CHAPTER – 2

MODELLING OF POWER SYSTEM COMPONENTS
2.1 INTRODUCTION

As discussed in Chapter 1, the power system adequacy is commonly referred to as composite power system reliability or bulk power system reliability evaluation. The research work presented in this thesis concentrates on Composite Power System Reliability. The power system adequacy is generally measured in the form of well-defined indices that reflect the capability of the power system to satisfy consumer requirements. The reliability of any system or component will be measured through the concept of probability theory by identifying the probability of successful operation with a specified degree of reliability. Generally, a component or system is said to operate satisfactorily if it does not fail during the time of service. On the other hand, a failed component can be repaired and returned to service many times during their entire useful life. Thus the appropriate measure of reliability is the probability of availability of the component or equipment, which is defined as follows.

“The availability of a repairable component or equipment is the proportion of time, during the intended time period of service, that the component is in, or ready for the service.”

Some of the defined reliability indices are listed below.

- SAIDI – System Average Interruption Duration Index
- CAIDI – Customer Average Interruption Duration Index
- SAIFI – System Average Interruption Frequency Index
- MAIFI – Momentary Average Interruption Frequency Index
- CAIFI – Customer Average Interruption Frequency Index
- CIII – Customers Interrupted per Interruption Index
- ASAI – Average Service Availability Index
EPNS – Expected Power Not Supplied
LOEE – Loss of Energy Expectation
LOLD – Loss of Load Duration
LOLE – Loss of Load Expectation
LOLP – Loss of Load Probability

The research work presented in the thesis mainly focused on the reliability indices LOLE (Loss of Load Expected) and LOLP (Loss of Load Probability). This chapter mainly describes the calculation of average power availability to the consumers in a large interconnected power system.

2.2 RELIABILITY EVALUATION TECHNIQUES

The Electric Power Systems are good examples for reliability evaluation. In many power systems the average duration of interruptions faced by a customer is just a few hours per year, which indicates that high availability of power supply to consumers is ensured considering scheduled and unscheduled outages (Random failures). The high power availability can be achieved by proper maintenance and monitoring of the equipment. There are several methodologies developed over the years for the reliability measurement. The early methods used were all deterministic and are not convenient to apply for large interconnected power system. Also the deterministic methods can not consider the stochastic nature of the system and load [14]-[38].

Later Probabilistic methods are developed to obtain meaningful information regarding the system reliability. The probability of random failure and repair durations during the operating life of the component are assumed to be exponentially distributed. Based on this the Mean Time to Failure (MTTF=1/λ) and the Mean Time to Repair (MTTR=1/μ) can be evaluated [21]. These indices for each component are
used to obtain the overall system reliability. In this chapter, the average power availability at the load bus is used as a measure for the reliability evaluation of the system [22]-[24]. The reliability study in the interconnected power system is complex due to the large number of components and network topology. So far the reliability analysis in interconnected power system is achieved through tracing of the power flow paths [25]-[29]. But tracing of power flow paths in a large power system network become difficult and takes time. Simple and more convenient method based on electrical circuit approach is presented here.

The probability of power availability and unavailability of a component having failure and repair rates \( \lambda \ & \mu \) is given in equation (2.1 & 2.2). Exponential probability distribution is assumed for the failure and repair rates of each component in the power system [24].

\[
Availability = \frac{\mu}{\lambda + \mu} \quad (2.1)
\]

\[
Unavailability = (1 - Availability) = \frac{\lambda}{\mu + \lambda} \quad (2.2)
\]

The existing methods for the reliability evaluation of composite power system are explained in the following chapters. The limitations and difficulties of those methods are also discussed.

### 2.3 SERIES – PARALLEL APPROACH

If two components are connected in series in a branch of the network and each component has its failure rate and repair rate as shown in Fig.2.1. The equivalent failure and repair rates for the branch are given in the equations (2.3) & (2.4) [25]-[26].
\[ \lambda_{eq} = \lambda_1 + \lambda_2 \]  
Equation (2.3)

\[ \mu_{eq} = \frac{\mu_1 \mu_2}{\mu_1 + \mu_2} \]  
Equation (2.4)

Similarly if two components are connected in parallel as shown in Fig. 2.2, then the equivalent failure and repair rates are given in equations (2.5) & (2.6).

\[ \lambda_{eq} = \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2} \]  
Equation (2.5)

\[ \mu_{eq} = \mu_1 + \mu_2 \]  
Equation (2.6)

Initially using these series – parallel approach most of the simple power system network reliability was evaluated.

