Sudan University of Science and Technology

College of Engineering

Electrical Engineering Department

Reliability Assessment of Sudanese National Grid

تقييم الموثوقية في الشبكة القومية السودانية

A project Submitted In Partial Fulfillment for Requirements of the Degree of B.Sc. (Honor) In Electrical Engineering

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الآية الكريمة

بسم الله الرحمن الرحيم

قال تعالى:

{يَرْفَعِ اللهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا
الْعِلْمَ دَرَجَاتٍ وَاللهُ بِمَا
تَعْمَلُونَ خَبِيرٌ}

صدق الله العظيم

سورة المجادلة(11)

DEDICATION

To our parents the reason of what we became today, Thanks for your great patience support and Continuous care.

To our friends and colleagues whom are always with us and force source to go forward.

ACKNOWLEDGEMENT

After all, greater thank and grace to Allah firstly and lastly, who always Inspire and guide us.

We would like to thank our supervisor Dr. Mohammed Osman Hassan for the opportunity to work with him, for his invaluable guidance, encouragement, suggesting and great support. He has been an advisor in true sense both academically and morally throughout the completion of this project.

We are highly grateful to school of electrical Engineering for providing all necessary support.

History of all great work is to witness that no great work was ever done without either the active or passive support a person’s surrounding or one's close quarters. Thus it's hard to conclude how active assistance from seniors.

ABSTRACT

Electric power system may suffer from unreliability condition due to scheduled and unscheduled outage of the system components such as transmission lines, generators and transformers. Therefore the system will not be able to meet the demands. This conditions cause massive loss to the economy. Thus, increase cost. Reliability in power system is measurement of the ability of power system to provide the electric power requirements of customer at all times continuously and economically. In this project the reliability analysis is done to Sudanese National Grid (SNG) as case study to determine and analyze the effect of reliability indices on all bus-bars in the system by considering Expected Interruption Cost (ECOST), and Effective Expected Energy Not Supplied (EENS) as reliability indicators.

The convenient results obtained from reliability analysis to SNG done by the aids of ETAP simulation software, all buses evaluated based on reliability and classified according to how they will be affected by the indices of reliability and more affected bus will be identified this is help in overcome the unreliability conditions. From result obtained it found that Sudanese National Grid unreliable.

المستخلص

تعاني منظومة القدرة الكهربائية من حالة عدم الموثوقية عند القطع المجدول وغير المجدول لأي من مكونات المنظومة مثل خطوط النقل ,المولدات والمحولات لذلك لن يكون بمقدور المنظومة تلبية القدرة المطلوبة . مما يتسبب في بعض المشكلات الاقتصادية الناتجة عن انقطاع التغذية . موثوقية النظام هي مقياس لمقدرة منظومة القدرة الكهربائية على تزويد المستهلك بالقدر المطلوب من الطاقة بصورة مستمرة واقتصادية .

أجريت الدراسة على الشبكة السودانية القومية للكهرباء لتحليل وتقييم عند تأثير بعض مؤشرات الموثوقية في كل الموصلات العمومية في المنظومة بأخذ المؤشرات ادناه مقياس للموثوقية كمؤشر لتوقع تكلفة القطوعات و مؤشر لتوقع الطاقة غير المنقولة.

النتائج المتحصل عليها من هذه الدراسة بواسطة برنامج تحليل منظومة القدرة الكهربائية في الحالة العابرة, لتقييم موثوقية جميع الموصلات العمومية وتصنيفها بناء على تأثير مؤشرات الموثوقية, وبناء على هذا التصنيف تم تمثيل الموصلات العمومية الاكثر تأثراً من حيث عدم الموثوقية. و من النتائج التي تحصلنا عليها من دراسة المشروع وجد أن الشبكة القومية السودانية غير موثوقة.

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LIST OF ABBREVIATIONS

SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
AENS	Average Energy Not Supplied Index
SNG	Sudanese National Grid
ASUI	Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
SVC	Static Var Compensator
EMS	Energy Management System
AC	Alternating Current
DC	Direct current
CIF	Customer Interruption Frequency
CID	Customer Interruption Duration
CC-P/ENS	Customer Curtailment – Power/Energy Not Served
RWS	Reliability Worth Study
MTC	Minimize Total Cost
RC	Reliability Cost
CTC	Consumer Interruption Cost
EIR	Energy index of reliability
ETAP	Electrical Transient Analysis Program
AFR	Afraa
ARO	Arooma
ATB	Atbara
BAG	Bagair
BNT	Bant
DEB	Debba
DON	Dongla
FAO	Alfao
FAR	Faroog
GAD	Giad
GAM	Gamoiea
GDF	Algadaref
GRB	Grba
GND	Gneed
HAG	AlhagAbdellah
HWT	Awata
IBA	Eid Babiker
IZB	Izbah
IZG	Izrgab
JAS	Japal Substation
KHE	Khortoum Earth

KHN	Khortoum North
KLX	Kilo 10
KSL	Kasala
KUK	Helat Kuku
LOM	Local Market
MAR	Marinjan
MAN	Managel
MHD	Mahdiea
MRK	Mrkheiat
MSH	Mshkoor
MUG	Mugran
MWP	Marwei plant
MWT	Marwei Town
OBD	Alobied
RBK	Rabak
RC	Reliability Cost
RNK	Alrank
ROS	Rlroseries
RWS	Reliability Worth Study
SHG	Shagara
SNG	Sengah
SNJ	SennarJuntion
SNP	Sennar Plant
TND	Tndelti
UMR	Umrawaba
WHL	WadiHalfa
WWA	Wawa

LIST OF SYMPOLES

Z	Impedance
Y	Admittance
I	Bus Current
V	Bus voltage
P	Active Power
Q	Reactive power
δ	Power Angle
α	Acceleration Factor
λ_A	Active Failure Fate
λ_P	Passive Failure Rate
μ	Mean Repair Rate
rp	Time For Replacing

LIST OF APPENDIX

CHAPTER ONE
INTRODUCTION

1.1Background:

In a modern society, professional engineers and technical managers are responsible for the planning, design, manufacture and operation of products and systems ranging from simple products to complex system.

The failure of these can often cause effects that range from inconvenience and irritation to a severe impact on society and on its environment. Users, customers and society in general expect that products and systems are reliable and safe[1].

Power system have to be designed to provide electrical supply to consumer economically, continuously and good quality. However in spite of very good planning and due to the sum failures of equipment, it may not possible to meet the demand all the time.

Power system security may be looked upon as probability of the systems operating point remaining within acceptable ranges, given the probabilities of changes in system (contingencies) and its environment.

Some contingency (such as line outage, generator or generators outage etc.). make the system unreliable, if the system is unsecure then this contingency may causes blackouts, such as blackout in London, on august 2003, which left thousands of commuters underground, cutting off supply to London underground metro.

An important aspect of power system design involves consideration of service reliability requirements of loads to be supplied and service reliability provided by any proposed system. To test how the system to be reliable and save during its operation life, by using reliability evaluation.

The security and adequacy of system is very important to achieve reliability of system or ability of this system to meet consumers demand.

1.2Project objective:

(1) Study the reliability analysis for bulk power system network.
(2)Reliability indices of system.
(3)Identify if the Sudanese National Grid reliable or not.

1.3 Statement of problem:

The ability of power system to meet its demand that is very important things, this not achieve all the time due to many random failure and un schedule outage make the system un reliable, so if the system adequate and secure then it can be reliable.

1.4 Methodology:

(1) Applying load flow to network by using (Gauss-Seidel) method under steady state.
(2) Screening reliability on the network by using (ETAP) software.

1.5 Project out lines:

Chapter1: represents the general literature, project objective statement of problem project layout and methodology.

Chapter2: represents a general introduction to power system and reliability analysis.

Chapter3: represents a general introduction to load flow and reliability methods.

Chapter4: represents the results and simulation of partial Sudanese National Gird by using ETAP program.

Chapter5: represent the project conclusion and recommendation.

CHAPTER TWO

RELIABILITY ANALYSIS

2.1 Definition:

Reliability is ability of power system to meet the demand
At largest time, or probability of a device or a system performing its function adequacy, for the period of time intended, under the operating condition intended, it can be broadly divided into two aspects:

(i) Power system security.
(ii) System adequacy.

2.2 Power System Security:

Ability of the system to respond favourably to disturbances arising with that system.

The central point of network security is associated with probability of maintaining adequate supply in event of contingencies. A contingencies is a loss of transmission equipment and/or generation units. For example, a generating unit may have be taken offline because of auxiliary equipment failure. By maintaining proper amount of spinning reserves, the remaining units on the system can make up the deficit without too low frequency drop or need to shed any load. Similarly, a transmission line may be damaged by storm and taken out by automatic relaying.

All equipment in power system is designed to such that it can be disconnected from the network. The reason for this disconnections are generally divided into two categories:

(i) Scheduled outages.

(ii) Forced outages.

Scheduled outages are typically done to perform maintenance or replacement of the equipment, and,as it name implies, the of the disconnect scheduled by operators to minimize impact on reliability of the system.

Force outages are those that happen at random and may be due to internal component failures or outside influences such as lightning, wind storm ice buildup, etc.[2]

2.2.1Security levels of system:

The control action to be taken is determined by the security level of the system. This function of the (EMS).

The security levels are as follows:

Level 1 (Secure): At this level, the load is supplied without violating any limits. None of the contingencies will cause any violations of system parameters. In this level, the network will survive any contingencies without need for post-contingency action.

Level 2 (Correctively secure): All load is supplied without violating any limits as in level1. Contingencies do not cause any load loss if the appropriate control action is taken.

Level 3 (Alert): Here, load still supplied without violation limits as in level 1 and level 2, but contingency cause some violations, which cannot be corrected without loss of load. The system can be brought back to level 1 or 2 by preventive rescheduling.

Level 4 (Correctable Emergency): Here, all load is supplied, but with operating limits violated. This violation cannot be corrected without loss of load. The system be brought back to level 3 by corrective actions. The long or medium–term limits in level 3 and level 1 can be violated, but not short term operation limits.

Level 5 (Non-Correctable Emergency): All loads are supplied with violation of operating limits. The situation can be corrected only by loss of load, the duration and amount optimized by an optional power flow program.

Level 6 (Restorative): Operating limits are not violated, but the system is operating with loss of load. [5]

2.2.2Function of system security:

System security deals with operation of power system reliability System security has three major functions monitoring, contingency analysis and optimal power flow.

2.2.2.1 System monitoring:

Monitoring provides operators of the power system with real time, information on the conditions. The parameters monitored are bus voltage current, power flow, status of circuit breakers, isolators, etc., and switches in every substation. Other system parameters telemeterd are frequency, output of generation units and tap position of transformers. The data to be handled are huge and modern digital computers have drastically improved the analysis of the voluminous data. The central computer checks the incoming data for violations, and immediately alerts the operator.

2.2.2.2 Contingency analysis /evaluation:

This second major function of the security system. Many faults and disturbances in power system can lead to serious troubles and cascading effects, which can causes a blackout, resulting loss of millions of rupees/$.

In general terms, contingency analysis can be defined as the evaluation of the security degree of a power system. Contingency analysis is generally related to the analysis of abnormal system conditions. [2]

2.2.2.3 Factor affecting security:

We have seen that there are two major objectives to be met:

1. Operate the system reliably.
2. Within the security constraints operate the system economically.

If unexpected events, unpredictable failures do not occur, then we can build a 100% reliable system by proper planning and design. However, the occurrences of unpredictable events sometimes more one by sheer coincidence, have known to cause catastrophic blackouts.

