ADDIS ABABA UNIVERSITY
INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

A Study on Blackout Problems of Ethiopian National Grid and Its Mitigation Techniques Using Adaptive Under Frequency Load Shedding Scheme

A Thesis Submitted to Addis Ababa University Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Power Engineering

By
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DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in this or any other universities, and that all source of materials used for the thesis work have been duly acknowledged.

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UFLS	: Under Frequency Load Shedding
AUFLS	: Adaptive Under Frequency Load Shedding
NLDC	: National Load Dispatch Center
EEP	: Ethiopian Electric Power
EEU	: Ethiopian Electric Utility
ROCOF	: Rate of Change of Frequency
HIS	: Historical Information system

ABSTRACT

An interconnected electric power system must balance load and generation in order to maintain frequency within acceptable range. The balance between generation and load within an interconnected electric power grid is expressed in the frequency of the system. Under frequency protection schemes are drastic measures employed if the system frequency falls below a specified value. Power system blackout is one of the worst events that power supply is totally interrupted so that industrial, commercial and domestic customers will be forced to use an alternate energy sources mainly diesel generators which are inefficient, expensive and environmentally not friendly. Under Frequency Load Shedding (UFLS) is a common technique to maintain power system stability by removing overload that might be created following system disturbance mainly during outage of power generating units. In this regard, the Ethiopian national grid under frequency load shedding scheme has been implemented many years before and it has not been revised despite the fact that a lot of big generating plants are connected in the grid. Due to this fact the system is unable to withstand major outages and system blackout is becoming frequent in our grid. The methodology used for the proposed load shedding algorithm is Adaptive Under Frequency Load Shedding (AUFLS) which considers both frequency and voltage as inputs for the design of AUFLS scheme. The disturbance magnitude is estimated using the rate of change of frequency and the location and the amount of load to be shed from each bus is decided using the voltage sensitivities. The national grid is properly modeled, and load flow and dynamic simulations are conducted using PSSE power system analyzing software for different disturbance cases that can affect the system frequency. The frequency and the voltage response for the simulated disturbance cases are analyzed and based on the results of the analysis new AUFLS scheme is proposed to improve performance of the existing UFLS scheme. The proposed AUFLS schemes are implemented on the modeled system and simulated again to see the performance of the new scheme. The study found out that the current under frequency load shedding protection is not supporting the grid for generation outage above 20%, and is the reason for the frequent blackout on the power grid.

Keywords / Phrases: under frequency load shedding scheme, under frequency relays, dynamic simulation, outgo of generating units, speed governors, speed droop, national grid, adaptive under Frequency load shedding scheme, conventional under frequency scheme, tie line.

CHAPTER-ONE

1. INTRODUCTION

1.1.Background

Any part of a power system will begin to deteriorate if there is an excess of load over available generation. The prime movers and their associated generators begin to slow down as they attempt to carry the excess load. Tie lines transmit excess load to the affected area out of the schedule. This combination of events can cause the tie lines to open from overload or the various parts of the systems to separate due to power swings and resulting instability[2]. The result may be one or more electrically isolated islands in which load may exceed the available generation.

Further, the drop-in frequency may endanger generation units and results in cascade outage of power generating units from the grid by under frequency protection. Loss of generation units drops the system frequency further and total or partial black out occurs if it is not counter acted by automatic load shedding of UFLS relays[3]

Automatic under Frequency Load Shedding

To prevent the complete collapse of the grid during system disturbances, under- frequency relays are used to automatically drop/shed load in accordance with a predetermined schedule to balance the load to the available generation in the affected area. Such action must be taken promptly and must be of sufficient magnitude to conserve essential load and enable the remainder of the system to recover from the under-frequency condition. This automatic operation of the under-frequency load shedding to keep the system from collapse is called automatic under frequency load shedding.

Load Restoration

If a proper load shedding scheme has been successfully implemented, the system frequency will stabilize and then recover to 50 Hz. This recovery is assisted by governor action on available spinning reserve generation, or by the addition of other generation to the system [4]. The recovery of system frequency to normal is likely to be quite slow and may extend over a period of several minutes. When 50 Hz operation has been restored to the grid, then interconnecting tie lines with other systems or portions of systems can be synchronized and closed in.

As the system frequency approaches the normal 50 Hz, the operators at National Load Dispatch Center (NLDC) will order the Distribution Control Center to connect the lines back within short period and the system restored back.

The amount of load that can be restored is determined by the ability of the system to serve it. The criterion is, the available generation must always exceed the amount of load being restored so that the system frequency will continue to recover towards 50 Hz.

1.2.Motivation

The balance between generation and demand is one of the criteria for the system to be stable. However, the balance between the supply and demand is disturbed due to faults on the system mainly, due to loss of generation. The system frequency drops following loss of generation and if the frequency drop is not counter acted by proportional load shedding the system frequency drops further which might lead to a total blackout.

The Ethiopian UFLS scheme was implemented long time ago when M/ Wakena was the biggest power plant and can support only 16% load shedding. Whereas the national grid is expanded and other big power plants are connected to the grid. However, the UFLS scheme is not revised and the system is suffering from frequent blackout for medium and big disturbance cases.

There were more than 16 blackouts in 2016/17 and from this 80% of the reason was poor UFLS scheme of the grid.

Depending on the above motives, this research work is done to design new UFLS scheme for the Ethiopian National Grid.

1.3. Statement of the Problem

The UFLS scheme should quickly recognize a generation deficiency, determine accurately the degree of overload, and then precisely shed only the amount of load required to restore system frequency to normal [4]

However, this needs a system equipped with perfect telecom media, central server and fast pharos measurement systems that can give input to the central server at NLDC and the central server calculate the level of disturbance and send command to the selected distribution lines for load shedding.

In the Ethiopian National Grid, conventional UFLS is implemented and has two stages for load shedding during system disturbance. The two stages are set at a frequency of 48.6Hz and 48Hz. The total load disconnected from both stages is 16%.

The existing under frequency load shedding scheme cannot serve its purpose if there is an outage of generation more than 16%.

1.4. Objective of the Study

1.4.1. General Objective

The general objective of this thesis is to study, analyze and identify the problem of the existing under frequency load shedding scheme of the national grid and propose AUFLS scheme which considers the drop in frequency below nominal, rate of change of frequency and the system voltage to improve the system defense mechanism following system disturbance.

1.4.2. Specific Objectives

The specific objectives of this thesis are: -

- Analyze the historical records of system blackout on the national Grid.
- Update the PSSE data's and dynamic models to represent the current power system
- Conduct load flow analysis to make the selected case to be ready for dynamic simulation.
- Simulate the case which is ready for dynamic simulation and analyze system response for different outage scenarios of the generating units using PSSE network simulating software.
- Based on the result of the simulation new AUFLS scheme is proposed for the national grid using the selected design procedures.
- The system will be simulated again by implementing the proposed AUFLS scheme to observe the impact performance of the proposed scheme. Conclusion, recommendation and future suggestion will be made based on the result of simulation.

1.5.Methodology

1.5.1. Literature Survey

Different literatures were published in the area of UFLS, and reviewed to use the important procedure for selection of the new AUFLS.

1.5.2. Data Collection

- The required data for this thesis is collected from Ethiopian Electric Power (EEP/ national load dispatch center) and Ethiopian Electric Utility (EEU) and used as an input for the simulating software.
- The Historical Information system (HIS) and all relevant information for the study are collected from the National Grid Control Center.

1.5.3. Power Flow Analysis

Before dynamic analysis, load flow study shall be conducted on the model save case for Power System Simulation for Engineers(PSSE) and the save case file for PSSE shall be updated and represent the existing network topology. All the required data for load flow analysis (Load data, generator data, transmission line data, transformer data, SHR and SHC data) are updated on PSSE software and load flow analysis is conducted.

1.5.4. Dynamic Simulation

The PSSE built in dynamic models are used for modeling and properly tuned to represent the selected power system network for study. Dynamic simulation to be conducted on the modeled power system to observe the system frequency, voltage and tie line flow response for different generation losses.

1.5.5. Simulation Studies and Analysis of the Proposed AUFLS Scheme

The result output of the dynamic simulation is used as an input for the design of new AUFLS scheme for the National Grid using both conventional and AUFLS scheme. Common design procedures mentioned on literatures [5] are used for proposing the new AUFLS scheme. The proposed AUFLS scheme is simulated again to observe its performance on the stability of the system.

1.6.Literature review

1.6.1. Approaches to Under Frequency Load Shedding

To prevent the complete collapse of the grid, under-frequency relays are used to automatically drop/shed load. Researchers used different techniques to optimize the amount of load to be shed and voltage stability of the system. Here are the main approaches that have been used for the UFLS,

i. Conventional Load shedding
ii. Adaptive UFLS

In this section, the different approaches that are used for the UFLS and review of some of research are discussed.

i. Conventional UFLS

The most commonly used UFLS in the power system is the conventional UFLS. Traditional UFLS are implemented in either discrete electromagnetic relays or microprocessor-based multifunctional relays. This type of UFLS is a decentralized deterministic scheme designed to shed a predefined amount of load after a predetermined time delay [4]. It reduces the same amount of load from the same location irrespective of how fast the frequency drops and without consideration of the disturbance location or dip in bus voltage. This causes voltage instability to the power system.

ii. Adaptive UFLS

Due to the shortcomings of the traditional UFLS method, most of the recent research is interested in enhancing the adaptability of the conventional method by developing the AUFLS.

The system state, topology and the magnitude of the disturbance are considered adaptively in AFLS. In other words, the UFLS plans were able to be updated according to the disturbance and the system view can be considered and optimized coordinately.

Several AUFLS approaches are used by researchers to rescue systems facing extreme disturbances due to under frequency dips.