2.4 STAR – DELTA APPROACH

In the complex interconnected power systems, there exist a number of star, delta configurations and series – parallel approach alone is not enough to reduce the network. During the evaluation of the availability, there will be a need for star-delta transformation for network reduction. The equivalent failure and repair rate transformations from star to delta or vice versa are given in the following equations.
from (2.7) to (2.12). The equivalents are based on the condition that the equivalent failure and repair rates for both the configuration should be same across any two terminals. The equivalent star-delta reliability models are shown in Fig. 2.3 and Fig.2.4 [25]-[26].

The equivalent failure rates are given by,

\[
\lambda_{ab} = \frac{\lambda_1 \lambda_2 + \lambda_2 \lambda_3 + \lambda_3 \lambda_1}{\lambda_3} \quad (2.7)
\]

\[
\lambda_{bc} = \frac{\lambda_1 \lambda_2 + \lambda_2 \lambda_3 + \lambda_3 \lambda_1}{\lambda_1} \quad (2.8)
\]

\[
\lambda_{ac} = \frac{\lambda_1 \lambda_2 + \lambda_2 \lambda_3 + \lambda_3 \lambda_1}{\lambda_2} \quad (2.9)
\]
Equivalent repair rates are given in the equations from (2.10) to (2.12) as follows,

\[ \mu_{ab} = \frac{\mu_1\mu_2}{\mu_1 + \mu_2 + \mu_3} \]  
\[ \mu_{bc} = \frac{\mu_2\mu_3}{\mu_1 + \mu_2 + \mu_3} \]  
\[ \mu_{ac} = \frac{\mu_1\mu_3}{\mu_1 + \mu_2 + \mu_3} \]  

2.5 DELTA – STAR APPROACH

Similarly the conversion from start to delta is as follows. The equivalent failure rate are given by equations from (2.13) to (2.18),

\[ \lambda_1 = \frac{\lambda_{ab}\lambda_{ac}}{\lambda_{ab} + \lambda_{bc} + \lambda_{ca}} \]  
\[ \lambda_2 = \frac{\lambda_{ab}\lambda_{bc}}{\lambda_{ab} + \lambda_{bc} + \lambda_{ca}} \]  
\[ \lambda_3 = \frac{\lambda_{ac}\lambda_{bc}}{\lambda_{ab} + \lambda_{bc} + \lambda_{ca}} \]  

Equivalent repair rates given by,

\[ \mu_1 = \frac{\mu_{ab}\mu_{bc}\mu_{ac} + \mu_{ab}\mu_{ac}}{\mu_{bc}} \]  
\[ \mu_2 = \frac{\mu_{ab}\mu_{bc}\mu_{ac} + \mu_{ab}\mu_{ac}}{\mu_{ac}} \]  
\[ \mu_3 = \frac{\mu_{ab}\mu_{bc}\mu_{ac} + \mu_{ab}\mu_{ac}}{\mu_{ab}} \]  

The interconnected power system network (IEEE 6 Bus reliability test system) used here consists of number of circuit breakers, two generating units and four load points as shown in Fig.2.5 [38]. In this IEEE 6 bus reliability test system, the failure and repair rates (\( \lambda \) & \( \mu \)) of each component are given in Appendix. The average probability of power availability at load bus is calculated by reducing the network by series-parallel and star-delta or delta - star conversion methods between the source node and the sink or load node. The equivalent reliability model of the IEEE 6 bus reliability test system is shown in Fig.2.6.
In the interconnected power system shown in Fig.2.5, the IEEE 6 bus reliability test system is reduced to simple delta connection, where it has two nodes of generating units and one node for load. The reduced reliability network is shown in Fig.2.7. Using the methodology explained above equivalent λ and μ are obtained between generator nodes 1, 2 and load node. From this probability of average power availability at the load are obtained using equation (2.1). The same procedure is used
to find the probability of availability at all load points one by one. The probabilities of average power availability at each load are calculated using series – parallel, Star – Delta approach and are given in Table 2.3.

Fig. 2.6 Equivalent Reliability Model of the IEEE 6 bus reliability test system
The evaluation of reliability in the interconnected power system is complex due to the large number of components connected and growing network topology. So far the reliability evaluation in interconnected power system is obtained through tracing of the power flow paths [25]-[26]. Tracing of paths is time consuming in the case of large networks. Simple and more convenient method based on electrical circuit approach is presented in the following section.