Two major factor affecting reliability are:

1. Generator outages.
2. Transmission line outages.

We need to consider the impact of these on voltage and line flows. This would require an AC power flow.

However, considering the large number of contingencies, we need to screen them first and decide on those contingencies which require a rigorous AC power flow.

To select critical contingency, there is a tendency to select most important ones.

Other strategies for contingency selection are also preset. On such strategy is simulate all single element contingencies (loss of one generator or of one line) and several multiple contingencies using a fast, approximate technique, like the DC powerflow. Those contingencies are deemed critical, which lead to system insecurity. A second strategy is to compute a severity index for each strategy and select those which have severity index above a threshold value. Each method. Its own pros and cons. While transmission equipment failure leads to voltage and line flow changes, generator loss, in addition, also involves changes in system frequency.

2.3 System Adequacy:

Generally to system investigated the demanded from it must be all components system are available sufficient.

2.3.1 Definition:

Adequacy refers to existence of sufficient generation, transmission and distribution facilities to meet the consumer demand at all points of time. Adequacy requirements have to be considered mainly in planning and design phases. Its therefore a static condition.

Adequacy is measure of the ability of the power system to supply the electric power and energy requirements of the customers within components ratings and voltage limits, taking into account planned and unplanned outages of system components. [7]

2.3.2 Requirement for power system adequacy assessment:

HL1 Level: This deals with only adequacy of generation facilities**.** The system generation is tested for its adequacy in meeting load requirement. This called generator capacity reliability evaluation. At this level, we do not consider the transmission system and its capabilities. An estimate of the generation capacity meet corrective and preventive control measures is made. The percentage reserve is estimated, either as fixed percentage of installed capacity or presented load. N-1 criterion has to be satisfied in this assessment. Limited transmission considerations can be included in HL1 studies to model multi-area generating systems.

HL2 Level: For HL2 studies, bulk transmission is included. Assessment at this level is called composite system of bulk transmission evaluation. HL2 studies are used to assess the adequacy of an existing of proposed system, assessing the reinforcement requirement and alternatives at generation and transmission levels. Two sets of indices are used:

Load point (individual bus) indices and overall system indices.

The bus indices show the effect at individual bus bar and are used for HL3 assessment. Two types of indices are used:

-Annualized indices which are calculated using a single load level (most often peak load).

-Annual indices, calculated considering load variation throughout the year.

Annualized indices are used to compare adequacy of different alternatives, while annual indices are used to evaluate the worth of reliability or damage cost of system unreliability. This index do not reflect the system dynamics or the ability of the system to respond to disturbances. This indices are only indicative of system's ability to meet its requirements in a specified set of probabilistic states. In this level of study, we consider independent and dependent line outage, weather effects, load uncertainly, etc. The HL2 studies include load flow (to determine overloading of lines), contingency analysis, overload alleviation, generation rescheduling, load- shedding philosophy, etc.

HL3 level: HL3 evaluation is very complex, starting at generation stations and terminating at consumer load points. HL3 indices reflect the individual customer adequacy. HL1 and HL2 indices are important as they indicate failures in the generation and transmission zones, which can have disastrous effects on large section of the system.

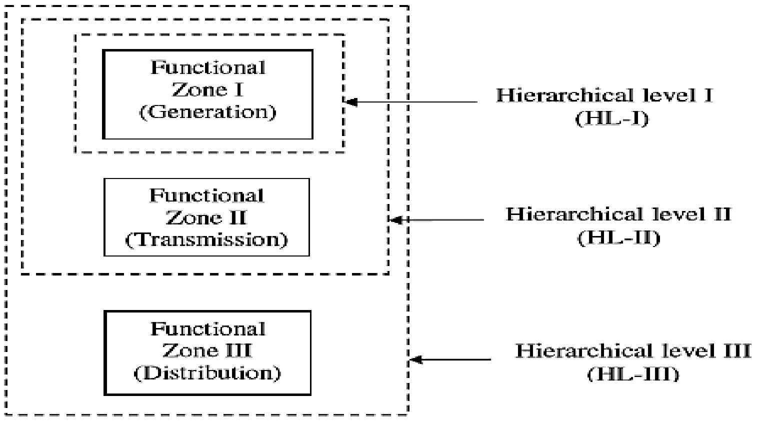


Figure 2.1 Hierarchical Levels of Power System Functional Zones

2.4 Power System Reliability analysis:

Reliability analysis is considers important analysis because it’s expression about range of system performance to the demanded whether quality of supply of each consumers or operation time, this analysis Used in system planning and operation.

There are two main ways by which the reliability can be affected. The first relates to quality and the second to redundancy. [1]

The object of a reliability study is to derive suitable measures of successful performance on the basis of component failure information and system configuration. For generation reliability studies the components of interest are the generating units and system configuration refers to the specific units scheduled to serve the load. [7]

2.4.1Reliability assessment:

-Generation station and generation capacity.

-Composite generation and transmission system.

-Distribution system.

-Substation and switching station.
-Protection system.

2.4.2 Indices to measure reliability:

The indices used to measure generation reliability are probabilistic estimates of the ability of a particular generation configuration to supply the load demand. These indices are better understood as estimates of system-wide generation adequacy and not as absolute measures of system reliability. The indices are sensitive to basic factors like unit size and unit availability, and they are most useful when comparing the relative reliability of different generation configurations. [7]

Various Indices Represented in:

- Customer Interruption Frequency (CIF).
- Customer Interruption Duration (CID).
- Customer Curtailment – Power/Energy Not Served (CC-P/ENS).
- Reliability worth Study (RWS).
- Minimum Total Cost (MTC) it includes:
  - Reliability Cost (RC).
  - Consumer Interruption Cost (CIC).

2.4.3 Reliability worth:

Reliability worth is a useful tool in value based system operation and investment planning, to optimise the reliability level versus the total cost of providing the electricity. In investment planning, reliability worth can be used to relate the value of possible investments to the worth of the reliability improvement that the investment would have. In operation planning, reliability worth can be used to identify optimum operational reserves versus the interruption cost.

The relation between cost and reliability can be described as shown in Figure (2.3), where the optimal reliability level can be identified as the point where the marginal increase in operating and investment costs equals the marginal decrease in interruption cost. The reliability worth varies with several parameters, such as time of day, type of customer, and duration of interruption.

The reliability worth varies with several parameters, such as time of day, type of customer, and duration of interruption. [6]

2.4.4Reliability cost:

Adequacy studies are extremely important to determine the economics involved in setting up alternative facilities. In the simplest method, we consider only the investment cost. The increase in reliability and the associated investment cost of each alternative is evaluates. Dividing the cost by increase in reliability gives the incremental cost of reliability in Rs/Unit increase in reliability. This is a good measure to compare alternative strategies. The lowest incremental cost of reliability is the best option.

This method does not consider the ROI (Return On Investment) or the real benefit accruing to the customer or society or utility. To make a comparison, we need to consider not only adequacy cost but also adequacy worth. We can set a level of incremental cost which is acceptable to consumers. Alternative schemes less than this are considered, while those above are rejected. The reliability and cost curves are shown in Figure (2.2).

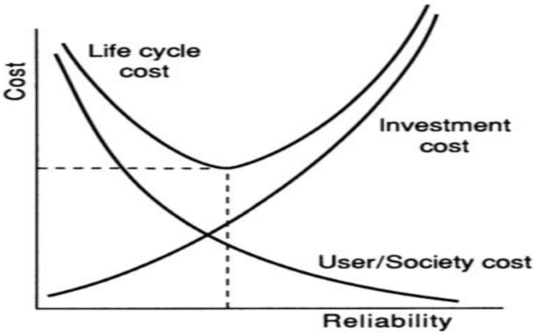


Figure (2.2): Reliability cost

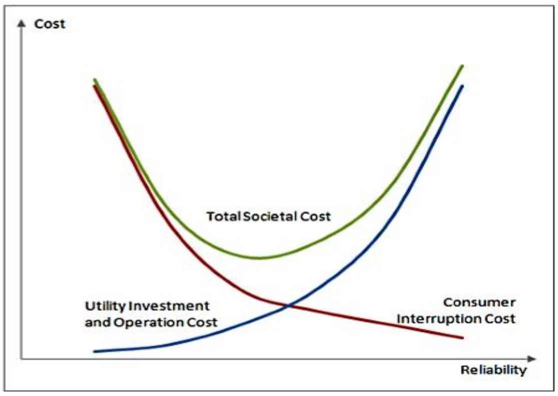


Figure (2.3): Reliability cost and reliability worth

The cost to the utility increases as reliability that it has to provide increases. On the contrary, as the reliability improves, the customer cost due to supply interruptions decreases. Total cost to society is the sum of the two. The point where this cost is minimum is optimum level of reliability or target level.

Reliability evaluation of Sudan's electrical network will be performed using the load flow method. The result of this analysis will be used to determine the security level of Sudanese electrical network.

CHAPTER THREE

LOAD FLOW AND RELIABILITY METHOD

3.1 Introduction of load flow:

The power system is assumed to operating under balanced condition and can be represented by single line diagram the power system network contain hundreds of buses and branches with impedance specified in per-unit on a common MVA base.

Power flow studies commonly referred to as long flow, are essential of power system, analysis and load flow studies are necessary for planning economic operation, scheduling and exchange of power between utilities. Load flow study is also required for other analysis such as transient stability, dynamic stability, contingency and state estimation.

Network equations can be formulated in variety of forms. However node equations voltage method is commonly used for power system analysis, the Network equations which are in the nodal admittance form results in complex linear simultaneous algebraic equations in term of node currents. The load flow result gives the bus magnitude and phase angle and hence the power flow through the transmission line losses and power injection at all the busses.

3.1.1 Bus classifications:

Four quantities are associated with each bus. These are voltage magnitude V, phase angle, real Power P and reactive Q. in a load flow study, two out of four quantities are specified and the remaining two quantities are to be classified into three categories.

Slack bus: Also known as swing bus and taken as a reference where the magnitude and phase angle of the voltage are specified. This bus provides the additional real and reactive power to supply the transmission losses, since these are unknown until the final solution is obtained .

Load bus: Also known as PQ bus. At these buses the real and reactive powers are specified. The magnitude and phase angle of the bus Voltage are unknown until the final solution is obtained. [3]

Table 3.1: Bus classification:

Bus type	Specified quantities	Unknown quantities
Slack bus	$\vert V\vert$, δ	P,Q
Load bus	P,Q	$\vert V\vert$,δ
Voltage control bus	P, $\vert V\vert$	Q, δ

3.1.2 Bus admittance matrix:

In order to obtain the bus-voltage equations, consider the simple 4-bus power system as shown in figure below: for simplicity resistance of the line are neglected and the impedances shown in above figure are expressed in per-unit on common MVA base.

