sized, a large amount of costumers may not be supplied, even though the generation subset is considered reliable. Therefore care must be taken in the application of a specific technique because the results provided are only valid in the scope of the problem formulation and its simplifications .Nowadays we witness the progressive deregulation of the electric sector. In the past, utilities were vertically oriented, frequently owned and controlled by the governments, comprising power production, transmission and delivery. Hence the planning and operation of the electric power systems were made in a monopolistic scenario and the reliability concerns were basically focused in the security of supply. Scale economics was the rule. The division of these utilities in production, transmission, distribution and commercialization was made to increase competition, to give the electricity consumers the opportunity of choosing their electric provider, and to allow that the future of the electricity power system is in the hands of their agents. Electricity is now treated as a commodity and the concept of consumer is being replaced by the term costumer. Reliability is a responsibility of the system agents (except costumers, obviously), imposed by the market regulator in the form of targets that have to be satisfied or otherwise they will incur in monetary penalties. This fact combined with the increased amount of generation in the distribution subset from intermittent sources, makes more difficult to solve any reliability related problem and HLIII studies are now growing on importance. This thesis addresses the static reserve problem by applying Population Based methods instead of the classical Monte Carlo simulation, namely adopting a special and new technique called Evolutionary Particle Swarm Optimization (EPSO). This problem is included in the HLI type of studies and measures the adequacy of the generating capacity considering future decommissioning of old power plants, the possibility of failure of the ones in service as well as outages due to scheduled maintenance, and the load growth estimates in a long-term horizon. It differs from the operating reserve problem, which evaluates the actual capacity to meet a given load level in a short-term horizon, being the fundamental difference between static and operating reserve, the period of time in study.

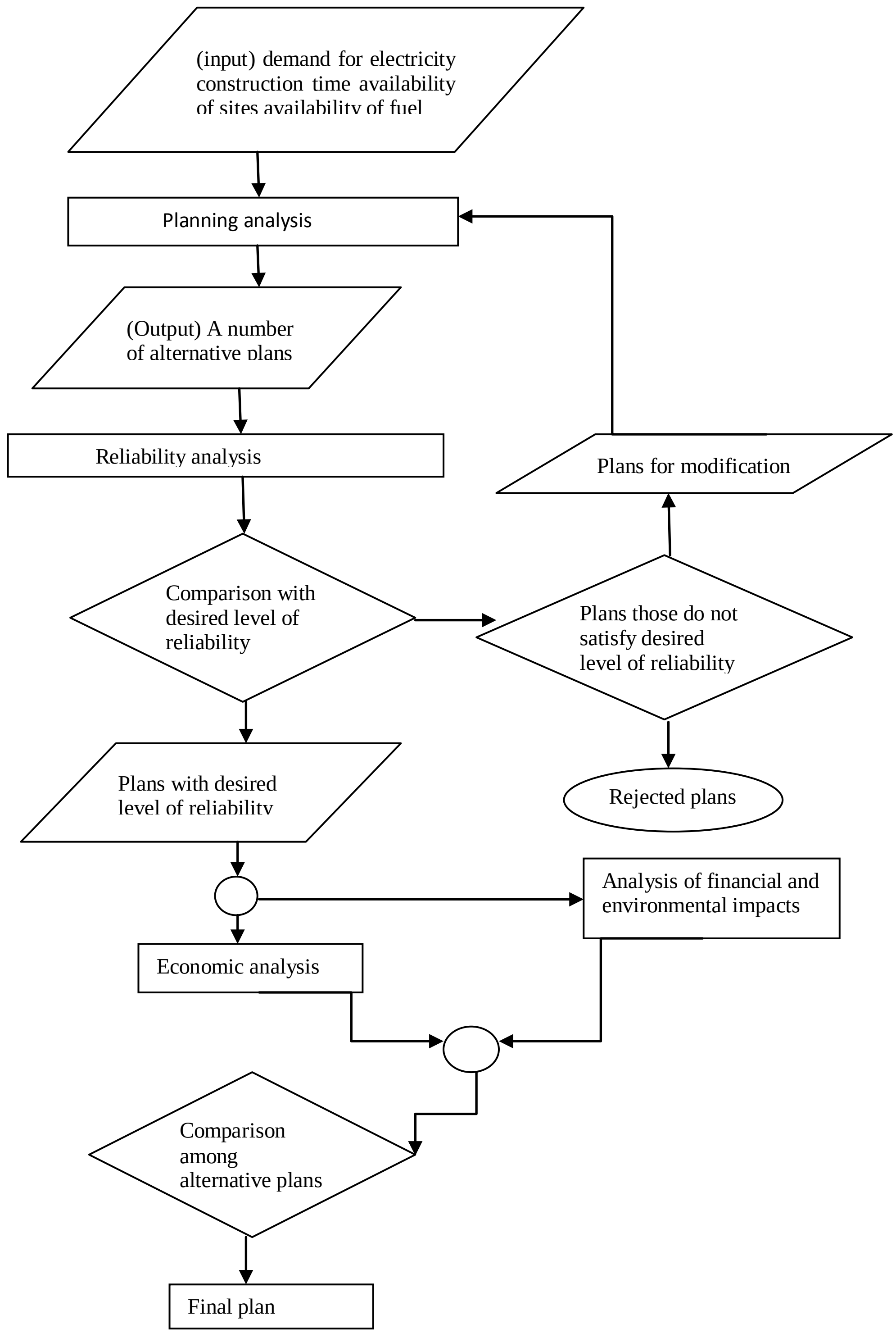


**Figure 3.1** : Generation expansion planning process.

## 3.2 The deterministic approach

Several techniques were developed to tackle the power production adequacy problem. Two approaches can be identified: the deterministic approach and the probabilistic approach. The deterministic approach is a simple method to measure the adequacy of the generating capacity and was widely used in the past by the electric utilities to support their decisions. In a few words, this approach quantifies the electrical power system reliability using a pre-specified rule based on the past experience of the utilities. Therefore, each utility adopted different criteria according to its internal organization and the electrical power system in question. Some of these criteria can be found in the specialized literature or in the utilities handbooks. A typical worldwide known example of this approach is the Planning Generating Capacity, which determines the minimum necessary installed capacity, which is equal to the expected maximum demand plus a fixed percentage of the expected maximum demand. Also it is common to determine the static reserve, which is the difference between the generating capacity and the expected maximum demand, using as reference the capacity of the largest generating unit. As the reader may have noticed, these deterministic criteria are not suitable for the reliability assessment of today's electrical power systems. From an economic point of view, this type of approach leads in most cases to solutions that waste financial resources without apparent justification, as this approach does not consider the stochastic behavior of the electrical power systems or, in other words, disregards the way in which this systems operates, the way that its components fail and the randomness of the system load. The main advantages of this approach are the straightforwardness and robustness of their results since the criteria used by the utilities were usually developed to be on the side of the security of supply. However, due to its limitations, this approach can also lead to under-investment solutions and probably to an unacceptable number of interruptions on load supply. Quantifying the cost of load curtailment is far behind the context of this thesis, but it is easy to understand that the modern society does not tolerate a too frequent failure of the electrical power systems. On the other hand this same society does questions the unjustified investment of large amounts of money to improve power system reliability. Therefore each dollar, euro or another currency invested to improve the system reliability has to be justified. For this reason the deterministic approach is being gradually replaced by probabilistic methods, although several utilities still use the deterministic approach (such as the n-1 criterion), especially in the transmission system.

## 3.3. The probabilistic approach

The probabilistic approach is the soundest way to assess power system reliability since this approach incorporates the fact that there is an uncertainty associated to the events that can occur in this type of systems. The most common types of uncertainties that can be found in the electric

Power systems are:

• The components state;

• The weather state;

• The hydrological resources state;

• The load state.

These types of uncertainties are incorporated in the probabilistic approach using stochastic models. The classical reference is the Markov model, which uses the exponential distribution to represent the duration of the system events, leading to constant transition rates between states .For this reason this type of stochastic model is called the homogeneous Markov model and it is attractive because of its mathematical elegance, allowing the inclusion of different system states and the way that the system evolves from on state to another. The stationary probability, which is the probability of a state occurrence when the Markov process tends to the infinity, or, in other words, the expected value the state probability, is calculated from the transition rates between different states.

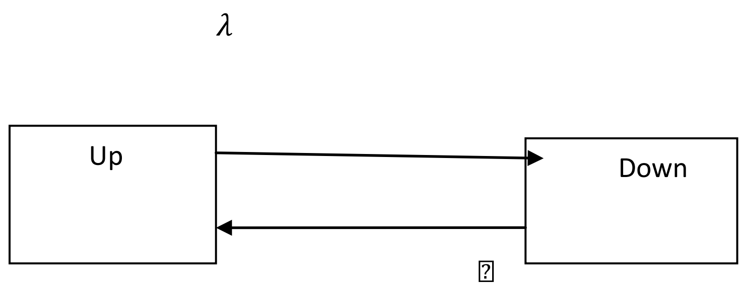


**Figure 3.2:** Two-state Markov model for a system component.

Modeling the durations of system events by the exponential distribution is extremely helpful on a mathematical point of view. However the duration of a specific type of event may not follow this distribution, like the case of the duration of the components repair. Several efforts had been made to conceal this fact and in [6] is presented a technique that enables the use of bell-shaped duration distributions such as the Weibull distributions in the homogeneous Markov models. Later we have discussed the use of others non-exponential distributions in the Markov process. The probabilistic approach is subdivided in analytical methods and simulation methods. The analytical methods describe the system behavior through a mathematical model and assess the system reliability by the numerical calculation of the mean values of the desired system reliability indices. This type of approach was used up to the 80´s basically for its low computational effort. However if a complex system is considered, several assumptions and simplifications have to be made for analytical tractability. Therefore there is a great possibility of these methods to provide unrealistic results.

The simulation methods, often called Monte Carlo simulation methods, estimate the reliability indices by the random sampling of scenarios. These types of methods have the advantage to incorporate multiple system dependencies and characteristics, electrical and non-electrical, which is extremely difficult to represent in the analytical methods.

