CONTINGENCY ANALYSIS AND RELIABILITY EVALUATION OF BANGLADESH POWER SYSTEM

Thesis Report

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DECLARATION

We hereby declare that this thesis is based on the investigations carried out by ourselves. Materials of the other research works related to this topic are mentioned in reference. This thesis, neither in whole nor in part, has been previously submitted for any degree.

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ABSTRACT

An over-riding factor in the operation of the power system is the desire to maintain security and expectable reliability level in all the sectors- power generation, transmission and distribution. System security can be assessed using contingency analysis. The result of this analysis allows system to be operated defensively and securely. In our thesis contingency analysis and reliability evaluation of Bangladesh power system will be performed that will ensure safe, secure and reliable operation of the system.

CHAPTER I

INTRODUCTION

1.1. POWER SYSTEM SECURITY

One of the most important factors in the operation of a power system is the desire to maintain system security. System security involves practices designed to keep the system operating when components fail. For example, a generating unit may have to be taken off-line because of auxiliary equipment failure. By maintaining proper amounts of spinning reverse, the remaining units on the system can make up the deficit without too low a frequency drop or need to shed any load. Similarly, a transmission line may be damaged by a storm and taken out by automatic relaying. If, in committing and dispatching generation, proper regard for transmission flows is maintained, the remaining transmission lines can take the increased loading and still remain within limit.

Because the specific times at which initiating events that cause components to fail are unpredictable, the system must be operated at all times in such a way that the system will not be left in a dangerous condition should any credible initiating event occur. Since power system equipment is designed to be operated within certain limits, most pieces of equipment are protected by automatic devices that can cause equipment to be switched out of the system if these limits are violated. If any event occurs on a system that leaves it opening with limits violated, the event may be followed by a series of cascading failures continues, the entire system or large parts of it may completely collapse. This is usually referred to as a system blackout.

An example of the type of event sequence that can cause a blackout might start with a single line being opened due to an insulation failure; the remaining transmission circuits in the system will take up the flow that was flowing on the now-opened line. If one of the remaining lines is now heavily loaded, it may open due to relay action, thereby causing even more load on the remaining lines. This type of process is often termed a cascading outage. Most power systems are operated such that any single initial failure event will not leave other components heavily overloaded, specifically to avoid cascading failures.

1.2. FACTORS AFFECTING POWER SYSTEM SECURITY

As a consequence of many widespread blackouts in interconnected power systems, the priorities for operation of modern power systems have evolved to the following:

1. Operate the systems in such a way that power is delivered reliably.

2. Within the constraints placed on the system operation by reliability considerations, the system will be operated most economically.

The power systems transmission and generation systems are always designed by engineers with reliability in mind. This means that adequate generation has been installed to meet the load and adequate transmission has been installed to deliver the generated power to the load. If the operation of the system went on without sudden failures or without experiencing unanticipated operating states, we would probably have no reliability problems. However, any piece of equipment in the system can fail, either due to internal causes or due to external causes such as lighting strikes, objects hitting transmission tower or human errors in setting relays. It is highly uneconomical if not possible, to build a power system with no such redundancy that failures never cause load to be dropped on a system. Rather systems are designed so that the probability of dropping load is accepted small. Thus, most power systems are designed to have sufficient redundancy to withstand all major failure events, but this does not guarantee that the system will be 100% reliable. Usually, a power system is never operated with all equipment in since failures occur or maintenance may require taking equipment out of service. Thus the security system designed for the power system play a considerable role in seeing that the system is reliable.

Two major types of failure events that affect the power system mostly are transmission line outage and generation unit failures. Transmission line failures cause changes in the flows and voltages on the transmission equipment remaining connected to the system. Therefore the analysis of transmission failures requires methods to predict these flows and voltages so as to be sure they are within their respective limits. Generation failures can also cause flows and voltages to change in the transmission system, with the addition of dynamic problems involving system frequency and operator output.

1.3. FUNCTIONS OF POWER SYSTEM SECURITY

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

1. System monitoring.

2. Contingency analysis.

3. Security-constrained optimal power flow.

System monitoring provides the operators of the power system with related up-to-date information on the conditions on the power system. From the time that utilizes went beyond systems of one unit supplying a group of loads, effective operations of the system required that critical quantities be measured and the values of the measurements be transmitted to a central location. Such systems of measurement and data transmission, called telemetry systems, that can monitor voltages, currents, power flows, and the status of circuit breakers and switches in every substation in a power system transmission network. In addition, other critical information such as frequency, generator unit outputs and transformer tap positions can also be telemetered. With so much information telemetered simultaneously, no human operator could hope to check all of it in a reasonable time frame. For this reason, digital computers are usually installed in operations control centers to gather the telemetered data, process them and place them in a data base from which operators can display information on large display monitors. More importantly, the computer can check incoming information against pre-stored limits and alarm the operators in the event of an over load or out-of-limit voltage.

Such systems are usually combined with supervisory control systems that allow operators to control circuit breakers and disconnect switches and transformer taps remotely. Together, these systems are often referred to as SCADA systems, standing for supervisory control and data acquisition system. The SCADA system allows a few operators to monitor the generation and high-voltage transmissions system and to take action to correct overloads or out-of-limit voltages.

The second major security function is the contingency analysis. The results of this type of analysis allow systems to be operated defensively. Many of the problems that occur on a power system can cause serious trouble within such a quick time period that the operator could not take action fast enough. This is often the case with cascading failures. Because of this aspect of systems operation, modern operations computers are equipped with contingency analysis programs that model possible systems troubles before they arise. These programs are based on a model of the power system and are used to study outage events and alarm the operators to any potential overloads or out-of-limit voltages. For example, the simplest form of contingency analysis can be put together with a standard power-flow program, together with procedures to set up the power-flow data for each outage to be studied by the power-flow program. Several variations of this type of contingency analysis scheme involve fast solution methods, automatic contingency event selection and automatic initializing of the contingency power flows using actual system data and state estimation procedures.

The third major security function is security-constrained optimal power flow. In this function, a contingency analysis is combined with an optimal power flow which seeks to make changes to the optimal dispatch of generation, as well as the other adjustments, so that when a security analysis is run, no contingencies result in violations. To show how this can be done, the power system can be divided into four operating states.

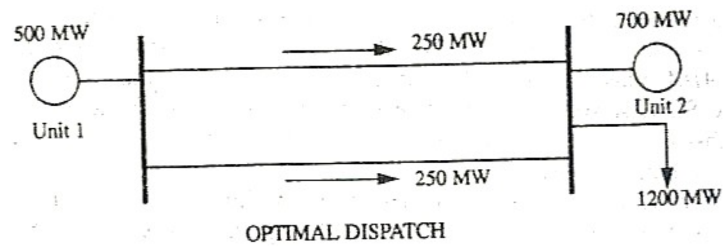
Optimal dispatch: This is the state that the power system is in prior to any contingency. It is optimal with respect to economic operation, but it may not be secure.

Post contingency: It is the state of the power system after a contingency has occurred. We shall assume here that this condition has a security violation (line or transformer beyond its flow limit, or a bus voltage outside the limit).

Secure dispatch: It is the state of the system with no contingency outages, but with corrections to the operating parameters to account for security violations.

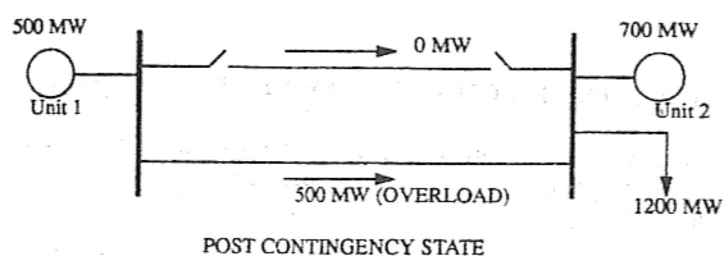
Secure post- contingency: It is the state of the system when the contingency is applied to the base-operating condition with corrections.

We shall illustrate the above with an example. Suppose the trivial power system consisting of two generators, a load, a double circuit line is to be operated with both generators supplying the load as shown below.

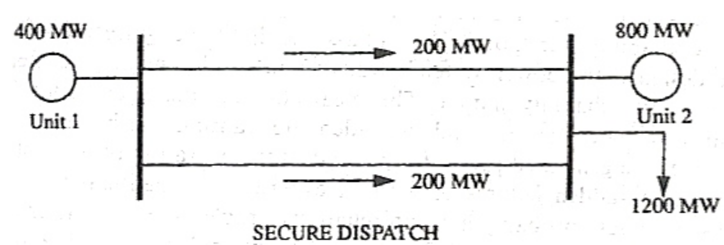


We assume that the system as shown is in economic dispatch, which is the 500 MW from unit 1 and 700 MW from unit 2 is the optimum dispatch. Further, we assert that each circuit of the double circuit line can carry a maximum of 400 MW, so that there is no loading problem in the base-operating condition.

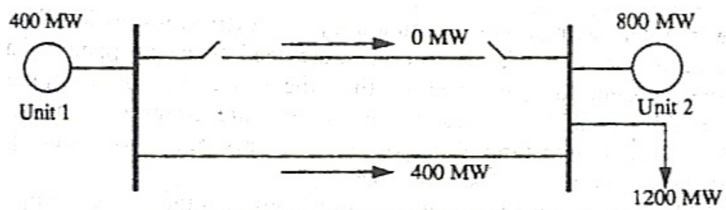
Now, we shall postulate that one of the two circuits making up the transmission line has been opened because of a failure. This result in-



Now there is an overload on the remaining circuit. We shall assume that we do not want this condition to arise and that we will correct the condition by lowering the generation on unit 1 to 400 MW. The secure dispatch is-



Now, if the same contingency analysis is done, the post-contingency condition is-



SECURE POST CONTINGENCY STATE

By adjusting the generation on unit 1 and unit 2, we have prevented the post-contingency operating system from having an overload. This is the essence of what is called “security corrections”. Programs which can make control adjustments to the base of pre- contingency operation to prevent violations in the post-contingency conditions are called “security-constrained optimal power flows” or SCOPF. These programs can take account of many contingencies and calculate adjustments to generator MW, generator voltages, transformer taps, interchange etc.

Together the functions of system monitoring, contingency analysis and corrective action analysis comprise a very complex set of tools that can aid in the secure operation of a power system.

In our thesis, we have mainly concentrated on contingency analysis.

CHAPTER II

POWER FLOW STUDY

2.1. What is power flow study?

Power flow analysis is probably the most important of all network calculations since it concerns the network performance in its normal operating conditions. It is performed to investigate the magnitude and phase angle of the voltage at each bus and the real and reactive power flows in the system components.

Power flow analysis has a great importance in future expansion planning, in stability studies and in determining the best economical operation for existing systems. Also load flow results are very valuable for setting the proper protection devices to insure the security of the system. In order to perform a load flow study, full data must be provided about the studied system, such as connection diagram, parameters of transformers and lines, rated values of each equipment, and the assumed values of real and reactive power for each load.

The steady state operation of power system as a topic for study is called 'Power flow study'. The objective of any power flow program is to produce the following information:

• Voltage magnitude at each bus.

• Real and reactive power flowing in each line.

• Phase angle of voltage at each bus.

Simply stated the power flow problem is as follows:

● At any bus there are four quantities of interest: $|V|$, θ, P, and Q.

● If any two of these quantities are specified, the other two must not be specified otherwise we end up with more unknowns than equations.

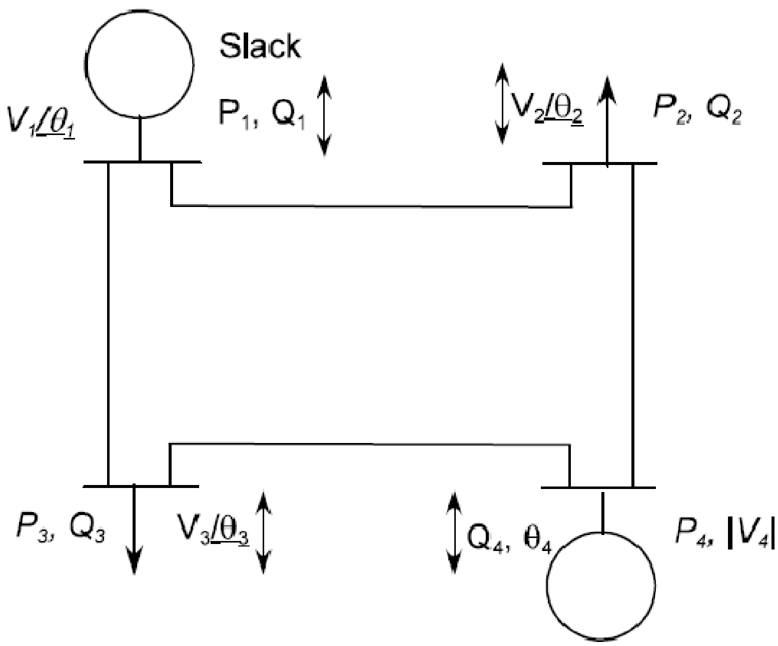
● Because records enable the real and reactive power to be accurately estimated at loads, P and Q are specified quantities at loads, which are called PQ buses.

● Likewise, the real power output of a generator is controlled by the prime mover and the magnitude of the voltage is controlled by the exciter, so and P and $|V|$ are specified at generators, which are called PV buses.

● This means that $|V|$ and θ are unknown at each load bus and θ and Q are unknown at each generator bus.

● Since the system losses are unknown until a solution to the load-flow problem has been found, it is necessary to specify one bus that will supply these losses. This is called the slack (or swing, or reference) bus and since P and Q are unknown, $|V|$ and θ must be specified. Usually, an angle of θ = 0 is used at the slack bus and all other bus angles are expressed with respect to slack.

The foregoing is summarized in the following one-line diagram in which the specified quantities are italicized, while the quantities that are free to vary during the iteration process are indicated with up-and-down arrows. Note that at each bus we can write TWO node equations.



2.2. Data needed for power flow

● One line diagram

● Either Y_{bus} or Z_{bus} (Value of series impedance and shunt admittance of transmission line are necessary to from Z_{bus})

● Power input from generator and from interconnection.

2.3. Bus Classification

Each bus in the system has four variables: voltage magnitude, voltage angle, real power and reactive power. During the operation of the power system, each bus has two known variables and two unknowns. Generally, the bus must be classified as one of the following bus types:

1. Slack or Swing Bus

This bus is considered as the reference bus. It must be connected to a generator of high rating relative to the other generators. During the operation, the voltage of this bus is always specified and remains constant in magnitude and angle. In addition to the generation assigned to it according to economic operation, this bus is responsible for supplying the losses of the system.

2. Generator or Voltage Controlled Bus

During the operation the voltage magnitude at this the bus is kept constant. Also, the active power supplied is kept constant at the value that satisfies the economic operation of the system. Most probably, this bus is connected to a generator where the voltage is controlled using the excitation and the power is controlled using the prime mover control (as you have studied in the last experiment). Sometimes, this bus is connected to a VAR device where the voltage can be controlled by varying the value of the injected VAR to the bus.

3. Load Bus

This bus is not connected to a generator so that neither its voltage nor its real power can be controlled. On the other hand, the load connected to this bus will change the active and reactive power at the bus in a random manner. To solve the load flow problem we have to assume the complex power value (real and reactive) at this bus.

2.4. Variables of power flow study

At each bus two of four quantities δ, $|V|$, P and Q are specified and the remaining two are calculated.