D. Y. Yang, G. W. Cai, Y. T. Jiang and C. Liu [6]**:** presents that under frequency load shedding (UFLS) is an effective way to prevent system blackout after a serious disturbance occurs in a power system. A centralized AUFLS scheme using the synchronous phase measurement unit (PMU) is proposed in this paper.

Two main stages are consisted in the developed technique. In the first stage, the active power deficit is estimated by using the simplest expression of the generator swing equation and static load model since the frequency, voltages and their rate of change can be obtained by means of measurements in real-time from various devices such as phase measurement units. In the second stage, the UFLS schemes are adapted to the estimated magnitude based on the presented model. The effectiveness of the proposed AUFLS scheme is investigated simulating different disturbance in IEEE10-generator 39-bus New England test system. [6]

The results of simulations also indicate that the AUFLS proposed in this work are capable of efficiently recovering system frequency and preserving system stability following the active power disturbances, while the amount of load to be shed by these algorithms is generally less than that of the conventional scheme. [6]

M. Karimi, H. Mohamad, H. Mokhlis and A. H. A. Bakar[7]**:** This paper demonstrated a new approach of UFLS Scheme for an islanded distribution network. The proposed method combined an AUFLS and Distribution State Estimation (DSE) for islanded distribution network. The scheme consists of three main modules;

a) Frequency Calculator Module (FCM).
b) Load Shedding Controller Module (LSCM) and
c) Distribution State Estimation Module (DSEM).

The disturbance magnitude is calculated based on rate of change of frequency by using the simplest expression of the generator swing equation.

$$\Delta P = 2 * \frac{\sum_{i=1}^{N} H_i}{f_n} * \frac{df_c}{dt} \quad \text{...Equation (1.1)}$$

Where: -ΔP: is the change in power

H_i: is moment of inertia

$\frac{df_c}{dt}$: is the rate of change of system frequency

f_n : is the nominal frequency of the system

Moreover, the process for assessing the power consumption of the customer can be achieved by state estimation method. In this paper, state estimation for a distribution network is developed and enhanced by composite load model to obtain the most practical value of the system state variables. Finally, the calculated value of the disturbance magnitude will be shed according to the estimated value of loads in each bus. Simulation results show that optimal amounts of load can be shed according to the well-estimation of the system state.

Mosab Salah Aldeen and Mohamed Zeyada[8]: This study presents hardware implementation of AUFLS based on real time simulation of IEEE39-bus system. The simulation tool used was OPAL-RT eMEGAsim real time digital simulator. To emulate the actual environment where the scheme could be used, a complete phasor network setup is established using actual devices, such as high accuracy Global Positioning System (GPS) clocks, PMUs and Synchro-phasor Vector Processor (SVP). The paper shows that the AUFLS scheme restored the frequency and curtailed the load based on voltage sag. Furthermore, the results are compared with conventional UFLS scheme.

Manijeh Alipour and Heresh Seyedi[9]:This paper presents that the conventional under frequency load shedding (UFLS) is used to balance generation and load when under frequency conditions occur by reducing a fixed, predetermined amount of load irrespective of disturbance location. Which is not effective due to over tripping of load and over frequency? Several AUFLS schemes are proposed in the literature.

Recent research discussed utilizing synchro phasor messages to implement AUFLS, but these studies have been using virtual PMUs. Of late, hardware implementations for AUFLS scheme using actual phasor measurement units (PMUs) are reported but also these studies are based on small power systems.

This study presents hardware implementation of AUFLS based on real time simulation of IEEE39-bus system.

The simulation tool used was OPAL-RT eMEGAsim real time digital simulator. To emulate the actual environment where the scheme could be used, a complete phasor network setup is established using actual devices, such as high accuracy Global Positioning System (GPS) clocks, PMUs and Synchrophasor Vector Processor (SVP). The results obtained show that the AUFLS scheme restored the frequency and curtailed the load based on voltage sag. Furthermore, the results are compared with conventional UFLS scheme.

Li Zhang [10]: suggests a method uses the both the frequency and the rate of change of frequency (df/dt) for UFLS design for a 50 Hz system of Northeast China power system. Traditional schemes required only the frequency decay information. The plots for the rate of change of frequency are oscillatory in nature; hence, this paper considers the integration of the rate of change of frequency (df/dt) to indicate the frequency drop.

he suggested new scheme consists of five load shedding steps for a 50 Hz system. These steps are from 50 to 49.2 Hz, 49.2 to 49 Hz, 49 to 48.8Hz, 48.8 to 48.6 Hz, and 48.6 to 48.4 Hz. The amount of load to be shed in each step is decided by integrating the df/dt value in each step. The simulation results are compared with the old conventional scheme and the frequency decay show a definite improvement in system frequency due to the presence of rate of change of frequency (df/dt) in the proposed scheme.

Vladimir V. Terzia[11]**:** discuss about under frequency load shedding in two stages. During the first stage the frequency and rate of frequency changes of the system are estimated by non-recursive Newton-type algorithm. In the second algorithm, the magnitude of the disturbance is estimated using the simple generator swing equation.

Kalmanfiltering[12]: to estimate the frequency and its rate of change from voltage waveforms. The buses are ranked based on their rate of change of voltage (dV/dt) values. The disturbance magnitude is calculated using the swing equation. The rate of change of frequency required for this equation is calculated using the Kalman filter. The load to be shed is determined using PV analysis.

1.7.Organization of the Thesis

The thesis is organized as six chapters. A brief overview of the chapters and their contents are as follows.

Chapter two gives an overview about power system stability and load frequency control.

Chapter three discusses about modeling of the power system network of the Ethiopian National Grid using the built-in model of the PSSE.

Chapter four and five starts by elaborates the under-frequency load shedding selection procedure using power system dynamic analysis. The new AUFLS scheme is proposed based on the results of the simulation.

Finally, Chapter six concludes the paperwork, gives recommendations and suggest the ways for further expansion for future study.

CHAPTER-TWO

2. Power System Stability and Load Frequency Control

2.1.Power System Stability

Power system has advanced from isolated operation to highly interconnected grid with network equipments with advanced technology with sophisticated protection scheme [13].For the stable operation of the power system, it is essential that generating units should maintain perfect synchronism under all operating conditions. For the reason, the power system stability is defined as the ability of the system to return to synchronism after having disturbance.

The stability of the power system is an important concern for any power utility, since the main objective of the power industry is to supply power to its customers having the network parameters within acceptable limit.

System frequency is a global variable that shows the stability of the power system and under normal operation the Generation and the load balance shall be kept to keep the system within acceptable limit.

Total generation is given by the sum of load and technical loss in the power system [5], [14].

$Total\ Generation = Total\ Load + Total\ Loss$ ……………………..…………… Equation (2.1)

The supply – demand balance of the system is affected by system disturbance mainly loss of power generating units. This makes the system frequency to be out of the normal operation range of 1%. The amount of frequency drop and also the rate of change of frequency is dependent on the disturbance level, the type of power system, system inertia to withstand the disturbance, etc.

The system total inertia is calculated using the following equation.

$J_o = \frac{\sum J_i S_i}{\sum S_i}$……………………………………………………………Equation (2.2)

Where:-J_i: are the individual machine inertias in $kgm^2$and
S_i: are the corresponding machine power ratings

$$\delta = \frac{\sum \delta_i S_i}{\sum S_i} \qquad \text{Equation (2.3)}$$

The equation of motion expressed in terms of aggregate rotor angle is follows:

$$J_o \frac{d^2\delta}{dt^2} = T_a = T_m - T_e \qquad \text{Equation (2.4)}$$

Where: - T_a: represents the accelerating torque,
T_m : represents the combined mechanical input torque to the system and
T_e: represents the combined electrical load torque

Multiplying both sides by the aggregate rotor speed ω gives [43]

$$\omega J_o \frac{d^2\delta}{dt^2} = \omega T_a = \omega T_m - \omega T_e = P_m - P_e = \sum G_i - \sum L_i \qquad \text{Equation (2.5)}$$

The inertia constant (H) is related to J. H is the kinetic energy stored in a machine at synchronous speed divided by its power rating [20]. Let the total system power rating be S_o. Then,

$$H_o = \frac{\frac{1}{2} J_o \omega_s^2}{S_o} \qquad \text{Equation (2.6)}$$

The equivalent system inertia constant can be calculated [15]

$$H_o = \frac{\sum H_i S_i}{\sum S_i} \qquad \text{Equation (2.7)}$$

Substituting for J_o in equation (2.5) gives [1]

$$\omega \frac{2H_o S_o}{\omega_s^2} \frac{d^2\delta}{dt^2} = P_m - P_e = \sum G_i - \sum L_i \qquad \text{Equation (2.8)}$$

The system frequency can be identified as the rate of change of the aggregate rotor angle

$$\frac{d^2\delta}{dt^2} = \frac{d\omega}{dt} = 2\pi \frac{df}{dt} \qquad \text{Equation (2.9)}$$

and thus equation (2.8) becomes [43]

$$f \frac{2H_o}{f_s^2} S_o \frac{df}{dt} = \sum G_i - \sum L_i \qquad \text{Equation (2.10)}$$

If the generators have an average power factor rating of p, then [1]

$$\sum G_i = pS_o \text{……………………………………………………………………Equation (2.11)}$$

And defining a relative load excess by a factor L:

$$\mathrm{L} = \frac{\sum L_i - \sum G_i}{\sum G_i} \text{……………………………………………………………………Equation (2.12)}$$

Equation (2.10) becomes:[16]

$$f\frac{df}{dt} = \frac{pL}{2H_o} f_s^2 \text{……………………………………...……………………………Equation (2.13)}$$

Equation (2.13) gives us the rate of change of frequency at a particular frequency point for a given system over load of L. However, it is necessary to determine the average rate of frequency for a given range of frequencies to define the setting of frequency relays.