## 3.4 The analytical methods

In order to evaluate the adequacy of the generation capacity two methods can be clearly defined: the basic probability methods and the frequency and duration (F&D) methods. The first one uses the concept of unavailability, which is the probability of finding the generation unit out of service, to construct, in a recursive manner, the so called Capacity Outage Probability Table. Usually, the unavailability of a generation unit, also known as Forced Outage Rate (FOR), is computed assuming a two state homogeneous Markov model to describe its operation cycle. This model is widely used on this type of study due to its simplicity. For instance, to completely describe generation system reliability it is only necessary to know the mean time to failure and the mean time to repair of the unit in question which can be obtained for analyzing the history of the unit in question. It is also possible to include in this type of study more detailed models to cover the unit's specific operation conditions like peaking service. The calculation of the Capacity Outage Probability Table is no more no less than the enumeration of all system states and their probability of occurrence, each state represented by its outage capacity. The result is the discrete probability distribution of an outage occurrence. For very large systems it is common to truncate this table by rejecting the states which possess a probability inferior to a pre-specified threshold, with the purpose of reducing the computational effort. It has also been found another approximation method to this table by a continuous distribution, valid for very large systems. After obtaining all the entrances of this table a discrete convolution with the system load curve is made to obtain the loss of load risk. To do this mathematical operation first the individual peak loads of the load curve are arranged in a descending order creating the cumulative load model. Then, for each value of the Capacity Outage Probability Table the number of hours, days or weeks is computed (depending on the base of the load diagram) where the load exceeds the capacity in-service. Dividing this number for maximum number hours, days or weeks of the load curve, the probability of the load being higher than the capacity in service is obtained for each particular state. this probability multiplied by the probability of the respective entry in the Capacity Outage Probability Table gives the loss of load probability for this particular state. The next step is to add the individual values of the loss of load probability to acquire the system loss of load probability. It is also possible to compute the loss of load risk multiplying the obtained value by the maximum number of hours, days or weeks of the load diagram. However if the diagram is in an hourly base, for example, the result of the risk of loss of load cannot be extrapolated to another base like days or weeks. The described process can be summarized in the following mathematical formula:

$$\text{LOLP}=\sum_{i}^{n} P(Xi)\, P(L > (Xmax - Xi)) \qquad (15)$$

This method also allows the calculation of energy indices. As a matter of fact the area bellow the load curve gives the total energy consumed in the period of study. Therefore, as it is easy to compute the number of hours, days or weeks that it will be a load curtailment, it is also easy to obtain the expected value of the loss of energy. This approach can also take into account in the indices calculation the effect of scheduled maintenance, the uncertainty in the load forecast and the FOR uncertainty. The indices calculated by the basic probability methods are the expected value of the number of hours in which the load exceeds the generation capacity and the expected value of energy not supplied in a given period of time. The focus of the F&D perspective is to provide indices that indicate the frequency of occurrence of a generation outage and the expected duration of these interruptions. These are the main advantages of the F&D methods. Their main disadvantage is the more complicated mathematical concepts that this type of approach possesses. To apply and to master these types of methods it is crucial to understand the concept of frequency and the concept of state transition. The F&D methods require the knowledge of the transition rates between the states that constitute the chosen homogeneous Markov model. Like the basic probability methods, the reliability indices are calculated through the convolution of the load model and the recursive constructed generation model. The F&D methods can also incorporate the uncertainty on the load forecast. The fundamental development of these types of methods can be found through out this paper/It can also found two different methods to analyze the adequacy of the generation capacity in interconnected systems, which are the Probability Array Method and the Equivalent Assisting Unit Method that can also be formulated in the basic probability approach and in the F&D approach, analyzing the effect of tie line capacity. As it is known, the electric power systems are progressively more interconnected and the effect of adjacent areas in the reliability analysis of the generation capacity cannot be forgotten.

## 3.5 The simulation methods – Monte Carlo

Simulation techniques, often known as Monte Carlo simulation, estimate the reliability indices by simulating the random behavior of the system. There are two major types of Monte Carlo simulation: the non-chronological type and chronological type. In the non-chronological type the samples are obtained by producing “snapshots” of the system state, without any dependence onetime between samples. Alternatively, in the chronological type, a virtual or fictitious clock is set in motion and, with the flow of time, sequences of events are randomly generated, like a “story of the life” of the simulated system. The number of the needed samples for given level of accuracy is independent of the system size(depends on the variance of the variable under estimation), which makes Monte Carlo simulation appropriate to assess the reliability of very large systems. Also, Monte Carlo methods have the advantage to provide information about the variability of the reliability indices as they provide their underlying probability distributions. Quoting “the probability distribution provides both a pictorial representation of the way the indices vary and important information on significant outcomes, which, although they occur very infrequently, can have very serious system effects. These effects, which can easily occur in practice, may be neglected if only average values are available”. Due to the incredible increase of the computational capabilities in the last two decades and the development of variance reduction techniques the Monte Carlo methods are the most commonly used methods for reliability assessment. However, in order to guarantee a certain degree of confidence in the estimates provided by these types of methods, a large number of samples have to be randomly obtained. Furthermore the number of samples needed depends on the system reliability which means that, for very reliable systems, the number of samples necessary to assure that the estimated indices belongs to the pre-specified confidence interval can be extremely large. The Monte Carlo simulation methods can be divided in two approaches: the non-chronological approach and the chronological approach. In the non-chronological approach the system states are randomly sampled without any preoccupation with the chronology of the system operation. A nonchronological system state is obtained by sampling the state of all system components according to their probability of failure. Therefore it cannot model time correlations or sequential events. In the chronological approach, the up and down cycles of all components are sampled in accordance with their probability distribution and a system operating cycle is obtained by combining all the component cycles . For that reason this technique allows to include in the reliability evaluation, chronological issues like the time-dependent load curve as well as the hydrological affluences or the sequential behavior of the system components. For instance, there is a correlation between the load curve and the unit's operation cycle. As a matter of fact some units are in service for long periods of time and others are only started when they are needed and normally operate for relatively short periods, usually when the system load is near its peak value. The first unit type is called base load unit and the second type peaking unit. This dependency cannot be easily incorporated in a non-chronological reliability evaluation scheme (although there is a specific Markov process to model the operation of peaking units which requires more detailed data than the traditional two state Markov model, usually extremely difficult to obtain) making the flexibility the main advantage of the chronological approach. On the other hand the main disadvantage of the chronological approach in relation to the non-chronological approach is the enormous computing time and effort required to verify the same convergence criteria. Two methods for single-area generating system adequacy assessment can be found: the State Duration Sampling Method and the State Sampling Method. The first method belongs to the chronological Monte Carlo simulation type. The second method is a non-chronological Monte Carlo type.

## 3.6 Reliability adequacy assessment using the new Population Based methods

The Population Based (PB) methods evaluate the system reliability by enumeration of the system states. The main concept of this technique is to drive the individuals of the population in a guided search through the state space in order to find the most significant ones. Usually a state is considered significant if it is a failure state and its probability is superior to a threshold value. Then, the obtained set of states is convoluted with the load curve to provide the reliability indices. From this point of view, this methodology is similar as the one used in the analytical methods(in fact, mainly due to the power systems dimension, the Capacity Outage Probability Table has also be truncated by the rejection of states which have a probability lower than a pre-specified value. However, the results provided by PB methods are underestimates of the correct value since only a subset of the total failure states is obtained. Eventually if the total number of the states which contribute to the formation of an index are within this subset then the PB methods give an exact value. In the PB approach, the estimate of a reliability index is obtained from:

$$F = \sum_{i \in D} Pi x Fi \qquad (18)$$

The reader may now question the usefulness of this type of methods since there are analytical methods which have the advantage of theoretically assessing the correct values of the indices. However the analytical methods grow in complexity as the power system increases in size as well as the type of problem that is to be solved (for example assessing the reliability of the composite gene ration/transmission system). These facts act in favor of the PB methods for the reason that an individual is constituted by the state of all the components which the power system possesses.

Therefore the complexity of the PB methods is widely immune to the system size and to the type of reliability study.

The PB methods also have an advantage over Monte Carlo. As it was previously mentioned, Monte Carlo is statistically based method, relying on the theorems of sampling to provide an estimate of a result plus some interval of confidence. Therefore in order to guarantee that the estimate belongs to the interval of confidence a large number of samples have to be drawn. In addition some of these samples are not failure states (characteristic of power systems) which also have to be evaluated. Thus reducing the number of evaluations, especially in the HLII and HLIII type of studies where the minimum load curtailment has to be determined by an Optimal Power Flow, can decrease considerably the computational effort. In PB methods this reduction is effective since it works with a state array with the most significant states. However, in order to determine during the search process if the state is worth to be memorized, some methodology has to be defined. the adoption of intelligent pattern recognition methods such as neural networks to discriminate between failure and success is used. In the particular reliability problem addressed in this thesis a state is classified as a failure state if the total generation capacity cannot meet the peak of the load curve. A simple modified GA is used to evaluate the generation capacity, not as an optimization tool but "as a search tool to truncate the probability states space and to track the most probable failure states". This methodology takes advantage of the chromosome concept allowing a binary representation of the system state according to the homogeneous two state Markov unit model. Also the authors use the fact that some generators have the same characteristics (in this case, the same generation capacity and the same FOR) to calculate from one particular state the number of states which have the same probability and the same load curtailment, discarding the need to visit all states. GA is also used to the assessment of the annual frequency and duration indices in composite system reliability, with the same search philosophy, modeling the transmission lines by the same two state Markov process. To determine if a state is worth to be saved the fitness function uses a linear programming module in order to minimize load curtailment without violating system constraints. The load at each load bus is considered fixed and equal to its yearly maximum value. In the application of a PSO based method, the Binary Particle Swarm Optimization (BPSO [is presented for reliability evaluation of power-generating systems including time-dependent sources. The authors used BPSO for the reason that it allows the coding of the generators states in a vector of binary numbers according to the homogeneous two state Markov model. BPSO, in its formulation is quite similar to PSO. However, unlike the typical PSO, in BPSO the velocity issued as a probability to determine whether a bit will be 1 or 0. Therefore after calculating the actual velocity with the same equation used in the traditional PSO, its value is squashed using a logistic function. Then if a randomly generated number within .0,1/ is less than the squashed value, the bit is set to be 1, otherwise is set to be 0.In the previous mentioned works two different methodologies of fitness assignment can be defined. One is based on the maximization of the state probability for the states which are classified as failure states and which were not previously saved. Therefore the population is driven to the zone of the space state which possesses a smaller number of failure states.

# CHAPTER 04

## RELIABILITY INDICES

To evaluate the standard reliability level different reliability indices are used. The commonly used reliability indices are:

1. Loss of load probability (LOLP)
2. Loss of energy probability (LOLE)
3. Frequency and duration(FAD)
4. Monte Carlo simulation(MCS)

## 4.1 Loss of Load Probability

A loss of load probability (LOLP) is a probabilistic approach for determination of required reserves, which was developed in the year 1947. This approach examines the probabilities of simultaneous outages of generating units that, together with a model of daily peak-hour loads, determine the number of days per year of expected capacity shortages. Today, LOLP is the most widely accepted approach in the utility industry for evaluating generation capacity requirements Loss of load occurs whenever the system load exceeds the available generating capacity. The LOLP is defined as the probability of the system load exceeding available generating capacity under the assumption that the peak load is considered as constant through the day. The loss of load probability does not really stand for a probability. It expresses statistically calculated value representing the percentage of hours or days in a certain time frame, when energy consumption cannot be covered considering the probability of losses of generating units. This time frame is usually 1 year, which can be represented as 100% of time frame. In other words, the LOLP stands for an expected percentage of hours or days per year of capacity shortage. The LOLP actually does not stand for a loss of load but rather for a deficiency of installed available capacity. The term LOLP is closely related to the term loss of load expectation (LOLE), which is presented in next section. If the time interval used for the LOLP is expressed in the time units instead in percentage values, the LOLE is obtained instead of the LOLP.The generation system planners can evaluate generation system reliability and determine how much capacity is required to obtain a specified level of LOLP. As demand grows over time, additional generating units are included in a way that the LOLP does not exceed the required criterion. LOLP usually varies exponentially with load changes. While the effect of random outages is evaluated probabilistically, scheduled outages are evaluated deterministically. Deterministic risk criteria such as percentage reserve and loss of target unit do not define consistently the true risk in the system.