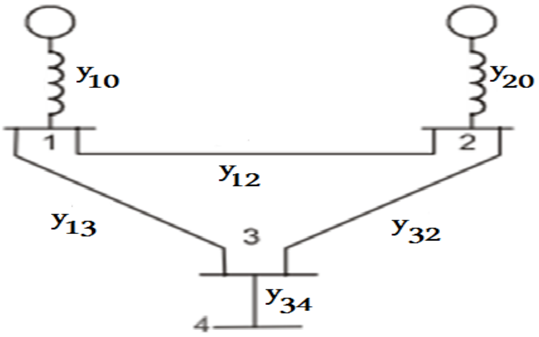


Figure (3.1): The impedance diagram of sample 4-bus power system

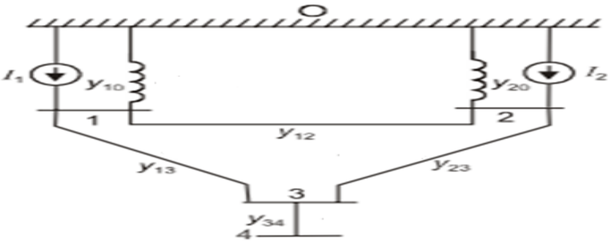


Figure (3.2):The ad mittance diagram of figure (3.1)

Applying KCL to the independent nodes 1, 2, 3, 4 we have,

$$I_1 = y_{10}V_1 + y_{12}(V_1 - V_2) + y_{13}(V_1 - V_3)$$

$$I_2 = y_{20}V_2 + y_{12}(V_2 - V_1) + y_{23}(V_2 - V_3)$$

$$0 = y_{23}(V_3 - V_2) + y_{13}(V_3 - V_1) + y_{34}(V_3 - V_4)$$

$$0 = y_{34}(V_4 - V_3)$$

Rearranging the above equations, we get

$$I_1 = (y_{10} + y_{12} + y_{13})V_1 - y_{12}V_2 - y_{13}V_3$$

$$I_2 = -y_{12}V_1 + (y_{20} + y_{12} + y_{23})V_2 - y_{23}V_3$$

$$0 = -y_{13}V_1 - y_{23}V_2 + (y_{13} + y_{23} + y_{34})V_3 - y_{34}V_4$$

$$0 = -y_{34}V_3 + y_{34}V_4$$

Let,

$$Y_{11} = (y_{10} + y_{12} + y_{13})$$

$$Y_{22} = (y_{20} + y_{21} + y_{23})$$

$$Y_{33} = (y_{31} + y_{32} + y_{34})$$

$$Y_{44} = y_{43}$$

$$Y_{12} = Y_{21} = -y_{12}$$

$$Y_{13} = Y_{31} = -y_{13}$$

$$Y_{23} = Y_{32} = -y_{23}$$

$$Y_{34} = Y_{43} = -y_{43}$$

The node equations reduce to :

$$I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + Y_{14}V_4$$

$$I_2 = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4$$

$$I_3 = Y_{31}V_1 + Y_{32}V_2 + Y_{33}V_3 + Y_{34}V_4$$

$$I_4 = Y_{41}V_1 + Y_{42}V_2 + Y_{43}V_3 + Y_{44}V_4$$

Above equations can be written in matrix form,

$$\begin{bmatrix} \mathrm{I}_1 \\ \mathrm{I}_2 \\ \mathrm{I}_3 \\ \mathrm{I}_4 \end{bmatrix} = \begin{bmatrix} \mathrm{Y}_{11} & \mathrm{Y}_{12} & \mathrm{Y}_{13} & \mathrm{Y}_{14} \\ \mathrm{Y}_{21} & \mathrm{Y}_{22} & \mathrm{Y}_{23} & \mathrm{Y}_{24} \\ \mathrm{Y}_{31} & \mathrm{Y}_{32} & \mathrm{Y}_{33} & \mathrm{Y}_{34} \\ \mathrm{Y}_{41} & \mathrm{Y}_{42} & \mathrm{Y}_{43} & \mathrm{Y}_{44} \end{bmatrix} \begin{bmatrix} \mathrm{V}_1 \\ \mathrm{V}_2 \\ \mathrm{V}_3 \\ \mathrm{V}_4 \end{bmatrix} \qquad (3.2)$$

Or

In general:

$$\mathrm{I}_{\mathrm{bus}}=\mathrm{Y}_{\mathrm{bus}}\mathrm{V}_{\mathrm{bus}} \qquad (3.3)$$

$\mathrm{V}_{\mathrm{bus}} \equiv$ vector of bus voltages

$\mathrm{I}_{\mathrm{bus}} \equiv$Vector of the injected currents

$\mathrm{Y}_{\mathrm{bus}} \equiv$Admittance matrix

Diagonal element of Y matrix:

$$Y_{ii} = \sum_{k=0}^{n} y_{ik} \ ,j \neq i \qquad (3.4)$$

Off-diagonal element of Y matrix:

$$Y_{ik} = Y_{ki} = -y_{ik} \qquad (3.5)$$

$$\mathrm{V}_{\mathrm{bus}} = \mathrm{Y}_{\mathrm{bus}}^{-1}\ \mathrm{I}_{\mathrm{bus}} \qquad (3.6)$$

3.1.3 Bus loading equations:

Consider ith bus of a power system as shown in Figure (3.3)Transmissionlines arerepresented by their equivalent p models π models. y_{i0} is the total charging admitance at bus i.

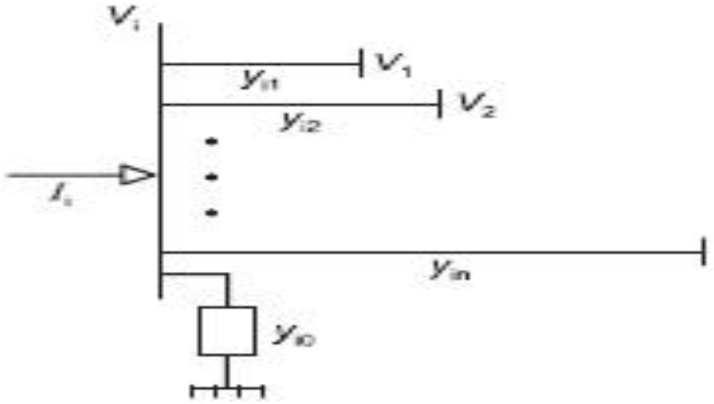


Figure (3.3): i-th bus of a powr system

Net injected current **I**i into the bus i can be written as:

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \cdots + y_{in}(V_i - V_n)$$

$$I_i = (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})V_i \; - y_{i1}V_1 - y_{i1}V_2 - \cdots - y_{i1}V_n \qquad (3.7)$$

Let us define:

$Y_{ii} = y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in}$

$Y_{i1} = -y_{i1}$

$Y_{i2} = -y_{i2}$
$\vdots$
$Y_{in} = -y_{in}$

$$I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{in}V_n \qquad (3.8)$$

Or:

$$I_i = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k \tag{3.9}$$

The real and reactive power injected at the bus$i$ is:

$$Pi - jQi = V_i * I_i$$

$$I_i = \frac{P_i - jQ_i}{v_i^*} \tag{3.10}$$

From eqns. (3.9) and (3.10) we get:

$$\frac{P_i - jQ_i}{v_i^*} = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k \tag{3.11}$$

$$Y_{ii}V_i = \frac{P_i - jQ_i}{v_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k$$

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{v_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right] \tag{3.12}$$

3.1.4 Calculation of net injected power:

From eqn. (3.11), we get:

$$\frac{P_i - jQ_i}{v_i^*} = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k$$

$$P_i - jQ_i = v_i^*\left[Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right] \tag{3.13}$$

$$\therefore P_i - jQ_i = |V_i|^2|Y_{ii}|\cos\theta_{ii} + j|V_i|^2|Y_{ii}|\sin\theta_{\mathrm{ii}}$$

$$+\sum_{\substack{k=1\\k\neq i}}^{n}|Y_{ik}||V_i||V_k| + \mathrm{j}\sum_{\substack{k=1\\k\neq i}}^{n}|Y_{ik}||V_i||V_k| \qquad (3.14)$$

separating real and imaginary part of equation (3.14):

$$P_i = \sum_{k=1}^{n}|Y_{ik}||V_i||V_k|\cos(\theta_{ik} + \delta_k - \delta_i) \qquad (3.15)$$

And:

$$Q_i = -\sum_{k=1}^{n}|Y_{ik}||V_i||V_k|\sin(\theta_{ik} + \delta_k - \delta_i) \qquad (3.16)$$

3.2 Gauss-Seidel Method:

The equations descript of the system is nonlinear equations in this state the instantaneous solution not successful, therefore using the iterative method to solution.

3.2.1 Inserted of the method:

The Gauss-Seidel method is also known as the method of successive displacements. To illustrate the technique, consider the solution of the nonlinear equation given by:

$$f\ (\mathrm{x}) = 0$$

The above Function is rearranged and written as:

$$\mathrm{X} = \mathrm{g}(\mathrm{X})$$

If $\mathrm{X}^{(K)}$ is an initial estimate following iterative of the variable X, following iterative sequence formed

$$X^{(K+1)} = g(x^{(k)})$$

A solution is obtained when the difference between the absolute value of successive iteration is less than a specified accuracy, i.e.

$$\left| X^{(\mathbf{K}+\mathbf{1})} - X^{(\mathbf{k})} \right| \leq \in$$

Where $\in$ is the desired accuracy?

3.2.1 Gauss-Seidel power flow solution:

In the power flow study, it is necessary to solve the set of nonlinear equations represented by (3.13) for two unknown variables at each node. In the Gauss-Seidel method (3.13) is solved for V_i, and the iterative sequence becomes:

$$V_i^{(k+1)} = \frac{\dfrac{P_i^{sch} - jQ_i^{sch}}{v_i^{*(k)}} + \sum y_{ij} v_j^{(k)}}{\sum y_{ij}} \qquad j \neq I \qquad (3.17)$$

Where y_{ij} shown in lowercase letters is the actual admittance in per unit. P_i^{sch} and Q_i^{sch} are the net real and reactive powers expressed in per unit In writing the KCL, current entering bus i was assume positive. Thus, for buses where real and reactive powers are injected into the bus, such as generator buses, P_i^{sch} and Q_i^{sch} have positive values. For load buses where real and reactive powers are flowing away from the bus, P_i^{sch} and Q_i^{sch} have negative values. If (3.13) is solved for P_i^{sch} and Q_i^{sch} we have

$$P_i^{(k=1)} = V_i^{*(k)} \left[V_i^{(k)} \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_i^{(k)} \right] \tag{3.18}$$

$$Q_i^{(k=1)} = V_i^{*(k)} \left[V_i^{(k)} \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_i^{(k)} \right] \tag{3.19}$$

The power low equation is usually expressed in terms of the elements of the bus admittance matrix. Since the off-diagonal elements of the bus admittance matrix Y_{bus}, shown by uppercase letters, are $Y_{ij} = y_{ij}$ and the diagonal elements are:

$$Y_{ij} = \sum y_{ij}$$

(3.17) becomes:

$$V_i^{(k+1)} = \frac{\dfrac{P_i^{sch} - jQ_i^{sch}}{v_i^{*(k)}} + \sum y_{ij} v_j^{(k)}}{\sum y_{ij}} \quad j \neq I \tag{3.20}$$

And

$$P_i^{(k+1)} = V_i^{*(k)} \left[V_i^{(k)} \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_i^{(k)} \right] \tag{3.21}$$

$$Q_i^{(k+1)} = V_i^{*(k)} \left[V_i^{(k)} \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_i^{(k)} \right] \tag{3.22}$$

Y_{ji} includes the admittance to ground inline charging susceptance and any other fixed admittance to ground.

For P-Q buses, the real and reactive powers P^{sch} and Qi^{sch} are known، starting with an initial estimate, (3.20) is solved for the real and imaging components of voltage. For the voltage-controlled buses(P-V) where P^{sch} and $|V_i|$ are specified first (3.22) is solved for $Q_i^{(k+1)}$, and then is used in (3.20) to solve $V_i^{(k+1)}$ However, since $|V_i|$ is specified, only the imaginary part is selected in order to satisfy.

$$(e_i^{(k+1)})^2 + (f_i^{(k+1)})^2 = |V_i|^2 \tag{3.23}$$

Or :

$$e_i^{(k+1)} = \sqrt{|Vi|^2 - (fi^{(k+1)2}} \tag{3.24}$$

Where $e_i^{(k+1)}$ and $f_i^{(k+1)}$ are the real and imaging components of the voltage $V_i^{(k+1)}$ in the iterative sequence.