Bus Type	Known variables	Unknown variables
Swing/ Slack/ reference bus	V , δ	P , Q
PV/ Generator/ Voltage Control Bus	P , V	Q , δ
PQ/ Load Bus	P , Q	V , δ

2.5. Developing Power Relation

$I = \frac{V}{Z} = YV$

$I_{BUS} = Y_{BUS} V_{BUS}$

$I_i = \sum_{K=1}^{N} Y_{ik} V_k$ ……… (1)

$V = |V| e^{j \angle V}$

$I = |I| e^{j \angle I}$

$I^* = |I| e^{-j \angle I}$

$S = V I^* = |V| |I| e^{j (\angle V - \angle I)}$

$= |V| |I| e^{j (\theta)}$

$= |V| |I| (\cos\theta + j \sin\theta)$

$= P + jQ$

$S^* = (V I^*)^* = V^* I = P - jQ$

$I_i = \frac{P_i - jQ_i}{V_i^*}$ ………………(2)

Using equation (1) replace I_i from (2)

$\frac{P_i - jQ_i}{V_i^*} = \sum_{K=1}^{N} Y_{ik} \; V_k$ ………………(3)

$= Y_{ii} V_i + \sum_{K=1}^{N} Y_{ik} \; V_k$ (k ≠ i)

$V_i = \frac{1}{Y_{ii}} [\frac{P_i - jQ_i}{V_i^*} - \sum_{K=1}^{N} Y_{ik} \; V_k]$ (k ≠ i) ……….(A)

Equation (3) can be written as,

$P_i - jQ_i = V_i^* \sum_{K=1}^{N} Y_{ik} \; V_k$

$= V_i^* \; [Y_{ii} V_i + \sum_{K=1}^{N} Y_{ik} \; V_k]$ (k ≠ i)

$Q_i = - I_m \; [V_i^* \; (Y_{ii} V_i + \sum_{K=1}^{N} Y_{ik} \; V_k)]$ (k ≠ i) ………. (B)

2.6. Techniques of Solution

Because of the nonlinearity and the difficulty involved in the analytical expressions for the above power flow equations, numerical iterative techniques must be used such as:

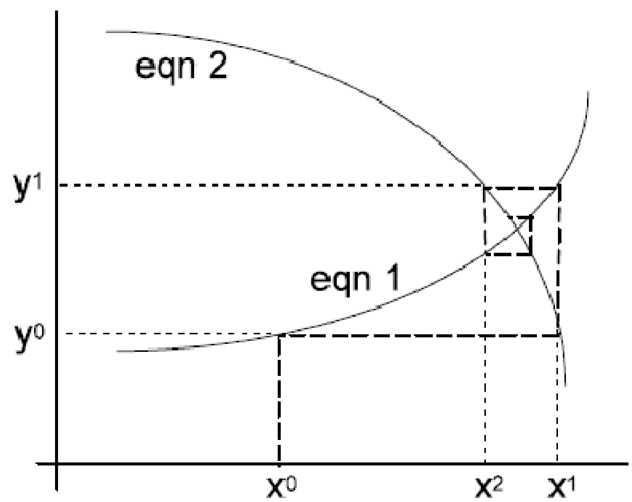
1. Gauss-Seidel method (G-S).
2. Newton-Raphson method (N-R).

The first method (G-S) is simpler but the second (N-R) is reported to have better convergence characteristics and is faster than (G-S) method.

2.7. The Gauss-Seidel Method

2.7.1. Definition

The Gauss-Seidel method was introduced late in the 1950. This method is based on substituting nodal equations into each other. It is the slower of the two but is the more stable technique. Its convergence is said to be Monotonic. The iteration process can be visualized for two equations:



Although not the best load-flow method, Gauss-Seidel is the easiest to understand and was the most widely used technique until the early 1970s.

2.7.2. Assumption

1. Bus 1 => Swing Bus
2. Remaining generator Buses are consecutively numbered as 2, 3, 4…
3. The load buses are numbered as G+1, G+2, …

2.7.3. Information regarding Variables

Bus types	**Knowns**	**Unknowns**
Swing Bus 1	$V_1 = V_1 \angle 0$	P_1 , Q_1
Generator Bus K = 1, 2, 3 …	V_k, P_k	Q_k, S_k
Load Bus K = G+1, G+2, G+3…	P_k , Q_k	V_k, S_k

2.7.4. Procedures

1. Form P.U. Y_{BUS}

2. Assume the following initial values

   For Generator Buses $S_k = 0$ k = 2, 3, 4…

   For Generator Buses $V_k = 1$ k = G+1, G+2, G+3…

   $S_k = 0$

3. Calculate Q_2 using equation (B)

4. Calculate

(i) $V_2 = V_{2c} \angle \delta_c$ using equation (A)

(ii) $V_2 = V_{2s} \angle \delta_{2c}$ Where V_{2s} is the specified (known) generator voltage

[In effect. the angle is adjusted, keeping the magnitude constant]

(iii) Substitute the new value of V_2 of (ii) to recalculate

$$V_2 = V_{2c'} \angle \delta_{c'}$$

And set $V_2 = V_{2s} \angle \delta_{c'}$

5. (i) Obtain ΔQ_2 and $\Delta \delta_2$ and

   (ii) Store the larger one as ΔX_{max}.

(iii) Replace the old value of V_2 with the newly calculated and corrected one.

6. Repeat steps 3 through 5 for K = 3, 4, 5…

7. (i) Calculate V_{G+1} (Voltage of load Bus) using equation (A)

   (ii) Then substitute the new value of V_{G+1} into equation (A) and recalculate.

8. (i) Obtain ΔV_{G+1} and $\Delta\delta_{G+1}$.

   (ii) Compare ΔV_{G+1} and $\Delta\delta_{G+1}$ with $\Delta X_{max}$and replace with larger change.

   (iii) Replace $V_{G+1}$by newly calculated value.

9. Repeat steps 7 and 8 for K = G+1, G+2,…

   This is the end of the first iteration.

10. Check the convergence of the solution

$$\Delta X_{max} \leq \mathcal{E}$$

If all calculation are with the tolerance specified then the solutions have been reached. Otherwise repeat steps 3 through 10 until the solution is reached.

11. Calculate P_i and Q_i if needed using

$$P_i = \sum_{K=1}^{N}(V_i G_{ik} V_k Cos\ \delta_{ik} - V_i B_{ik} V_k Sin\ \delta_{ik})$$

$$Q_i = \sum_{K=1}^{N}(V_i B_{ik} V_k Cos\ \delta_{ik} + V_i G_{ik} V_k Sin\ \delta_{ik})$$

Where

$$Y_{ij} = Y_{ij}\ e^{-j\phi_{ij}} = G_{ij} - jB_{ij}$$

Convergence to the solution can be accelerated someone by using an acceleration factor 1.3 to 1.6 in steps 4 and 7.

2.8. Newton-Raphson Method

2.8.1. Definition

In numerical analysis, Newton's method (also known as the Newton-Raphson method), named after Isaac Newton and Joseph Raphson, is perhaps the best known method for finding successively better approximations to the zeroes (or roots) of a real-valued function. The Newton-Raphson (NR) method is widely used for solving nonlinear set of equations. It transforms the original nonlinear problem into a sequence of linear problems whose solutions approach the solution of the original problem. This method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses). Next, a Taylor Series is written, with the higher order terms ignored, for each of the power balance equations included in the system of equations.

Taylor's series of expansion is used

$$y = b_0 + b_1X + b_2X^2 + b_3X^3 + b_4X^4$$

$$y = f(x)$$

Let, Solution of X is,

$$x = x^0 + \Delta x$$

$$\Delta x = x - x^0$$

According to Taylor's series:

$$y = f(x) = f(x^0) + \frac{\Delta x}{1!} f'(x)\,|_{x^0} + \frac{\Delta x^2}{2!} f''(x)\,|_{x^0} + \cdots + \frac{\Delta x^n}{n!} f^n(x)\,|_{x^0}$$

Where $f'(x) = \frac{df(x)}{dx}$

If $\Delta x << 1$

$$y = f(x) \approx f(x^0) + \frac{\Delta x}{1!} f'(x)\,|_{x^0}$$

Or, $\quad y\, f(x^0) = \; f'(x)\,|_{x^0}\, \Delta x$

$$[\text{k}] = [\text{J}]\, \Delta x$$

$$\Delta x \;=\; [J]^{\;-1}\, [\text{k}]$$

If $\Delta x = \varepsilon \; then\, x^0 = \, x^0 + \, \Delta x$

Otherwise continue iteration assuming

$x^{i+1} = \, x^i + \, \Delta x$ (That is new value of x = previous value + Difference)

$$S_i^* = \, P_i \, - \, jQ_i = \, v^* \, I$$

$$I = \, \sum_{k=1}^{N} Y_{ik}\, V_k$$

$$S^* = \, P_i \, - \, jQ_i = \, \sum_{k=1}^{N} V_i^* Y_{ik}\, V_k$$

$$V_i = |V|\, e^{jS_i} = \, D_i + \, jF_i$$

$$Y_{ik} = |Y_{ik}|\, e^{-j\varphi_{ik}} = \, G_{ik} - \, jB_{ik}$$

$$\therefore S = \, P_i - \, jQ_i = (D_i - \, jF_i)(G_{ik} - \, jB_{ik})(D_i + \, jF_i)$$

Equating real and imaginary terms,

$$P_k = \, \sum_{m=1}^{N}(\, D_k \;\, G_{km}\, D_m \, + \, D_k\, B_{km}\, F_m - \, F_k\, B_{km}\, D_m + \, F_k\, G_{km}\, F_m \,)$$

$$Q_k = \, \sum_{m=1}^{N}(\, D_k \;\, B_{km}\, D_m \, + \, D_k\, G_{km}\, F_m - \, F_k\, G_{km}\, D_m + \, F_k\, B_{km}\, F_m \,)$$

$$P = f(D, F)$$

$$Q = f(D, F)$$

2.8.2. Information regarding variables

KNOWN

$V_{1=} V_1 \angle 0$ For swing bus

V_k , P_k k = 2……..G (Gen. Bus)

P_k , Q_k k = G+1……..N (Local Bus)

UNKNOWN

P_1 , Q_1

Q_k , S_k k = 2……..G

V_k , S_k k = G+1……..N

2.8.3. Procedures

1. Form P.U. Y_{BUS}

2. Assume initial values:

$D_k^0 = V_{ks}$ $F_k^0 = 0$ k=2,3,….G

$D_k^0 = 1$ $F_k^0 = 0$ k=G+1,…N

3. Calculate P_k^i, Q_k^i

4. Calculate,

$\Delta P_k^i = P_{ks} - P_k^i$ k= 2,…N (For both Generator and Load buses)

$\Delta Q_k^i = Q_{ks} - Q_k^i$ k= G+1…N (Only for Load buses)

$$\Delta V_k^{i^2} = V_{ks}^2 - V_k^{i^2}$$ k= 2,3,…G (Only for Generator buses)

Where P_{ks} , Q_{ks} and V_{ks} are scheduled (known) quantities and

$$V_k^{i^2} = (D_k^i)^2 + (F_k^i)^2$$

Set, $\Delta x_{max} = Max\ \{\Delta P_{k_{max}}^i,\ Q_{k_{max}}^i,\ \Delta V_{k_{max}}^{i^2}\}$

Whichever is large.

5. Calculate the bus currents using,

$$I_k^i = \frac{P_k^i - jQ_k^i}{(V_k^*)^*} = A_k^i + jC_k^i$$ k=2,3….N

6. Calculate the Jacobian matrix

7. Obtain by matrix inversion the correction

   ΔD_k^i , ΔF_k^i k=2,3,….N (For all generator and load buses)

8. Calculate the new bus voltages
   a. At generator buses (voltage controlled Bus = PU Bus)

   $$D_k^{i+1} = V_{ks}\ Cos\ \delta_k^{i''}$$

   $$F_k^{i+1} = V_{ks}\ Cos\ \delta_k^{i''}$$ k= 2,3,….G

   Where $\delta_k^i = tan^{-1}\ ({F_k^i}/{D_k^i})$

   b. At the remaining buses (load buses)

$$D_k^{i+1} = D_k^i + \Delta D_k^i$$

$$F_k^{i+1} = F_k^i + \Delta F_k^i \qquad \text{k=G+1, G+2,….N}$$

9. Replace D_k^i *and* F_k^i *by* D_k^{i+1} *and* F_k^{i+1}, *For* $k = 2,3, \dots N$

10. This is the end of the current iteration, check the $\Delta x_{max} \leq \varepsilon$

If all corrections are within the tolerance specified,

Then the solution has been reached. Otherwise, repeat steps 3-10 until the solution is reached.

11. Calculate

$$P_i = \sum_{k=1}^{N} (V_i \; G_{ik} \, V_k \, Cos\delta_{ik} - \; V_i B_{ik} \, V_k \, Sin\delta_{ik} \;)$$

$$Q_i = \sum_{k=1}^{N} (V_i \; B_{ik} \, V_k \, Cos\delta_{ik} - \; V_i G_{ik} \, V_k \, Sin\delta_{ik} \;)$$

Where, $\delta_{ik} = \delta_i - \delta_k$

CHAPTER III

SHUNT CAPACITANCE COMPENSATION

3.1. SHUNT CAPACITANCE COPENSATION

In order to solve the faulty conditions found in our network, we used a technique called “Shunt capacitance compensation”.

An electric transmission system must provide power transmission within voltage limits at safe and high quality conditions. By industrial development, demand of electrical energy has become harder to provide acceptable voltage profile in power system. Therefore voltage stability and voltage collapse studies have become increasingly important.

Voltage collapse is a type of system instability, and it is defined as the ability of power system to keep bus voltages at acceptable steady state values following a disturbance and under normal operating conditions. Main reason of voltage instability is an insufficient injection of reactive power to the system. Consequently, sufficient amount of reactive power reserve must be placed at suitable points. The load flow analysis involves the calculation of load flows and voltages of network for specified terminal and bus conditions. Shunt compensating is applied to electric power transmission system to confirm transmission effectively.

A shunt compensation system ideally performs the following functions:
1) It helps produce a substantially flat voltage profile at all levels of power transmission,
2) It improves stability by increasing the maximum transmissible power,
3) It provides an economical means for meeting the reactive power requirements of transmission.

Shunt capacitors are also used at the distribution level. Reactive power injected to the network by these capacitors helps regulate the voltage at the desired level and limit its deviations within a certain range. Moreover, by correcting the load power factor (especially for the highly inductive loads) and therefore releasing the capacity of the power lines and transformers, they can help reduce the investment cost of the network, as well as the power losses.

It is well known that shunt capacitance is both socially and economically beneficial to power system network. These devices reduce the apparent power (S) which is produced by generators allowing more customers to be served and increasing the income of electrical companies.

3.2. TECHNIQUES OF SHUNT CAPACITANCE COMPENSATION

Capacitance units were placed on different substations (buses) according to the following three categories:

A. Single Bus Compensation

In this case the computer program places a capacitor on each bus of the system separately. The capacitance is then increased until the highest compensation of reactive power on that bus is achieved, provided that the generators are not converted to capacitive power generation

B. Double Bus Compensation

The computer program places capacitors on two buses, simultaneously maintaining the same condition on both (system not converted to be capacitive).

C. Triple Bus Compensation

The computer program places three capacitors on three different substations simultaneously.

To solve the abnormal conditions in our network, we used Single Bus Compensation Technique.