### 4.1.1 Loss of Load Probability Definition:

Loss of one generating unit causes the expected risk of loss of power supply E(t),which is also known as mathematical expectation and is defined as:

$$E_i(t)=p_i t_i \qquad (19)$$

Where $p_i$ is the probability of loss of capacity, and $t_i$ is the duration of loss of capacity in percent. Loss of load probability for the whole system is defined as a sum of all mathematical expectations for all units;

$$LOLP= {}^{n}{}_{i-1}\sum p_i t_i \qquad (20)$$

### 4.1.2 Loss of Load Probability During Scheduled Outages:

The planner of power generation must schedule planned outages during the year, because the generating units must be regularly maintained and inspected. Short-term maintenance process is continually updated. If a generating unit experiences a long-forced outage, the annual maintenance schedule for the power system can be reshuffled to further improve system reliability and to decrease the power system production costs. Planned outage requirements of power plants usually have a cyclical pattern. The maintenance procedure schedules the maintenance of generating units, so that available generation capacity reserve is the same for all weeks. This kind of procedure has the lowest LOLP.The most widely used algorithm for scheduling maintenance consists of four steps:

- Arrange generating units by size with the largest unit first and the smallest unit last.
- Schedule the largest generating unit for maintenance during periods of the
lowest load.
- Adjust weekly peak load by the generating unit capacity on maintenance.
- Repeat the second and the third step until all generating units are scheduled for maintenance.

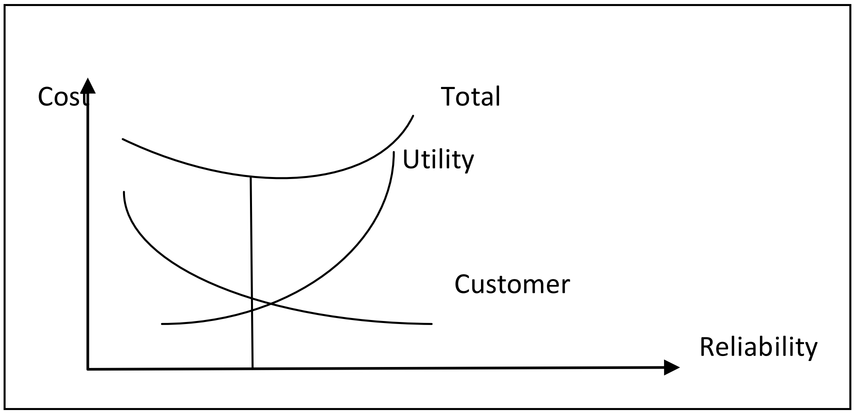


**Figure 4.1:** Costs of power system and its reliability.

## 4.2 Loss of energy probability (LOEP)

### 4.2.1 Concepts and evaluation techniques

The generation system model illustrated in the previous section can be convolved with an appropriate load model to produce a system risk index. There are a number of possible load models which can be used and therefore there are a number of risk indices which can be produced. The simplest load model and one that is used quite extensively is one in which each day is represented by its daily peak load. The individual daily peak loads can be arranged in descending order to form a cumulative load model which is known as the daily peak load variation curve. The resultant model is known as the load duration curve when the individual hourly load values arc used, and in this case the area under the curve represents the energy required in the given period. This is not the case with the daily peak load variation curve.

In this approach, the applicable system capacity outage probability table is combined with the system load characteristic to give an expected risk of loss of load. The units are in days if the daily peak load variation curve is used and in hours if the load duration curve is used. Prior to combining the outage probability table it should be realized that there is a difference between the terms 'capacity outage ‘and 'loss of load'. The term 'capacity outage' indicates a loss of generation which may or may not result in a loss of load. This condition depends upon the generating capacity reserve margin and the system load level. A 'loss of load' will occur only when the capability of the generating capacity remaining in service is exceeded by the system load level.

The individual daily peak loads can be used in conjunction with the capacity outage probability table to obtain the expected number of days in the specified period in which the daily peak load will exceed the available capacity. The index in this case is designated as the loss of load expectation (LOLE).

$$LOLE = \sum_{i-1}^{n}(C,-L,.) \text{ days/period} \qquad (21)$$

where *C,* = available capacity on day /.

*LJ* = forecast peak load on day;'.

*P,{C, - LJ)* = probability of loss of load on day /'. This value is obtained directly
from the capacity outage cumulative probability table.

## 4.2.2 Loss of Load Expectation Definition

Loss of load expectation can be obtained using the daily peak load variation curve. A particular capacity outage contributes to the system by an amount equal to the product of the probability of existence of the particular outage and the number of time units. The period of study could be week, month or a year.

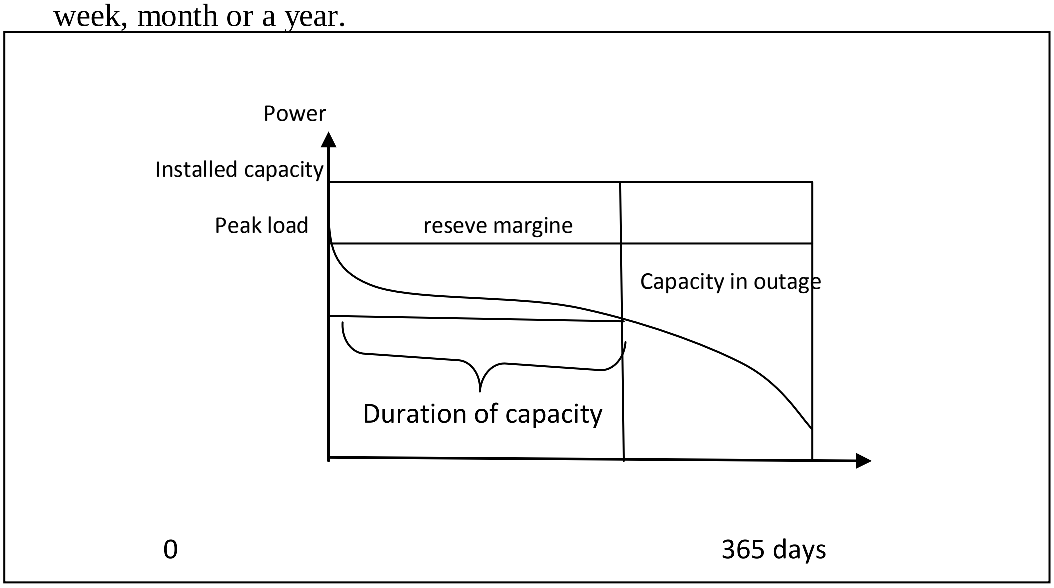


**Figure 4.2**: Yearly Load diagram.

The simple application is the use of the curve on yearly basis. When using a daily peak load variation curve on annual basic, the LOLE is in days per year.

LOLP= $^{n}{}_{i-1}\sum p_i t_i$

where pi is the individual probability of capacity in outage and ti is the duration of loss of power supply in days. When the cumulative probability Pi is used, LOLE is defined as:

LOLE= $^{n}{}_{i-1}\sum p_{i(}t_i\ {}_{-}t_{i-1})$ (21)

LOLE is also defined with a probability that consumption L will not be covered during working power capacity C.

LOLP= $^{n}{}_{i-1}\sum p_i(Ci\text{-}Li\text{-}1)$ (22)

## 4.3 Frequency and duration (FAD):

The frequency and duration (F&D) approach is undoubtedly a more complete technique to evaluate the static capacity adequacy for a given generation system. Although the loss of load expectation (LOLE)method is very simple to handle, it does not give any indication of the frequency of occurrence of an insufficient capacity condition, nor the duration for which it is likely to exist. This is only achieved by the F & D method. The use of F & D methods in capacity evaluation was formalized in a sequence of papers published in1968-1969 .These papers presented recursive algorithms for capacity model building and load model combination.

The capacity model was constructed by adding one generator at a time to the model. The common two-state representation of a generator was initially assumed, and after extended to account for generating units with partial capacity states . Basic formulas have been derived to build up the cumulative probability and frequency of a system by adding elements, whose cumulative probability and frequency are known. Also important concept of incremental frequency was introduced presents the F & D method described in its general form, i.e., the generation units are represented by multi-state models, how to estimate the expected number of starts of generating units in a power system using the F&D approach.

The frequency and duration method uses the transition rate ų and ƛ in addition to availability. Parameter ƛ represents failure rate. Parameter ų represents the repair rate. Figure shows two state model for a base load unit. A power system is usually composed of a set of statistically independent companies. In generating capacity reliability evaluation, these components are generating units that are described by two-or multi state capacity models.

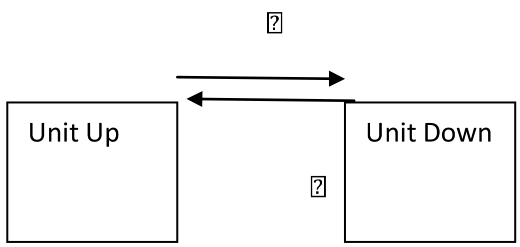


**Figure 4.3:** Two state model for a base load unit.

There are three basic steps of frequency and duration (F&D) approach:

1. Develop a suitable generation model from the parameters of the individual generating units.
2. Develop a suitable load model from the given data over a defined period.
3. Combine these two models to obtain the probabilistic model of the system capacity reserve or adequate.

## 4.4 Monte Carlo simulation (MCS):

In the past decades, several methods for assessing the distribution system reliability have been developed. These methods can be roughly categorized as the simulation and analytical methods. Analytical methods are based on some assumptions concerning the system outage records but there exists the execution time problem for large-scale systems. The simulation methods are the most flexible due to two reasons, first, it considers the random occurrence of faults and second, it gives the variability of indices. Major advantage of the Monte Carlo Simulation is that, it gives detailed knowledge of the probability distributions of reliability indices.

Monte Carlo techniques solve difficult reliability problems using random numbers. Monte Carlo methods are non-deterministic, and they fall into the category of statistical calculations. It is based on transforming set of random numbers into another set of numbers (random variables) which have the same distribution of the variable considered. In each iteration, the result is stored and, at the end of all iterations, the sequence of results generated is transformed into a frequency distribution that permits the calculus of descriptive statistics such as mean and standard deviation. Monte Carlo simulation can provide information related to the probability distributions of the reliability indices in addition to their average values. They require heavy use of computers for repetitively solving the problems as each solution is different from the others.