The approximate average rate of change of frequency over an interval can be calculated by taking an average of the rates at the two ends of the interval, or possible to calculate the average rate by considering the ratio of the frequency difference and the time interval.

For example, if the average rate of frequency changes over a frequency interval [f1, f2] is needed; integrating Equation (2.13), gives: [16]

$$\frac{f_2^2 - f_1^2}{t_2 - t_1} = \frac{pL}{H} f_s^2 \text{……………………………………...……………………………Equation (2.14)}$$

The average rate of frequency change, R is given by: [16]

$$R = \frac{f_2 - f_1}{t_2 - t_1} = \frac{f_2^2 - f_1^2}{(t_2 - t_1)(f_2 + f_1)} = \frac{f_S^2}{f_1^2}\frac{pL}{H}\frac{(f_2 - f_1)}{(1 - \frac{f_2^2}{f_1^2})} \text{…...……………………………Equation (2.15)}$$

For drop in frequency R is negative and for rise in frequency R is positive.

2.2.Load Frequency Control

The Load Frequency Control (LFC) is a very important in power system operation and control for supplying sufficient and reliable interconnected power systems. Control action is performed using power system control reserves with different successive steps, each with different characteristics. Here are the subsequent control reserves;

i. Primary reserves
ii. Secondary reserves
iii. Tertiary reserves

2.2.1. Primary Control Reserves

Primary control consists of changing a generating unit's power versus the frequency, according to its static generation characteristic as determined by the speed governor settings.

The objective of primary control is to re-establish a balance between generation and demand within the synchronous area at a frequency different from the nominal value following miner system disturbances. This is done at the expense of the kinetic energy of rotating masses of generating sets and connected motors.

The primary control action time is 0 to 30 seconds after disturbance of the balance between generation and demand. The primary control acts from 0 to 30seconds to balance the generation and the demand after disturbance.

Under normal conditions the system operates at nominal frequency. However, following disturbance, the primary control of generating units act and the frequency drop to new value called dynamic frequency deviation (Figure 2-1),[17].

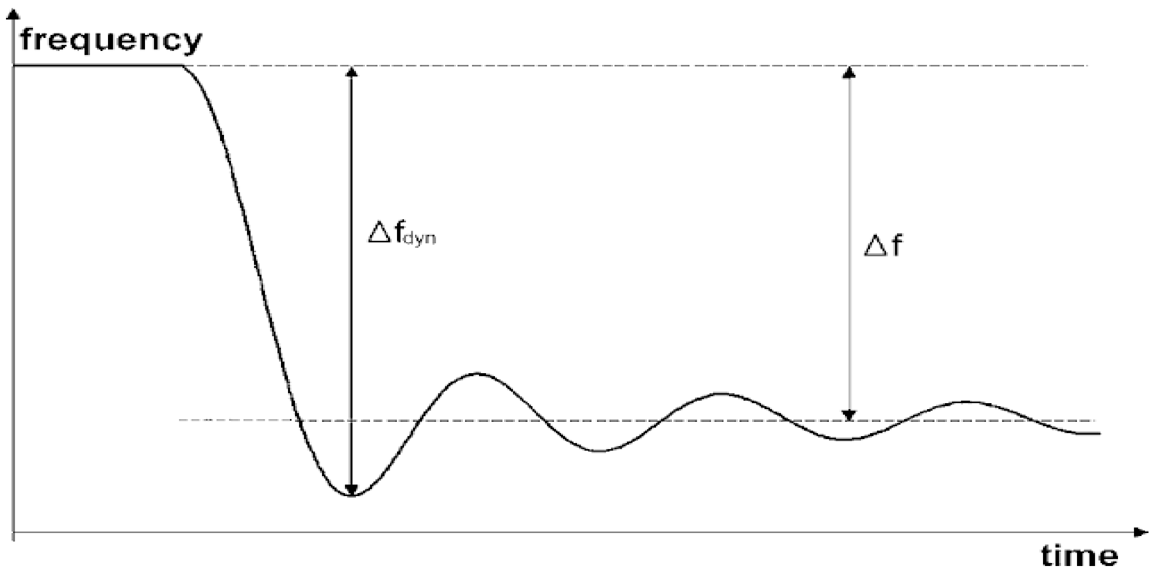


Figure 2-1: Definition of the dynamic (Δf/dt) and quasi-steady-state frequency (Δf) deviation

This deviation in the system frequency will cause the primary controllers of all generators subject to primary control to respond within a few seconds.

The response and the participation of generating units is depend on the speed droop setting of the speed governors.

2.2.2. Secondary Control Reserve

Secondary control makes use of a central regulator, modifying the active power set points of generator based on the frequency and tie line information. Secondary control reserve is used to restore power interchanges with adjacent control areas to their scheduled values and also keeps the system frequency within acceptable limit.

By altering the operating points of individual generating units, secondary control ensures that the full reserve of primary control power activated again.

Secondary control operates slower than primary control, in a timeframe of minutes it may take up to 15minutes [17].

Secondary control requires Central Regulator or Automatic Generation Control (AGC) to monitor and control the tie line flow and frequency from load dispatch center.

2.2.3. Tertiary Control Reserve

Tertiary control reserve is any automatic or manual change in the working points of the generating units, to restore an adequate secondary control reserve or to provide desired (in terms of economic considerations) allocation of this reserve within the set of generating units in service.

Tertiary control may be achieved by means of changing the set operating points of thermal power plant generation sets, connection/disconnection of pump storage hydro power stations operated an intervention mode, altering the power interchange schedule of tie lines or controlled load shedding. Figure 2-2. Shows the time line from primary, secondary and tertiary control of power system [17].

The frequency drops below the acceptable limit following loss of generating units or frequency raise above acceptable limit in case of loss of load and the system is forced to enter into emergency conditions. In such circumstances supplementary actions are needed to re-establish the active power balance. These include:

- Emergency load tripping (under frequency load shedding) in case of a major frequency drop.
- Emergency disconnection of generators in case of a large frequency increase.

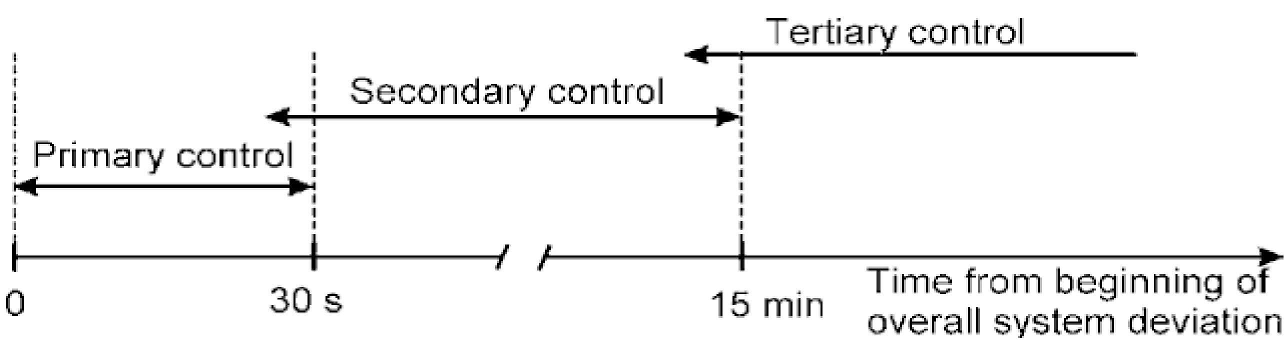


Figure 2-2: The timing of the primary, secondary and tertiary control ranges in a power system

This thesis focuses on the studies of the existing UFLS scheme of Ethiopian National Grid for emergency operating conditions.

CHAPTER-THREE

3. MODELING OF THE POWER SYSTEM NETWORK EQUIPMENTS

3.1.Introduction

Power system stability can be improved by better understanding of the behavior both under normal and abnormal operation conditions.

Before going to detail dynamic study of the Ethiopian National Grid, the following general information about the status of the system particularly the generation, transmission and the topology of the network, the models and the existing UFLS and other related events is presented as follows:

3.2.Existing Power System Network Topology

Ethiopian electric power system has two classified major system, namely ICS (Interconnected System) and SCS (self-contained system). Currently it has a total installed capacity of 4303 MW, of which an overwhelming majority is represented by ICS. Within the ICS the regional interconnection to Sudan and Djibouti is considered.

The power generation from Hydro power plants account for around 95% of installed capacity of Ethiopian power network.

3.2.1. Generation Facilities

The Generation facilities in the National Grid are distributed throughout the country and are located far from the big load centers. Table 1.1 below shows existing hydro power plants having a total installed capacity of 3,809 MW.

Table 3-1: Existing Hydro Power Plants

No	***Existing Hydro Power Plants***	***Capacity in MW***	***Energy in GWH***	***Commissioning date***
1	Koka	43.2	80	1960/61
2	Awash II	32	135	1966/67
3	Awash III	32	135	1971/72
4	Finchaa	134	740	1973 & 2001
5	Melka Wakena	153	434	1988
6	Tis Abay I & II	84	367	1964/65 & 2000/01
7	Gilgel Gibe-I	184	830	2003/04
8	Tekeze	300	957	2009/10
9	Gilgel Gibe-II	420	1826	2009/10
10	Tana Beles	460	1860	2009/10
11	FinchaAmertinesh	97	215	2011/12
12	Gilgel Gibe III	1870	8130	2016
	Total	**3,809.2**	**15,709**	

Table 3-2: Existing Wind Power Plant

No	***Existing Wind Power Plants***	***Capacity in MW***	***Energy in GWH***	***Commissioning date***
1	Ahsegoda Wind park	120	197	2011/12
2	Adama I Wind park	51	161	2011/12
3	Adama II Wind park	153	402	2015
	Total	**324**	**760**	

Table 3-3: Existing Geothermal Power Plant

No	***Existing Geo thermal Power Plants***	***Capacity in MW***	***Energy in GWH***	***Commissioning date***
1	AlutoLangano	7.3	42	1998/99

Table 3-4: Existing standby Diesel Power Plant

No	**Existing standby diesel Power Plants**	**Capacity in MW**	**Energy in GWH**	**Commissioning date**
1	Dire Dawa	40	231	2003/04
2	Awash 7 kilo	36	202	2003/04
3	Kaliti	12	81	2003/04
	Total	**88**	**514**	

3.2.2. Transmission Facilities

The National Grid links the major generation to load centers via transmission lines at 400 kV, 230 kV and 132 kV and sub-transmission lines at 66 kV and 45 kV. There are a total of 172 substations across the system; 12 hydro, 3 thermal, 3 small hydro stations and 154 transmission substations. The total circuit lengths of transmission and sub-transmission lines on the existing system are shown in Table 3-5. EEP plans to phase out 45 kV in favor of 66 kV and also to replace some 66 kV lines with 132 kV.