3.3. IMPLEMENTING SHUNT CAPACITANCE COMPENSATION

To maintain least possible losses, our required per unit voltage solution for a certain bus ranges from 0.9 to 1.1. When any bus doesn’t meet these criteria, the bus is beyond our expected voltage limit. To get the voltage within the range, we include capacitor as a shunt to the specific bus using shunt capacitance technique.

In our case, we have collected the apparent power (Q) and voltage rating (KV) from the database for those under loaded buses. Then we did the following calculations:

We know, $Q = V^2/ X_c$
Therefore, $X_c = V^2/Q$

We also know that, $C = 1/(wX_c)$
But, $w = 2\pi f$
Therefore, $C = 1/(2\pi f X_c)$

This way, we get the exact value of the shunt capacitor needed for a specific bus.

CHAPTER IV

CONTINGENCY ANALYSIS

4.1. Contingency Analysis

Many possible outage conditions could happen to a power system. Thus, there is a need to have a mean to study a large number of them, so that operation personnel can be warned ahead of time if one or more outages will cause serious overload on other equipments. The problem of studying all possible outages becomes very difficult to solve since it is required to present the results quickly so that corrective actions could be taken. To meet this requirement, a special type of analyzing program is designed named Contingency analysis that model failure events, one after the other in sequence until all credible outages have been studied. In today's world, contingency analysis is an important component of the security function which is considered to be an integral part of the modern power management system at power control centers.

Contingency Analysis actually provides and prioritizes the impacts on an electric power system when problems occur. A contingency is the loss or failure of a small part of the power system (e.g. a transmission line), or a individual equipment failure (such as a generator or transformer). This is also called an unplanned "outage". Contingency analysis is a computer application that uses a simulated model of the power system, to evaluate the effects, and calculate any overloads resulting from each outage event. In other word, Contingency Analysis is essentially a "preview" analysis tool that simulates and quantifies the results of problems that could occur in the power system in the immediate future.

This Analysis is used as a study tool for the off-line analysis of contingency events, and as an on-line tool to show operators what would be the effects of future outages. It allows operators to be better prepared to react to outages by using pre-planned recovery scenarios.

After a contingency event, power system problems can range from:

- None: When the power system can be re-balanced after a contingency, without overloads to any element.
- Severe: When several elements such as lines and transformers become overloaded and have risk of damage.
- Critical: When the power system becomes unstable and will quickly collapse.

By analyzing the effects of contingency events in advance, problems and unstable situations can be identified, critical configurations can be recognized, operating constraints and limits can be applied, and corrective actions can be planned.

4.2. Contingency Analysis Procedure

How contingency analysis can be performed is described in a simple way in the following flowchart:

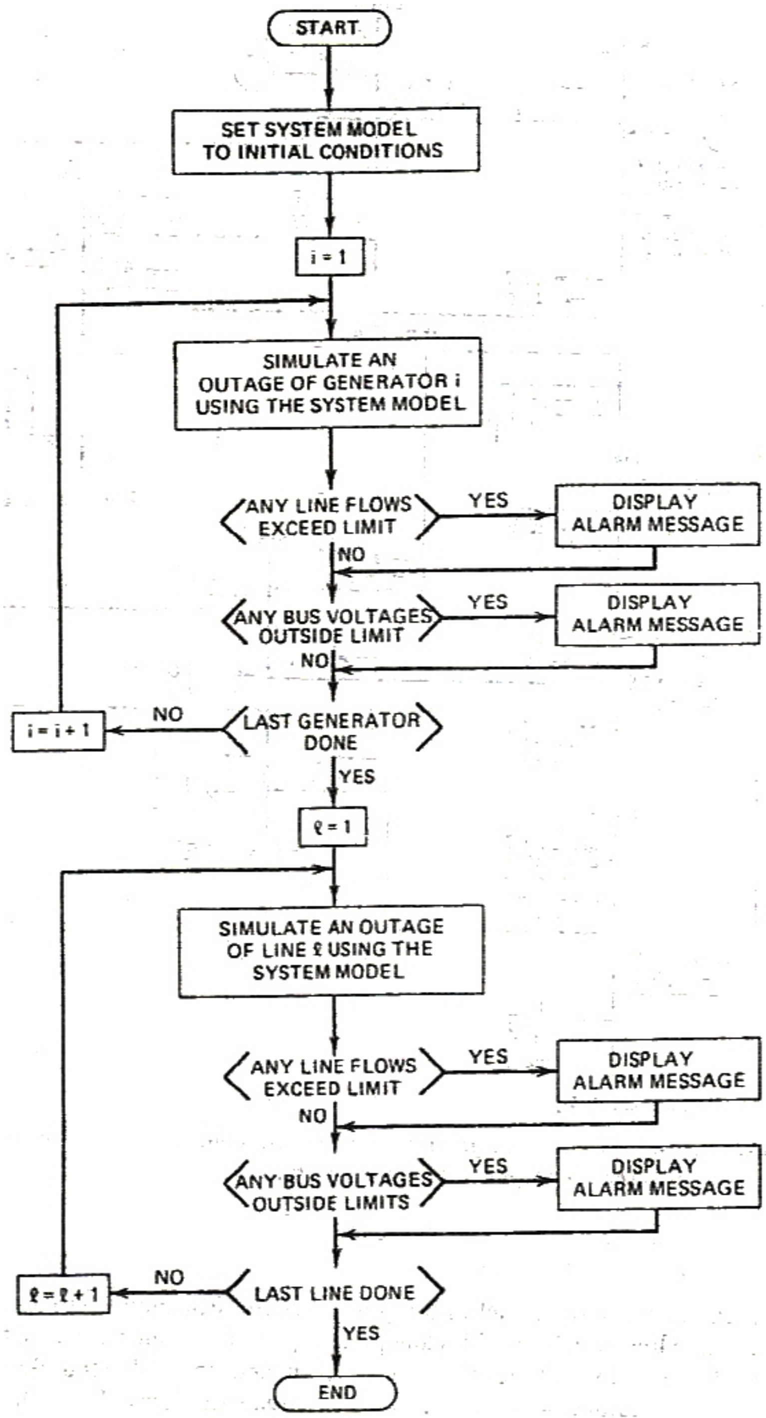


Figure: A simple technique for contingency analysis

4.3. Necessity of Contingency 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 contingency 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 contingency analysis and design a parallel line and avoid this kind of problem. Thus contingency analysis helps us to expand transmission line and improve future power system.

4.4. Power Flow Study for Contingency Analysis

Power flow calculations provide active and reactive power flows and bus voltage magnitude and their phase angle at all the buses for a specified power system and operating condition subject to the regulating capability of generators, synchronous condensers, static VAR compensators, tap changing under load transformers and specified net interchange between individual operating systems (utilities). This information is essential for the continuous evaluation or contingency analysis of the current performance of a power system and for analyzing the effectiveness of alternative plans for system expansion to meet increased load demand. These analyses require the calculation of numerous power flow cases for both normal, and emergency (contingency) operating conditions.

4.5. Contingency Ranking using Overloading Performance Index

We would like to get some measure as to how much a particular outage might affect the power system. The idea of a performance index seems to fulfill this need. The definition for the overloading performance index (PI) is as follows:

$$PI = \sum_{\substack{all\ branches \\ l}} \left(\frac{P_{flow\ l}}{P_l^{\max}} \right)^n \qquad (11.8)$$

If n is a large number, the PI will be a small number if all flows within limit, and it will be a large if one or more lines are overloaded. The problem then is how to use this performance index.

Various techniques have been tried to obtain the value of PI when a branch is taken out. These calculations can be made exactly if n=1; that is, a table of PI value, one for each line in the network, can be calculated quite quickly. The selection procedure then involves ordering the PI table from the largest value to least. The lines corresponding to the top of the list are then the candidates for the short list. One procedure simply ordered the PI table and then picked the top N_c entries from this list and placed them on the short list.

However when n =1, the PI does not snap from near zero to near infinity as the branch exceeds its limit. Instead, it rises as a quadratic function. A line that is just below its limit contributes to PI almost equal to one that is just over its limit. The result is a PI that maybe large when many lines are loaded just below their limit. Thus the PI’s ability to distinguish or detect bad cases is limited when n=1. Ordering the PI values when n=1 usually results is a list that is not at all representative of one with the truly bad cases at the top. Trying to develop an algorithm that can quickly calculated PI when n=2 or larger has proven extremely difficult.

One way to perform an outage case selection is to perform what has been called the $|P|Q$ method. Here, a decoupled power flow is used. As shown in figure 11.10, the solution procedure is interrupted after one iteration (one P – θ calculation and one Q – V calculation; thus, the name $|P|Q$). With this procedure, the PI can use as large an n values as desired, say n = 5, there appears to be sufficient information in the solution at the end of the first iteration of the decoupled power flow to give a reasonable PI. Another advantages to this procedure is the fact that the voltages can also be included in the PI. Thus, a different PI can be used, such as:

$$PI = \sum_{\substack{all\ branches \\ l}} \left(\frac{P_{flow\ l}}{P_l^{max}}\right)^{2n} + \sum_{\substack{all\ branches \\ l}} \left(\frac{\Delta|E_i|}{\Delta|E|^{max}}\right)^{2n} \qquad (11.9)$$

Where $\Delta|E_i|$ is the difference between the voltage magnitude as solved at the end of the $|P|Q$ procedure and the base-case voltage magnitude $\Delta|E|^{max}$ is a value set by utility engineers indicating how much they wish to limit a bus voltage from changing on one outage.

To complete the security analysis, the PI list is sorted so that the largest PI appears at the top. The security analysis can then start by executing full power flows with the case which is at the top of the list, then solve the case which is second, and so on down the list. This continues until either a fixed number of cases are solved, or until predetermined number of cases are solved which do not have any alarms.

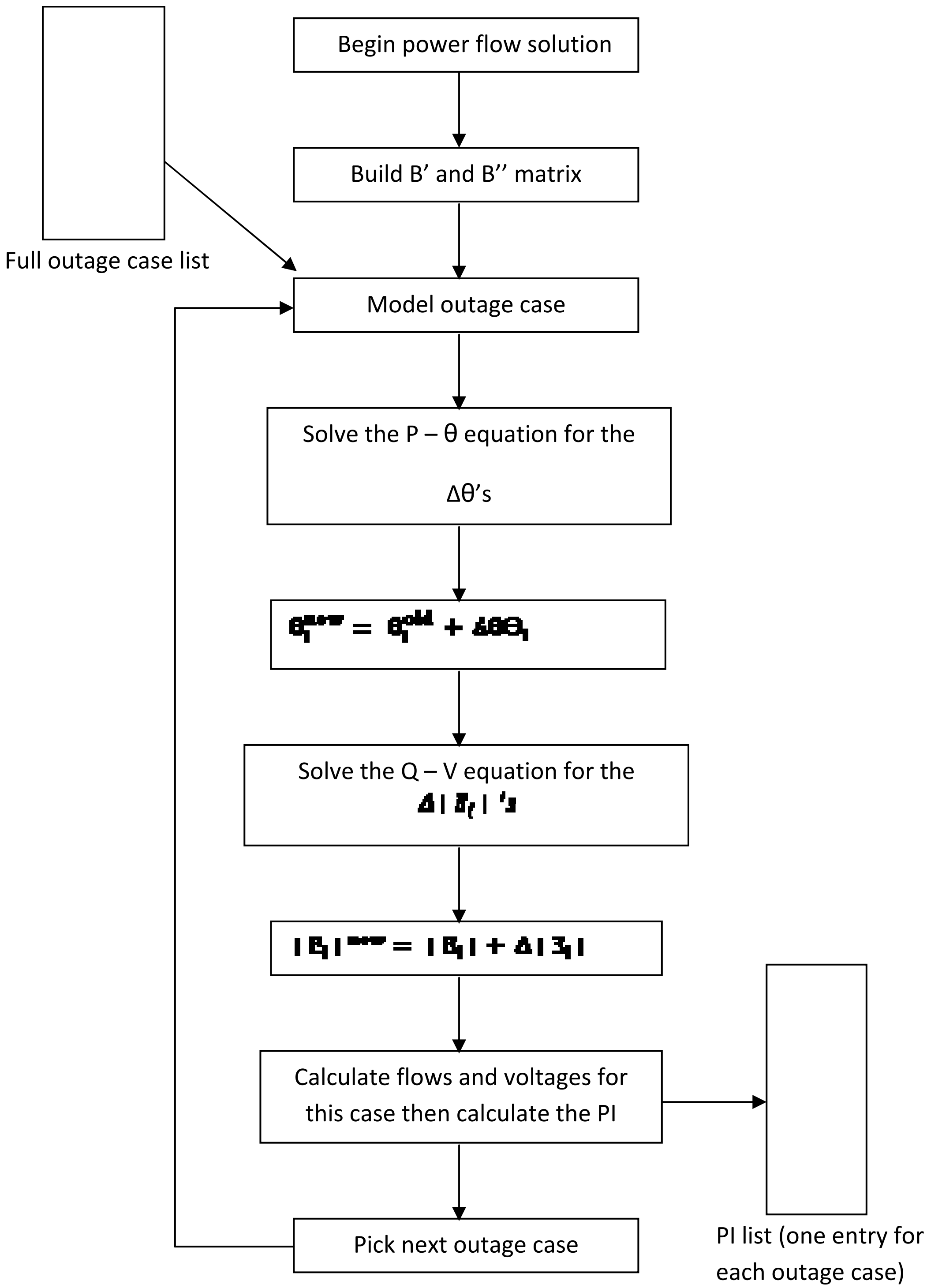


FIG. 11.10: The | P | Q contingency selection procedure

CHAPTER V

RELIABILITY EVALUATION

5.1. Reliability Evaluation

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. A method for incorporating the failures due to aging in power system reliability evaluation is presented in. It includes the development of a calculation approach with two possible probability distribution models for unavailability of aging failures and implementation in reliability evaluation. Adverse weather such as hurricanes can have significant impact on power system reliability. One of the challenges of incorporating weather effects in power system reliability evaluation is to assess how adverse weather affects the reliability parameters of system components. A fuzzy inference system (FIS) built by using fuzzy clustering method is combined with the regional weather model to solve the preceding problem is illustrated in. A new computationally efficient methodology for calculating the reliability indices of a bulk power system using the state enumeration approach is depicted in. The approach utilizes topological analysis to determine the contribution of each system state to the frequency and duration indices at both the system and the bus level. Common cause outage is also considered in power system reliability evaluation. Power system reliability evaluation and quality assessment using fuzzy logic and genetic algorithm are depicted in and, respectively.

5.2. 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 as,

$$FOR\,, q = \frac{FOH}{FOH + SH} \qquad (1)$$

Where,

FOH = Forced outage hours

SH = Service hours or operating hours at full availability

Unit availability of a generating unit can be defined as,

$$Unit\ availability, p = \frac{SH}{FOH + SH} \qquad (2)$$

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.1.

BPS has sixty one generators and a total installed capacity of 5275 MW. The individual capacity and FOR of the generators are shown in Table I.

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.1.