The methodology consists of development of computer algorithm based on time sequential Monte Carlo simulation for calculating reliability indices. It uses a random number generator, the probability distributions of the component failure and restoration processes to generate up and down time history of components of distribution system. The system reliability indices and their distributions are obtained from the generated system history. The index probability distributions reflect the future reliability performance of the system. They can be broadly classified into, namely state sampling and sequential methods.

The Monte Carlo simulation (MCS) method gives the results close to the results obtained by analytical method, MCS method gives additional information related to variation of indices, the sequential analysis gives the information of probability of occurrence of failures, failure duration, number of customer getting affected for each load point, also it gives the probability distributions for system indices.Thus it gives the nature of variation of indiceswhich is not possible to by analytical methods. Hence Monte Carlo simulation method is more practical as it include random nature of occurrences of failures.

### 4.4.1 Sequential Monte Carlo (SMC)

While the load-modifier method is easy to use and understand, it is at best a single draw from a random variable (in statistical sense). According to Marnay and Strauss (1989) cited in Milligan (2005), repeated Monte Carlo simulations can be more accurately used to represent outages by selecting the available generation in each hour based on drawing from the probability distribution that describes its availability. The SMC is a collective method taking a broader perspective on wind variability. The technique develops a probabilistic model of the underlying wind speed or wind power data. According to Milligan (2001), a number of techniques can be used for this, and examples include the auto-regressive integrated moving average approach applied by Billinton et. al. (1996) and the Markov modelling applied by Milligan (1996b) and Milligan and Graham (1997). These methods involve extensive computational time and effort, mentioned Milligan (2001), but produced probabilistic estimates of a number of parameters related to wind-power production. The issues related to inter-annual variations in wind generation can be assessed by using this probability distribution. Besides, the expected wind-induced variation in reliability could be estimated.

# CHAPTER 05

## METHODS OF LOLP

There are six methods of LOLP calculation:

1. State enumeration technique

2. Capacity outage table building algorithm

3. Recursive method

4. Cumulant method

5. Segmentation method

6. Graphical method

## 5.1 Segmentation method:

The segmentation method applied to the evaluation of loss of load probability (LOLP) of power systems with independent as well as correlated loads. The method obtains the probability density function (PDF) of load by sampling the daily load for a given period and assigning to each sample equal probability, the resulting PDF is expressed in terms of capacity segments. Convolution of generating units and load is achieved by suitably shifting and adding the probability values of the capacity segments, continue up to the last generating unit. Last segment of finally obtained distribution gives the LOLP of the system.

### 5.1.1 Segmentation method example-

| Generator | capacitor | For | probability |
|---|---|---|---|
| $G_1$ | 10 | 0.2 | 0.8 |
| $G_2$ | 10 | 0.2 | 0.8 |
| $G_3$ | 25 | 0.1 | 0.9 |

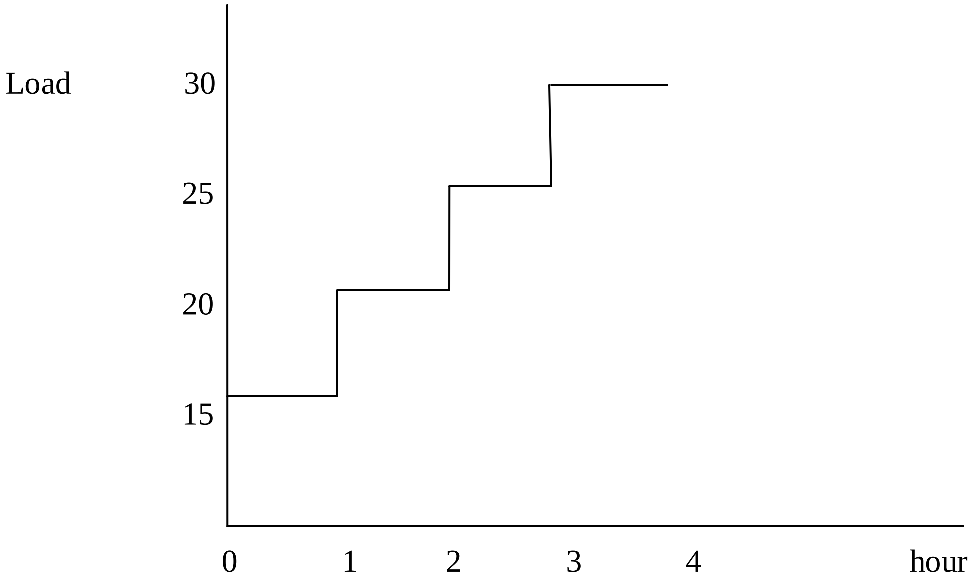


**Figure 5.1**: HOURLY LOAD PROFILE

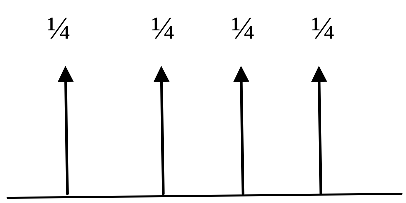


**Figure 5.2**: LOAD PDF (PROBABILITY DENSITY FUNCTION) FOR SEGMENTATION

Segment size, $\blacktriangle C$ = GDC{C1,C2…Cn} or HCF{C1,C2….Cn} (27)

$\blacktriangle C$ = HCF (10, 10, 25) = 5

Ci= capacity of $i^{th}$ unit

No. of segment Nc = $\sum_{i=1}^{N} Ci/\blacktriangle C+1$ (28)

= (2*10+25)/5 +1 = 10

For $G_1$

0 10 15 20 25 30 35 40 45 50

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1/4 | 1/4 | 1/4 | 1/4 | | | | | |

10 15 20 25 30 35 40 45 50

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ¼ | 1/4 | 1/4 | 1/4 | | | | |

Multiply by 0.8

20 25 30 35 40 45 50

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 1/4 | 1/4 | ¼ | 1/4 | |

Multiply by 0.2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.2 | 0.2 | 0.2 | 0.2 | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0.05 | 0.05 | 0.05 | 0.05 | | |

Addition

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.2 | 0.2 | 0.25 | 0.25 | 0.05 | 0.05 | | |

For $G_2$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.2 | 0.2 | 0.25 | 0.25 | 0.05 | 0.05 | | |

Multiply by 0.8

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0.2 | 0.2 | 0.25 | 0.25 | 0.05 | 0.05 |

Multiply by 0.2

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.16 | 0.16 | 0.2 | 0.2 | 0.04 | 0.04 | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0.04 | 0.04 | 0.05 | 0.05 | 0.01 | 0.01 |

Addition

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.16 | 0.16 | 0.24 | 0.24 | 0.09 | 0.09 | 0.01 | 0.01 |

For $G_3$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.16 | 0.16 | 0.24 | 0.24 | 0.09 | 0.09 | 0.01 | 0.01 |

Multiply by 0.9

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | 0.16 | 0.16 | 0.68 |

Multiply by 0.1

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.144 | 0.144 | 0.216 | 0.216 | 0.081 | 0.081 | 0.009 | 0.009 |
| | | | | | 0.016 | 0.016 | 0.068 |

Addition

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.144 | 0.144 | 0.216 | 0.216 | 0.081 | 0.097 | 0.025 | 0.077 |

LOLP =0.077=0.077*100=7.7%

## 5.2 Cumulant method:

The cumulant method also known as the method of moment is an approximation technique which approximates the discrete distribution of load through Gram– Charlier series expansion as a continuous function. In this method, convolution of generating unit outage with the distribution of load is performed through a very fast algorithm. The steps of calculating LOLP (Loss of Load Probability) using cumulant method is described in what follows.

(i) The moments about the origin for each generating unit is determined at first. For any i-t machine, the moments about the origin can be calculated using the following relations.

$$m_1\ (i)\text{-}C_i^1.q_i \qquad (29)$$

$$m_2\ (i)\text{-}C_i^2.q_i \qquad (30)$$

$$m_3\ (i)\text{-}C_i^3.q_i \qquad (31)$$

… … …

$$m_n(i)=C_i^n.q_i \qquad (32)$$

Where,

$m_n(i)$ = n-th moment about the origin of the i-th machine

$C_i$= Capacity of the i-th machine

$q_i$= FOR of the i-th machine

(ii) In the second step, the central moments or moments about the mean of each generating unit is calculated. For any i-th machine, the central moments can be calculated as,

$$M_1(i)=0 \qquad (33)$$

$$M_2(i)=m_2(i)-[m_1(i)]^2 \qquad (34)$$

$$M_3(i)=m_3(i)-3m_2(i).m_1(i)+2[m_1(i)]^3 \qquad (35)$$

$$M_4(i)=m_4(i)-4m_3(i).m_1(i)+6[m_1(i)]^2.m_2(i)-3[m_1(i)]^4 \qquad (36)$$

…. …. ….

$M_n(i)=[-m_1(i)]^n.P_i+[C_i-m_1(i)]^n.q_i$ (36)

Where,

$M_n$ (i) = n-$^{th}$ central moment of the i-$^{th}$ machine

$p_i$ = Availability of the i-$^{th}$ machine

(iii) In the third step, cumulant of each machine is calculated. For i-th machine, the cumulants can be determined as follows,

$k_1(i)=m_1(i)$ (38)

$k_2(i)=M_2(i)$ (39)

$k_3(i)=M_3(i)$ (40)

$k_4(i)=M_4(i)-3[M2(i)]^2$ (41)

$k_5(i)=M_5(i)-10M_2(i).M_3(i)$ (42)

(iv) In the fourth step, the culुlants of the load is obtained. For this, at first, the moments about the origin and the central moments of the load are calculated. Using these moments, cumulants of the load are obtained using (38) to (42).

(v) In this step, total system cumulant is obtained by summing the machine cumulants and load cumulants. It can be represented as,

$k_j=\sum kj(\text{generators}) + kj(\text{load})$ (43)

(vi) Now standardized random variable, z is calculated using the relation,

$Z= (IC-k_1)/\sqrt{k_2}$ (44)

Where,

IC = Installed capacity of the power system

$k_1$, $k_2$= System cumulants

(vii) LOLP can be calculated using the relationship given by,

$LOLP=Q(z)+F(z)$ (45)

Where, Q (z) can be calculated as, $Q(z)=N(z)[b_1t+b_2t^2+b_3t^3]$

Here,

$N(z)=1/\sqrt{(2\pi)}\exp(-z^2/2)$ (46)

$t=1/(1+rz)$ (47)

And r, b1, b2 and b3 are constants

(viii) F (z) is calculated using Gram- Charlier series which is given by,

$F(z) = [G_1N^{(2)}(z)]/3! - [G_2N^{(3)}(z)]/4! + [G_3N^{(4)}(z)]/5! - \ldots.$ (48)

Where, the expansion factors G1, G2, G3 are calculated using the following relationship.

$G_i = k_{(i+2)}/(k_2)^{((i+2)/2)}$ (49)

And the derivatives of the normal PDF N (z) may be obtained using the following recursive relations.