Table 3-5: Summary of Existing High Voltage Transmission Lines

Year	**Transmission line Data in km**						
	Voltage level						
	500KV	**400KV**	**230KV**	**132KV**	**66KV**	**45KV**	**Total**
2010/2011		875	2479	4401	1969	252	**9976**
2011/2012		875	2869	4871	1969	252	**10836**
2012/2013		908	3597	4871	1969	252	**11597**
2013/2014		908	4020	4871	1969	252	**12020**
2014/2015		1511	5161	5048	1969	252	**13941**
2015/2016	1240	1609	6053	5048	1969	252	**16171**
2016/2017	**1240**	**2114**	**6053**	**5048**	**1969**	**252**	**16676**
2017/2018	**1240**	**2238.12**	**8559.6**	**5494.292**	**1842.73**	**221.42**	**19596.16**

Table 3-6: List of Substation

No.	**Location of Substations**	**Number of Substations**
1	Hydro Power Plant Sub-Stations – Ics	12
2	Stand by Diesel Sub-Stations – Ics	3
3	Small Hydro Power Plant Sub-Stations – Scs	3
4	Eastern Addis Ababa Region Sub-Stations	11
5	Northern Addis Ababa Region Sub-Stations	9
6	Southern Addis Ababa Region Sub-Stations	12
7	Western Addis Ababa Region Sub-Stations	7
8	South Eastern Region Sub-Stations	11
9	Southern Region Sub-Stations	16
10	Eastern Region Sub-Stations	13
11	Jigjiga Region Sub-Stations	1

No.	Location of Substations	Number of Substations
12	Semera Region Sub-Stations	4
13	North Eastern Region Sub-Stations	11
14	Northern Region Sub-Stations	10
15	North Western Region Sub-Stations	14
16	WESTERN Region Sub-Stations	12
17	ASOSA Region Sub-Stations	3
18	GAMBELA Region Sub-Stations	1
19	Rail Way Traction Substations	19
	TOTAL	***172***

3.3.Existing UFLS scheme

Under frequency shedding is one of the most crucial and effective strategy to retain the generation power margin at required level and prevent the widespread system collapse following system disturbance.

In the Ethiopian National Grid there are two stages of under frequency load shedding scheme which are set at a frequency of 48.6Hz and 48Hz. The total load disconnected from both stages is 16% of the system load at the time of generation disturbance. The existing under frequency load shedding scheme cannot serve its purpose if there is an outage of generation more than 16%. In the contrary the maximum generation of the grid is from Gibe III which has more than 45% contribution and if there is outage of Gibe III power plant with planned loading, the existing under frequency load shedding scheme cannot help hence total blackout will occur.

Table 3-7: List of distribution lines connected to under frequency load shedding stage 1 and 2

Substation Name	Stage 1 (48.6 Hz)			Stage 2 (48.0 Hz)		
	Feeder name	Maximum Load (A)	Maximum Load (MW)	Feeder name	Maximum Load (A)	Maximum Load (MW)
Gafarssa	L1	345	7.17			
	L2	394	8.18			
	L7	324	6.7			
Kaliti I				F14	300	6
Sebeta I	L3	420	8.72	L2	450	10
	L4	480	9.96			
Addis Centre				L3	270	5.6
				L11	260	5.4
				L16	280	5.8
Addis East II				L1	529	11
				L4	520	10.8
Addis North	L5	180	3.74	L2	380	8
	L6	280	5.81			
Cotobie	L3	345	8.4	L1		2.4
	L5		5.6	L4		5
Kaliti II	L5		14	L2		4.9
	L6		7			
Kaliti North	K5	70	1.5	K4	176	3.7
	K2	328	7			
Mekanissa	L5	270	5.6	L4	230	4.78
	L2	301	6.3			
Woregenu	L1	320	6.6	L6	320	6.6
				L8	400	8.3
Addis south II				L4	450	9.5
Yesu	L1	256	5.31			
Addis East I				L2	220	4.6
				L5	54	1.5
Addis West	L3	169	3.5	L1	338	7
	L6	170	3.5	L4	176	3.7
Akaki I				Akaki 3	130	2.7
Nifas Silk	L2		6.8	L1		4
Total for each stage			**131.39**			**131.28**

3.3.1. Existing under frequency set point of generating units

The under frequency tripping of generating units is one of the parameter that determines the under-frequency load shed point as it is the minimum frequency that shall be considered for UFLS design.

Table 3-8: Existing under frequency tripping points of Generators

S.No	Power Plant Name		UF Tripping Stage 1		UF Tripping Stage 2		Remark
			Freq (HZ)	Time (Sec)	Freq (HZ)	Time (Sec)	
1	Amerinesh		49.5	300	48	30sec	Generating units will trip way before the system enters to stage 1 under frequency trip.
2	Gilgel Gibe I		48				Even though there is UF protection but the UV protection with a setting of 5% down to the Generator Voltage acts first.
3	Gilgel Gibe II		47.5	10	45	1sec	
4	Tekeze		47.5	0.5	45	0.1sec	
5	Koka		47.5	30	45	10sec	
6	Awash II & III		47.5	30			
7	Finchaa	Unit I, II & III	47.5	10			
		Unit IV	48.5	10			
8	Beles		No Setting		No Setting		There is no UF protection rather UV protection with a setting of 15% down of the generating voltage for 3sec at stage 1 and 20% down of the generating voltage for 0.2sec at stage 2.
9	Melka-wakena		No Setting		No Setting		

As it is observed from table 3.8, some power plants like Fincha unit IV,Gibe I and Amertinesh trips before the frequency reaches 47.5HZ and need to be corrected immediately. Since they will trip before the UFLS which aggravate the disturbance of the system

For the purpose of this thesis the under frequency tripping of generating units is assumed to be 47.5Hz.

3.4.Equivalent Network of Sudan

The Ethiopian national grid is connected Sudan network and the tie line to Sudan is connected by double line 230KV transmission. The total generation of Sudan for the case considered for this thesis is 1320MW with import from the Ethiopian grid is 94MW on each 230KV lines and total import of 188MW.

The following figure shows the equivalent network and dynamic model of the Sudan network.