### 2.6 NODE ELIMINATION METHOD

The interconnected power system (IEEE 6 bus reliability test system) consists of number of components and each component has its own failure and repair rates ($\lambda$ & $\mu$). From equations (2.3), (2.4), (2.5) and (2.6) it can be observed the failure rate ($\lambda$) is similar to the resistance ($R$) and the repair rate ($\mu$) is similar to the Capacitance ($C$) in an equivalent electrical network. Hence the reliability model of interconnected power network shown in Fig.2.6 can be replaced by an equivalent R-C network for reliability analysis. The classical node elimination method is a known technique. The Classical node elimination method is used for power system analysis and has not been used so far for reliability studies. This is the first time the classical node elimination method for reliability evaluation in interconnected power system is adapted. It is used to reduce the equivalent electrical network to calculate power availability at load bus.
The equivalent reliability model between generator node 1, 2 and the load bus 4 is shown in Fig. 2.8.

In the analogous electrical model this network is replaced by two networks where in the first one, all failure rates ($\lambda$) in each branch is represented by a resistance (equal to $\lambda$) and in the second one each branch is represented by a capacitance equal to $\mu$. For reliability evaluation, each of these equivalent electrical networks are reduced to a simplified network connecting the sources to the load nodes where the average power availability is required to be calculated. For simplification of the network, node elimination method is used as explained in the following paragraph.

The power system network consists of eight nodes. The power supply node is considered as a current injection node and the load node where the availability is to be
computed is treated as current sink. This reliability model is used to obtain the power availability at load bus 4 only. The other load nodes do not have any current injection.

To reduce the network the nodes in which the current does not enter or leave are eliminated. The equivalent electrical network is described by the nodal equation.

\[
\begin{bmatrix}
I_1 \\
I_2 \\
\vdots \\
I_8
\end{bmatrix} =
\begin{bmatrix}
Y_{11} & Y_{12} & \cdots & Y_{18} \\
Y_{21} & Y_{22} & \cdots & Y_{28} \\
\vdots & \vdots & \ddots & \vdots \\
Y_{81} & Y_{82} & \cdots & Y_{88}
\end{bmatrix}
\begin{bmatrix}
V_1 \\
V_2 \\
\vdots \\
V_8
\end{bmatrix}
\] (2.19)

where the matrix \( Y_{bus} \) in the above equation (2.19) is the nodal admittance matrix and \( I \) & \( V \) are the nodal injected currents vector and voltages vector of the equivalent R-C network. To evaluate the equivalent failure rate the nodal \( Y_{bus} \) is made up of only the resistive component (\( \lambda \)) for each element and for equivalent repair rate the capacitance component (\( \mu \)) is used for each element. From the equivalent reliability model shown in Fig.2.8 it is clear that currents \( I_1, I_3, I_8 \) are injected currents and remaining currents are made zero for eliminating the corresponding nodes in the reduced network. Hence the name of this method is called Node Elimination method. Then equation (2.19) becomes as

\[
\begin{bmatrix}
I_A \\
I_B
\end{bmatrix} =
\begin{bmatrix}
X & Y \\
Y^T & Z
\end{bmatrix}
\begin{bmatrix}
V_A \\
V_B
\end{bmatrix}
\] (2.20)

In the equation (2.20), \( I_A \) is a vector containing the currents that are injected \( (I_1, I_3, I_8) \), \( I_B \) vector is a null vector \( (I_2, I_4, I_5, I_6, I_7) \), \( V_A \) is a vector containing the voltages at the injected currents \( (V_1, V_3, V_8) \), \( V_B \) is a vector of null vector \( (V_2, V_4, V_5, V_6, V_7) \) and \( Y_{bus} \) is formed by the combination of matrices \( X, Y \) and \( Z \).

From equation (2.20) the following variables are derived as,

\[
I_A = XV_A + YV_B \\
0 = I_B = Y^TV_A + ZV_B
\] (2.21)
\[ V_B = -Z^{-1}Y^T V_A \]
\[ I_A = (X - Z^{-1}Y^T V_A)V_A \]  \hspace{1cm} (2.22)

The reduced \( Y_{Bus} \) is given in equation (2.23) and with the help of this reduced \( Y_{Bus} \) matrix, we can draw the simple equivalent delta network as shown in Fig.2.7.

\[ Y_{Bus}^{Reduced} = (X - Z^{-1}Y^T V_A) \]  \hspace{1cm} (2.23)

From the above equation (2.23) the equivalent \( \lambda \) and \( \mu \) between the source node and the load node are obtained.