$N^{(m)}(Z) = -(m-1).N^{(m-2)(}z).N^{(m-1)}(Z)$ (50)

m=3,4,5…

and $N^{(1)}(Z) = -Z.N(Z)$ (51)

$N^{(2)}(Z)=(Z^2-1)N(Z)$ (52)

(ix) The value of constants are set as, r = 0.232, b1 = 0.319, b2 = -0.356, b3 = 1.781. Finally LOLP is evaluated using (45).

### 5.2.1 Cumulant method example:

| Unit | Capacity(MW) | For |
|---|---|---|
| $G_1$ | 5 | 0.2 |
| $G_2$ | 10 | 0.1 |

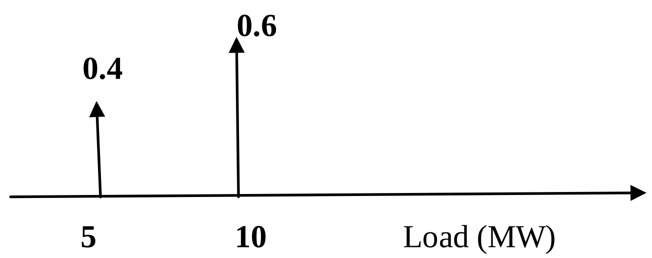


**Figure 5.3**: LOAD PDF(PROBABILITY DENSITY FUNCTION) FOR CUMULANT METHOD.

For unit 1:

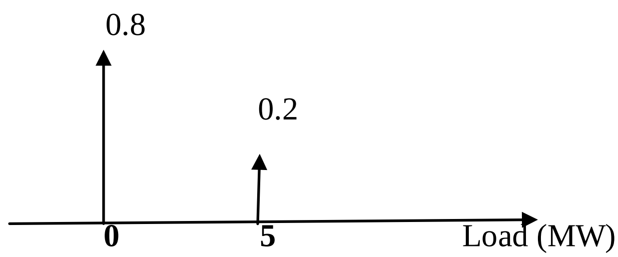


**Figure 5.4**: CAPACITY OUTAGE PDF(PROBABILITY DENSITY FUNCTION) FOR CUMULANT METHOD.

$m_1=\sum x.P(x) = 0*0.8+5*0.2=1$
$M_1=\sum(x-m)^r.P(x)=(0-1)(0.8)+(5-1)(0.2)=0$
$M_2= (-1)^2\ (0.8) +4^2(0.2) =4$
$M_3=12$
$M_4=52$
$M_5=204$

Unit 1 cumulants : $k_1=m_1=1$
$k_2=M_2=4$
$k_3=M_3=12$
$k_4=M_4-3M_2^2=4$
$k_5=M_5-10M_2M_3=-276$

For unit 2:

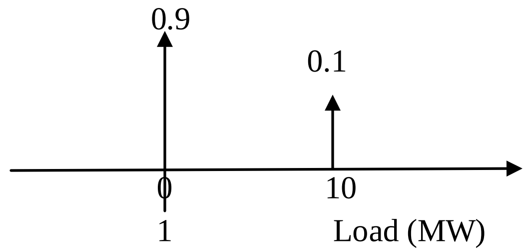


**Figure 5.5**: CAPACITY OUTAGE PDF (PROBABILITY DENSITY FUNCTION) FOR CUMULANT METHOD.

$m_1=0*(0.9)+10(0.1)=1$

$M_1=(0-1)(0.9)+(10-1)(0.1)=0$

$M_2= (-1)^2\ (0.9) +(10-1)^2(0.1) =4$

$M_3=72$

$M_4=657$

$M_5=5904$

Unit 2 cumulants : $k_1=m_1=1$

$k_2=M_2=9$

$k_3=M_3=72$

$k_4=M_4-3M_2^2=414$

$k_5=M_5-10M_2M_3=-576$

for load:

$m_1=5*(0.4)+10(0.6)=8$

$M_1=(5-8)(0.4)+(10-8)(0.6)=0$

$M_2= 6$

$M_3=-6$

$M_4=42$

$M_5=-78$

load cumulants : $k_1=m_1=8$

$k_2=M_2=6$

$k_3=M_3=-6$

$k_4=M_4-3M_2^2=-66$

$k_5=M_5-10M_2M_3=282$

system cumulants:

$k_1=k_1(\text{unit 1})+k_1(\text{unit2})+k_1(\text{load}) = 1+1+8=10$

k2=4+9+6=19

k3=12+72-6=78

k4=4+414-66=352

k5=-276-576+282=-570

$z = (IC-k_1)/\sqrt{k_2} = [(5+10)-10]/\sqrt{19} = 1.147$

$Q(z)=N(z)[b_1 t+b_2 t^2+b_3 t^3]$

$N(z)=1/\sqrt{(2\pi)} \exp(- z^2/2) = 1/\sqrt{(2\pi)} \exp(- (1.147)^2/2) = 0.2066$

$t=1/(1+rz)=$ $t=1/(1+(0.232)(1.147))=0.7898$

, r = 0.232, b1 = 0.319, b2 = -0.356, b3 = 1.781

$Q(z)=0.2066[(0.319)(0.7898)+(-0.356)(0.7898)^2+(1.781)(0.7898)^3]=0.18743$

Gram- Charlier series, $F(z) = [G_1 N^{(2)}(z)]/3! - [G_2 N^{(3)}(z)]/4! + [G_3 N^{(4)}(z)]/5! - \ldots$

The expansion factor $G_i = k_{(i+2)}/(k_2)^{((i+2)/2)}$

$G_1=k_3/(k_2)^{1.5} = 78/(19)^{1.5} = 0.9418$, $G_2=k_4/(k_2)^2=352/(19)2=0.9750$,

$G_3=k_5/(k_2)^{2.5} = -570/(19)^{2.5} = -0.3622$

Derivatives of N(z),

$N^{(1)}(Z)= -Z.N(Z) = -0.237$

$N^{(2)}(Z)=(Z^2-1)N(Z) = 0.0652$

$N^{(m)}(Z)= -(m-1).N^{(m-2)(}z).N^{(m-1)}(Z)$ ,m=3,4,5…

$N^{(3)}(Z)= -(3-1).N^{(3-2)(}z).N^{(3-1)}(Z) = 0.3992$

$N^{(4)}(Z)= -(4-1).N^{(4-2)(}z).N^{(4-1)}(Z) = -0.6535$

$F(z) = [G_1 N^{(2)}(z)]/3! - [G_2 N^{(3)}(z)]/4! + [G_3 N^{(4)}(z)]/5! = - 0.00401188$

LOLP=F(z)+Q(z)= - 0.00401188+0.18743=0,1834=18.34%

# CHAPTER 06

## RELIABILITY ANALYSIS

## 6.1 Reliability Analysis

An electric utility's main concern is to plan, design, operate and maintain its power supply to provide an acceptable level of reliability to its users. This clearly requires that standards of reliability be specified and used in all three sectors of the power system, i.e., generation, transmission and distribution. Reliability indices have been defined for the three sectors separately as well as for the bulk power system. Reliability criteria may be determined at the selected load points in the system for different combination of generators and transmission line failures.

A survey of literature reveals the fact that there has been a considerable activity in the development and application of reliability techniques in electric power systems. In power system reliability evaluation, usually component failures are assumed independent and reliability indices are calculated using methods based on the multiplication rule of probabilities. But in some cases, for instance when the effects of fluctuating weather are considered, the previous assumption is invalid. Generally, two kinds of methodologies are adopted to solve this problem, analytical methods based on Markov processes, and Monte Carlo simulation. A DC-OPF based Markov cut-set method (DCOPF-MCSM) to evaluate composite power system reliability considering weather effects is presented in where the DC-OPF approach is used to determine minimal cut sets (MCS) up to a preset order and then MCSM is used to calculate reliability indices.

The appropriate incorporation and presentation of the implications of uncertainty are widely recognized as fundamental components in the analyses of complex systems. There are two fundamentally different forms of uncertainty in power system reliability assessment. Aleatory and epistemic uncertainties are considered in power system reliability evaluation in where aleatory uncertainty arises because the study system can potentially behave in many different ways.

## 6.2 Generator Model

The simplest model for a generating unit for continuous operation is a Run-Fail-Repair-Run cycle that states that every generator has two states. They are— i) Unit availability and ii) Unit unavailability or forced outage rate (FOR). The unit availability means the long term probability that the generating unit will reside in on state and unit unavailability or FOR means the long term probability that the generating unit will reside in off state. Mathematically FOR can be defined

F0R,q = FOH/(FOH+SH) (53)

Where,

FOH = Forced outage hours

SH = Service hours or operating hours at full availability

Unit availability of a generating unit can be defined as,

Unit Availability=SH/(FOH+SH) (54)

For a generating unit with capacity = C MW and FOR = q and unit availability = p, the probability density function (PDF) of forced outage capacity is shown in Fig.

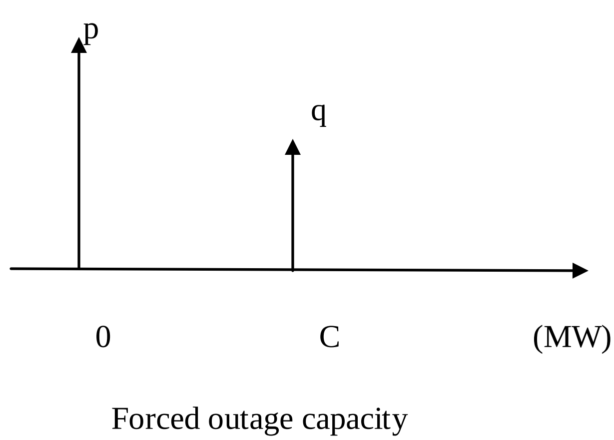


**Figure 6.1**. PDF of forced outage capacity of a generating unit.

## 6.3 Load model:

In order to develop the load model of BPS, hourly loads of last year (2011). Hourly loads are divided in 6 groups having a group size of 500 MW. The probability of occurrence of each group is calculated as,

$$Pg = Ng/Nt \qquad (55)$$

Where, Pg = Probability of occurrence of a group

Ng = No. of occurring days of that group in observation period of 1 year
Nt= Total no. of days in observation period