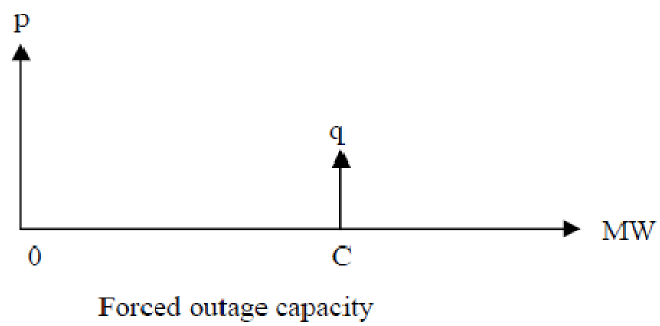


Figure1. PDF of forced outage capacity of a generating unit

5.3. Load Model

In order to develop the load model of BPS, hourly loads of last five years (2006-2010) are collected from NLDC of Bangladesh. Hourly loads are divided in seven groups having a group size of 500 MW. The occurrence of each group is then counted. The probability of occurrence of each group is calculated as,

Where, $$P_g = \frac{N_g}{N_t} \qquad (3)$$

P_g = Probability of occurrence of a group

N_g = No. of occurring days of that group in observation period of 5 years

N_t = Total no. of days in observation period of 5 years

Finally the average value of each group is taken and the corresponding probabilities reside for that average value of the load.

5.4. LOLP using 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 are described in what follows.

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

$$m_1(i) - C_i^{1}.q_i \qquad (4)$$

$$m_2(i) = C_i^{2}.q_i \qquad (5)$$

$$m_3(i) = C_i^{3}.q_i \qquad (6)$$

$$\ldots \quad \ldots \quad \ldots$$

$$m_n(i) = C_i^{n}.q_i \qquad (7)$$

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,

$$M_1(i) = 0 \qquad (8)$$

$$M_2(i) = m_2(i) - [m_1(i)]^2 \qquad (9)$$

$$M_3(i) = m_3(i) - 3m_2(i).m_1(i) + 2[m_1(i)]^3 \qquad (10)$$

$$M_4(i) = m_4(i) - 4m_3(i).m_1(i) + 6[m_1(i)]^2.m_2(i) - 3[m_1(i)]^4 \qquad (11)$$

$$\ldots \quad \ldots \quad \ldots$$

$$M_n(i) = [-m_1(i)]^n.p_i + [C_i - m_1(i)]^n.q_i \qquad (12)$$

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,

$$k_1(i) = m_1(i) \qquad (13)$$

$$k_2(i) = M_2(i) \qquad (14)$$

$$k_3(i) = M_3(i) \qquad (15)$$

$$k_4(i) = M_4(i) - 3[M_2(i)]^2 \qquad (16)$$

$$k_5(i) = M_5(i) - 10M_2(i).M_3(i) \qquad (17)$$

(iv) In the fourth step, the culultants 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 (13) to (17).

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

$$k_j = \sum k_j(Generators) + k_j(Load) \qquad (18)$$

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

$$z = \frac{IC - k_1}{\sqrt{k_2}} \qquad (19)$$

Where,

IC = Installed capacity of the power system

k_1, k_2 = System cumulants

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

$$LOLP = Q(z) + F(z) \qquad (20)$$

Where, Q (z) can be calculated as,

Here,

$$N(z) = \frac{1}{\sqrt{2\pi}} \exp(-\frac{z^2}{2}) \qquad (22)$$

$$t = \frac{1}{1 + rz} \qquad (23)$$

And r, b_1, b_2 and b_3 are constants

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

$$F(z) = \frac{G_1 N^{(2)}(z)}{3!} - \frac{G_2 N^{(3)}(z)}{4!} + \frac{G_3 N^{(4)}(z)}{5!} - \cdots \qquad (24)$$

Where, the expansion factors G_1, G_2, G_3 are calculated using the following relationship.

$$G_i = \frac{k_{(i+2)}}{(k_2)^{(\frac{i+2}{2})}} \qquad (25)$$

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

$$N^{(m)}(z) = -(m-1).N^{(m-2)}(z) - z.N^{(m-1)}(z) \qquad (26)$$

$$m = 3, 4, 5, \ldots$$

And

$$N^{(1)}(z) = -z.N(z) \qquad (27)$$

$$N^{(2)}(z) = (z^2 - 1)N(z) \qquad (28)$$

(ix) The value of constants are set as, r = 0.232, b_1 = 0.319, b_2 = -0.356, b_3 = 1.781. Finally LOLP is evaluated using (20).

CHAPTER VI

PREPERATION, ANALYSIS & RESULTS

6.1. Data Collection

According to one of the primary objective of our thesis, to be able to analyze the contingency 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). According to the database, we have got the following major components:

- ✓ Buses: 426
- ✓ Generators: 79
- ✓ Fixed Tap Transformer: 305
- ✓ Underground Cables: 06
- ✓ Transmission Lines: 225
- ✓ Induction Motors: 21
- ✓ Static Loads: 234

6.2. Software Selection

As a major part of our thesis is about performing software based contingency 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 PSAF from all those to do our analysis. PSAF (Power Systems Application Framework) is a software package that offers both graphical and tabular data entry modes, single-line diagram drawing options and many other sophisticated facilities for reporting, plotting and customizing the simulation reports. PSAF is developed by CYME International TD Inc. We found that, this software would be perfect for analyzing contingency of Bangladesh power system using the data we have collected. Here we want to mention that, we are using PSAF version 2.81 (Revision 2.8) for our thesis purpose.

6.3. Network Construction

After the database is collected and suitable software is selected, it comes to the task of network construction. Using the database, we have constructed (simulated) the whole network of Bangladesh power system in PSAF. Some of the screenshots of the simulated network are given in Appendix ‘A’.

6.4. Exploring the Abnormal Conditions

Before performing contingency analysis, we need to converge the network using power flow study. We used Newton-Raphson Method among the two methods of power flow study to converge it. After converging, we found a lot of faulty conditions which we had to solve first in order to do contingency analysis properly. Some of the faults like buses with outside voltage limits are shown in APPENDIX ‘B’.

6.5. Eliminating the Abnormal Conditions using Shunt Compensation Technique

We have calculated every specific value of shunt capacitor that is needed for eliminating the abnormal condition of each under loaded bus using shunt compensation technique. The detailed calculations with results are mentioned in tabular format in Appendix ‘C’.

6.6. Contingency Ranking

After solving all the abnormal conditions using shunt compensation technique and converging the system using power flow analysis, our network is finally prepared for contingency analysis, which is our main concern. So we have performed contingency analysis on the system and determined a detailed overloading performance index for all the transmission lines of the network. As described earlier, we know, the higher the value of overloading index, the higher the contingency ranking. Thus we have determined the contingency ranking structure for the whole power system network of Bangladesh. The contingency ranking along with the values of overloading index for the system is shown in Appendix 'D'.

6.7. Reliability Evaluation

Cumulant 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 sixty one generators and a total installed capacity of 5275 MW. The individual capacity and FOR of the generators are shown in Table I.

Gen No.	Capacity (MW)	FOR	Gen No.	Capacity (MW)	FOR
1	40	1.4×10^{-6}	32	15	0.15
2	40	1.4×10^{-6}	33	15	0.15
3	50	1.4×10^{-6}	34	15	0.15
4	50	1.4×10^{-6}	35	15	0.15
5	50	1.4×10^{-6}	36	35	0.10
6	210	0.16	37	35	0.10
7	50	0.113	38	21	0.122
8	109	0.07	39	120	0.04
9	55	0.185	40	77	0.101
10	55	0.185	41	100	0.04
11	210	0.095	42	125	0.10
12	210	0.019	43	125	0.10
13	210	0.08	44	110	0.301

Gen No.	Capacity (MW)	FOR	Gen No.	Capacity (MW)	FOR
14	210	0.08	45	60	0.402
15	64	0.116	46	28	0.50
16	64	0.116	47	28	0.50
17	150	0.013	48	20	0.045
18	150	0.014	49	20	0.20
19	150	0.014	50	20	0.20
20	56	0.321	51	20	0.119
21	56	0.321	52	60	0.50
22	30	0.15	53	8	0.30
23	100	0.30	54	450	0.07
24	210	0.197	55	235	0.07
25	210	0.197	56	125	0.07
26	60	0.117	57	142	0.07
27	28	0.60	58	45	0.07
28	28	0.60	59	45	0.07
29	12	0.15	60	110	0.11
30	12	0.15	61	110	0.07
31	12	0.15			

TABLE I. CAPACITY AND FOR OF THE GENERATORS OF BPS

Table II shows the load model of BPS.

Load (MW)	**Occurrence probability**
1750	0.0124
2250	0.0728
2750	0.1834
3250	0.3331
3750	0.2816
4250	0.1120
4750	0.0048

TABLE II. LOAD MODEL OF BPS

Using the generator and load model of BPS shown in Table I and Table II respectively and employing (4) to (17) from Chapter V, the cumulants of generating units and load are calculated. Table III represents the cumulants.

Cumulants	**Generators (**Σ==611*nnnk)*	**Load**
k_1	626.76	3326.83
k_2	69973.58	333749.80
k_3	1.75×10^{7}	-5.2×10^{7}
k_4	2.18×10^{9}	-7.81×10^{10}
k_5	1.53×10^{11}	4.12×10^{13}

TABLE III. CUMULANTS OF GENERATORS AND LOAD

Now system cumulants are calculated combining the cumulants of the generating units and the load. Table IV presents the system cumulants.

System cumulants	$k_j = \sum k_j(Generators) + k_j(Load)$
k_1	3953.59
k_2	403723.38
k_3	-3.45 x 10^{7}
k_4	-7.59 x 10^{10}
k_5	4.14 x 10^{13}

TABLE IV. SYSTEM CUMULANTS

Using (19), standardized random variable z is

$$z = \frac{5275 - 3953.59}{\sqrt{403723.38}} = 2.08 \qquad (29)$$

Using (22) and (23), normal PDF, N (z) and t are calculated as,

$$N(z) = \frac{1}{\sqrt{2\pi}} \exp[\ \frac{(2.08)^2}{2}\ ] = 0.045 \qquad (30)$$

$$t = \frac{1}{1 + (0.232)(2.08)} = 0.674 \qquad (31)$$

Now using (30) and (31) in (21),

$$Q(z) = 0.045\ [(0.319)(0.674) + (-0.356)(0.674)^2 + (1.781)(0.674)^3\ ] = 0.027 \qquad (32)$$

Expansion factors G_1, G_2 and G_3 are calculated using (25) as,

$$G_1 = \frac{k_3}{(k_2)^{1.5}} = \frac{-3.45 \times 10^7}{(403723.38)^{1.5}} = -0.134 \qquad (33)$$

$$G_2 - \frac{k_4}{(k_2)^2} - \frac{-7.59 \times 10^{10}}{(403723.38)^2} - -0.465 \qquad (34)$$

$$G_3 = \frac{k_5}{(k_2)^{2.5}} = \frac{4.14 \times 10^{13}}{(403723.38)^{2.5}} = 0.399 \qquad (35)$$

Derivatives of normal PDF are calculated using (26) to (28) as,

$$N^{(1)}(z) = -(2.08)(0.45) = -0.093 \qquad (36)$$

$$N^{(2)}(z) - [(2.08)^2 - 1](0.45) - 0.149 \qquad (37)$$

$$N^{(3)}(z) = -2(-0.093) - (2.08)(0.149) = -0.123 \qquad (38)$$

$$N^{(4)}(z) = -3(0.149) - (2.08)(-0.123) = -0.191 \qquad (39)$$

Now using (33) to (35) and (37) to (39) in (24) F (z) is determined as,

$$F(z) = \frac{(-0.134)(0.149)}{3!} - \frac{(-0.465)(-0.123)}{4!} + \frac{(0.399)(-0.191)}{5!} = -6.33 \times 10^{-3} \qquad (40)$$

Finally using (32) and (40) in (20), LOLP is evaluated as,

$$LOLP = 0.027 - 6.33 \times 10^{-3} = 0.0206 = 2.06\%$$

Thus, the reliability index ‘LOLP’ of Bangladesh Power System is 2.06%.

CONCLUSION

A security analysis study which is run in an operations center must be executed very quickly in order to be of any use to the operators. The problem of studying thousands of possible outages becomes very difficult to solve if it is desired to present the results quickly. So it is very important to have a system which can detect the possible future outages and prioritize among them to determine the most critical cases for detailed analysis. This is done by Contingency Analysis which allows operators to be better prepared to react to outages by using pre-planned recovery scenarios.

In our thesis, we have performed the complete contingency analysis of Bangladesh Power System. We have presented a detailed contingency 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 contingency 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 Cumulant Method which is a very fast computational technique. The simulation results in our thesis reveal that the Loss of Load Probability of Bangladesh Power System is 2.06%.

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.

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APPENDIX ‘A’