The rate of convergence is increased by applying an acceleration factor to the approximate solution obtained from each iteration.

$$V_i^{(k+1)} = V_i^{(k)} + \alpha(V_{ical}^{(k)} - V_i^{(k)}) \tag{3.25}$$

Where α is the acceleration factor، its value depends upon the system. The range of 1.3 to 1.7 is found to be satisfactory for typical systems.

The updated voltages immediately replace the previous values in the solution of the subsequent equations. The process is continued until changes in the real and imaging components of bus voltages between successive iterations are within a specified accuracy i.e.

$$\left[e_i^{(k+1)} - e_i^{(k)}\right] \leq \varepsilon$$

$$\left[f_i^{(k+1)} - f_i^{(k)}\right] \leq \varepsilon \tag{3.26}$$

For the power mismatch to be reasonably small and acceptable, a very tight tolerance must be specified on both components of the voltage. A voltage accuracy in the range of 0.0001 to 0.00005 pu is satisfactory.[4]

3.3 Adequacy Indices:

There are many indices defined at various hierarchical levels. Computation of these indices require data which include frequency and duration of interruptions. In defining the induces, we consider expectation indices which are the long-run average of the phenomenon under study. Some of the common indices are discussed in the subsequent subsections.

3.3.1Indices at Hl1 :

1. Loss of load Expectation (LOLE): This is measured in hr/yr or days. It defined as:

$\text{LOLE} = \sum_{\text{IES}} (P_i T)$ (3.47)

Where S the set all system state associated with the loss of load IS the probability of system state i. It is the average number of hours or days in a time (usually a year) in which the daily peak load exceed the available generating capacity. If we use the unit days/yr, depends on comparison of daily beak load and capacity. If it is hr/yr, p_i depends comparison of the load with the available generating capacity. This index does not indicate severity of deficiency, the duration or frequency of load interruption.

2. loss of load energy Expectation (LOLEE) MW/yr:

$$\text{LOLEE} = \sum_{IES} (8760 C_i P_i) \qquad (3.48)$$

There C_i, the load for system stat. This index is the expected energy which cannot be sup because the demand exceed generation capacity, (8,760 is number of hours in a year) this index takes into account the severity of the deficit and the impact of energy shortfalls. A normalized index called Energy Index of Reliability (EIR) can be obtained as the supplied divided by the total energy demanded index is useful in comparing the adequacy of system that differ significantly size.

3. Loss of Load Frequency (LOLF) (number of occ/yr)

$$\text{LOLF} = \sum_{IES} (F_i - f_i) \qquad (3.49)$$

Here F is the frequency of departing system state i and f , is the portion of F , which does not go through the boundary between loss-of-load state and no-loss-of' load state set.

4. Probability of Load Duration (LOLD) hr/disturbance:

$$\text{LOLD} = \frac{\text{LOLE}}{\text{LOLF}} \qquad (3.50)$$

Un extension of LOLE index is the frequency (LOLF) and duration (LOLD) of loss of load.

3.3.2 HL2 level:

Some of the popular o discussed below:

1. Probability of Load Curtailment (PLC):

$$\text{PLC} = \sum_{\text{IES}} (P_i) \qquad (3.51)$$

Where S is the set of all system states associated with load curtailment and is probability of state i.

2. Expected Frequency of Load Curtailment (EFLC) (occ/yr):

This is the same as LOLF.

3.Expected Duration of Load Curtailments (EDLC) (hr/yr):

$$\text{EDLC} = \text{PLC} \times 8760 \qquad (3.52)$$

4. Average Duration of Load Curtailment (ADLC) (br/disturbance):

$$\text{ADLC} = \frac{\text{ELC}}{\text{EFLC}} \qquad (3.53)$$

5. Expected Load Curtailment (ELC) (MW/yr):

$$\text{ELC} = \sum_{\text{IES}} (C_i F_i) \qquad (3.54)$$

C_i- Load Curtailment in state

F_i-System State Frequency

6. Expected Demand Not Supplied (EDNS) (MW):

$$\text{EDNS} = \sum_{\text{IES}} (C_i P_i) \qquad (3.55)$$

7.Expected Energy Not Supplied(EENS) (MWhr/yr):

$$\text{EENS} = \sum_{\text{IES}} (8760 C_i P_i) \qquad (3.56)$$

8.Bulk Power-Supply Average MW Curtailment Index (BPACI) (MW/disturbance):

$$\text{BPACI} = \frac{\text{ELC}}{\text{EFLC}} \qquad (3.57)$$

3.3.3 Indices at HL3:

distribution system are more complex calculate . Some indices are defined below:

1.System Average Interruption Frequency Index (SAIFI)(Interruptions/system Customer/yr):

$$\text{SAIFI} = \frac{\sum_{ieR} \lambda_i N_i}{\sum_{ieR} M_i} \qquad (3.58)$$

λ_i =failure rate

N_i = number of costumer at load points

R= set of load points in the system

2.System Average Interruption Duration Index (SAIDI) (hr/system customer/yr):

$$\text{SAIDI} = \frac{\sum_{ieR} U_i N_i}{\sum_{ieR} M_i} \qquad (3.59)$$

U_i -annual unavailability or outage time (hr/yr).

3.Customer Average Interruption .Frequency Index (CAIFI) (Interruptions customers affected/yr):

$$\text{CAIFI} = \frac{\sum_{ieR} \lambda_i N_i}{\sum_{ieR} M_i} \qquad (3.60)$$

M_i - number of customers affected at load point

4. Customer Average Interruption Duration Index (CAIDI) (hr/customer interruption):

$$\text{CAIDI} = \frac{\text{SAIDI}}{\text{SAIFI}} \tag{3.61}$$

Reliability of different zones is generally different. Generation and transmission failure can affect the whole system while distribution failures are localized.

3.4 ETAP overview:

"ETAP" is an abbrev for "Electrical Transient Analysis Program ". ETAP is full spectrum analytical engineering software company specializing in analysis simulation, monitoring, control, optimization, and automation of electrical power system.

ETAP software offers the most comprehensive and integrated suite of power system enterprise solution that spans from model to operation.

3.4.1 AC load flow method

In ETAP the nodal equations used to represent the analyzed network are Implemented using two different formulation:

- Gauss-Seidel (current equations).
- Gauss-Seidel(power equations , classical).

In both formulations, the resulting nonlinear equations system must be Solved by an iteration method.

ETAP uses the Gauss-Seidel method as its non linear equations solver. The selection of the method used to formulate the nodal equations is User. Defined, and should be selected based on the type of network to be calculated.

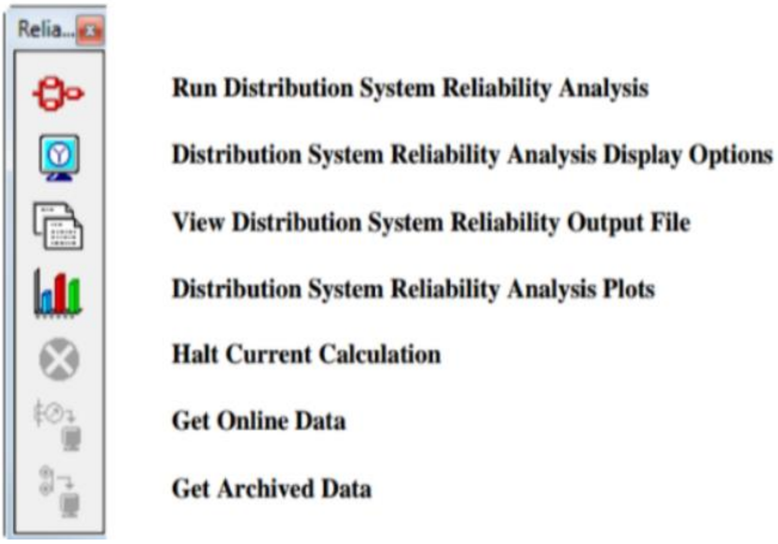
3.4.2 Reliability analysis

Assesses reliability level for redial and looped system with a very Efficient algorithm, it Considers single and double contingencies.

Assesses reliability level for system and each load point based on Component failure model and system configuration.

Performs sensitivity analysis to identify the optimal location to make Greatest improvement on system reliability at minimum cost.

To access the various reliability analysis related functions within ETAP, Click on the icon change Toolbar and select “Reliability Analysis”.



Figure(3.4)The Reliability Analysis Toolbar ,with all the related functions

3.5 Reliability Analysis by using ETAP:

Procedure the reliability analysis wherein simulation program and explanation calculations by knowingly factors and how obtaining this factors.

3.5.1 Component Model:

λ_A -Active Failure Rate (No of Failures/Year):

- Causes the operation of the protection devices around the failed component, i.e. a short-circuit fault.
- Failed component itself (and those components that are directly connected to this failed component) restores to service after repair or replacement.

λ_P - Passive Failure Rate (No of Failures/Year):

- Does not cause the operation of protection around the failed component, i.e. an open circuit fault.
- Failed component itself restores to service after repair or replacement.

- Mean Time To Repair in hours (MTTR):

Time required to repair a component outage and/or restore the system to its normal operating state

- Mean Repair Rate (No of repairs per year) (μ):

$$\mu = 8760/\mathrm{MTTR} \tag{3.62}$$

- Mean Time To Failure (years) (MTTF):

$$\mathrm{MTTF} = 1.0/(\lambda_A + \lambda_P) \qquad (3.63)$$

- Mean Time Between Failure (Year) (MTBF):

$$\mathrm{MTBF} = \mathrm{MTTF} + \mathrm{MTTR}/8760 \qquad (3.64)$$

- Forced Outage Rate (Unavailability)(FOR)

$$\mathrm{FOR} = \mathrm{MTTR}/(\mathrm{MTBF}\times 8760) \qquad (3.65)$$

- Switching Time:

– Time in hours for isolating a fault occurred at the component.

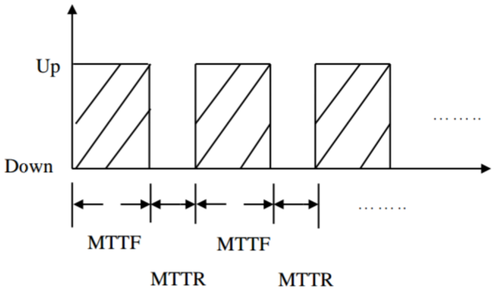
– Assume that CB/Fuse trip a fault instantaneously.

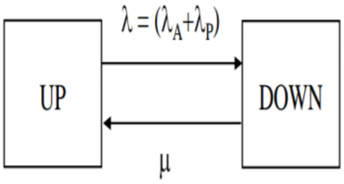
- Time for replacing a failed element by a spare one, in hours (r_P).

3.5.2 Single-Component Concepts:

- Two-State Model:

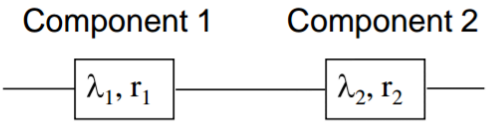
– A two-state up/down representation is used for the operation repair cycle component (such as lines, cables, transformers, breakers, fuses, switches, loads and bus bars).