**Table 6.1- FREQUENCY and PROBABILITY from year 2011.**

| DATA(MW) | FREQUENCY (f) | PROBABILITY (p=f/365) |
|---|---|---|
| 2836.00 | 1 | 1 |
| 3764.00 | 1 | 1 |
| 3850.00 | 3 | 3 |
| 3900.00 | 5 | 5 |
| 3950.00 | 3 | 3 |
| 3951.00 | 1 | 1 |
| 4000.00 | 6 | 6 |
| 4050.00 | 6 | 6 |
| 4100.00 | 6 | 6 |
| 4150.00 | 4 | 4 |
| 4200.00 | 2 | 2 |
| 4225.00 | 1 | 1 |
| 4249.00 | 1 | 1 |
| 4250.00 | 4 | 4 |
| 4259.50 | 1 | 1 |
| 4300.00 | 1 | 1 |
| 4309.50 | 1 | 1 |
| 4314.50 | 1 | 1 |
| 4315.50 | 1 | 1 |
| 4325.00 | 1 | 1 |
| 4350.00 | 2 | 2 |
| 4358.00 | 1 | 1 |
| 4400.00 | 4 | 4 |
| 4425.00 | 1 | 1 |
| 4449.00 | 1 | 1 |

| | | |
|---|---|---|
| 4450.00 | 1 | 1 |
| 4530.00 | 1 | 1 |
| 4550.00 | 1 | 1 |
| 4578.50 | 1 | 1 |
| 4595.50 | 1 | 1 |
| 4600.00 | 6 | 6 |
| 4633.50 | 1 | 1 |
| 4637.80 | 1 | 1 |
| 4664.00 | 1 | 1 |
| 4700.00 | 2 | 2 |
| 4721.00 | 1 | 1 |
| 4721.50 | 1 | 1 |
| 4727.50 | 1 | 1 |
| 4730.00 | 1 | 1 |
| 4732.50 | 1 | 1 |
| 4750.00 | 1 | 1 |
| 4775.00 | 1 | 1 |
| 4800.00 | 1 | 1 |
| 4814.00 | 1 | 1 |
| 4832.00 | 1 | 1 |
| 4844.00 | 1 | 1 |
| 4850.00 | 7 | 7 |
| 4869.00 | 1 | 1 |
| 4870.00 | 1 | 1 |
| 4878.00 | 1 | 1 |
| 4893.00 | 1 | 1 |
| 4900.00 | 6 | 6 |
| 4911.50 | 1 | 1 |
| 4920.50 | 1 | 1 |
| 4925.00 | 2 | 2 |
| 4930.00 | 1 | 1 |
| 4933.50 | 1 | 1 |
| 4941.00 | 1 | 1 |
| 4950.00 | 5 | 5 |
| 4956.00 | 1 | 1 |
| 4958.50 | 1 | 1 |
| 4959.50 | 1 | 1 |
| 4967.50 | 1 | 1 |
| 4978.00 | 1 | 1 |
| 4981.00 | 1 | 1 |
| 4991.00 | 1 | 1 |
| 4992.50 | 1 | 1 |
| 4993.00 | 1 | 1 |
| 4997.00 | 1 | 1 |

| | | |
|---|---|---|
| 5000.00 | 17 | 17 |
| 5005.00 | 1 | 1 |
| 5006.00 | 1 | 1 |
| 5008.50 | 1 | 1 |
| 5010.00 | 1 | 1 |
| 5014.00 | 1 | 1 |
| 5016.50 | 1 | 1 |
| 5025.00 | 1 | 1 |
| 5026.00 | 1 | 1 |
| 5025.50 | 1 | 1 |
| 5033.50 | 1 | 1 |
| 5037.00 | 1 | 1 |
| 5050.00 | 5 | 5 |
| 5060.00 | 1 | 1 |
| 5068.00 | 1 | 1 |
| 5075.00 | 1 | 1 |
| 5092.50 | 1 | 1 |
| 5100.00 | 19 | 19 |
| 5112.50 | 1 | 1 |
| 5131.00 | 1 | 1 |
| 5137.50 | 2 | 2 |
| 5150.00 | 8 | 8 |
| 5173.50 | 1 | 1 |
| 5200.00 | 21 | 21 |
| 5250.00 | 15 | 15 |
| 5300.00 | 24 | 24 |
| 5350.00 | 9 | 9 |
| 5400.00 | 27 | 27 |
| 5425.00 | 1 | 1 |
| 5450.00 | 11 | 11 |
| 5500.00 | 27 | 27 |
| 5550.00 | 15 | 15 |
| 5600.00 | 13 | 13 |
| 5650.00 | 4 | 4 |
| 5700.00 | 2 | 2 |
| 5728.00 | 1 | 1 |
| 5800.00 | 1 | 1 |
| 5841.00 | 1 | 1 |

Firstly we obtained Table (6.1) from Load model of BPS (Bangladesh Power System), hourly loads of year 2011 for each month (Jan-Dec). Hourly loads are divided in 6 groups having a group size of 500 MW. The probability of occurrence of each group is calculated as,

Pg=Ng/Nt

**Table 6.2-Load range,Average load,Frequency and Probability.**

| Load Range (MW) | Average Load(MW) | Frequency | Probability |
|---|---|---|---|
| 2836-3336 | 3086 | 1 | 1/365 |
| 3337-3837 | 3587 | 1 | 1/365 |
| 3838-4338 | 4088 | 50 | 50/365 |
| 4339-4839 | 4589 | 34 | 34/365 |
| 4850-5340 | 5090 | 167 | 167/365 |
| 5341-5841 | 5591 | 112 | 112/365 |

With the help of this data we draw a PDF (probability of density function) of load model (Fig: 6.2).

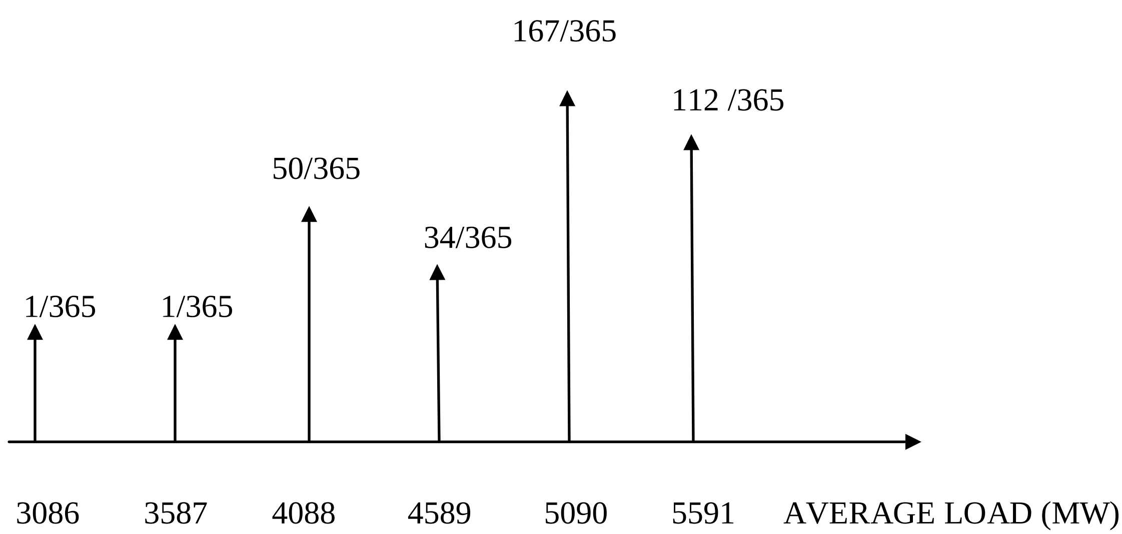


**Figure 6.2**: PDF (probability of density function) of load model.

## 6.4 LOLP Using Recursive formula:

The recursive expression for a state of X MW on forced outage after the addition of a generating unit of capacity C MW with forced outage rate q is given by

$$P(X) = (1-q)*P'(X) + q*P'(X-C) \quad (23)$$

P'(X) =cumulative probability of capacity outage of XMW or greater before a unit of C MW is added to the grid.

P(X) = cumulative probability of capacity outage of X MW or greater after a unit of C MW is added to the grid and q= for of the unit, FOR=the long term probability that the generating unit will reside in off state

The above expression is initialized by setting'(X)= 1.0 for x<0 and P'(X)= 0 otherwise.
$P'(X-C) = 0$

Consider a power system with tow generators of capacityC1 and C3. Unit's availability is a1, a2 and a3, respectively and FOR is q1 and q2, respectively. The steps of recursive algorithm for this small system are presented below in tabular format.

**TABLE 6.3-1ST UNIT IS ADDED**

| State No. | Capacity on outage | P'(X)(1-q) | P'(X-C)*q | p ( X ) |
|---|---|---|---|---|
| 1 | 0 | $1*(1-q_1)$ | $0*(q_1)$ | $P_1$ |
| 2 | C1 | $0*(1-q_1)$ | $1*(q_1)$ | $P_2$ |

**TABLE 6.4-2ND UNIT IS ADDED**

| State No. | Capacity on outage | P'(X)(1-q) | P'(X-C)*q | p ( X ) |
|---|---|---|---|---|
| 1 | 0 | $P1*(1-q_2)$ | $0*(q_2)$ | $P_1$ |
| 2 | $C_1$ | $P2*(1-q_2)$ | $0*(q_2)$ | $P_2$ |
| 3 | $C_2$ | $0*(1-q_2)$ | $P_1*(q_2)$ | $P_3$ |
| 4 | $C_1+C_2$ | $0*(1-q_2)$ | $P_2*(q_2)$ | $P_4$ |

After considering all the states, they are sorted in ascending order and cumulative probabilities are calculated. A sample calculation is shown in Table

**TABLE 6.5-SAMPLE CALCULATION**

| State No. | Capacity on outage | p ( X ) | Cumulative probability |
|---|---|---|---|
| 1 | 0 | $P_1$ | $P_4+ P_3+P_2+P_1=1$ |
| 2 | $C_1$ | $P_2$ | $P_4+P_3+P_2$ |
| 3 | $C_2$ | $P_3$ | $P_4+P_3$ |
| 4 | $C_1+C_2$ | $P_4$ | $P_4$ |

After arranging all the states in ascending order, reserve of the power system is calculated using,

Reserve= Installed capacity-Load (24)

LOLP of a particular load is then calculated using,

$LOLP_{load}$= probability (Outage> Reserve) (25)

And finally, Total LOLP of the system is calculated using,

LOLP =Σ ($LOLP_{load}$)( pr.of load) (26)

Where, Pr. of load = Occurrence probability of a particular Load.