SOME SCREENSHOTS OF THE SIMULATED NETWORK

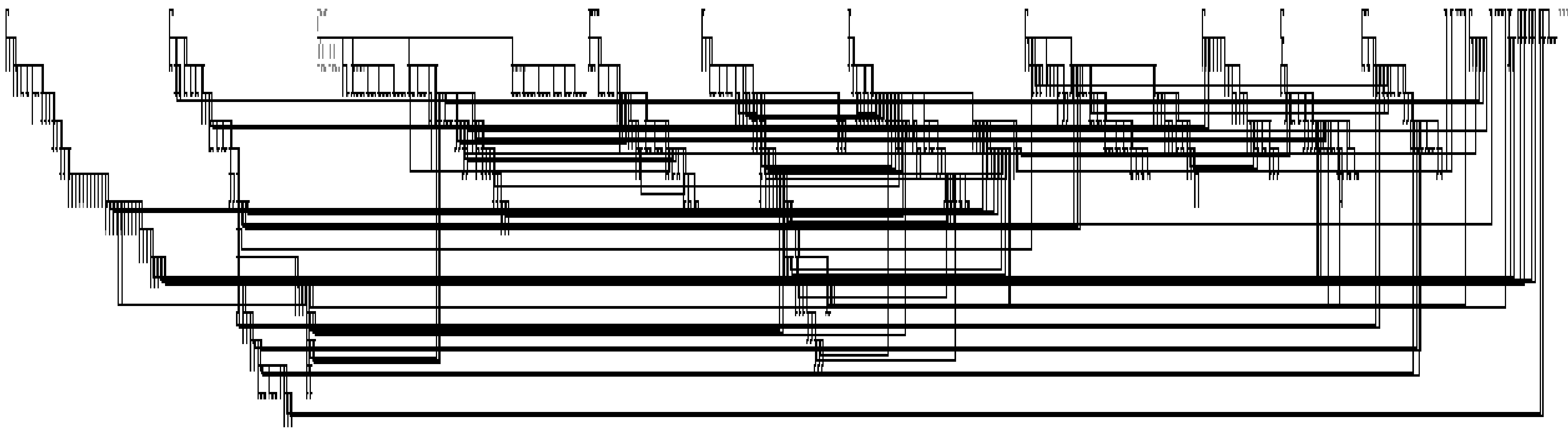
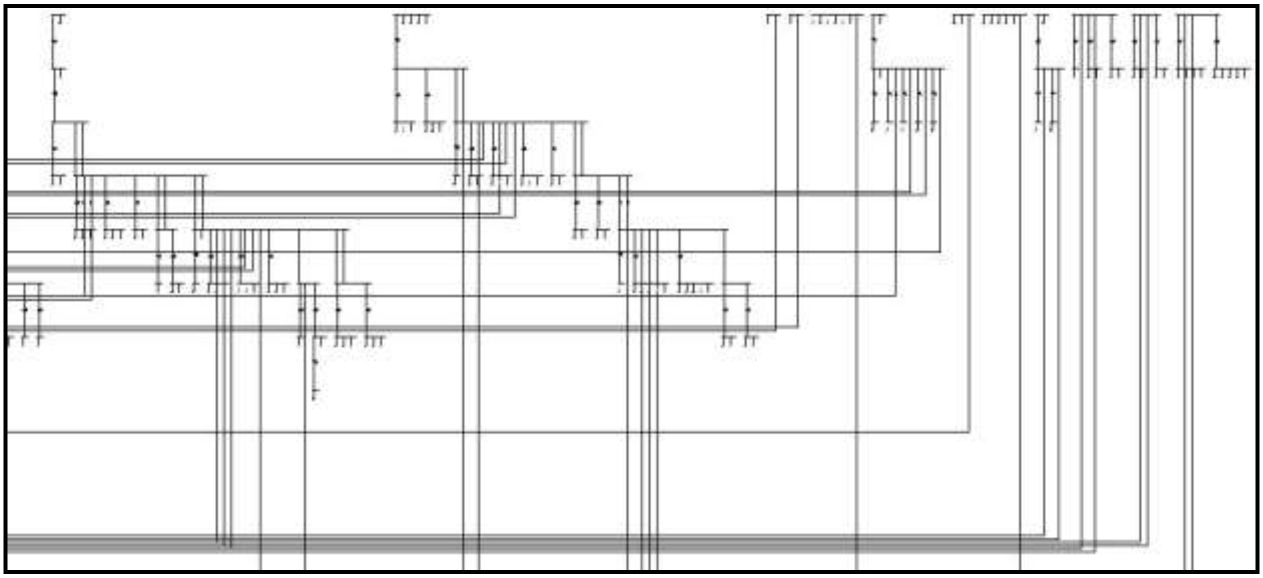
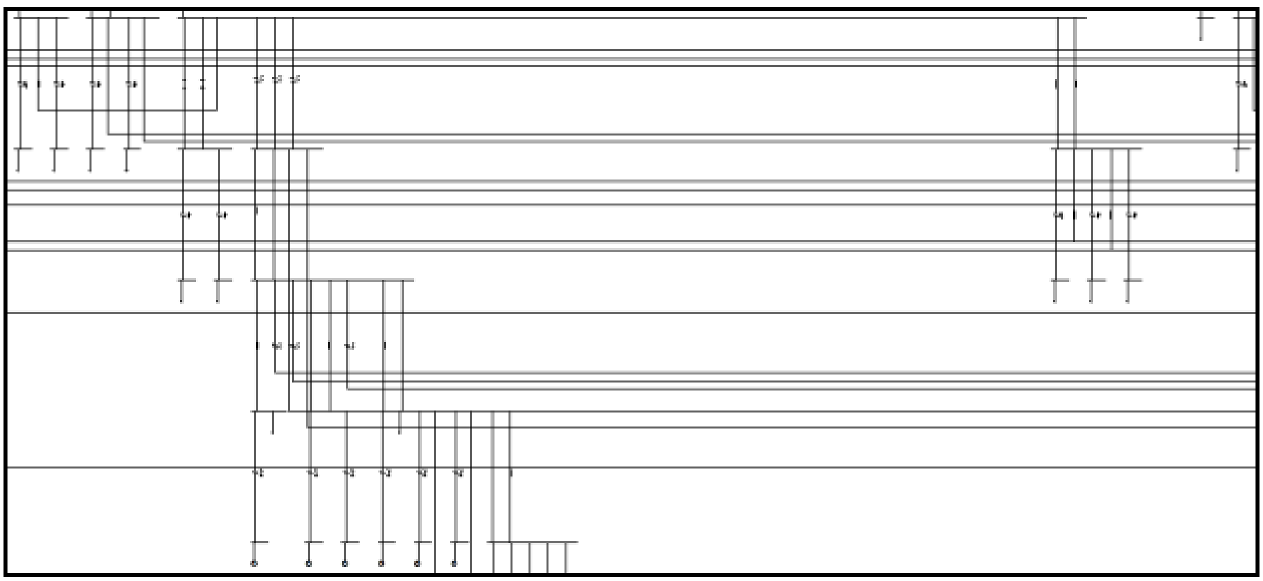
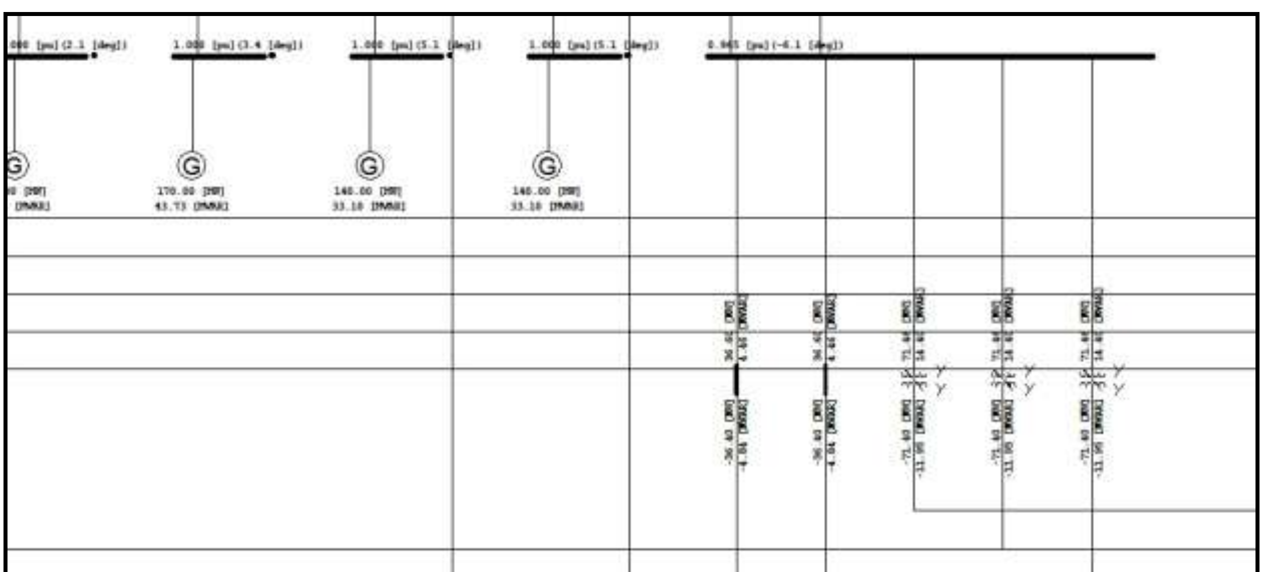
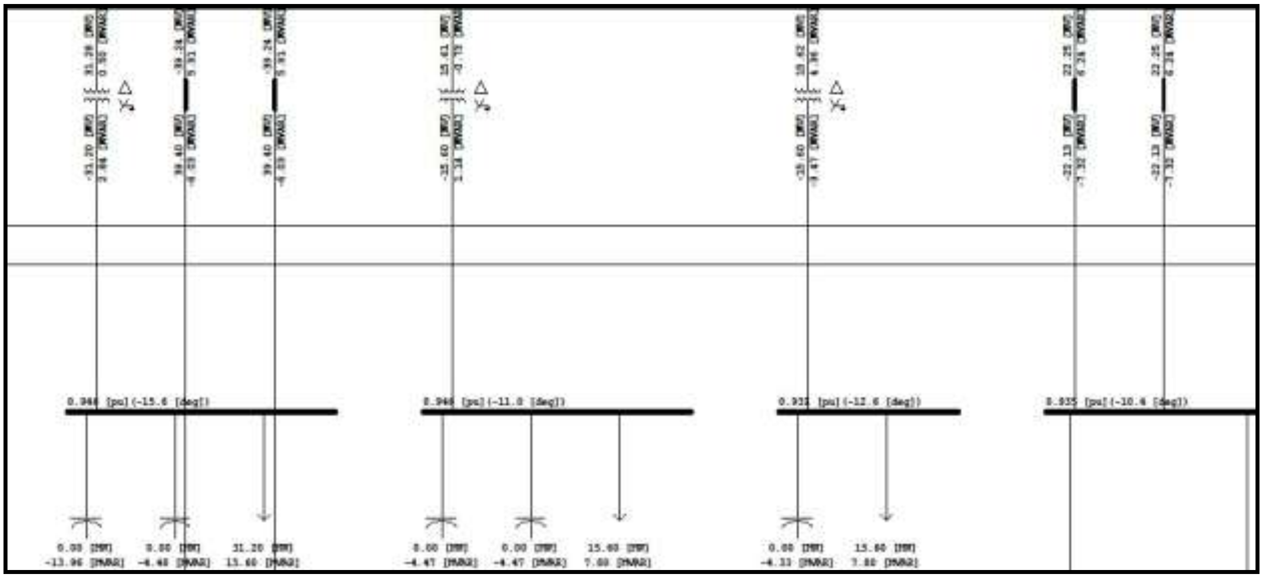