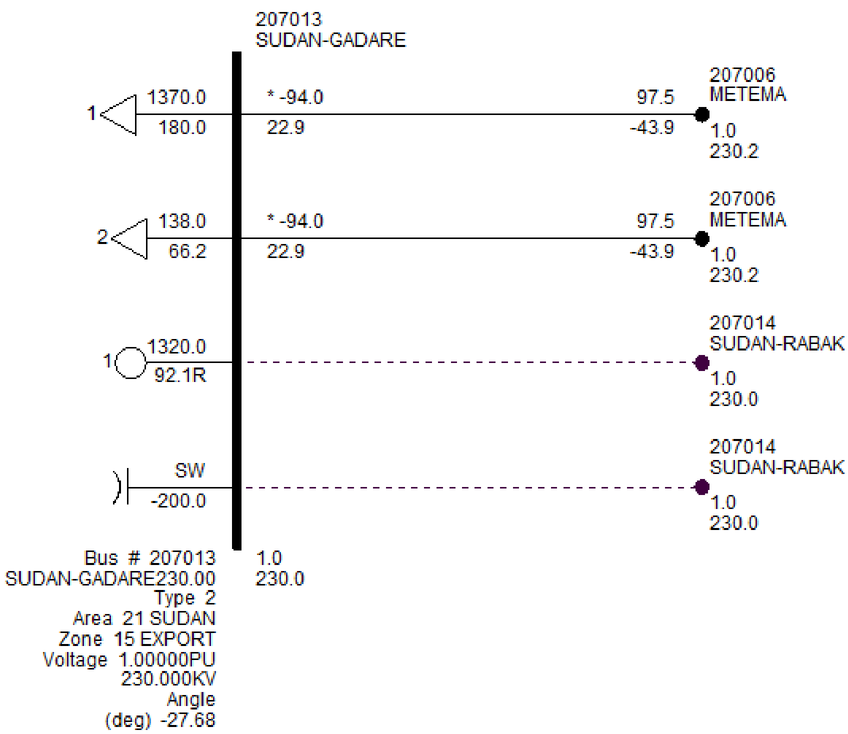
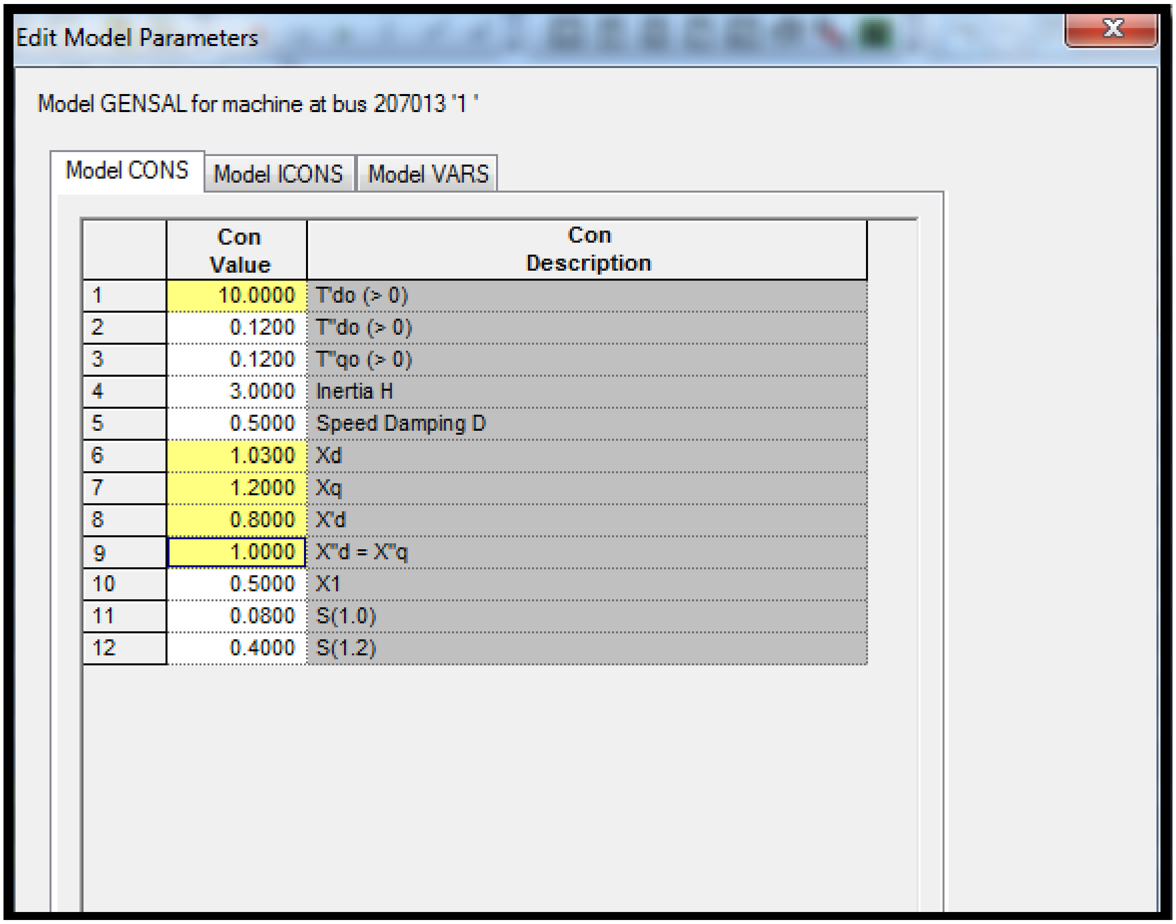


Figure 3-1: Single line diagram of the tie line to Sudan



	Con Value	Con Description
1	10.0000	T'do (> 0)
2	0.1200	T''do (> 0)
3	0.1200	T''qo (> 0)
4	3.0000	Inertia H
5	0.5000	Speed Damping D
6	1.0300	Xd
7	1.2000	Xq
8	0.8000	X'd
9	1.0000	X''d = X''q
10	0.5000	X1
11	0.0800	S(1.0)
12	0.4000	S(1.2)

Figure 3-2: Dynamic Model Data for Sudan Network

3.5.Existing UFLS scheme of Sudan

Here is the existing under frequency load shedding scheme of Sudan National grid:

Table 3-9: Existing UFLS scheme of Sudan

Stages	Frequency	% of Peak
1	49.2	5
2	49.1	10
3	49	7
4	48.9	4
5	48.7	4
6	48.5	10
7	48.3	4
8	48.1	3
9	48	3

As is observed on table 3.9 the Sudan network has nine stages of under frequency load shedding and the amount of load disconnected is as shown on the percentage column.

3.6.Modeling

The stability of the grid can be studied using proper modes of PSSE and updated to represent the actual system. For the modeling of network equipments, the built-in models of PSSE are used.

Load model

There are four distinct methods for load modeling.

- Constant MVA model: -the load boundary condition is a specification of load real and/or reactive power consumption.
- constant current model: -loads are specified as a given active or reactive component of current
- Constant admittance model: -load are specified by a given real and reactive parts of shunt admittance.
- Composite model: -

Generator model

Table 3-10summarizes the built-in model used for different generators in the Grid and parameters to be tuned are shown on Figure 3.3.

The model to be selected is defined by the type of technology used and based on the manufacturer design data submitted during installation of the generating units.

Table 3-10: Generator, speed governor and excitation built in models

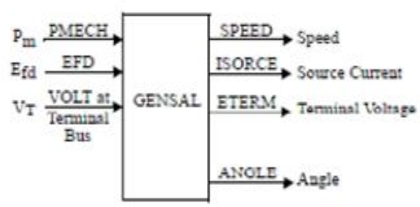
Generator type	Generator model	Excitation system model	Speed governor model
Hydro	GENSAL	EXST1/SCRX/EXDC2/IEEX1	HYGOV
Wind	WT4G1	WT4E1	
Diesel	GENROU	SEXS	TGOV1
Geothermal	GENROU	SEXS	TGOV1

GENSAL: Salient Pole Generators Model

GENSAL: Salient Pole Generator Model			
Cons	Value	Description	
J		T'do (>0) (sec)	d-axis open circuit transient time constant
J+1		T''do (>0) (sec)	d-axis open circuit subtransient time constant
J+2		T''qo (>0) (sec)	q-axis open circuit subtransient time constant
J+3		H (sec)	Inertia
J+4		D (pu)	Speed Damping
J+5		Xd (pu)	d-axis synchronous reactance
J+6		Xq (pu)	q-axis synchronous reactance
J+7		X'd (pu)	d-axis transient reactance
J+8		X''d=X''q (pu)	d-axis subtransient reactance
J+9		Xl (pu)	Stator leakage reactance
J+10		S(1.0) (pu)	Saturation factor
J+11		S(1.2) (pu)	Saturation factor

Note: X_d, X_q, X'_d, X''_q, X_l, H, and D are in machine MVA base and X''q must be equal to X''_d.

States	Values	Description
K		E'_q
K+1		Ψkd
K+2		Ψ''_q
K+3		Δ speed (pu)
K+4		Angle (radians)

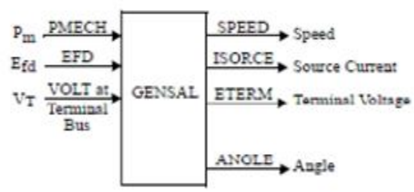


GENSAL: Salient Pole Generators Model

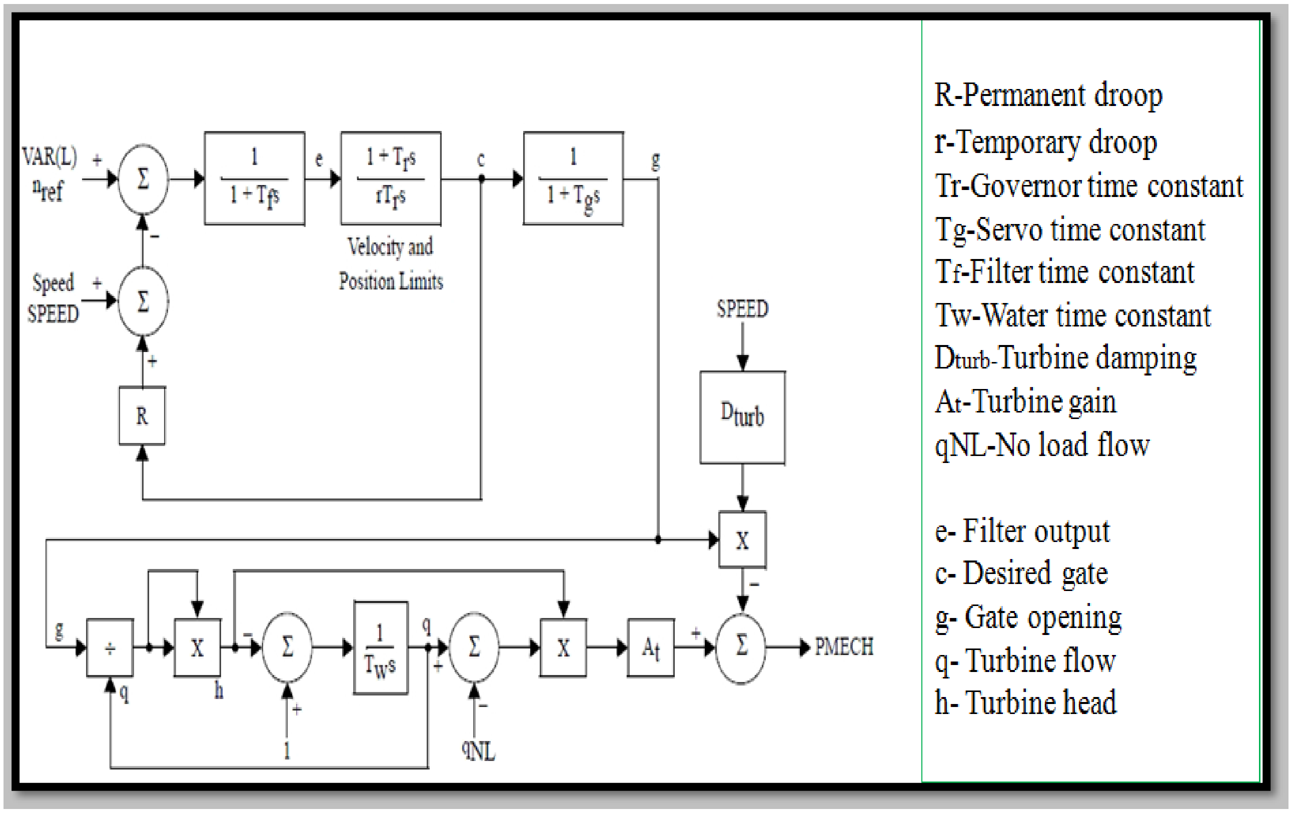
GENSAL: Salient Pole Generator Model			
Cons	Value	Description	
J		T'do (>0) (sec)	d-axis open circuit transient time constant
J+1		T''do (>0) (sec)	d-axis open circuit subtransient time constant
J+2		T''qo (>0) (sec)	q-axis open circuit subtransient time constant
J+3		H (sec)	Inertia
J+4		D (pu)	Speed Damping
J+5		Xd (pu)	d-axis synchronous reactance
J+6		Xq (pu)	q-axis synchronous reactance
J+7		X'd (pu)	d-axis transient reactance
J+8		X''d=X''q (pu)	d-axis subtransient reactance
J+9		Xl (pu)	Stator leakage reactance
J+10		S(1.0) (pu)	Saturation factor
J+11		S(1.2) (pu)	Saturation factor

Note: X_d, X_q, X'_d, X''_q, X_l, H, and D are in machine MVA base and X''q must be equal to X''_d.