### 6.4.1 Recursive method example:

| Generator | Capacitor(MW) | For(q) |
|---|---|---|
| $G_1$ | 200 | 0.02 |
| $G_2$ | 300 | 0.03 |

First, $G_1$ is added to the grid

Here x=0,200; c=200 MW; q=0.02

Using recursive formula P(X) = (1-q)*P'(X) +q*P' (X-C)

When x=0,

P (0) = (1-0.02)*p' (0) +0.02*p' (0-200) = 0.98*1+0.02*1=1

When x-200,

P (200) = (1-0.02)*p' (200) +0.02*p' (200-200)=0.98*0+0.02*1=0.02

| Capacity outage (MW) | Cumulative probability |
|---|---|
| 0 | 1 |
| 200 | 0.02 |

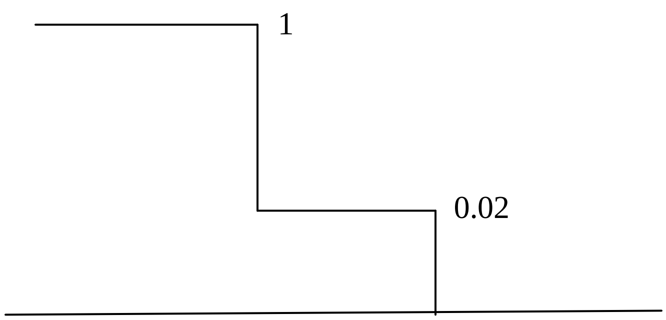


**Figure 6.3** : CDF (CUMULATIVE DENSITY FUNCTION) OF RECUSIVE ALGORITHM FOR 2 UNITS.

G2 is added to the grid

Here x=0,200,300,500; c=300MW; q=0.03

Using recursive formula p(x) = (1-q)*p'(x) +q*p' (x-c)

When x=0,

P (0) = (1-0.03)*p' (0) +0.03*p' (0-300) =0.97*1+0.03*1=1

When x=200,

P (200) = (1-0.03)*p' 20(0) +0.03*p' (200-300) =0.97*0.02+0.03*1=0.0494

When x=300,

P (300) = (1-0.03)*p' (300) +0.03*p' (300-300) =0.97*0+0.03*1=0.03

When x=500,

P (500) = (1-0.03)*p' (500) +0.03*p' (500-300) =0.97*0+0.03*0.02=0.0006

**TABLE 6.6**- Cumulative probability.

| Capacity outage (MW) | Cumulative probability |
|---|---|
| 0 | 1 |
| 200 | 0.0494 |
| 300 | 0.03 |
| 500 | 0.0006 |

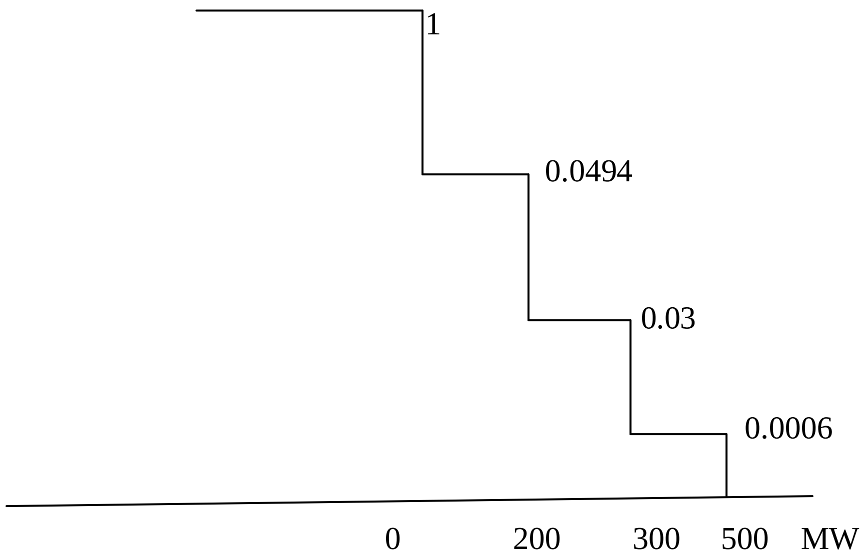


**Figure 6.4**: CDP (CUMULATIVE DENSITY PROBABILITY) OF RECUSIVE ALGORITHM FOR 4 UNITS.

For one given Load =350 MW

LOLP calculation:

LOLP=probability (available capacity< load) or probability (outage>reserve)

LOLP=probability (available capacity< load) = 0.0494

OR

Reserve =Installed capacity – Load

=500-350=150 MW

LOLP=probability (outage>reserve) =0.0494

So LOLP =0.0494*100= 4.94%

For many given load LOLP equation= $\sum_{i=0}^{n} \text{LOLPi} * \text{probability (Li)}$

Let given load =350 and $LOLP_1$=0.0494, probability=0.7; load=250MW, $LOLP_2$ =0.03, probability=0.3;

So total, LOLP=$LOLOP_1$*probability ($L_1$) +LOLOP2*probability ($L_2$) .

# CHAPTER 07

## PREPARATION, CALCULATION AND RESULT

## 7.1 Data Collection

According to one of the primary objective of our thesis, to be able to analyze the reliability of the power system network of Bangladesh, we need to get a complete network database first. So we collected detailed database from the Power Generation Company Bangladesh (PGCB).We collected the database of the power generated months from January 2011 to December 2011 According to the database, we have got the following major components:

- Capacity of Generators(MW): 74
- Forced outage rate(FOR) of generators
- Average load(MW)
- Frequency
- Probability

## 7.2 Software Selection

As a major part of our thesis is about performing software based reliability analysis, we had to collect the right software that would be suitable for our analysis. There is a number of software available in the market for this type of analysis. We selected DR.JAVA from all those to do our analysis. DR.JAVA is a software package that offers tabular data entry modes and many other sophisticated facilities for reporting and delivering the necessary data for each generator separately. We found that, this software would be perfect for analyzing reliability of Bangladesh power system using the data we have collected. Here we want to mention that, we are using DR.JAVA-20110205-R5425 2.81 for our thesis purpose.

## 7.3 Reliability of a system

After obtaining all detailed database from the Power Grid Company Bangladesh (PGCB) our data is finally prepared for finding LOLP of reliability analysis, which is our main concern. We know, the lower the value of LOLP, the higher the reliability of a system. Thus we have determined the LOLP of year 2011 of the existing power system of Bangladesh.

### 7.4 Reliability Evaluation OF Bangladesh Power System (BPS) IN Year 2011

Recursive method, a very fast computational technique is used to evaluate the reliability of Bangladesh Power System in our thesis. Reliability index LOLP (Loss of Load Probability) is assessed for this intention. LOLP gives the probability that the available generation capacity will be insufficient to meet the daily peak loads.

BPS has 74 generators and a total installed capacity of 6500 MW. A true to life load model has been presented in Table 6.1 for the year 2011 and the individual capacity and FOR of the generators used in BPS are shown in Table 7.1.

Our algorithms, calculation and results would be corresponding to the data from these tables.

**TABLE 7.1-CAPACITY AND FOR OF THE GENERATORS OF BPS YEAR(2011).**

| Gen No. | Cap (MW) | FOR |
|---|---|---|
| 1 | 40 | 0.0000014 |
| 2 | 40 | 0.0000014 |
| 3 | 50 | 0.0000014 |
| 4 | 50 | 0.0000014 |
| 5 | 50 | 0.0000014 |
| 6 | 210 | 0.16 |
| 7 | 50 | 0.113 |
| 8 | 109 | 0.07 |
| 9 | 55 | 0.185 |
| 10 | 55 | 0.185 |
| 11 | 210 | 0.095 |
| 12 | 210 | 0.019 |
| 13 | 210 | 0.08 |
| 14 | 210 | 0.08 |
| 15 | 64 | 0.116 |
| 16 | 64 | 0.116 |
| 17 | 150 | 0.013 |
| 18 | 150 | 0.014 |
| 19 | 150 | 0.014 |
| 20 | 56 | 0.321 |
| 21 | 56 | 0.321 |
| 22 | 30 | 0.15 |
| 23 | 100 | 0.3 |
| 24 | 210 | 0.197 |
| 25 | 210 | 0.197 |
| 26 | 60 | 0.117 |
| 27 | 28 | 0.6 |
| 28 | 28 | 0.6 |
| 29 | 12 | 0.15 |
| 30 | 12 | 0.15 |
| 31 | 12 | 0.15 |
| 32 | 15 | 0.15 |
| 33 | 15 | 0.15 |
| 34 | 15 | 0.15 |
| 35 | 15 | 0.15 |
| 36 | 35 | 0.1 |
| 37 | 35 | 0.1 |

| Gen No. | Cap (MW) | FOR |
|---|---|---|
| 38 | 21 | 0.122 |
| 39 | 120 | 0.04 |
| 40 | 77 | 0.101 |
| 41 | 100 | 0.04 |
| 42 | 125 | 0.1 |
| 43 | 125 | 0.1 |
| 44 | 110 | 0.301 |
| 45 | 60 | 0.402 |
| 46 | 28 | 0.5 |
| 47 | 28 | 0.5 |
| 48 | 20 | 0.045 |
| 49 | 20 | 0.2 |
| 50 | 20 | 0.2 |
| 51 | 20 | 0.119 |
| 52 | 60 | 0.5 |
| 53 | 8 | 0.3 |
| 54 | 450 | 0.07 |
| 55 | 235 | 0.07 |
| 56 | 125 | 0.07 |
| 57 | 142 | 0.07 |
| 58 | 45 | 0.07 |
| 59 | 45 | 0.07 |
| 60 | 110 | 0.11 |
| 61 | 110 | 0.07 |
| 62 | 25 | 0.6 |
| 63 | 100 | 0.04 |
| 64 | 100 | 0.04 |
| 65 | 100 | 0.04 |
| 66 | 100 | 0.04 |
| 67 | 100 | 0.04 |
| 68 | 100 | 0.04 |
| 69 | 100 | 0.04 |
| 70 | 100 | 0.04 |
| 71 | 100 | 0.04 |
| 72 | 100 | 0.04 |
| 73 | 100 | 0.04 |
| 74 | 100 | 0.04 |

## 7.5 Calculation:

### 7.5.1 Java Code for Recursive Algorithm

```
importjava.util.*;

public class Solve {

public static void main (String args []) {

        Scanner sc = new Scanner (System.in);

System.out.print("Type number of genarators:");

intnum = sc.nextInt();

System.out.print("Type Load (MW):");

int load = sc.nextInt();

System.out.println("Input C give a space then input Q of a generator.");


        Vector <Integer>v  = new Vector<Integer>();

        Vector <Integer>point  = new Vector<Integer>();

doubleqq [] = new double [num];

int cc [] = new int [num];

doublepp [] = new double [20000];

double pp1 [] = new double [20000];

        //intinn[] = new int[20000];

pp[0] =pp1 [0]= 1;

int c, size;


        c = 0; // init

v.add(c);
```

```
for(int i = 0; i <num; ++i) {

            c = sc.nextInt();
            cc [i] = c;
qq [i] = sc.nextDouble();

if(!v.contains(c)) {
v.add(c);
for(int j = v.size() - 2; j >= 0 ; --j) {
int temp = v.get(j) + c;
if(!v.contains(temp)) {
v.add(temp);
                    }
                }
Collections.sort(v);
            } else {
for(int j = v.size() - 1; j >= 0 ; --j) {
int temp = v.get(j) + c;
if(!v.contains(temp)) {
v.add(temp);
                    }
                }
Collections.sort(v);
            }
size =  v.size();
```

```
int c1 = cc[i];
double q = qq[i];
for (int j=0 ; j<v.size() ; j++){
int index = v.elementAt(j)  ;
int temp = index - c1;
if(temp<=0 ){
                    // System.out.println(pp[index]);
if(!point.contains(index)){
point.add(index);
Collections.sort(point);
                    }
pp[index] = (1-q) * pp1[index] + q;
fill(pp,index,point);


                 } else{
                     //System.out.println(pp[temp]);
if(!point.contains(index)){
point.add(index);
Collections.sort(point);
                    }
pp[index] = (1-q) * pp1[index] + q* pp1[temp];
fill(pp,index,point);
                 }


           }
```

```
//System.out.println(pp1[0]+":\t"+pp1[200]+":\t"+pp1[300]+":\t"+pp1[400]+":\t"+pp1[500]+":\t"
+pp1[700]+":\t"+pp1[900]);

if(! (i <num)){break;}

copy(pp,pp1);

        }

System.out.println("Cap outage(MW)\t  Cum Px");

for(int j = 0; j <v.size() ; ++j) {

System.out.println(v.get(j) +":\t\t  "+pp[v.get(j)] );

         }

calL(v,pp,load);

       //System.out.println(pp1[500]+"  "+point.elementAt(3));

    }


    /*public static double solve (double q, int c, int x, double pp) {

intqq = (x - c);

doubleqN = 0;


doubleequ = (1 - q) * pp + q * qN;

returnequ;

    }

   */

public static void copy(double [] s, double [] d){

     // d= new double[s.length];

for (int n=0 ; n<s.length ; n++){
```

```
d[n] = s[n];
      }
    }
public static void fill(double [] p,intindex,Vector<Integer>point){
int i = point.indexOf(index);
int j= i-1;
if(!(j<0)){
int c= point.elementAt(j);
for(int n= index-1;n>c ; n--){

p[n] = p[index];

          }
       }
    }

public static void calL(Vector <Integer>v ,double [] p, int load){
int s = v.size()-1;
int max =(int) v.get(s);
int index = max - load;
double f = p[index] * 100;
System.out.println("\n\nReserve:\t  "+ index);
System.out.println("LOLP:\t\t  "+f+"%");
    }
}
```