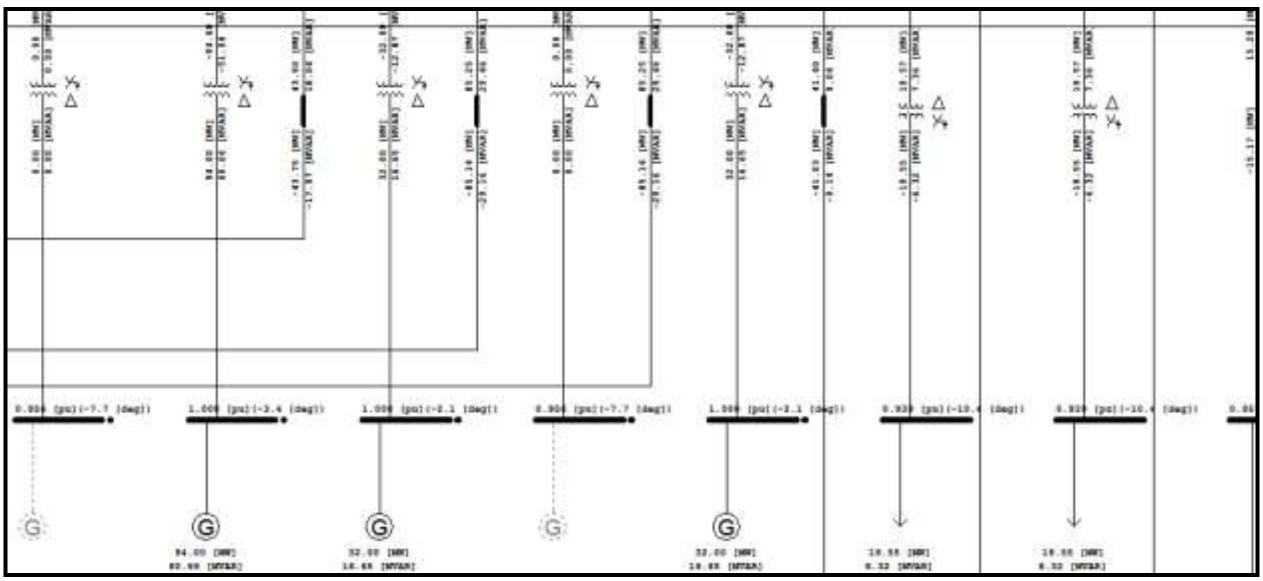
FIGURE : SIMULATED POWER SYSTEM NETWORK OF BANGLADESH

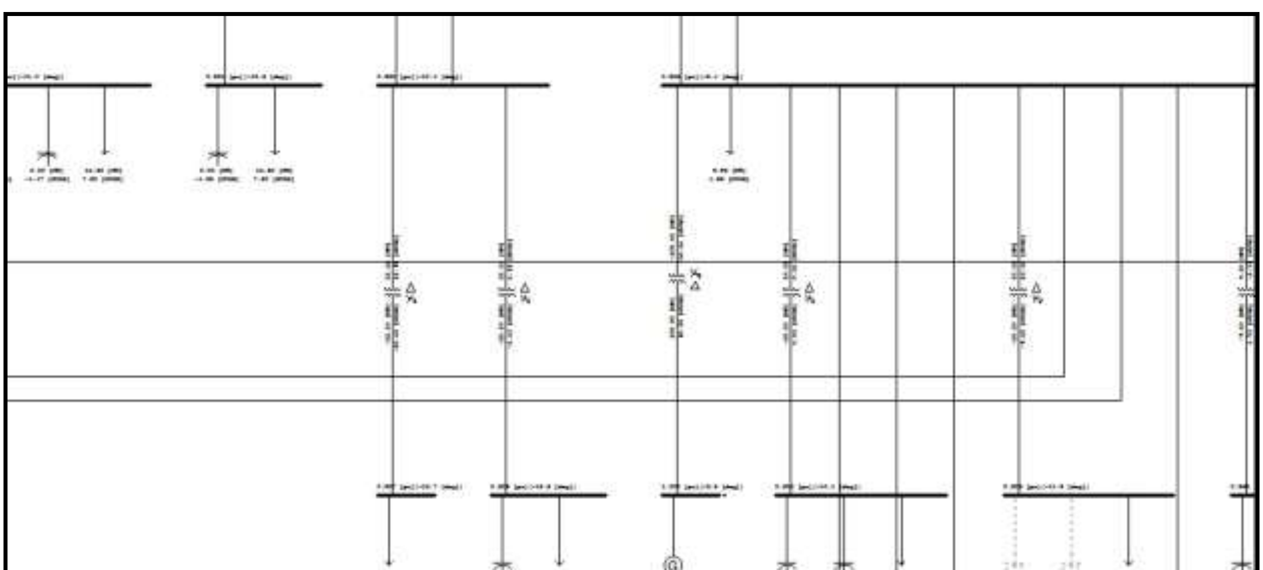


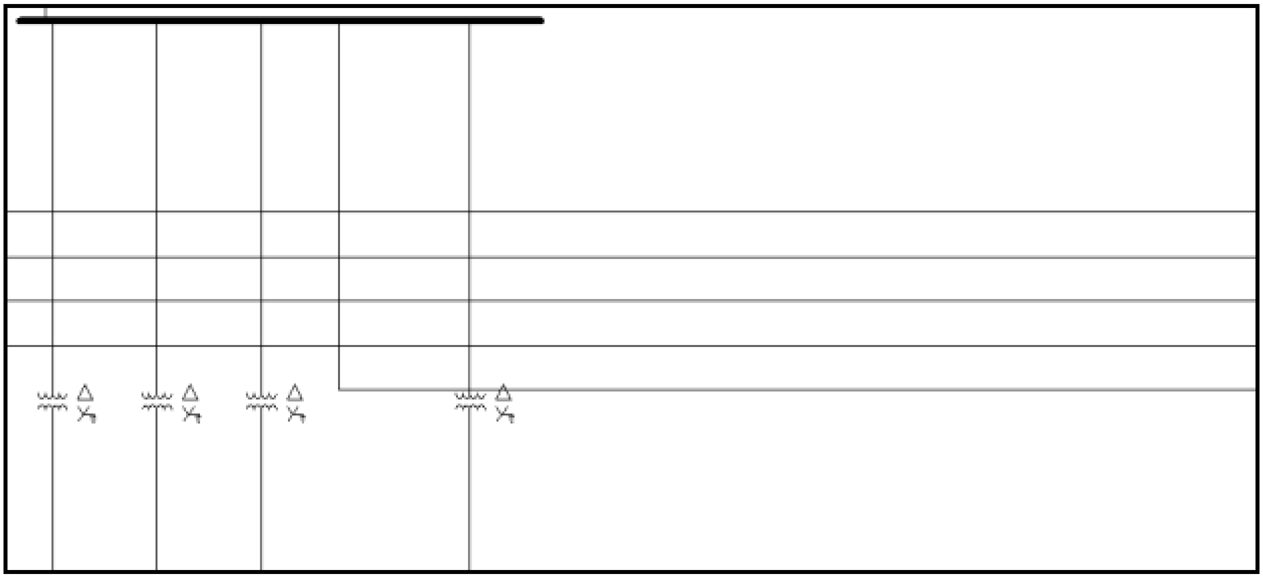


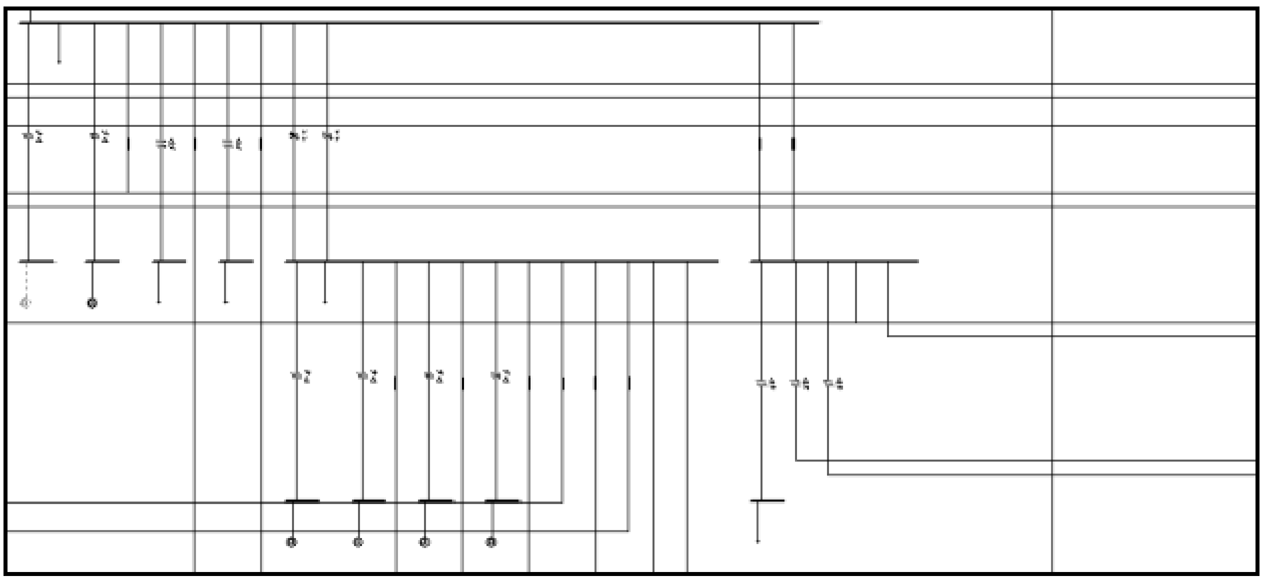

1.000 [pu] (3.4 [deg])
1.000 [pu] (5.1 [deg])
1.000 [pu] (5.1 [deg])
0.965 [pu] (-6.1 [deg])
170.00 [MW]
43.73 [MVAR]
140.00 [MW]
33.10 [MVAR]
140.00 [MW]
33.10 [MVAR]

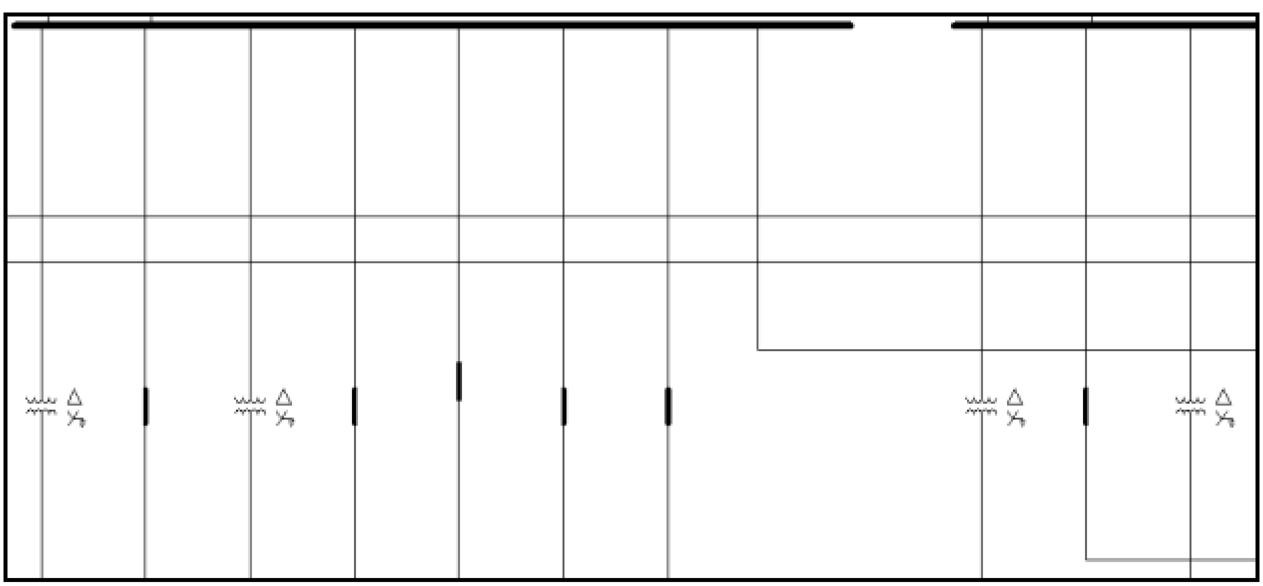


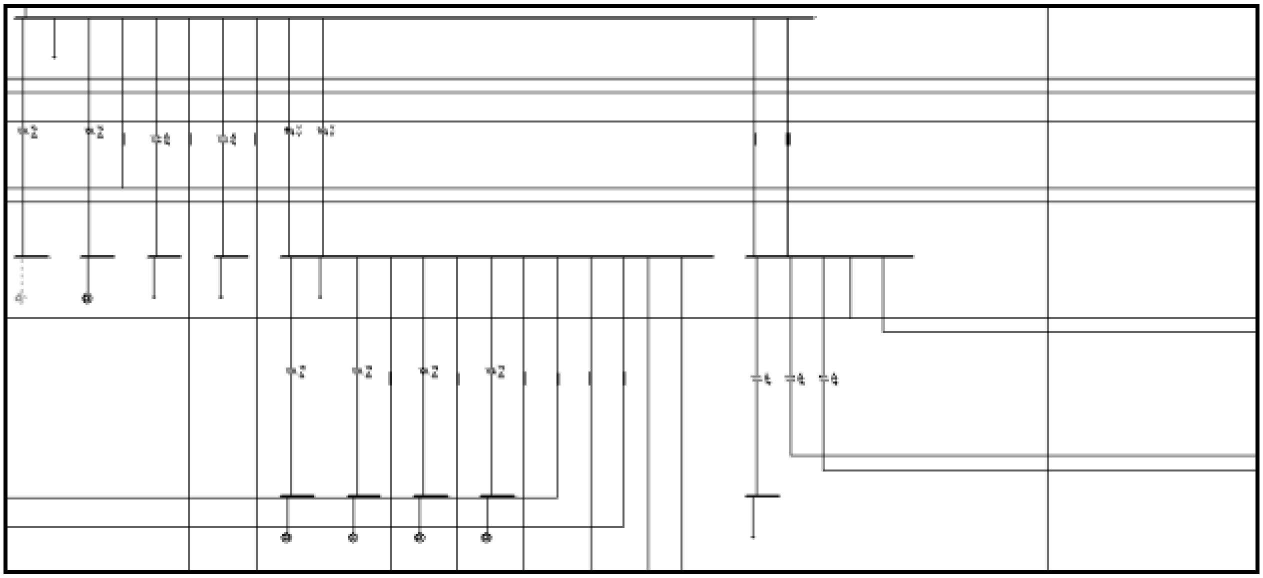


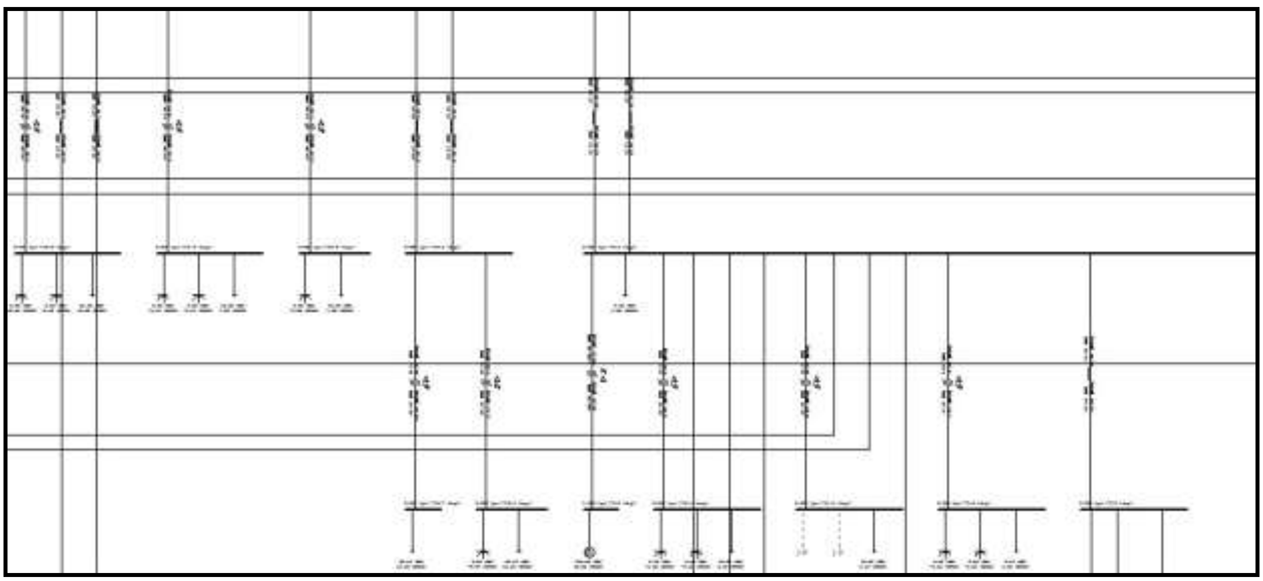


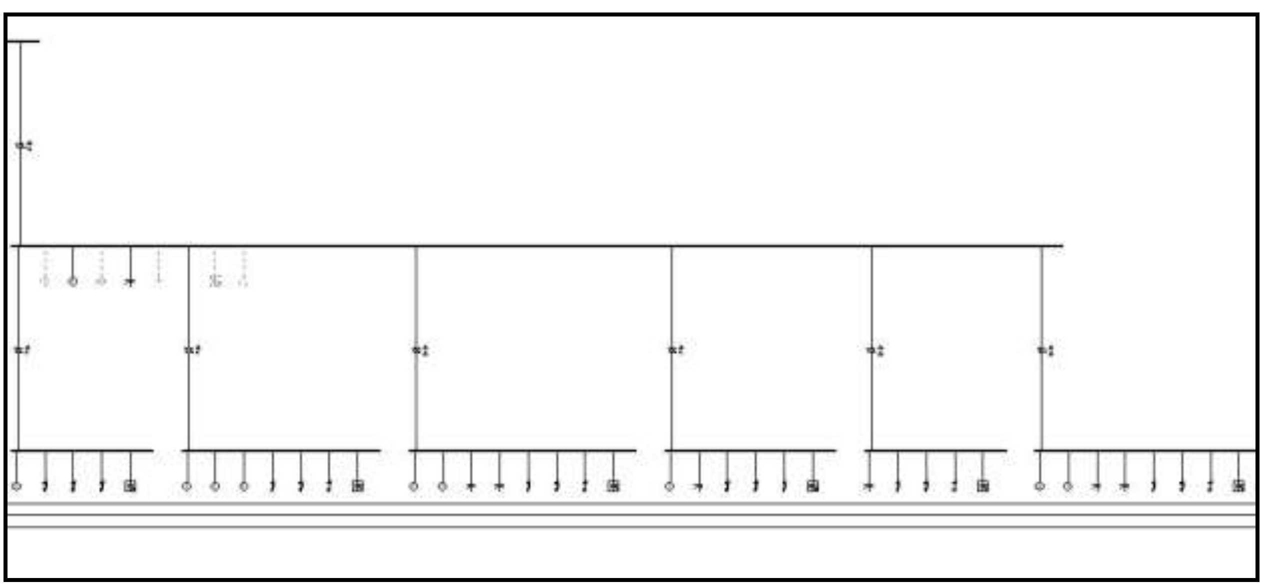












APPENDIX ‘B’

BUSES OUTSIDE VOLTAGE LIMITS

Bus ID	Zone	kV Base	Vmin - [pu]	Vmax - [pu]	V sol - [pu]	Ang sol - [deg]
CHANDPUR2	z1	33	0.9	1.1	0.899	-14.5
KSTEEL33_2	z1	33	0.9	1.1	0.888	-18.9
HSTEEL11_2	z1	11	0.9	1.1	0.878	-17.4
CHANDPUR1	z1	33	0.9	1.1	0.899	-14.5
KSTEEL33_1	z1	33	0.9	1.1	0.867	-18.2
HSTEEL11_1	z1	11	0.9	1.1	0.878	-18.2
DHANMON1	z4	33	0.9	1.1	0.895	-12.6
DHANMON2	z4	33	0.9	1.1	0.895	-12.6
DHANMON3	z4	33	0.9	1.1	0.895	-12.6
HSTEEL575_1A	z1	0.57	0.9	1.1	0.816	-22.7
HSTEEL575_3A	z1	0.57	0.9	1.1	0.816	-21.9
HSTEEL575_4A	z1	0.57	0.9	1.1	0.816	-21.9
HSTEEL575_5A	z1	0.57	0.9	1.1	0.835	-19.2
HSTEEL575_1B	z1	0.57	0.9	1.1	0.817	-22.6
HSTEEL575_3B	z1	0.57	0.9	1.1	0.817	-21.7
HSTEEL575_4B	z1	0.57	0.9	1.1	0.814	-22
HSTEEL575_5B	z1	0.57	0.9	1.1	0.833	-19.4
HSTEEL575_2A	z1	0.57	0.9	1.1	0.816	-22.7
HSTEEL575_2B	z1	0.57	0.9	1.1	0.816	-22.7
NARINDA1	z4	33	0.9	1.1	0.896	-13.9
NARINDA2	z4	33	0.9	1.1	0.896	-13.9
NAOGAON1	z5	33	0.9	1.1	0.891	-21.4
NAOGAON2	z5	33	0.9	1.1	0.877	-21.4
NAOGAON3	z5	33	0.9	1.1	0.824	-25.2
TANGAIL2	z4	33	0.9	1.1	0.864	-18.6
JOYDEVP1	z3	33	0.9	1.1	0.899	-12.2
JOYDEVP2	z3	33	0.9	1.1	0.899	-12.2
JOYDEVP3	z3	33	0.9	1.1	0.899	-12.2
PATUAKHA3	z6	33	0.9	1.1	0.888	-27.1
KABIRP1	z4	33	0.9	1.1	0.873	-16.4
MANIKG1	z4	33	0.9	1.1	0.88	-14.1
MIRPUR2	z4	33	0.9	1.1	0.883	-14.8
ULLON1	z4	33	0.9	1.1	0.884	-13.8
GOPALG1	z6	33	0.9	1.1	0.874	-26.8
MIRPUR3	z4	33	0.9	1.1	0.876	-14.8
MYMENS1	z3	33	0.9	1.1	0.882	-9.4
GOPALG2	z6	33	0.9	1.1	0.874	-26.8
MYMENS2	z3	33	0.9	1.1	0.882	-9.4
UTTARA2	z4	33	0.9	1.1	0.896	-14.7
MYMENS3	z3	33	0.9	1.1	0.882	-9.4
COMILLAS4	z1	33	0.9	1.1	0.885	-14.8
MANIKG2	z4	33	0.9	1.1	0.88	-14.1
PALASHB1	z5	33	0.9	1.1	0.868	-22.3