States	Values	Description
K		E'_q
K+1		Ψ_{kd}
K+2		Ψ''_q
K+3		Δ speed (pu)
K+4		Angle (radians)

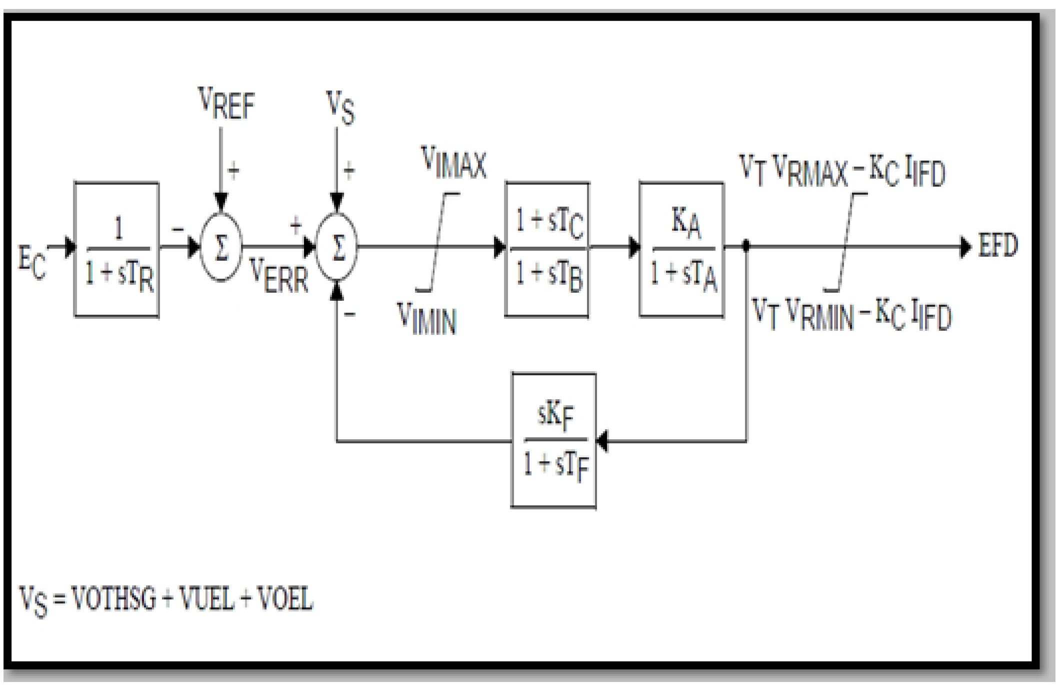


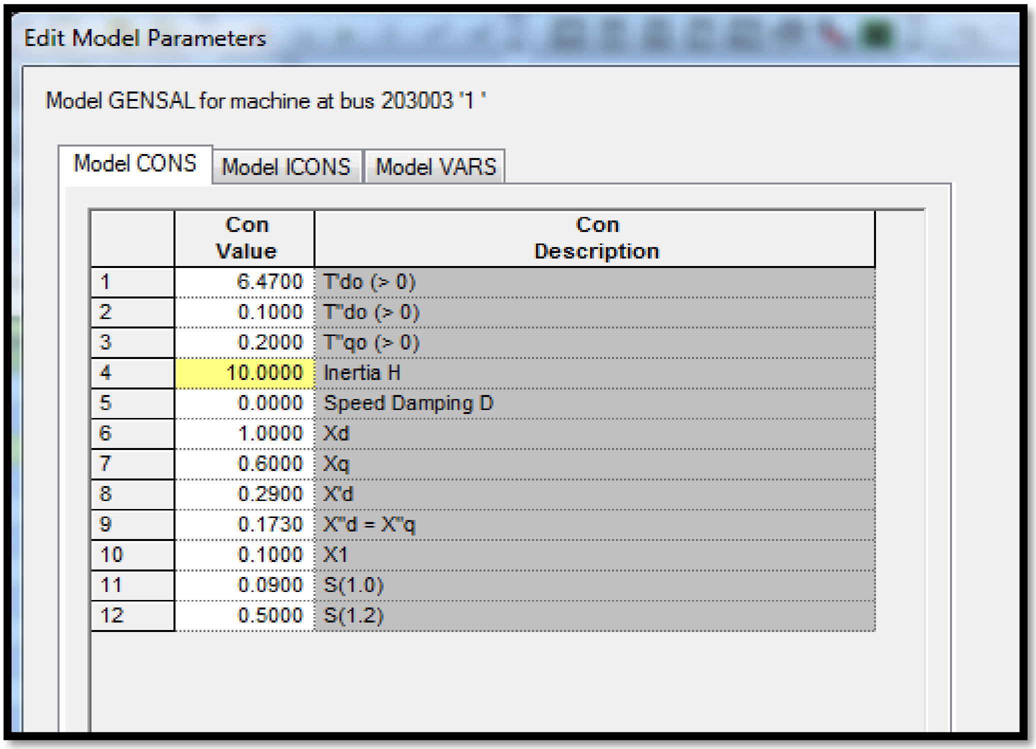
Speed Governor: HYGOV



Excitation Model: Models: EXST1, SCRX, IEEEX1, EXDC2

EXST1:





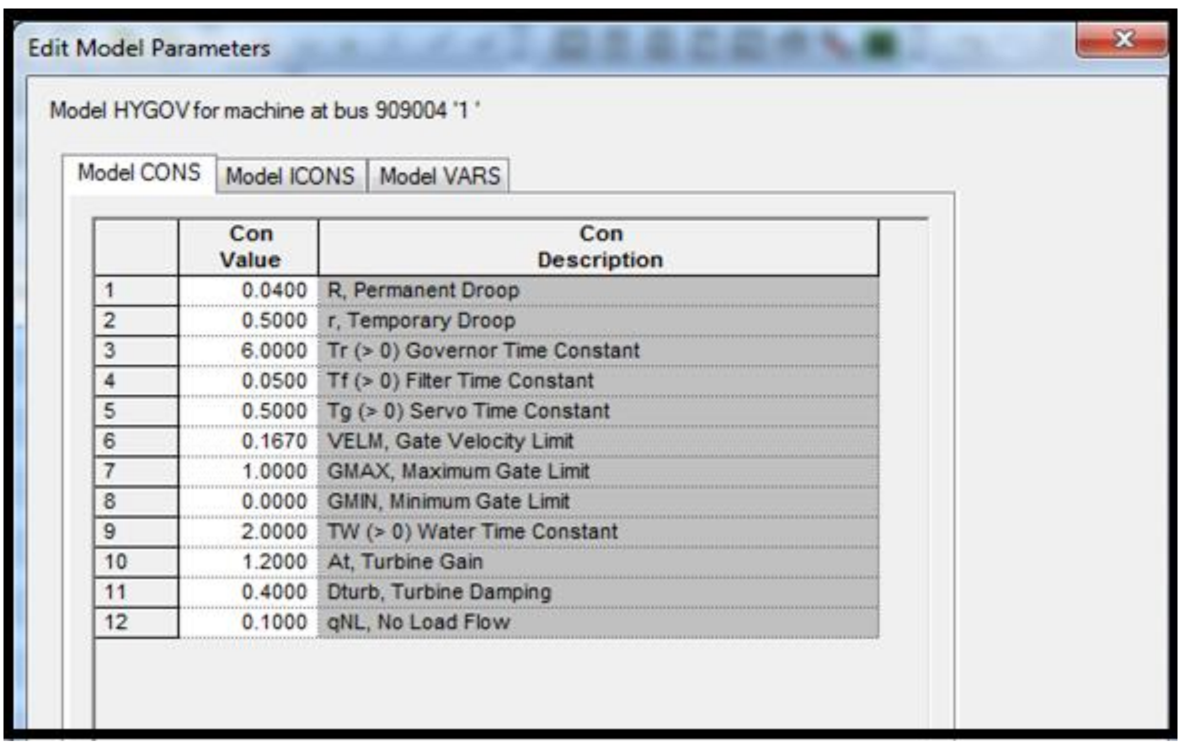
Edit Model Parameters

Model GENSAL for machine at bus 203003 '1 '

Model CONS | Model ICONS | Model VARS

	Con Value	Con Description
1	6.4700	T'do (> 0)
2	0.1000	T"do (> 0)
3	0.2000	T"qo (> 0)
4	10.0000	Inertia H
5	0.0000	Speed Damping D
6	1.0000	Xd
7	0.6000	Xq
8	0.2900	X'd
9	0.1730	X"d = X"q
10	0.1000	X1
11	0.0900	S(1.0)
12	0.5000	S(1.2)