The reduced \( Y_{Bus} \) indicates the nodal equation of the simplified delta network shown in Fig.2.7. The equivalent failure and repair rates are obtained from the reduced \( Y_{Bus} \) one at a time by assuming \( \lambda \) as resistance \( R \) and \( \mu \) as capacitance \( C \). Since the generator failure and repair rates are already considered in the \( Y_{Bus} \) formation, the nodes 1 and 2 of generators in the equivalent reliability model of the network shown in Fig.2.7 have 1.0 availability and so can be combined together to evaluate the average availability of power at the load node. So the corresponding network elements between Generator 1, Generator 2 and load will be in parallel and over all equivalent \( \lambda \) & \( \mu \) are calculated. The same procedure is used if there are more than two generators in the power system network. The average power availability at the remaining load points are calculated by adapting the same procedure. The results obtained from this method are given in Table 2.3.

### 2.7 MONTE CARLO SIMULATION METHOD

The most common probabilistic method for reliability evaluation is Monte Carlo Simulation method and this technique is used here to calculate the average power availability at consumer or load end [10], [30], [31], [62], [63]. Monte Carlo simulation method is well known method and is used to estimate the reliability indices by simulating the actual process and random nature of the failure and repair of the
system/components. This method, therefore, treats the problem as a series of experiments. After calculation of the equivalent failure and repair rates from the node elimination method, the Monte Carlo Simulation method is adopted to estimate the average power availability. In this method the exponential probability distribution is assumed for the equivalent failure and repair rates of the power system network. The time to fail and repair are given in the following equations (2.24) and (2.25) as

\[ Time\ to\ Fail\ (on\ time) = -\frac{1}{\lambda_e} \ln (1 - U) \]  \hspace{1cm} (2.24)

\[ Time\ to\ Repair = -\frac{1}{\mu_e} \ln (1 - U) \]  \hspace{1cm} (2.25)

where \(\lambda_e, \mu_e\) are the equivalent failure and repair rates for each load obtained from the Node Elimination method discussed in earlier section. \(U\) is a uniformly distributed random number.

For the calculation of the mean time to fail and repair, an uniformly distributed random number \((U)\) is generated using MATLAB code. Totally 13 years of data is developed and the corresponding histograms for each path of the equivalent reliability model (Fig.2.7) are generated as shown in Fig.2.9 and the times to fail and times to repair are evaluated and given in Table 2.1.

![Fig. 2.9 Generated Histograms for 13 Years](image-url)
Table 2.1 Time to Fail and Time to Repair generated by Monte Carlo Method

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Duration</th>
<th>Load 1</th>
<th>Load 2</th>
<th>Load 3</th>
<th>Load 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>ON</td>
<td>1.5868</td>
<td>1.7677</td>
<td>2.0017</td>
<td>1.9466</td>
</tr>
<tr>
<td>2.</td>
<td>OFF</td>
<td>0.0916</td>
<td>0.1472</td>
<td>0.1496</td>
<td>0.2348</td>
</tr>
<tr>
<td>3.</td>
<td>ON</td>
<td>0.2867</td>
<td>0.3194</td>
<td>0.3617</td>
<td>0.3518</td>
</tr>
<tr>
<td>4.</td>
<td>OFF</td>
<td>0.2201</td>
<td>0.3535</td>
<td>0.3595</td>
<td>0.5640</td>
</tr>
<tr>
<td>5.</td>
<td>ON</td>
<td>1.7815</td>
<td>1.9845</td>
<td>2.2472</td>
<td>2.1854</td>
</tr>
<tr>
<td>6.</td>
<td>OFF</td>
<td>0.0496</td>
<td>0.0797</td>
<td>0.0810</td>
<td>0.1271</td>
</tr>
<tr>
<td>7.</td>
<td>ON</td>
<td>1.3179</td>
<td>1.4681</td>
<td>1.6625</td>
<td>1.6167</td>
</tr>
<tr>
<td>8.</td>
<td>OFF</td>
<td>0.0589</td>
<td>0.0947</td>
<td>0.0963</td>
<td>0.1511</td>
</tr>
<tr>
<td>9.</td>
<td>ON</td>
<td>0.1447</td>
<td>0.1612</td>
<td>0.1825</td>
<td>0.1775</td>
</tr>
<tr>
<td>10.</td>
<td>OFF</td>
<td>0.0314</td>
<td>0.0505</td>
<td>0.0514</td>
<td>0.0806</td>
</tr>
<tr>
<td>11.</td>
<td>ON</td>
<td>0.2409</td>
<td>0.2683</td>
<td>0.3038</td>
<td>0.2955</td>
</tr>
<tr>
<td>12.</td>
<td>OFF</td>
<td>0.0233</td>
<td>0.0374</td>
<td>0.0381</td>
<td>0.0597</td>
</tr>
<tr>
<td>13.</td>
<td>ON</td>
<td>0.5024</td>
<td>0.5596</td>
<td>0.6337</td>
<td>0.6163</td>
</tr>
<tr>
<td>14.</td>
<td>OFF</td>
<td>0.0620</td>
<td>0.0995</td>
<td>0.1012</td>
<td>0.1588</td>
</tr>
<tr>
<td>15.</td>
<td>ON</td>
<td>0.0933</td>
<td>0.1039</td>
<td>0.1177</td>
<td>0.1144</td>
</tr>
<tr>
<td>16.</td>
<td>OFF</td>
<td>0.2675</td>
<td>0.4296</td>
<td>0.4368</td>
<td>0.6853</td>
</tr>
<tr>
<td>17.</td>
<td>ON</td>
<td>5.3032</td>
<td>5.9077</td>
<td>6.6897</td>
<td>6.5056</td>
</tr>
<tr>
<td>18.</td>
<td>OFF</td>
<td>0.0775</td>
<td>0.1244</td>
<td>0.1265</td>
<td>0.1985</td>
</tr>
</tbody>
</table>