3.5.3 Model for Components in Series/Parallel:

Two Components in Series:

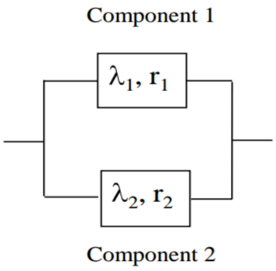


$$\lambda_{sys} = \lambda_1 + \lambda_2$$

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

3.5.4 Model for Components in Series/Parallel:

Two Components in Parallel:



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

$$r_{sys} = \frac{r_1 r_2}{r_1 + r_2}$$

3.5.5 Library for Reliability Analysis:

- Component Reliability:

– Data for each type of component.

- transformer, bus, line, etc.

- Active Failure Rate.
- Passive Failure Rate.
- Repair Time.
- Switching Time.
- Replacement Time.

– Typical data from IEEE Standard.

3.5.6 Reliability Indices

-Average Failure Rate at Load Point , (f/yr):

$$\lambda_i = \sum_{j\in Ne} \lambda_{ej} \qquad (3.66)$$

$\lambda_{e,j}$ -The average failure rate of element j (or element combination j, such as double contingency).

N_e -The total number of the elements whose faults will interrupt load point i.

-Annual Outage Duration at Load Point i, Ui (hr/yr):

$$U_i = \sum_{j\in Ne} \lambda_{e,j} r_{i,j} \qquad (3.67)$$

$r_{i,j}$ -Failure duration at load point i due to a failed element j.

-Average Outage Duration at Load Point, ri (hr):

$$r_i = U_i / \lambda_i \qquad (3.68)$$

-Expected Energy Not Supplied Index at Load Point, EENSi:

$$EENS_i = P_i U_i \qquad (3.69)$$

Pi - the average load of load point i.

-Expected Interruption Cost Index at Load Point, $ECOST_i$ ($/yr):

$$\mathrm{ECOST} = \mathrm{P_i}\textstyle\sum_{j\in Ne} f(\mathrm{r_{ij}})\lambda_{e,j} \tag{3.70}$$

The EENS and ECOST for a bus are calculated based on loads that are directly connected to that bus due to the outage of that bus.

-Interrupted Energy Assessment Rate Index at Load Point, $\mathrm{IEAR_i}$ ($/kWhr):

$$\mathrm{IEAR_i} = \frac{\mathrm{ECOSTi}}{\mathrm{EENSi}} \tag{3.71}$$

-System Average Interruption Frequency Index, SAIFI (f/customer. yr):

$$\mathrm{SAIFI} = \frac{\text{Total number of customer interruptions}}{\text{Total number of customer served}} = \frac{\sum\lambda iNi}{\sum Ni} \tag{3.72}$$

Where N is the number of customers at load point i

-System Average Interruption Duration Index, SAIDI (hr/customer. yr):

$$\mathrm{SAIDI} = \frac{\text{sum of customer interruption on duration}}{\text{Total number of customer served}} = \frac{\sum\mathrm{UiNi}}{\sum\mathrm{Ni}} \tag{3.73}$$

-Customer Average Interruption Duration Index, CAIDI (hr/customer interruption on duration):

$$\mathrm{CAIDI} = \frac{\text{sum of customer interruption on duration}}{\text{Total number of customer interruption}} = \frac{\sum\mathrm{UiNi}}{\sum\mathrm{Ni\lambda i}} \tag{3.74}$$

-Average Service Availability Index, ASAI (pu):

$$\mathrm{ASAI} = \frac{\text{Customer hours of available service}}{\text{Customer hours demanded}} = \frac{\sum\mathrm{Ni}\times 8760-\sum\mathrm{NiUi}}{\sum\mathrm{Ni}\times 8760} \tag{3.75}$$

Where 8760 is the number of hours in a calendar year

-Average Service Unavailability Index, ASUI (pu):

$$\mathrm{ASUI} = 1\text{- }\mathrm{ASAI} \tag{3.76}$$

-System Expected Energy Not Supplied Index, EENS (MWhr/yr):

EENS = Total energy not supplied by the system = $\sum EENS_i$ (3.77)

-System Expected Interruption Cost Index, ECOST ($/yr):

ECOST = $\sum ECOST_i$ (3.78)

-Average Energy Not Supplied Index, AENS (MWhr/customer. yr):

$$\text{AENS} = \frac{\text{Total energy not supplied by the system}}{\text{Total number of customer served}} = \frac{\sum \text{EENSi}}{\sum \text{Ni}} \quad (3.79)$$

-System Interrupted Energy Assessment Rate Index, IEAR ($/kWhr):

$$\text{IEAR} = \frac{\text{ECOST}}{\text{EENS}} \quad (3.80)$$

CHAPTER FOUER

SIMULATION AND RESULTS ANYLISIS

4.1 Introduction:

The voltage profile of the entire system is presented from the load flow simulation as shown in Table(4,2), it can be noticed that are seven buses are under voltage.

The model analysis method has been successfully applied to the partial power system network shown in appendix(A), a power flow program (ETAP) is develop to:

-Calculate the power flow solution.

-Reliability analysis based on model analysis.

-Screening and assessment of Sudanese National Grid

4.2 case study:

The network which has been studied is Sudanese electrical power system network. It contains of 81 transmission lines, 53 load, 7 synchronous machines, 15 2-winding transformers, 82 bus bar, external grid and 10 shunts have been table (4,1).

Table 4.1: The statistics of the power system network components:

Number	**Type**	**Number of units**
1	Line	81
2	Load	53
3	Synchronous machine	7
4	2-winding transformer	15
5	Bus bar	82
6	External grid	1
7	Shunt	10

4.3 Power Flow Results:

Table 4.2: The Bus Bar Load Flow Results:

Bus number	Bus name	Voltage (KV)	Voltage (p .u) %	Angle (degree)
1	MWP500	500	100	0
2	ATB5	501.209	100.24	-3.7
3	MRK5	495.062	99.01	-7.5
4	KAB5	497.596	99.52	-8.2
5	WHL2	217.32	98.78	-8.9
6	WWA2	224.199	101.909	-8.2
7	DBE2-DEB1	224.488	102.040	-6.5
8	DEB2-DEB2	229.482	104.310	-5.3
9	DON2	225.354	102.434	-7.9
10	MWT2	226.710	103.050	-3.0
11	MWP2	228.250	103.750	-1.7
12	ATB2	204.044	92.747	-9.1

13	SHN2	213.564	97.07	-13.8
14	MRK2	219.804	99.911	-19.2
15	GAM2	216.634	98.470	-20.3
16	KAB2	217.989	99.086	-16.6
17	FRZ2	219.605	99.820	-16.3
18	GER2	220	100.000	-16.4
19	IBA2	219.108	99.594	-18.5
20	MHD2	218.74	99.427	-19.8
21	KLX2	218.663	99.392	-19.4
22	JAS2	216.358	98.345	-20.7
23	GAD2	216.822	98.555	-20.9
24	SOB2	218.261	99.209	-19.7
25	NHAS2	212.38	96.536	-23.6
26	MAR2	212.869	96.759	-24.2
27	MSH2	219.601	99.819	-20.6
28	RBK2	220	100	-20.5
29	SNJ2	216.894	98.588	-23.9
30	SNG2	220.215	100.098	-23.3
31	ROS2	220	100	-18.7
32	RNK2	221.743	100.792	-19.6
33	HWT2	222.164	100.984	-23.9
34	OBD2	219.753	99.888	-23.5
35	UMR2	221.215	100.552	-21.9
36	TND2	221.593	100.724	-21.4
37	DBT2	220.451	100.205	-24.2
38	ZBD2	220.172	100.078	-24.4
39	FUL2	220.578	100.263	-24.9
40	BBN2	221.008	100.458	-25.0

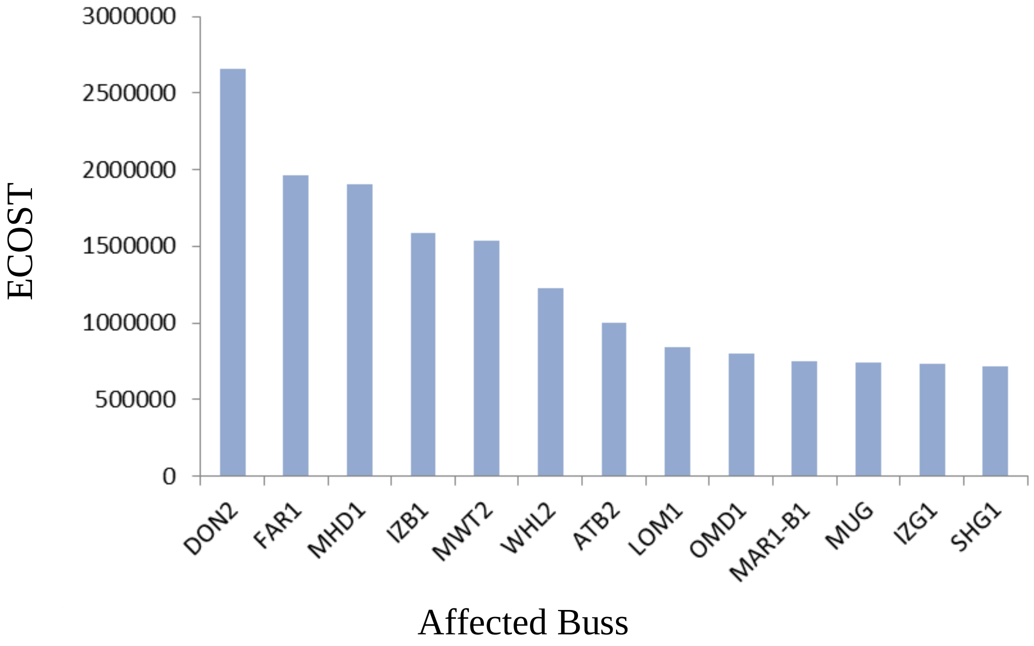
41	GDF2	222.1	100.955	-24.3
42	GRB2	221.562	100.710	-24.6
43	SHK2	222.108	100.958	-24.4
44	NHLF2	221.526	100.694	-24.7
45	ARO2	223.079	101.400	-24.9
46	KSL2	222.843	101.292	-24.9
47	HUD	219.056	99.571	-19.5
48	UTP2	222.204	101.002	-24.4
49	SHD2	220	100.000	-23.0
50	KHE1	108.179	98.345	-26.8
51	IZB1	106.438	96.762	-25.7
52	IBA1	107.226	97.478	-25.3
53	KHN1	110	100.000	-26.3
54	KUK1	108.472	98.611	-26.6
55	IZG1	107.955	98.141	-26.4
56	MHD1	107.232	97.483	-26.1
57	FAR1	102.906	93.551	-26.9
58	AFR1	103.735	94.305	-26.5
59	KLX1	104.558	95.053	-26.0
60	LOM1	104.526	95.023	-26.2
61	SHG1	105.233	95.666	-26.3
62	MUG	105.579	95.981	-26.6
63	BNT1	105.992	96.357	-26.5
64	OMD1	106.133	96.484	-26.5
65	GAM1	108.335	98.487	-25.5
66	JAS1	110.267	100.242	-24.7
67	BAG1	101.981	92.710	-24.0
68	SOB1-B1	103.634	94.212	-25.3

69	GAD1-B2	102.382	93.074	-23.7
70	NHAS1	114.092	103.720	-25.8
71	OHAS1	113.737	103.398	-25.9
72	GND1	113.374	103.067	-26.1
73	MAR1-B1	112.703	102.457	-26.8
74	MAN1	111.544	101.403	-27.7
75	ORBK1	111.36	101.237	-25.3
76	SNJ1	111.412	101.283	-25.2
77	HAG1	110.962	100.874	-26.5
78	SNP1	110	100.000	-25.2
79	MIN1	104.298	94.816	-26.2
80	FAO1	110.476	100.433	-27.3
81	GDF1	112.654	102.413	-25.9
82	GRB69	66	100.000	-25.3

Discussion of Buses Results:

From the load flow results shown in Table (4.2) it can be noticed there are seven buses are out of tolerance ±10 (marginal state) which are shaded (violet) color, and other buses within limits.