Figure 3-3: User interface for data input for GENSEL generator model



Edit Model Parameters

Model HYGOV for machine at bus 909004 '1 '

Model CONS | Model ICONS | Model VARS

	Con Value	Con Description
1	0.0400	R, Permanent Droop
2	0.5000	r, Temporary Droop
3	6.0000	Tr (> 0) Governor Time Constant
4	0.0500	Tf (> 0) Filter Time Constant
5	0.5000	Tg (> 0) Servo Time Constant
6	0.1670	VELM, Gate Velocity Limit
7	1.0000	GMAX, Maximum Gate Limit
8	0.0000	GMIN, Minimum Gate Limit
9	2.0000	TW (> 0) Water Time Constant
10	1.2000	At, Turbine Gain
11	0.4000	Dturb, Turbine Damping
12	0.1000	qNL, No Load Flow

Figure 3-4: User interface for speed governor HYGOV and tuning parameters

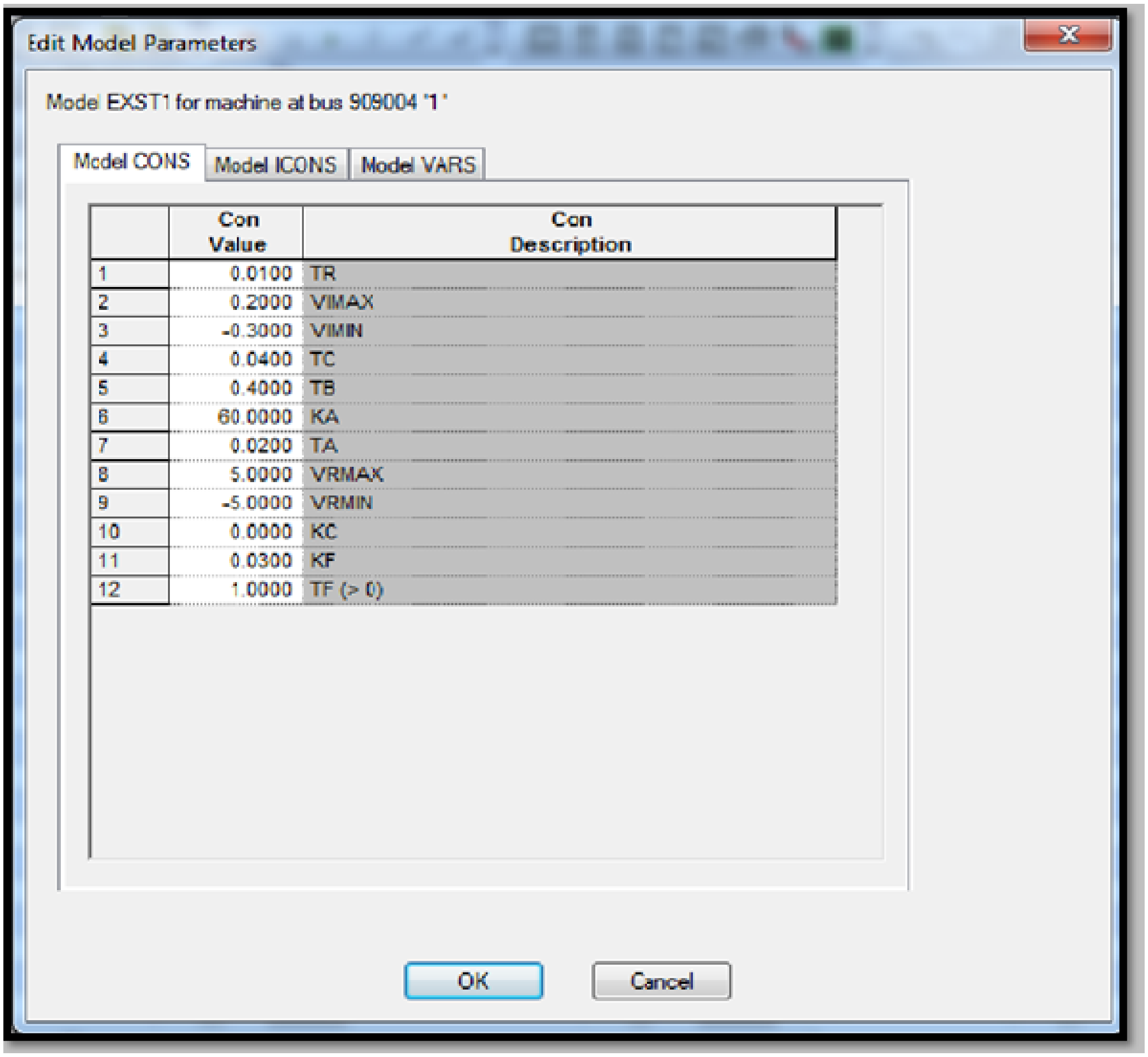


Figure 3-5: User interface for Excitation system model1

3.7.Dynamic simulation

Dynamic simulation is the simulation of the power grid for different outage or disturbance conditions and observe the response of the system parameters, mainly frequency, voltage active/reactive power, etc.

On PSSE Simulation software load flow analysis shall be conducted and the converged save case for the selected network topology is ready for dynamic analysis.

3.7.1. Data Input

The existing data available in EEP is updated for the purpose of this thesis and all the load data transmission parameters, power transformer data, shunt reactors and capacitor data and the existing topology of the network that EEP-NLDC operating is considered for the dynamic analysis.

3.7.2. Dynamic data files

The generator speed governor data, the excitation system and the UFLS model are properly tuned to represent the actual situation of the system for dynamic simulation.

All input data that are used for the simulation are attached as **Annex1**.

Dynamic simulation is conducted for a particular topology of the network and for this thesis the system load of 2200MW with the regional interconnection to Sudan and Djibouti are considered.

3.7.3. Simulation Studies for the Frequency Response of the Existing System

3.7.3.1. Frequency response of the system

Dynamic analysis is conducted using PSSE software on the existing system and the response of the system frequency for different disturbance cases are as shown below:

For all disturbance cases the system is operating normally up to the 5^{th} second and disturbance is applied on the 5^{th} second on the time line.