The mean time to fail and Repair computed from the Table 2.1 are given in Table 2.2.

Table 2.2 Mean Time to Fail and Repair

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameter</th>
<th>Load 1</th>
<th>Load 2</th>
<th>Load 3</th>
<th>Load 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mean Time to Fail</td>
<td>1.25084</td>
<td>1.3939</td>
<td>1.57787</td>
<td>1.53445</td>
</tr>
<tr>
<td>2.</td>
<td>Mean Time to Repair</td>
<td>0.09803</td>
<td>0.1574</td>
<td>0.16000</td>
<td>0.25115</td>
</tr>
</tbody>
</table>

2.8 RESULTS AND DISCUSSION

In this chapter three methods for modelling of power system components for reliability analysis are presented and discussed. The average probability of power
availability at load bus is taken as the index for reliability analysis. The traditional methods and proposed Node Elimination method are applied on the IEEE 6 bus reliability test system as shown in Fig 2.5. The results obtained from all the methods are compared and shown in Table 2.3. The 13 years average power availability is computed from the histograms (Fig.2.9) generated using the equivalent repair and failure rates obtained between the supply and load nodes and the result is also shown in Table 2.3. The result shows the effectiveness of the methods proposed for reliability modelling of power system.

Table 2.3 Average Power Availability at Different Loads in IEEE 6 bus reliability test system

<table>
<thead>
<tr>
<th>Load No</th>
<th>Series-Parallel &amp; Stat-Delta conversion method</th>
<th>Classical Node Elimination Method</th>
<th>Monte Carlo Simulation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load 1</td>
<td>0.94098</td>
<td>0.94088</td>
<td>0.92737</td>
</tr>
<tr>
<td>Load 2</td>
<td>0.91707</td>
<td>0.91701</td>
<td>0.89847</td>
</tr>
<tr>
<td>Load 3</td>
<td>0.92490</td>
<td>0.92399</td>
<td>0.90790</td>
</tr>
<tr>
<td>Load 4</td>
<td>0.88418</td>
<td>0.88410</td>
<td>0.85934</td>
</tr>
</tbody>
</table>

The Monte Carlo Simulation method takes large computation time compared to the proposed Node Elimination method. The effectiveness of the proposed method is shown by the results obtained. The generation of histograms for each component in Monte Carlo method takes large computation time. Hence this method is difficult to apply for large systems. But the proposed method is suitable for any type of systems.