Bus ID	Zone	kV Base	Vmin - [pu]	Vmax - [pu]	V sol - [pu]	Ang sol - [deg]
PALASHB2	z5	33	0.9	1.1	0.867	-22.4
COMILLAS3	z1	33	0.9	1.1	0.885	-14.8
COMILLAN1	z1	33	0.9	1.1	0.893	-14.6
COMILLAS2	z1	33	0.9	1.1	0.885	-14.8
FARIDPUR2	z6	33	0.9	1.1	0.883	-24.4
COMILLAN2	z1	33	0.9	1.1	0.875	-16.3
COMILLAS1	z1	33	0.9	1.1	0.885	-14.8
FARIDPUR1	z6	33	0.9	1.1	0.898	-24.3
KISHORG3	z3	33	0.9	1.1	0.888	-9.7
KISHORG1	z3	33	0.9	1.1	0.888	-9.7
KISHORG2	z3	33	0.9	1.1	0.888	-9.7
KALYANP3	z4	33	0.9	1.1	0.872	-15.1
KALYANP1	z4	33	0.9	1.1	0.872	-15.1
KALYANP2	z4	33	0.9	1.1	0.872	-15.1
KAMRANG1	z4	33	0.9	1.1	0.895	-13.4
KAMRANG2	z4	33	0.9	1.1	0.895	-13.4
MOGHBAZ1	z4	33	0.9	1.1	0.885	-15.1
MOGHBAZ2	z4	33	0.9	1.1	0.885	-15.1
LALMONIR2	z5	33	0.9	1.1	0.869	-22.5
LALMONIR1	z5	33	0.9	1.1	0.869	-22.5
1204	z3	132	0.9	1.1	0.893	-6.8
NETRO2	z3	33	0.9	1.1	0.856	-11.8
MADARIP1	z6	33	0.9	1.1	0.885	-25.7
MADARIP2	z6	33	0.9	1.1	0.885	-25.7
NETRO1	z3	33	0.9	1.1	0.856	-11.8
RAJSHA1	z5	33	0.9	1.1	0.898	-24.8
JAMALPUR3	z3	33	0.9	1.1	0.856	-11
MANIKNAG1	z4	33	0.9	1.1	0.887	-15.4
JAMALPUR2	z3	33	0.9	1.1	0.856	-11
JAMALPUR1	z3	33	0.9	1.1	0.856	-11
CHNAWAB1	z5	33	0.9	1.1	0.888	-25.4
CHNAWAB2	z5	33	0.9	1.1	0.888	-25.4
CHNAWAB3	z5	33	0.9	1.1	0.888	-25.4
CHNAWAB4	z5	33	0.9	1.1	0.87	-24.2

APPENDIX ‘C’

SHUNT CAPACITORS FOR UNDERLOADED BUSES

Bus ID	Q (MVAR)	V (KV)	$X_c = V^2/Q$	$C = 1/2\pi fX_c$ (F)	C (μF)
BAKULIA1_1	5	33	217.8	1.46148E-05	14.61477923
BAKULIA1_2	5	33	217.8	1.46148E-05	14.61477923
BAKULIA1_3	5	33	217.8	1.46148E-05	14.61477923
BAKULIA1_4	5	33	217.8	1.46148E-05	14.61477923
BAKULIA2_1	5	33	217.8	1.46148E-05	14.61477923
BAKULIA2_2	5	33	217.8	1.46148E-05	14.61477923
BAKULIA2_3	5	33	217.8	1.46148E-05	14.61477923
BARISAL1_1	5	33	217.8	1.46148E-05	14.61477923
BARISAL1_2	5	33	217.8	1.46148E-05	14.61477923
BARISAL2_1	5	33	217.8	1.46148E-05	14.61477923
BARISAL2_2	5	33	217.8	1.46148E-05	14.61477923
BAROAULIA1_1	5	33	217.8	1.46148E-05	14.61477923
BAROAULIA1_2	5	33	217.8	1.46148E-05	14.61477923
BAROAULIA1_3	5	33	217.8	1.46148E-05	14.61477923
BAROAULIA1_4	5	33	217.8	1.46148E-05	14.61477923
BAROAULIA2_1	5	33	217.8	1.46148E-05	14.61477923
BAROAULIA2_2	5	33	217.8	1.46148E-05	14.61477923
BAROAULIA2_3	5	33	217.8	1.46148E-05	14.61477923
BOGRA1_1	5	33	217.8	1.46148E-05	14.61477923
BOGRA1_2	5	33	217.8	1.46148E-05	14.61477923
BOGRA2_1	5	33	217.8	1.46148E-05	14.61477923
BOGRA2_2	5	33	217.8	1.46148E-05	14.61477923
BOGRA3	5	33	217.8	1.46148E-05	14.61477923
BOGRA4	5	33	217.8	1.46148E-05	14.61477923
CHANDPUR02	12.25	33	88.89795918	3.58062E-05	35.80620911
CHAPAI1	5	33	217.8	1.46148E-05	14.61477923
CHAPAI2	5	33	217.8	1.46148E-05	14.61477923

Bus ID	**Q (MVAR)**	**V (KV)**	**$X_c = V^2/Q$**	**$C = 1/2\pi fX_c$ (F)**	**C (μF)**
CHAPAI3	5	33	217.8	1.46148E-05	14.61477923
CHAPAI4	5	33	217.8	1.46148E-05	14.61477923
CHNAWAB4	5.4	33	201.6666667	1.5784E-05	15.78396157
COMILLAN2	6.8	33	160.1470588	1.98761E-05	19.87609975
COMILLAS4	8.25	33	132	2.41144E-05	24.11438573
COX1_1	5	33	217.8	1.46148E-05	14.61477923
COX1_2	5	33	217.8	1.46148E-05	14.61477923
COX1_3	5	33	217.8	1.46148E-05	14.61477923
COX1_4	5	33	217.8	1.46148E-05	14.61477923
COX2_1	5	33	217.8	1.46148E-05	14.61477923
COX2_2	5	33	217.8	1.46148E-05	14.61477923
COX2_3	5	33	217.8	1.46148E-05	14.61477923
DHANMON01	16.12	33	67.55583127	4.7118E-05	47.11804824
DHANMON02	16.12	33	67.55583127	4.7118E-05	47.11804824
DOHAZAR1_1	5	33	217.8	1.46148E-05	14.61477923
DOHAZAR1_2	5	33	217.8	1.46148E-05	14.61477923
DOHAZAR1_3	5	33	217.8	1.46148E-05	14.61477923
DOHAZAR2_1	5	33	217.8	1.46148E-05	14.61477923
DOHAZAR2_2	5	33	217.8	1.46148E-05	14.61477923
DOHAZAR2_3	5	33	217.8	1.46148E-05	14.61477923
FARIDPUR02	9	33	121	2.63066E-05	26.30660261
FARIDPUR1	5	33	217.8	1.46148E-05	14.61477923
FARIDPUR2	5	33	217.8	1.46148E-05	14.61477923
GOPALG1	3.3	33	330	9.64575E-06	9.645754291
GOPALG2	3.3	33	330	9.64575E-06	9.645754291
HALISHAHAR-0	5	33	217.8	1.46148E-05	14.61477923
HALISHAHAR-1	5	33	217.8	1.46148E-05	14.61477923
HALISHAHAR2	5	33	217.8	1.46148E-05	14.61477923

Bus ID	Q (MVAR)	V (KV)	$X_c = V^2/Q$	$C = 1/2\pi fX_c$ (F)	C (μF)
HALISHAHAR3	5	33	217.8	1.46148E-05	14.61477923
HASNABAD1	5	33	217.8	1.46148E-05	14.61477923
HASNABAD2_1	5	33	217.8	1.46148E-05	14.61477923
HASNABAD2_2	5	33	217.8	1.46148E-05	14.61477923
HASNABAD3_1	5	33	217.8	1.46148E-05	14.61477923
HASNABAD3_2	5	33	217.8	1.46148E-05	14.61477923
HASNABAD4_1	5	33	217.8	1.46148E-05	14.61477923
HASNABAD4_2	5	33	217.8	1.46148E-05	14.61477923
HATHAZ1_1	5	33	217.8	1.46148E-05	14.61477923
HATHAZ1_2	5	33	217.8	1.46148E-05	14.61477923
HATHAZ1_3	5	33	217.8	1.46148E-05	14.61477923
HATHAZ1_4	5	33	217.8	1.46148E-05	14.61477923
HATHAZ2_1	5	33	217.8	1.46148E-05	14.61477923
HATHAZ2_2	5	33	217.8	1.46148E-05	14.61477923
HATHAZ2_3	5	33	217.8	1.46148E-05	14.61477923
HSTEEL11_1	6	11	20.16666667	0.00015784	157.8396157
HSTEEL11_2	8	11	15.125	0.000210453	210.4528209
HSTEEL132	6	132	2904	1.09611E-06	1.096108442
HSTEEL33-1	0.013	33	83769.23077	3.79984E-08	0.037998426
HSTEEL33-2	0.013	33	83769.23077	3.79984E-08	0.037998426
HSTEEL33-3	0.013	33	83769.23077	3.79984E-08	0.037998426
HSTEEL33-4	0.013	33	83769.23077	3.79984E-08	0.037998426
HSTEEL575_-0	3.31	0.57	0.0981571	0.032428616	32428.61623
HSTEEL575_-1	3.31	0.57	0.0981571	0.032428616	32428.61623
HSTEEL575_-2	3.31	0.57	0.0981571	0.032428616	32428.61623
HSTEEL575_-3	3.31	0.57	0.0981571	0.032428616	32428.61623
HSTEEL575_1	0.013	0.575	25.43269231	0.000125158	125.1577646
HSTEEL575_1A	3.31	0.57	0.0981571	0.032428616	32428.61623

Bus ID	Q (MVAR)	V (KV)	X_c = V^2/Q	C = $1/2\pi fX_c$ (F)	C (µF)
HSTEEL575_1B	3.31	0.57	0.0981571	0.032428616	32428.61623
HSTEEL575_2	0.013	0.575	25.43269231	0.000125158	125.1577646
HSTEEL575_3	0.013	0.575	25.43269231	0.000125158	125.1577646
HSTEEL575_3A	3.31	0.57	0.0981571	0.032428616	32428.61623
HSTEEL575_4	0.013	0.575	25.43269231	0.000125158	125.1577646
HSTEEL575_4A	3.31	0.57	0.0981571	0.032428616	32428.61623
ISHURDI1_1	5	33	217.8	1.46148E-05	14.61477923
ISHURDI1_2	5	33	217.8	1.46148E-05	14.61477923
ISHURDI2	5	33	217.8	1.46148E-05	14.61477923
ISHURDI3	5	33	217.8	1.46148E-05	14.61477923
JAMALPUR2	6.5	33	167.5384615	1.89992E-05	18.999213
JAMALPUR3	9.3	33	117.0967742	2.71835E-05	27.18348937
JESSORE1	5	33	217.8	1.46148E-05	14.61477923
JESSORE2	5	33	217.8	1.46148E-05	14.61477923
JESSORE3	5	33	217.8	1.46148E-05	14.61477923
JHENAI1	5	33	217.8	1.46148E-05	14.61477923
JHENAI2	5	33	217.8	1.46148E-05	14.61477923
KABIRP1	16.6	33	65.60240964	4.85211E-05	48.52106704
KABIRPUR1	5	33	217.8	1.46148E-05	14.61477923
KABIRPUR2	5	33	217.8	1.46148E-05	14.61477923
KABIRPUR3_1	5	33	217.8	1.46148E-05	14.61477923
KABIRPUR3_2	5	33	217.8	1.46148E-05	14.61477923
KALYANP1	24.7	33	44.08906883	7.2197E-05	72.19700939
KALYANP2	24.7	33	44.08906883	7.2197E-05	72.19700939
KALYANP3	24.7	33	44.08906883	7.2197E-05	72.19700939
KHULNAC1_1	5	33	217.8	1.46148E-05	14.61477923
KHULNAC1_2	5	33	217.8	1.46148E-05	14.61477923
KHULNAC2_1	5	33	217.8	1.46148E-05	14.61477923

Bus ID	Q (MVAR)	V (KV)	$X_c = V^2/Q$	$C = 1/2\pi fX_c$ (F)	C (μF)
KHULNAC2_2	5	33	217.8	1.46148E-05	14.61477923
KHULNAC3	5	33	217.8	1.46148E-05	14.61477923
KSTEEL33_02	6	33	181.5	1.75377E-05	17.53773508
KSTEEL33_1	12.25	33	88.89795918	3.58062E-05	35.80620911
KULSHI1	5	33	217.8	1.46148E-05	14.61477923
KULSHI2	5	33	217.8	1.46148E-05	14.61477923
KULSHI3	5	33	217.8	1.46148E-05	14.61477923
LALMONIR1	5.5	33	198	1.60763E-05	16.07625715
LALMONIR2	5.5	33	198	1.60763E-05	16.07625715
MADHUNA1_1	5	33	217.8	1.46148E-05	14.61477923
MADHUNA1_2	5	33	217.8	1.46148E-05	14.61477923
MADHUNA2	5	33	217.8	1.46148E-05	14.61477923
MANIKG1	10.4	33	104.7115385	3.03987E-05	30.3987408
MIRPUR1_1	5	33	217.8	1.46148E-05	14.61477923
MIRPUR2_2	5	33	217.8	1.46148E-05	14.61477923
MIRPUR2_3	5	33	217.8	1.46148E-05	14.61477923
MIRPUR2_4	5	33	217.8	1.46148E-05	14.61477923
MIRPUR2	23.4	33	46.53846154	6.83972E-05	68.39716679
MIRPUR2_1	5	33	217.8	1.46148E-05	14.61477923
MIRPUR2_2	5	33	217.8	1.46148E-05	14.61477923
MIRPUR2_3	5	33	217.8	1.46148E-05	14.61477923
MIRPUR2_4	5	33	217.8	1.46148E-05	14.61477923
MIRPUR3	23.4	33	46.53846154	6.83972E-05	68.39716679
MIRPUR3_1	5	33	217.8	1.46148E-05	14.61477923
MIRPUR3_2	5	33	217.8	1.46148E-05	14.61477923
MYMENS1	11	33	99	3.21525E-05	32.1525143
MYMENS2	11	33	99	3.21525E-05	32.1525143
MYMENS3	11	33	99	3.21525E-05	32.1525143