4.4 Reliability Analysis Results:



Figure(4.1): The maximum ECOST at base case

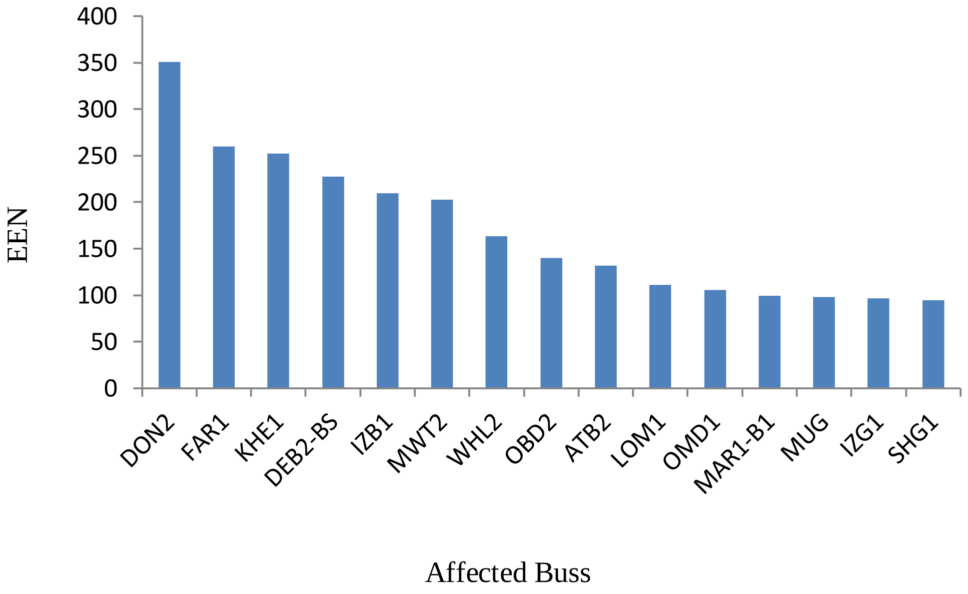


Figure (4.2): The maximum EENS at base case

4.4.1Generators outage:

From the graphical shown in Figure (4.3) and (4.4), the ECOST and EENS of the component after the all generators outage have been applied. The results show that the bus 12 (ATB2) which have ECOST (996520.3$/yr) and EENS (131.9421 MWhr/yr) at base case was most affected elements with the outage of all generators, led the ECOST and EENS to became higher than it was ECOST (7346675$/yr) and EENS(965.6497 MWhr /yr).

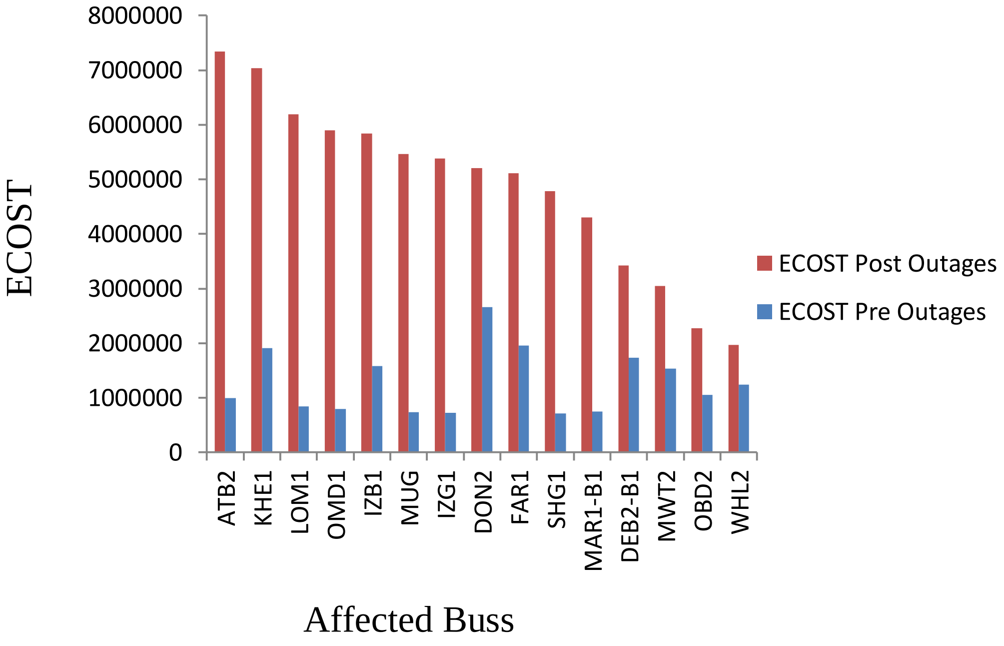


Figure (4.3): The ECOST at Generators outage

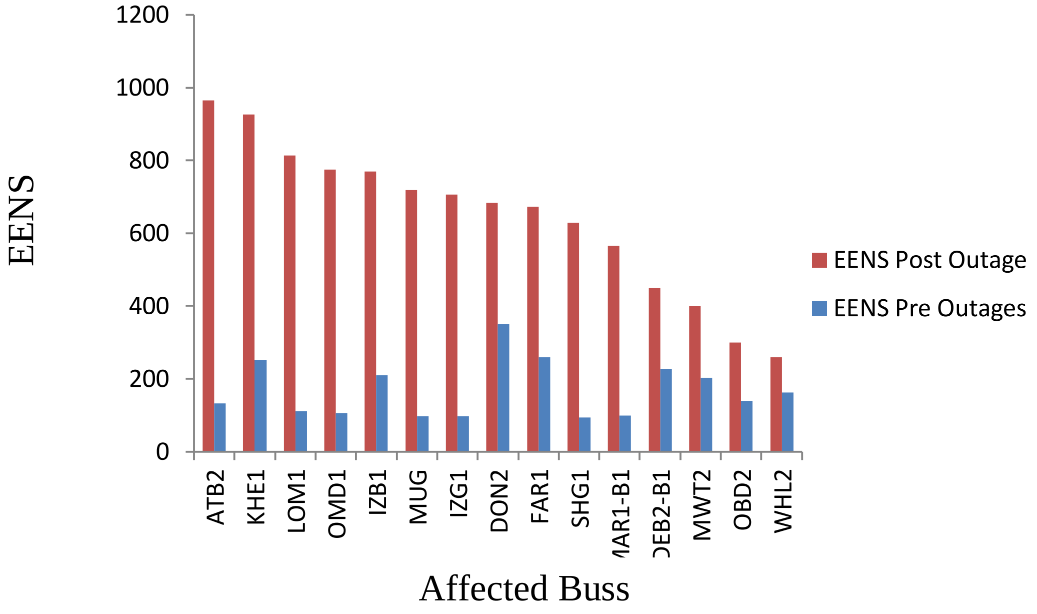


Figure (4.4): The EENS at Generators outage

4.4.2Transformers outage:

From the graphical shown in Figure (4.5) and (4.6), the ECOST and EENS of the component after several transformers outage have been applied. The results show that the bus 51 (IZB1) which have ECOST (1583137$/yr) and EENS (209.7305 MWhr/yr) at base case, was most affected element with outage of transformers (T23-69) which connected between (RNK2) and (GAD1-B2), (T25-70) which connected between (NHAS2) and (NHAS1), (T26-73)which connected between (MAR2) and (MAR1-B1), (T29-76)which connected between (SNJ2) and (SNJ1), (T41-81)which connected between (GRB2) and (GDF1), (T42-82)which connected between (GRB2) and (GRB66), (T52-19)which connected between (IBA1) and (IBA2) and (T56-20) which connected between (MHD1) and (MHD2), led the ECOST and EENS to became higher than it was, ECOST(2075457$/yr) and EENS (275.1522 MWhr /yr).

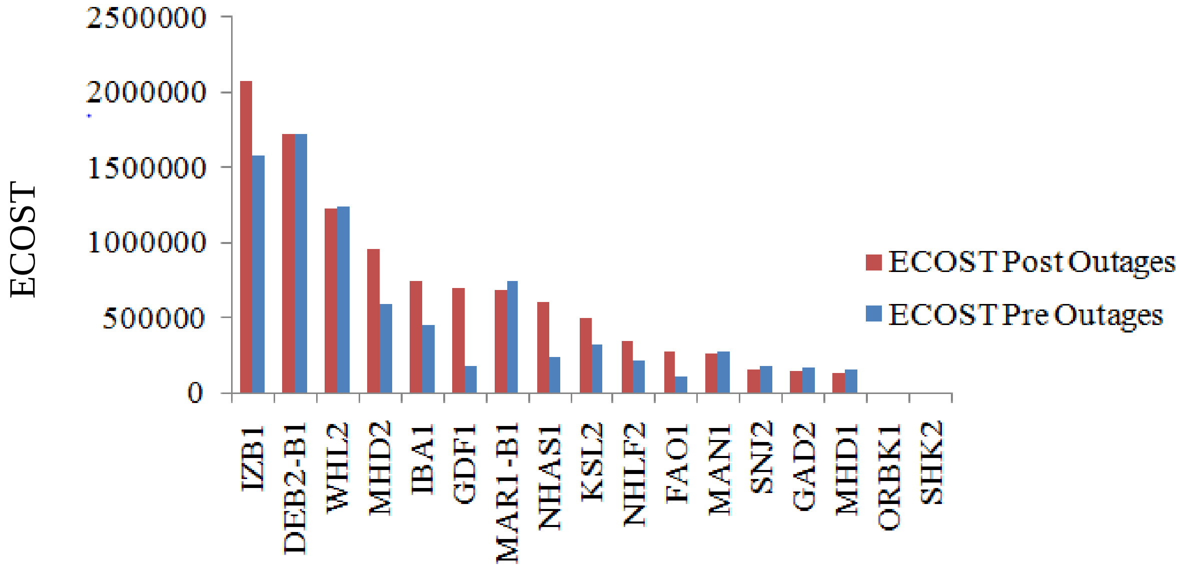


Figure (4.5): The ECOST at transformers outage

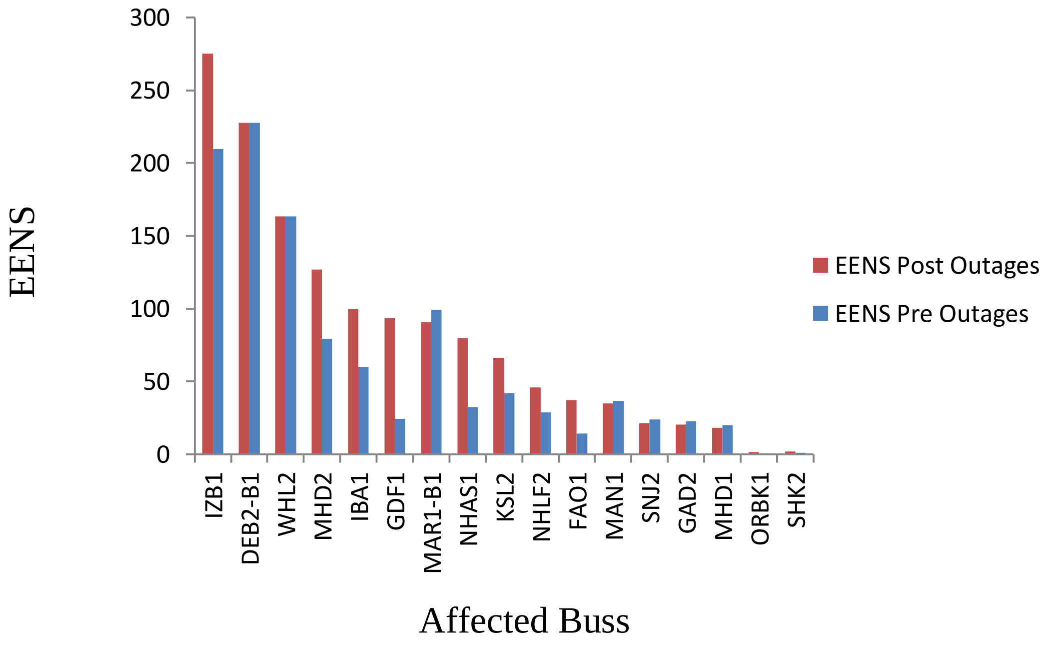


Figure (4.6): the EENS at transformers outage

4.4.3Transmission lines outage:

From the graphical shown in Figure (4.7) and (4.8), the ECOST and EENS of component after several Transmission lines outage have been applied. The results show that the bus 12 (ATB2) which have ECOST(996520.3$/yr) and EENS (131.9421MWhr/yr) at base case, was most affected element with outage of (L5-6) which connected between(WHL2) and (WWA2),(L6-9)which connected between(WWA2) and (DON2),(L7-9) which connected between(DEB2-B1) and (DON2), (L7-10)which connected between (DEB2-B1) and (MWT2), (L8-9)which connected between (DEB2-B2) and (DON2),(L8-11)which connected between (DEB2-B2) and (MWP2) ,(L10-11) which connected between (MWT2) and (MWP2) , (L12-13)which connected between (ATB2) and (SHN2) and(L13-17)which connected between (SHN2) and (FRZ2), led the ECOST and EENS to became higher than it was ECOST (6135992$/yr) and EENS (809.285 MWhr /yr).

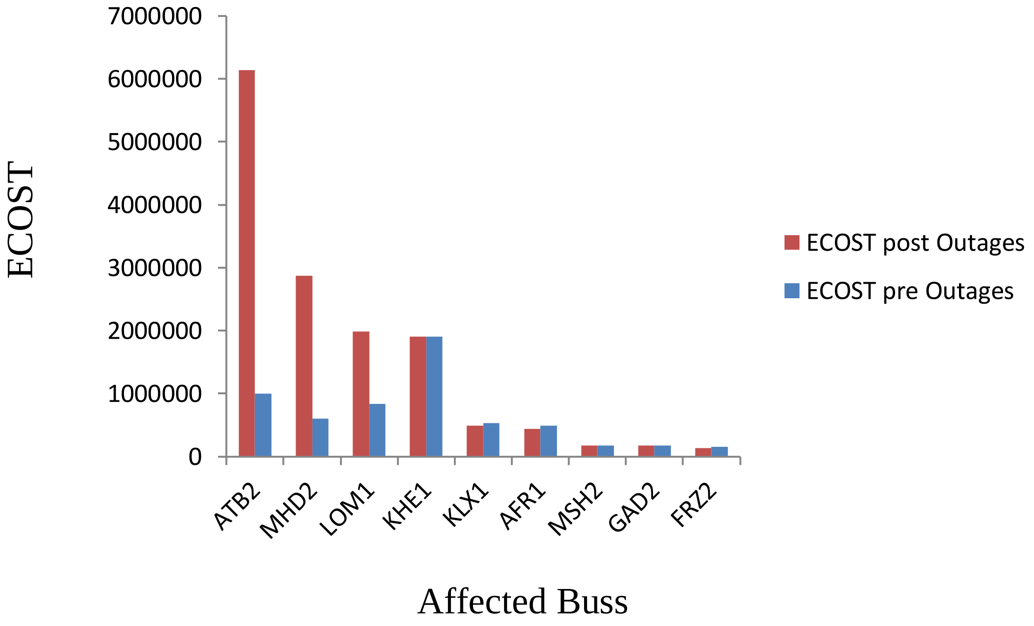


Figure (4.7): The ECOST at transmission lines outage

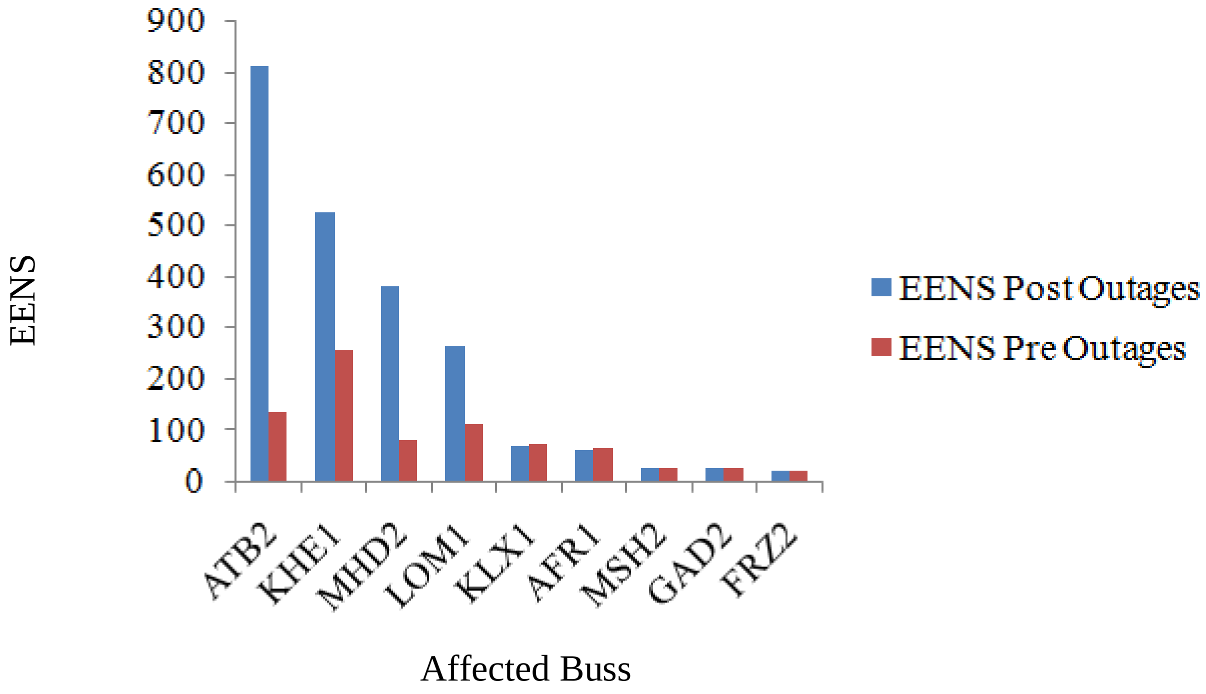


Figure (4.8): The EENS at transmission lines outage

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCOLUSION:

Reliability analysis has been performed for Sudanese National Grid and the ECOST and EENS have been founded based on ETAP program.

In this work, the number of probability of outages occurrence and the ECOST and EENS for the most affected elements was represented .

Hence the Sudanese National Grid has been found not reliable, because; the ECOST and EENS OF a wide number of load buses were increased. The most affect buss in network under the case study are namely; bus(ATB2) and bus (IZB1) respectively.

5.2 RECOMMENDATION:

(1) In this project for reliability assessment of Sudanese National Grid (SNG) using two indices: Expected Interruption Cost (ECOST), and Effective Expected Energy Not Supplied (EENS). Others indices are available such as: Interrupted Energy Assessment Rate Index at Load Point (IEAR), System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Average Energy Not Supplied Index (AENS), Average Service Unavailability Index (ASUI), and Customer Average Interruption Duration Index (CAIDI).

(2) Reliability assessment with split out without condition of FACTS controllers.

(3) The study can be expended to include Static Var Compensator (SVC).

(4) load flow can be procedure by other methods as: Newton-Raphson method.

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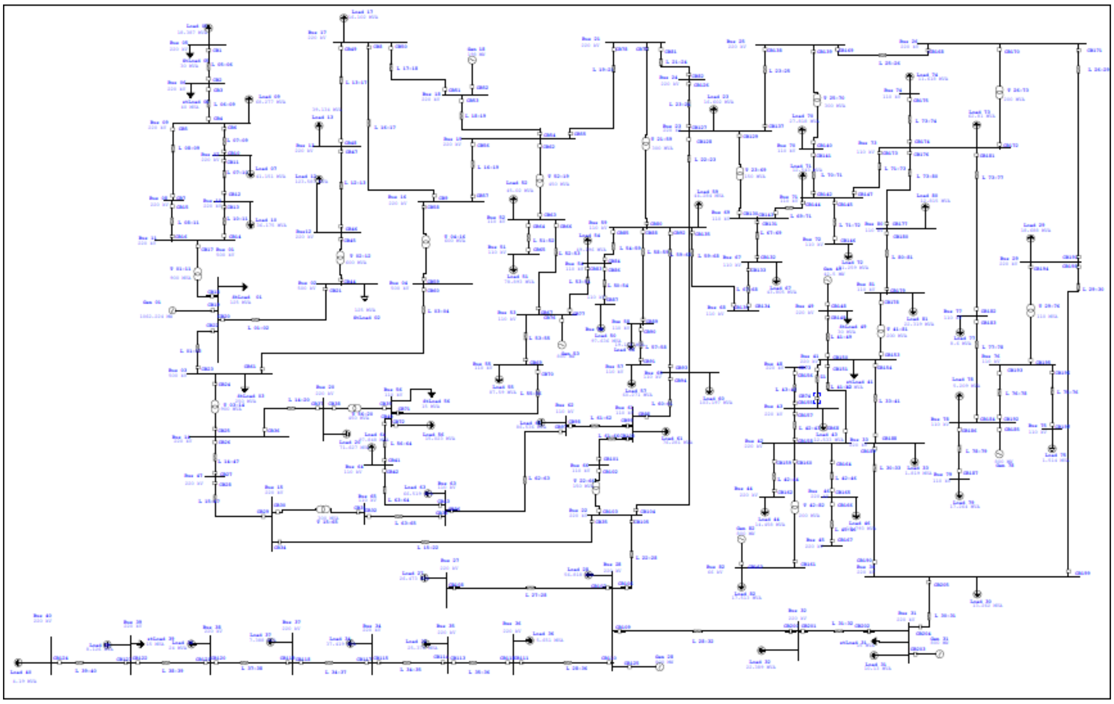
APPPENDIX (A)



APPPENDIX (B)

System Data:

B.1 Bus Data:

Bus No.	Bus Name	Bus Type	Voltage (KV)	Pg. (MW)	Qg. (MVAr)	Injected power (MVAr)
1	MWP500	Slack	500	0	0	-125
2	ATB5	Load	500	0	0	-125
3	MRK5	Load	500	0	0	-250
4	KAB5	Load	500	0	0	0
5	WHL2	Load	220	0	0	-30
6	WWA2	Load	220	0	0	-40
7	DEB2-B1	Load	220	0	0	0
8	DEB2-B2	Load	220	0	0	0
9	DON2	Load	220	0	0	0
10	MWT2	Load	220	0	0	0
11	MWP2	Load	220	0	0	0
12	ATB2	Load	220	0	0	0
13	SHN2	Load	220	0	0	0
14	MRK2	Load	220	0	0	0
15	GAM2	Load	220	0	0	0
16	KAB2	Load	220	0	0	0
17	FRZ2	Load	220	0	0	0
18	GER2	Regulated	220	186	0	0
19	IBA2	Load	220	0	0	0
20	MHD2	Load	220	0	0	0