This Node Elimination method is helpful to power system planners for the determination of average availability of power at load bus and for evaluating CAIDI and SAIDI. If the data on consumers connected to the load bus are known. Electrical circuit approach using node elimination method is simple and more convenient to apply even for large systems compared to Monte Carlo Simulation method. To show
the efficiency of the proposed method for the reliability analysis of large system, the
IEEE 14 bus system and single area IEEE RTS-96 system are used to obtain the
probability of average power availability at load buses using Node Elimination
method. The IEEE 14 bus system is shown in Fig.2.10. The equivalent failure and
repair rates of the lines and components are given in Appendix. The average power
availability in IEEE 14 bus system is shown in Table 2.4.

![Fig. 2.10 IEEE 14 Bus reliability test system](image)

Table 2.4 Average Power Availability at Different Loads in IEEE 14 bus system

<table>
<thead>
<tr>
<th>S.No</th>
<th>Load No</th>
<th>Classical Node Elimination Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Load 1</td>
<td>0.9674</td>
</tr>
<tr>
<td>2.</td>
<td>Load 2</td>
<td>0.9676</td>
</tr>
<tr>
<td>3.</td>
<td>Load 3</td>
<td>0.96762</td>
</tr>
<tr>
<td>4.</td>
<td>Load 4</td>
<td>0.93825</td>
</tr>
<tr>
<td>5.</td>
<td>Load 5</td>
<td>0.91473</td>
</tr>
<tr>
<td>6.</td>
<td>Load 6</td>
<td>0.91716</td>
</tr>
<tr>
<td>7.</td>
<td>Load 7</td>
<td>0.95183</td>
</tr>
<tr>
<td>8.</td>
<td>Load 8</td>
<td>0.93976</td>
</tr>
</tbody>
</table>
The proposed methodology is tested with single area RTS-96 system to validate the complexity of the system. The configuration of the system is shown in Fig. 2.11. The reliability data of this system is given in Appendix and available in [38].

Fig. 2.11 Single area IEEE RTS-96 System

The probability of average power availability in single area RTS-96 System is given in Table 2.5.
Table 2.5 Average Power Availability at Different Loads in single area IEEE RTS-96 system

<table>
<thead>
<tr>
<th>S.No</th>
<th>Load No</th>
<th>Classical Node Elimination Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Load 1</td>
<td>0.8858</td>
</tr>
<tr>
<td>2.</td>
<td>Load 2</td>
<td>0.8191</td>
</tr>
<tr>
<td>3.</td>
<td>Load 3</td>
<td>0.5586</td>
</tr>
<tr>
<td>4.</td>
<td>Load 4</td>
<td>0.8469</td>
</tr>
<tr>
<td>5.</td>
<td>Load 5</td>
<td>0.8122</td>
</tr>
<tr>
<td>6.</td>
<td>Load 6</td>
<td>0.8122</td>
</tr>
<tr>
<td>7.</td>
<td>Load 7</td>
<td>0.8129</td>
</tr>
<tr>
<td>8.</td>
<td>Load 8</td>
<td>0.8368</td>
</tr>
<tr>
<td>9.</td>
<td>Load 9</td>
<td>0.8596</td>
</tr>
<tr>
<td>10.</td>
<td>Load 10</td>
<td>0.8573</td>
</tr>
<tr>
<td>11.</td>
<td>Load 11</td>
<td>0.8188</td>
</tr>
<tr>
<td>12.</td>
<td>Load 12</td>
<td>0.8325</td>
</tr>
<tr>
<td>13.</td>
<td>Load 13</td>
<td>0.8451</td>
</tr>
<tr>
<td>14.</td>
<td>Load 14</td>
<td>0.7885</td>
</tr>
<tr>
<td>15.</td>
<td>Load 15</td>
<td>0.7636</td>
</tr>
<tr>
<td>16.</td>
<td>Load 16</td>
<td>0.8683</td>
</tr>
<tr>
<td>17.</td>
<td>Load 17</td>
<td>0.8085</td>
</tr>
</tbody>
</table>

2.9 CONCLUSION

In this chapter reliability modelling of power system components is analysed by the Node Elimination method. The IEEE 6 bus system, IEEE 14 bus systems and single area IEEE RTS-96 system are used to evaluate the reliability. The three methods gave similar results on average power availability at load bus. The series-parallel & star-delta method is quite difficult for the reduction of complex networks where as the node elimination method is easy even for large systems. Monte Carlo simulation method for complex systems will take large computation time compared to
Node Elimination method. The computation time of Node Elimination method and Monte Carlo simulation method are 1.077msec, 30msec. The new methodology proposed in this chapter is very useful for power system planners and utility consumers. The Electrical circuit approach method is further useful to the power system operators to make decision on the future average power availability.