Bus ID	Q (MVAR)	V (KV)	$X_c = V^2/Q$	$C = 1/2\pi f X_c$ (F)	C (μF)
NAOGAON1	12	33	90.75	3.50755E-05	35.07547015
NAOGAON2	12	33	90.75	3.50755E-05	35.07547015
NAOGAON3	12	33	90.75	3.50755E-05	35.07547015
NATOR1_1	5	33	217.8	1.46148E-05	14.61477923
NATOR1_2	5	33	217.8	1.46148E-05	14.61477923
NATOR2_1	5	33	217.8	1.46148E-05	14.61477923
NATOR2_2	5	33	217.8	1.46148E-05	14.61477923
NETRO1	6.5	33	167.5384615	1.89992E-05	18.999213
NETRO2	6.5	33	167.5384615	1.89992E-05	18.999213
NEWTONGI1_1	5	33	217.8	1.46148E-05	14.61477923
NEWTONGI1_2	5	33	217.8	1.46148E-05	14.61477923
NEWTONGI2_1	5	33	217.8	1.46148E-05	14.61477923
NEWTONGI2_2	5	33	217.8	1.46148E-05	14.61477923
NOAGA1_1	5	33	217.8	1.46148E-05	14.61477923
NOAGA1_2	5	33	217.8	1.46148E-05	14.61477923
NOAGA2	5	33	217.8	1.46148E-05	14.61477923
NOAGA3	5	33	217.8	1.46148E-05	14.61477923
PALASHB1	5.5	33	198	1.60763E-05	16.07625715
PALASHB2	5.5	33	198	1.60763E-05	16.07625715
PATUAKHA3	3.5	33	311.1428571	1.02303E-05	10.23034546
RAJSHAHI1_1	5	33	217.8	1.46148E-05	14.61477923
RAJSHAHI1_2	5	33	217.8	1.46148E-05	14.61477923
RAJSHAHI2_1	5	33	217.8	1.46148E-05	14.61477923
RAJSHAHI2_2	5	33	217.8	1.46148E-05	14.61477923
RAJSHAHI3_1	5	33	217.8	1.46148E-05	14.61477923
RAJSHAHI3_2	5	33	217.8	1.46148E-05	14.61477923
RAJSHAHI3_3	5	33	217.8	1.46148E-05	14.61477923
RAJSHAHI3_4	5	33	217.8	1.46148E-05	14.61477923

Bus ID	Q (MVAR)	V (KV)	$X_c = V^2/Q$	$C = 1/2\pi f X_c$ (F)	C (μF)
RANGPUR1_1	5	33	217.8	1.46148E-05	14.61477923
RANGPUR1_2	5	33	217.8	1.46148E-05	14.61477923
RANGPUR1_3	5	33	217.8	1.46148E-05	14.61477923
RANGPUR1_4	5	33	217.8	1.46148E-05	14.61477923
RANGPUR2_1	5	33	217.8	1.46148E-05	14.61477923
RANGPUR2_2	5	33	217.8	1.46148E-05	14.61477923
RANGPUR2_3	5	33	217.8	1.46148E-05	14.61477923
RANGPUR2_4	5	33	217.8	1.46148E-05	14.61477923
SAIDPUR1_1	5	33	217.8	1.46148E-05	14.61477923
SAIDPUR1_2	5	33	217.8	1.46148E-05	14.61477923
SAIDPUR1_3	5	33	217.8	1.46148E-05	14.61477923
SAIDPUR1_4	5	33	217.8	1.46148E-05	14.61477923
SAIDPUR2_1	5	33	217.8	1.46148E-05	14.61477923
SAIDPUR2_2	5	33	217.8	1.46148E-05	14.61477923
SAIDPUR2_3	5	33	217.8	1.46148E-05	14.61477923
SAIDPUR2_4	5	33	217.8	1.46148E-05	14.61477923
SYLHET1_1	5	33	217.8	1.46148E-05	14.61477923
SYLHET1_2	5	33	217.8	1.46148E-05	14.61477923
SYLHET2	5	33	217.8	1.46148E-05	14.61477923
SYLHET3	5	33	217.8	1.46148E-05	14.61477923
TANGAIL2	11	33	99	3.21525E-05	32.1525143
THAKUR1_1	5	33	217.8	1.46148E-05	14.61477923
THAKUR1_2	5	33	217.8	1.46148E-05	14.61477923
THAKUR1_3	5	33	217.8	1.46148E-05	14.61477923
THAKUR1_4	5	33	217.8	1.46148E-05	14.61477923
THAKUR2_1	5	33	217.8	1.46148E-05	14.61477923
THAKUR2_2	5	33	217.8	1.46148E-05	14.61477923
THAKUR2_3	5	33	217.8	1.46148E-05	14.61477923

Bus ID	Q (MVAR)	V (KV)	$X_c = V^2/Q$	$C = 1/2\pi fX_c$ (F)	C (μF)
TONGI1_1	5	33	217.8	1.46148E-05	14.61477923
TONGI1_2	5	33	217.8	1.46148E-05	14.61477923
TONGI2_1	5	33	217.8	1.46148E-05	14.61477923
TONGI2_2	5	33	217.8	1.46148E-05	14.61477923
TONGI3_1	5	33	217.8	1.46148E-05	14.61477923
TONGI3_2	5	33	217.8	1.46148E-05	14.61477923
ULLON1	15.6	33	69.80769231	4.55981E-05	45.5981112
ULLON1_1	5	33	217.8	1.46148E-05	14.61477923
ULLON1_2	5	33	217.8	1.46148E-05	14.61477923
ULLON1_3	5	33	217.8	1.46148E-05	14.61477923
ULLON2_1	5	33	217.8	1.46148E-05	14.61477923
ULLON2_2	5	33	217.8	1.46148E-05	14.61477923
ULLON2_3	5	33	217.8	1.46148E-05	14.61477923
ULLON3_1	5	33	217.8	1.46148E-05	14.61477923
ULLON3_2	5	33	217.8	1.46148E-05	14.61477923

APPENDIX ‘D’

CONTINGENCY RANKING

Contingency Ranking	Contingency Name	Overloading Index
1	1103_1107 OUT	85.144
2	1105_1107 OUT	84.741
3	1323_1324 OUT	84.3
4	1415_1440_1 OUT	84.225
5	1415_1440_2 OUT	84.225
6	1101_1102_1 OUT	84.174
7	1101_1102_2 OUT	84.174
8	1201_1211_1 OUT	84.127
9	1201_1211_2 OUT	84.127
10	2010_2011_1 OUT	84.116
11	2010_2011_2 OUT	84.114
12	1130_1201_1 OUT	84.101
13	1130_1201_2 OUT	84.101
14	1003_1015_1 OUT_1	84.089
15	1003_1015_2 OUT_1	84.089
16	2012_2043 OUT	84.054
17	2001_2002_1 OUT_2	84.038
18	2001_2002_2 OUT_2	84.038
19	1003_1005_1 OUT_1	84.037
20	1003_1005_2 OUT_1	84.037
21	1101_1104_1 OUT	83.996
22	1101_1104_2 OUT	83.996
23	1403_1405_1 OUT	83.995
24	1111_1113 OUT	83.994
25	1403_1405_2 OUT	83.99
26	1030_1031 OUT	83.975
27	1122_1134_1 OUT	83.974
28	1122_1134_2 OUT	83.974
29	1203_1444_1 OUT	83.974
30	1203_1444_2 OUT	83.974
31	1113_1122 OUT	83.967
32	1320_1323 OUT	83.962
33	1310_1401_1 OUT	83.927
34	1310_1401_2 OUT	83.927
35	2013_2014_1 OUT	83.92
36	2013_2014_2 OUT	83.92
37	1101_1111 OUT	83.911
38	1123_1125 OUT	83.906
39	1001_1005 OUT_2	83.899

Contingency Ranking	Contingency Name	Overloading Index
40	1113_1114 OUT	83.896
41	1401_1403_1 OUT	83.883
42	1401_1403_2 OUT	83.882
43	1005_1006_1 OUT	83.842
44	1005_1006_2 OUT	83.842
45	1101_1112 OUT	83.842
46	1301_1302_1 OUT	83.835
47	1301_1302_2 OUT	83.835
48	1130_1132_1 OUT	83.833
49	1130_1132_2 OUT	83.833
50	1101_1109 OUT	83.825
51	1413_1415_1 OUT	83.813
52	1413_1415_2 OUT	83.813
53	2012_2015_1 OUT	83.805
54	2012_2015_2 OUT	83.805
55	1412_1413_1 OUT	83.797
56	1412_1413_2 OUT	83.797
57	1411_1412 OUT	83.792
58	1001_1002 OUT_2	83.791
59	1120_1125 OUT	83.786
60	1005_1013_1 OUT	83.781
61	1005_1013_2 OUT	83.781
62	1013_1015 OUT	83.778
63	1310_1313_1 OUT	83.772
64	1113_1118 OUT	83.77
65	1125_1126_1 OUT	83.769
66	1125_1126_2 OUT	83.767
67	1310_1313_2 OUT	83.758
68	1425_1442_1 OUT	83.754
69	1425_1442_2 OUT	83.754
70	1415_1417_1 OUT	83.748
71	1415_1417_2 OUT	83.748
72	2010_2020_1 OUT	83.744
73	2010_2020_2 OUT	83.744
74	1302_1305_1 OUT	83.739
75	1302_1305_2 OUT	83.739
76	2010_2016_1 OUT	83.739
77	2010_2016_2 OUT	83.739
78	1401_1412 OUT	83.733

Contingency Ranking	Contingency Name	Overloading Index
79	1425_1430_1 OUT	83.729
80	1425_1430_2 OUT	83.729
81	1120_1134_1 OUT	83.724
82	1120_1134_2 OUT	83.724
83	2008_2036_1 OUT	83.724
84	2008_2036_2 OUT	83.724
85	1420_1442_1 OUT	83.721
86	1420_1442_2 OUT	83.721
87	1410_1411 OUT	83.709
88	1002_1005 OUT_2	83.705
89	2020_2032_1 OUT	83.701
90	2020_2032_2 OUT	83.701
91	2030_2036_1 OUT	83.701
92	2030_2036_2 OUT	83.701
93	1030_1032 OUT	83.692
94	2013_2034_1 OUT	83.692
95	2013_2034_2 OUT	83.692
96	1126_1132_1 OUT	83.688
97	1126_1132_2 OUT	83.688
98	1203_1204_1 OUT	83.686
99	1203_1204_2 OUT	83.686
100	1118_1122 OUT	83.684
101	1011_1013_1 OUT	83.683
102	1011_1013_2 OUT	83.683
103	1104_1109 OUT	83.682
104	1305_1306_1 OUT	83.681
105	1305_1306_2 OUT	83.681
106	2005_2008_1 OUT_2	83.681
107	2005_2008_2 OUT_1	83.681
108	1102_1105_1 OUT	83.678
109	1102_1105_2 OUT	83.678
110	1443_1015 OUT	83.676
111	1130_1133 OUT	83.674
112	1101_1130 OUT	83.672
113	2020_2030_2 OUT	83.671
114	1201_1202_1 OUT	83.669
115	1201_1202_2 OUT	83.669
116	1213_1214_1 OUT	83.666
117	1213_1214_2 OUT	83.666

Contingency Ranking	Contingency Name	Overloading Index
118	2012_2016_1 OUT	83.666
119	2012_2016_2 OUT	83.666
120	1006_1008_1 OUT	83.665
121	1006_1008_2 OUT	83.665
122	1126_1128_1 OUT	83.665
123	1126_1128_2 OUT	83.665
124	1405_1406_1 OUT	83.663
125	1405_1406_2 OUT	83.663
126	1020_1030_1 OUT	83.659
127	1020_1030_2 OUT	83.659
128	1126_1127_1 OUT	83.659
129	1126_1127_2 OUT	83.659
130	2011_2034_1 OUT	83.659
131	2011_2034_2 OUT	83.659
132	1430_1432_1 OUT	83.656
133	1430_1432_2 OUT	83.656
134	1214_1215_1 OUT	83.643
135	1214_1215_2 OUT	83.643
136	2020_2030_1 OUT	83.643
137	1030_1101_1 OUT	83.64
138	1030_1101_2 OUT	83.64
139	1013_1443 OUT	83.637
140	1125_1445_1 OUT	83.637
141	1125_1445_2 OUT	83.637
142	1401_1410 OUT	83.637
143	1313_1315_1 OUT	83.632
144	1313_1315_2 OUT	83.632
145	1203_1205_1 OUT	83.627
146	1203_1205_2 OUT	83.627
147	1008_1009_1 OUT	83.625
148	1008_1009_2 OUT	83.625
149	2012_2014_1 OUT	83.625
150	2012_2014_2 OUT	83.625
151	1011_1017 OUT	83.623
152	1101_1133 OUT	83.623
153	1403_1415_1 OUT	83.622
154	1403_1415_2 OUT	83.622
155	1013_1016_1 OUT	83.621
156	1013_1016_2 OUT	83.621

Contingency Ranking	Contingency Name	Overloading Index
157	1212_1213_1 OUT	83.621
158	1212_1213_2 OUT	83.621
159	1215_1216_1 OUT	83.621
160	1215_1216_2 OUT	83.621
161	1411_1413 OUT	83.62
162	1202_1203_1 OUT	83.619
163	1202_1203_2 OUT	83.619
164	1003_1020_1 OUT_1	83.616
165	1003_1020_2 OUT	83.616
166	2040_2042_1 OUT	83.616
167	2040_2042_2 OUT	83.616
168	1211_1212_1 OUT	83.612
169	1211_1212_2 OUT	83.612
170	1006_1016_1 OUT	83.611
171	1006_1016_2 OUT	83.611
172	1124_1125_1 OUT	83.611
173	1124_1125_2 OUT	83.611
174	1302_1332_1 OUT	83.609
175	1302_1332_2 OUT	83.609
176	1308_1310_1 OUT	83.609
177	1308_1310_2 OUT	83.609
178	1006_1017 OUT	83.607
179	1112_1114 OUT	83.607
180	1006_1018_1 OUT	83.606
181	1006_1018_2 OUT	83.606
182	1104_1446_1 OUT	83.603
183	1104_1446_2 OUT	83.603
184	1307_1308_1 OUT	83.603
185	1307_1308_2 OUT	83.603
186	1017_1018_1 OUT	83.602
187	1017_1018_2 OUT	83.602
188	1020_1021_1 OUT	83.601
189	1020_1021_2 OUT	83.601
190	1415_1418_1 OUT	83.601
191	1415_1418_2 OUT	83.601

Contingency Ranking	Contingency Name	Overloading Index
192	1021_1032_1 OUT	83.6
193	1021_1032_2 OUT	83.6
194	1315_1320_1 OUT	83.6
195	1315_1320_2 OUT	83.6
196	1420_1425_1 OUT	83.6
197	1420_1425_2 OUT	83.6
198	1306_1307_1 OUT	83.599
199	1306_1307_2 OUT	83.599
200	1418_1420_1 OUT	83.598
201	1418_1420_2 OUT	83.598
202	1107_1124_1 OUT	83.595
203	1107_1124_2 OUT	83.595
204	1103_1105 OUT	83.584
205	1031_1032 OUT	83.583
206	2005_2014_1 OUT_1	83.581
207	2005_2014_2 OUT_1	83.581
208	2002_2005_1 OUT_2	83.578
209	2002_2005_2 OUT_2	83.578
210	1001_1003_1 OUT_2	83.572
211	1001_1003_2 OUT_2	83.572
212	2008_2010_1 OUT_1	83.571
213	2008_2010_2 OUT_1	83.571
214	1120_1123 OUT	83.569
215	2036_2040_1 OUT	83.545
216	2036_2040_2 OUT	83.545
217	1324_1326 OUT	83.419
218	1332_1334 OUT	83.32
219	1314_1315 OUT	83.101
220	1320_1330 OUT	83.099
221	1310_1447 OUT	83.021
222	1420_1421 OUT	82.652
223	1015_KSTEEL OUT	82.497
224	1015_HSTEEL OUT	77.739