### 7.5.2 Java Code for Segmentation Method Algorithm

```
public class dataSet{

	private int year;
	int data[];
	double probability[];
	public int indexData, indexProbability;

	dataSet(){
		data =  new int[6501];
		probability = new double[6501];
		indexData = 0;
		indexProbability = 5;
	}

	dataSet(int year){
		this();
		this.year = year;
	}

	void addData(int val){
		data[indexData] = val;
		indexData++;
	}

	void addProbability(int val){
		probability[indexProbability] = (double)val/365;
		indexProbability++;
	}

	int getYear(){
		return year;
	}


}
import java.util.*;
import java.io.*;

public class lolp2{
```

```
	public static int first;
	public static dataSet ds;
	public static double [][] arr;

	public static void shift(int k, int here){

		double [] tempStore = new double[ds.probability.length - first];

		for(int i = first, j = 0; i<ds.probability.length; i++, j++){

			tempStore[j] = arr[here][i];
			arr[here][i] = 0;

		}

		int savJ = 7000;

		for(int i = first+k, j = 0; i<ds.probability.length; i++, j++){
			savJ = j;
			arr[here][i] = tempStore[j];

		}
		double temp = 0;
		if(savJ+1<tempStore.length){

			for(int i = savJ+1; i<tempStore.length; i++){

				temp = temp + tempStore[i];
			}
			arr[here][ds.probability.length-1] = arr[here][ds.probability.length-1] +
temp;

		}


	}



	public static void main(String []args)throws Exception{

		Scanner sc;

		sc = new Scanner(new File("b.txt"));

		ds = new dataSet(2011);
```

```
double temp2;
int temp3;


for(int i = 0; i<106; i++){

        temp2 = sc.nextDouble();
        temp3 = sc.nextInt();
        if(i == 0){
                first = (int)Math.ceil(temp2);

        }
        ds.probability[(int)Math.ceil(temp2)] = temp3/365.0;

}

sc = new Scanner(new File("a.txt"));

int [] gG = new int [74];
double [] qQ = new double [74];
double [] pP = new double [74];

for(int i =0; i<74; i++){

        gG[i] = sc.nextInt();
        qQ[i] = sc.nextDouble();
        pP[i] = sc.nextDouble();

}

arr = new double[75][6501];
double [] temp = new double [6501];
double [] temp1 = new double [6501];





for(int i = 0; i<6501; i++){

        arr[0][i] = ds.probability[i];
}

for(int i = 1; i<75; i++){
```

```
			for(int j = 0; j<6501; j++){

				temp[j] = arr[i-1][j]*pP[i-1];

			}

			shift(gG[i-1],i-1);


			for(int j = 0; j<6501; j++){


				temp1[j] = arr[i-1][j]*qQ[i-1];
			}

			for(int j = 0; j<6501; j++){

				arr[i][j] = temp[j]+temp1[j];
			}
		}

		for(int i = 0; i<6501; i++){


//			if(arr[74][i] != 0)
				System.out.println(arr[74][i] + " ");

		}



  }

}
```

## 7.6 Results:

Firstly we obtained table (4) from Load model of BPS (Bangladesh Power System), hourly loads of year 2011 for each month (Jan-Dec). Hourly loads are divided in 6 groups having a group size of 500 MW. The probability of occurrence of each group is calculated as,

Pg=Ng/Nt

Then we calculated load range (Mw), average load (MW), frequency and probability of occurrences. With the help of this data we draw a PDF (probability of density function) of load model (fig: 4).

Then we obtained table (5) of Capacity and FOR of the generators of BPS. BPS has 74 generators and a total installed capacity of 6490 MW. Using the recursive algorithm, LOLP (loss of load probability) of BPS year 2011 is evaluated. According to our java codes:

For the recursive algorithm, the obtained **LOLP** is 6.938096369817615%.

For the **segmentation method** of LOLP determination, the load data is collected from table 6.1 and the generator data from table 7.1. The HCF of the generator capacity is 1 which is equal to the segment size and the total number of segments were calculated to be 6501. The probability values were put in for their corresponding load values in their respective segments. The original segment is multiplied by the probability of successful operation, p, of the generator. Another copy of the original segment is then shifted according to the generator's capacity and multiplied by its probability of failure, q. The two multiplied segments are then added. The original segment prior to this operation would now be replaced by this outcome of addition of segments. The same procedure is repeated for all 74 generating components and the operational segments keep getting replaced. One very important factor, that is to be kept under consideration during this process, if the number of segments available to be filled becomes less than the number of numerically occupied segments that is to be fit in, the segments would be used normally until the last empty segment. In this last segment, values of the all the remaining segments would be added up and the summation would be placed in. After working all the components the value of the very last segment would be the answer for the value of LOLP.

For the segmentation algorithm, the obtained **LOLP** is 5.0067757183985054%

# CONCLUSION

In this thesis, we have performed the complete reliability analysis of Bangladesh Power System. We have presented a detailed reliability ranking structure of Bangladesh Power System through which problems and unstable situations in the system can be identified, critical configurations can be recognized, operating constraints and limits can be applied and corrective actions can be planned. Thus, our results of reliability analysis will help the components of Bangladesh Power System to be operated more safely and effectively as well as to improve the stability of future power system.

The basic function of a power system is to supply electrical energy to both large and small consumers as economically as possible with an acceptable degree of reliability and quality. Reliability is the ability of a power system to provide service to consumers while maintaining the quality and price of electricity at an acceptable level. Our thesis evaluates the reliability of Bangladesh Power System using Recursive Method and the Segmentation Method which are two very fast computational techniques. The analysis results in our thesis reveal that the Loss of Load Probability of Bangladesh Power System are 6.938096369817615% and 5.0067757183985054% for the two mentioned methods of reliability determination, respectively.

Lower reliability level imperils energy supply continuity and increases the possibility of additional maintenance and the restoration costs due to the higher rate of system outages. The costs associated with low reliability or poor system qualities are enormous and can be largely avoided by enhancing the level of reliability. Thus the reliability assessment of Bangladesh Power System will help estimating the service quality of the system. It will also create awareness among the utility and the consumers of the system and will assist in planning and operation process of Bangladesh Power System.

# REFERENCE

[1] “Reliability Evaluation of Power Systems”.By-Roy Billinton & Roland N.Allan.

[2] “Assessment of Power System  Reliability.”By-Marco Cepin.

[3] “Power system analysis and design”; By- J. Duncan Glover, Mulukutla S. Sarma, Thomas J. Overbye

[4] “Power System Analysis”; By- Grainger & Stevenson

[5] “Power Generation, Operation & Control”; By- Allen J. Wood, Gruce F. Wollenberg

[6] C. Singh, and R. Billinton, System Reliability Modeling and Evaluation, London, U.K., Hutchinson Educational, 1977.

[7] El-Abiad, A.H., Stagg, G.W., “Automatic Evaluation of Power System Performance—Effects of line and transformer Outages.” AIEE truncations on power apparatus andsystems, Vol. PAS-81, February 1963, pp- 712-716

[8] Debs, A.S., Bemson, A.R.,”Security Assessment of Power Systems,” System engineering for Power Status and prospects, U.S. Government Document, CONF-75086, 1967, pp-1-29.

[9] Thanikchalam, A., Tudor, J.R., “Optimal Rescheduling of Power for System Reliability,” IEEE Truncations on power apparatus and systems, Vol. PAS-90, July/August 1971, pp-1776-1781.

[10]  Li, W. “Incorporating Aging Failures in Power System Reliability Evaluation” , IEEE Power Engineering Review, vol. 22, no. 7, pp. 59, July 2002

[11] “Power System Planning”.By-Sullivan,R.L.

[12] “Probability Concepts of electric power systems.”By-Anders,G.J.

[13] http://en.wikipedia.org/

[14] http://books.google.com/

[15] http://ieeexplore.ieee.org/

[16]http://libra.msra.cn/Publication/51070399/reliability-evaluation-of-bangladesh-power-system-using-cumulant-method.

[17]https://www.waset.org/journals/waset/v60/v60-60.pdf

[18]http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=5222290&contentType=Journals+%26+Magazines

[19]https://www.waset.org/journals/waset/v64/v64-81.pdf

[20]http://books.google.com.bd/books?hl=en&lr=&id=YN1JRn9-02oC&oi=fnd&pg=PA4&dq=reliability+analysis+of+power+systems&ots=h8DFhy_a-c&sig=cW3X45hLR7oNg7bwE-vMDm-nAaY&redir_esc=y#v=onepage&q=reliability%20analysis%20of%20power%20systems&f=false

[21] http://web.mit.edu/energylab/www/pubs/el99-005wp.pdf

[22] http://www.buet.ac.bd/ces/p-renuga.pdf

[23] http://www.eeinstitute.org/european-review-of-energy-market/erem-4-article-d.-nevius

[24] IMPROVING POWER SYSTEM RELIABILITY USINGMULTIFUNCTION PROTECTIVE RELAYSArmando GuzmánSchweitzer Engineering Laboratories, Inc. Pullman, WA 99163.

[25]http://www.rflelect.com/pdf_files/Improving%20Reliability%20for%20Power%20System%20Protection.pdf

[26] http://scholar.lib.vt.edu/theses/available/etd-05162003-090532/unrestricted/Power_System.pdf