21	KLX2	Load	220	0	0	0
22	JAS2	Load	220	0	0	0
23	GAD2	Load	220	0	0	0
24	SOB2	Load	220	0	0	0
25	NHAS2	Load	220	0	0	0
26	MAR2	Load	220	0	0	0
27	MSH2	Load	220	0	0	0
28	RBK2	Regulated	220	85	0	0
29	SNJ2	Load	220	0	0	0
30	SNG2	Load	220	0	0	0
31	ROS2	Regulated	220	148	0	-15
32	RNK2	Load	220	0	0	0
33	HWT2	Load	220	0	0	0
34	OBD2	Load	220	0	0	0
35	UMR2	Load	220	0	0	0
36	TND2	Load	220	0	0	0
37	DBT2	Load	220	0	0	0
38	ZBD2	Load	220	0	0	0
39	FUL2	Load	220	0	0	-15
40	BBN2	Load	220	0	0	0
41	GDF2	Load	220	0	0	-30
42	GRB2	Load	220	0	0	0
43	SHK2	Load	220	0	0	0
44	NHLF2	Load	220	0	0	0
45	ARO2	Load	220	0	0	0
46	KSL2	Load	220	0	0	0
47	HUD	Load	220	0	0	0
48	UTP2	Load	220	0	0	0

49	SHD2	Regulated	220	38	0	-30
50	KHE1	Load	110	0	0	0
51	IZB1	Load	110	0	0	0
52	IBA1	Load	110	0	0	0
53	KHN1	Regulated	110	76	0	0
54	KUK1	Load	110	0	0	0
55	IZG1	Load	110	0	0	0
56	MHD1	Load	110	0	0	15
57	FAR1	Load	110	0	0	0
58	AFR1	Load	110	0	0	0
59	KLX1	Load	110	0	0	0
60	LOM1	Load	110	0	0	0
61	SHG1	Load	110	0	0	0
62	MUG	Load	110	0	0	0
63	BNT1	Load	110	0	0	0
64	OMD1	Load	110	0	0	0
65	GAM1	Load	110	0	0	0
66	JAS1	Load	110	0	0	0
67	BAG1	Load	110	0	0	0
68	SOB1-B2	Load	110	0	0	0
69	GAD1-B2	Load	110	0	0	0
70	NHAS1	Load	110	0	0	0
71	OHAS1	Load	110	0	0	0
72	GND1	Load	110	0	0	0
73	MAR1-B1	Load	110	0	0	0
74	MAN1	Load	110	0	0	0
75	ORBK1	Load	110	0	0	0
76	SNJ1	Load	110	0	0	0

77	HAG1	Load	110	0	0	0
78	SNP1	Regulated	110	7	0	0
79	MIN1	Load	110	0	0	0
80	FAO1	Load	110	0	0	0
81	GDF1	Load	110	0	0	0
82	GRB66	Regulated	66	2	0	0

B.2 Transmission Lines Data:

from	To	V KV	R p.u	X p.u	B/2 p.u
BAG1	GAD B2	110	0.86281	1.04379	0.098
WHL2	WWA2	220	2.83781	12.7913	40.698
MWP2	MWT2	220	0.54252	2.87679	4.74
DON2	DEB2 B1	220	2.18861	11.6054	19.099
ATB 2	SHN2	220	0.96901	4.36777	55.597
MWT2	DEB2 B1	220	2.18421	11.5821	19.099
MWP2	DEB2 B2	220	2.72988	14.4755	23.799
DON2	WWA2	220	1.14897	4.61302	65.896
DON2	DEB2 B2	220	2.18861	11.6054	19.099
ATB5	MWB500	500	0.2651	2.61317	243
MWB500	MRK5	500	0.19376	1.90992	711
KAB5	MRK5	500	0.04122	0.40627	37.8
SHN2	FRZ2	220	0.79597	3.19576	45.697
GER2	FRZ2	220	0.03461	0.12959	1.99
KAB2	IBA2	220	0.20764	0.93595	11.899
IBA1	IZB1	110	0.30455	1.22273	1.09
KUK1	KHE1	110	0.0886	0.3557	0.318
IBA1	KHN1	110	0.33222	1.33388	1.19
IZG1	MHD1	110	0.22149	0.88926	0.794
KUK1	KHN1	110	0.0714	0.56157	0.325
KHN1	IZG1	110	0.33222	1.33388	1.19
MRK2	MHD2	220	0.14535	0.58357	8.34
KLX1	AFR1	110	0.30455	1.22273	1.09
AFR1	FAR1	110	0.38759	1.5562	1.39
KLX1	KUK1	110	0.52488	2.28653	1.089

KLX1	LOM1	110	0.08306	0.33347	0.298
LOM1	SHG1	110	0.21595	0.86702	0.774
SHG1	MUG	110	0.30455	1.22273	1.09
MUG	BNT1	110	0.10521	0.4224	0.377
OMD1	BNT1	110	0.16335	0.65583	0.586
MHD1	OMD1	110	0.25748	1.0376	0.923
GAM1	BNT1	110	0.45682	1.83409	1.64
KLX2	SOB2	220	0.07851	0.41632	2.74
SOB2	GAD2	220	0.25909	1.37386	9.049
SOB1 B2	BAG1	110	5.17686	6.26281	0.588
KLX1	SOB1 B2	110	2.87602	3.47934	0.327
SHG1	JAS1	110	1.07975	4.33512	3.87
JAS1	GAD2	220	0.24938	1.00041	14.299
GAD2	NHAS2	220	0.67521	3.58037	23.599
GAD B2	OHAS1	110	22.1454	26.7909	2.52
OHAS1	NHAS1	110	0.13843	0.55579	0.496
OHAS1	GND1	110	0.41529	1.66736	1.49
OHAS1	MAR1 B1	110	15.8182	19.1364	1.8
JAS2	RBK2	220	1.0223	4.10447	58.697
MSH2	RBK2	220	0.74198	2.99258	42.598
NHAS2	MAR2	110	0.43182	2.28977	15.099
MAN1	MAR1 B1	110	5.66653	15.5964	2.4
MAR2	SNJ2	220	0.6595	3.49711	22.999
MAR1 B1	HAG1	110	10.0661	12.1777	1.14
HAG1	SNP1	110	17.2562	20.876	1.936
SNJ1	SNP1	110	2.87595	3.47934	0.363
ORBK1	SNJ1	110	27.601	33.4016	3.146
MAR1 B1	FAO1	220	19.8446	24.0074	2.299
SNJ2	SNG2	220	0.39256	2.08161	13.552
SNG2	ROS2	220	1.39752	7.41054	48.884
ROS2	RNK2	220	0.96901	3.8905	55.66
SNG2	HWT2	220	0.62293	2.50103	35.816
RBK2	TND2	220	0.76829	3.08461	44.044
UMR2	OBD2	220	1.74421	7.00289	25.168
OBD2	DBT2	220	1.23202	4.94649	17.908
DBT2	ZBD2	220	0.91364	3.66818	13.068
ZBD2	FUL2	220	1.64731	6.61384	23.716
FUL2	BBN2	220	1.0936	4.3907	15.488
TND2	UMR2	220	0.54195	2.1759	30.976
RBK2	RNK2	220	1.1282	4.52965	64.856

HWT2	GDF2	220	0.69215	2.77893	39.688
GRB2	KSL2	220	0.65754	2.63946	37.752
GDF2	GRB2	220	0.4845	1.94525	27.588
SHK2	GRB2	220	0.4845	1.94525	27.588
GRB2	NHLF2	220	0.33825	1.35806	19.36
KSL2	ARO2	220	0.30288	1.21606	17.424
MRK2	HUD	220	0.06229	0.2501	3.388
GAM2	HUD	220	0.1938	0.7781	11.132
KAB2	FRZ2	220	0.26302	1.05599	15.004
SHK2	UTP2	220	0.1938	0.7781	11.132
GER2	IBA2	220	0.41529	1.66736	23.716
IBA2	KLX2	220	0.0969	0.38905	5.324
GDF2	SHD2	220	1.34277	5.39112	76.956
FAO1	GDF1	110	44.0033	50.1992	5.203
GAM2	JAS2	220	0.1938	0.87355	11.132

B.3 Load Data:

Bus No.	Bus Name	P (MW)	Q (MVAr)
5	WHL2	14.360	11.483
7	DEB2-B1	33.456	23.961
9	DON2	50.320	46.148
10	MWT2	29.808	20.496
12	ATB2	101.338	70.734
13	SHN2	33.264	20.615
17	FRZ2	13.574	8.661
20	MHD2	60.883	37.732
23	GAD2	14.112	8.746
27	MSH2	6.989	25.534
28	RBK2	46.704	32.357

29	SNJ2	16.464	8.842
30	SNG2	12.029	5.585
31	ROS2	8.333	5.760
32	RNK2	0.403	22.385
33	HWT2	1.546	0.958
34	OBD2	19.757	31.778
35	UMR2	3.629	25.117
36	TND2	1.008	5.560
37	DBT2	6.250	3.939
38	ZBD2	3.360	23.764
39	FUL2	6.720	4.568
40	BBN2	3.360	2.503
43	SHK2	0.672	12.515
44	NHLF2	12.029	8.021
46	KSL2	16.666	10.678
50	KHE1	81.917	53.127
51	IZB1	68.006	39.992
52	IBA1	41.328	17.854
54	KUK1	44.621	20.718
55	IZG1	74.189	46.562
56	MHD1	12.634	8.128
57	FAR1	50.266	33.255
58	AFR1	17.203	8.477
59	KLX1	40.387	18.165
60	LOM1	85.344	58.018
61	SHG1	64.915	40.060
62	MUG	75.466	42.566

63	BNT1	59.069	30.588
64	OMD1	81.312	54.430
67	BAG1	36.490	24.236
70	NHAS1	24.730	12.738
71	OHAS1	11.088	5.864
72	GND1	27.821	14.253
73	MAR1-B1	56.717	26.986
74	MAN1	10.886	4.058
75	ORBK1	0.336	1.476
77	HAG1	7.594	4.037
78	SNP1	4.704	2.238
79	MIN1	14.381	9.552
80	FAO1	11.021	6.539
81	GDF1	18.614	12.315
82	GRB66	15.254	8.604

B.4 Transformer Data:

Name	KV (Primary)	KV (Secondary)	MVA	R PU	X PU	Frequency (HZ)	Tap ratio
TR NHAS	220	110	300	0	0.1534	50	0.905
TR KLX	110	220	300	0	0.1788	50	0.922
TR IBA	110	220	450	0	0.2895	50	0.905
TR ATB	220	500	600	0	0.2360	50	0.905
TR KAB	220	500	600	0	0.3360	50	0.915
TR MRK	500	220	900	0	0.5040	50	0.911
TR GDF	220	110	200	0	0.2400	50	0.975
TR GRB	220	66	200	0	0.2506	50	0.905
TR MAR	220	110	200	0	0.1409	50	0.918
TR GAD	110	220	150	0	0.2010	50	0.905
TR	220	110	110	0	0.1567	50	0.945

SNJ							
TR MHD	110	220	450	0	0.3801	50	0.975
TR GAM	220	110	300	0	0.2574	50	0.925
TR MWP	500	220	900	0	0.2194	50	0.967
TR JAS	220	110	150	0	0.1300	50	0.913