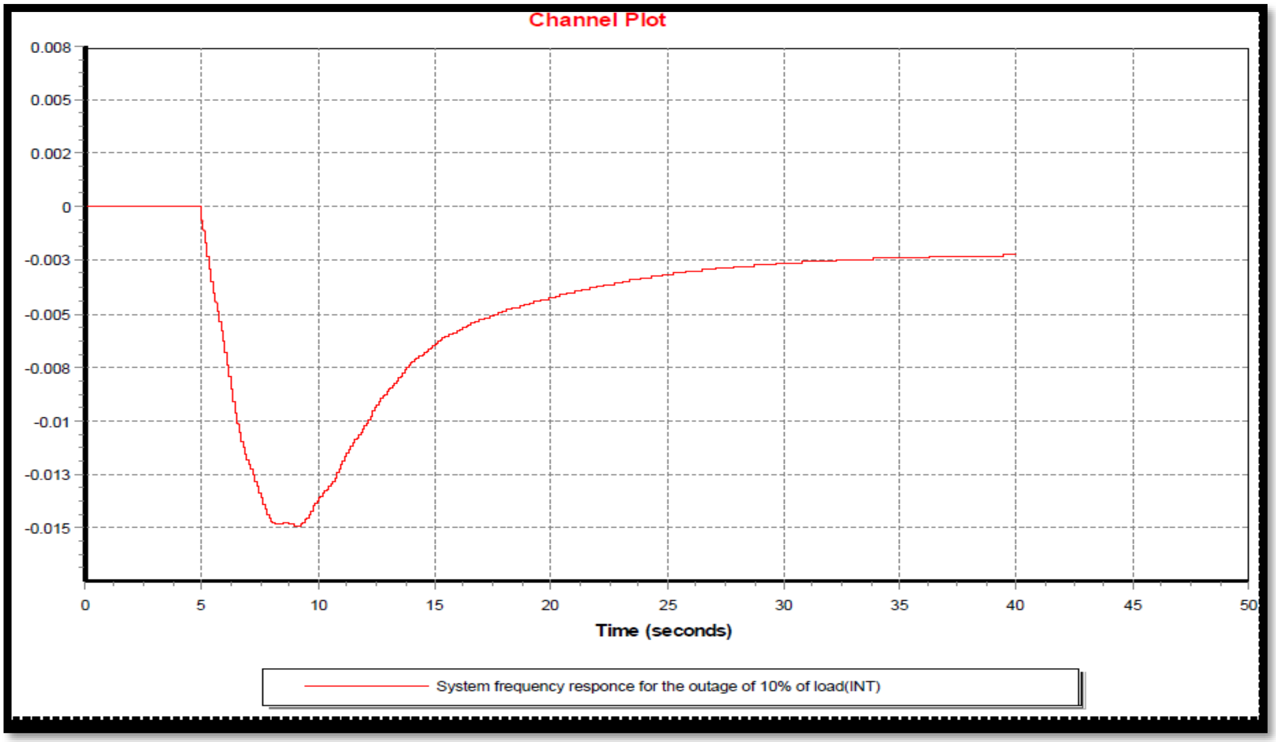


Chart 3-1: Frequency response for 10% generation loss

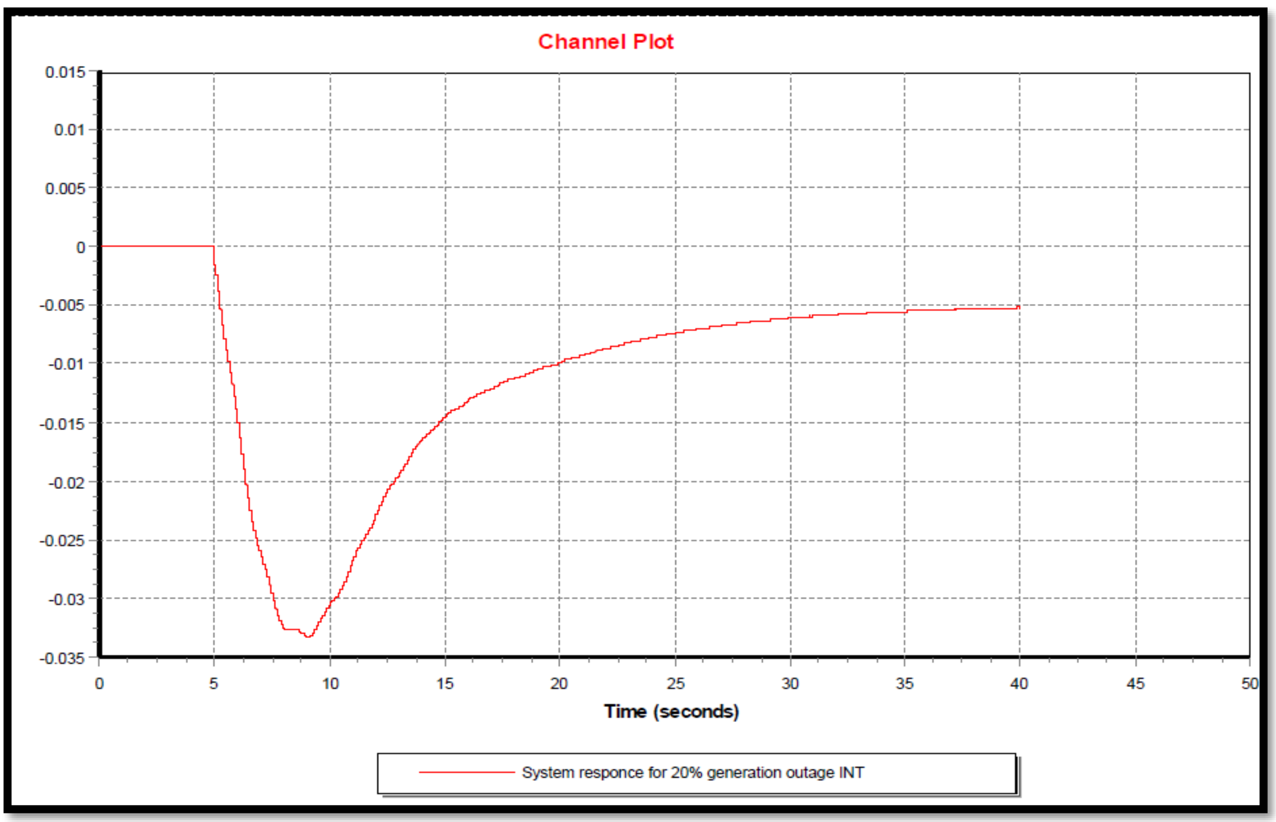


Chart 3-2: Frequency response for 20% generation loss

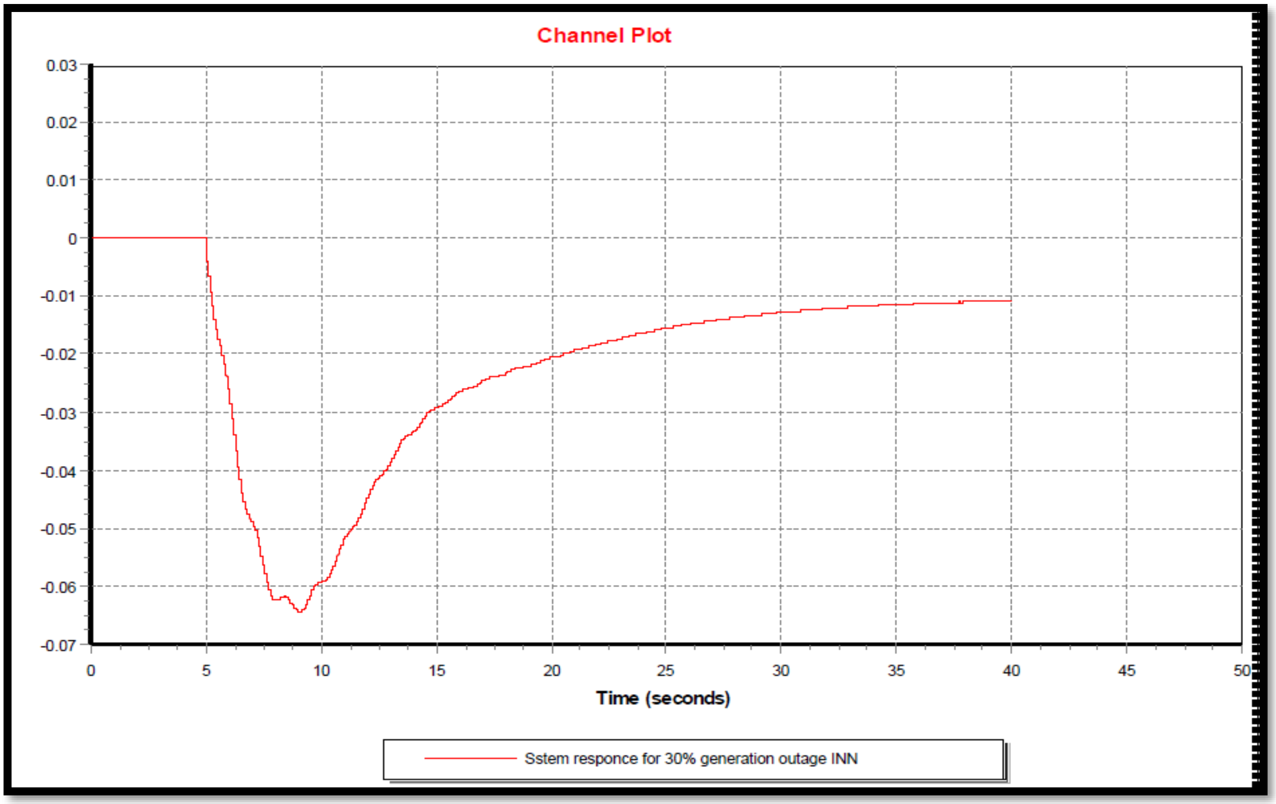


Chart 3-3: Frequency response for 30% generation loss

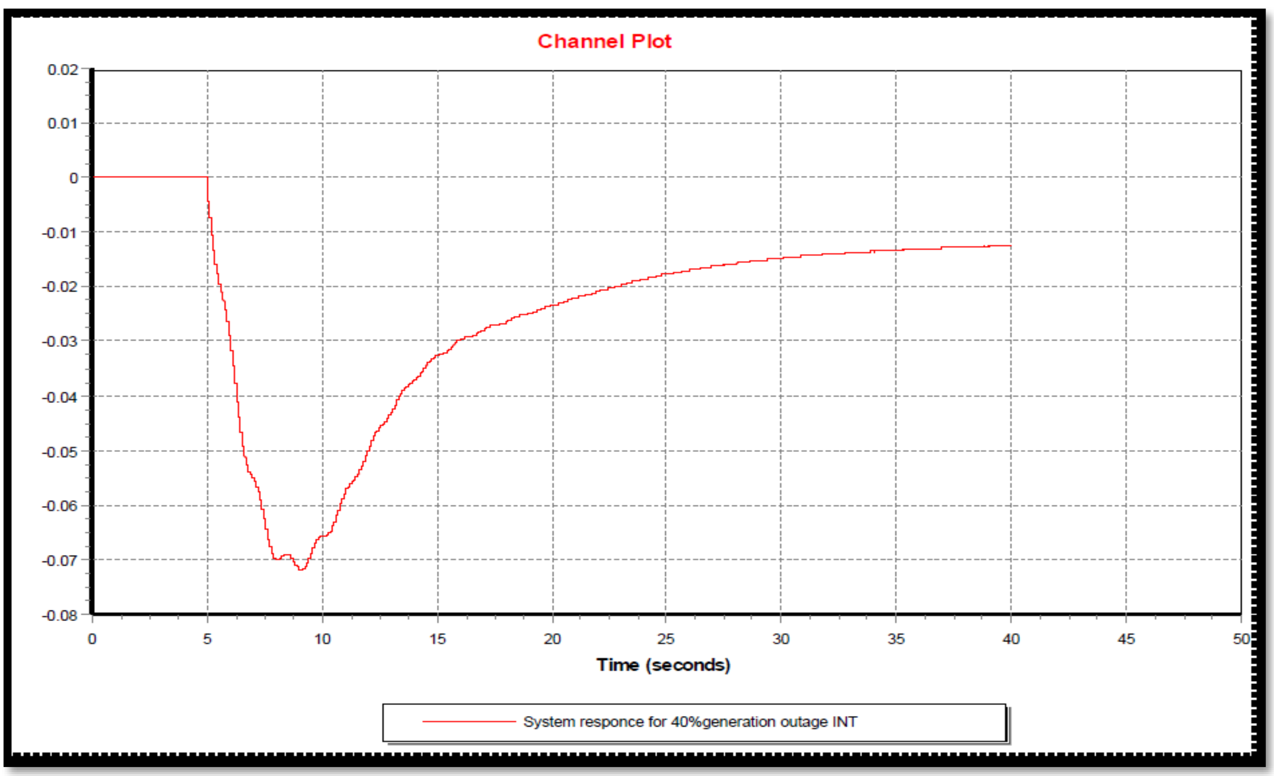


Chart 3-4: Frequency response for 40% generation loss

Frequency response after the action of old under frequency load shedding

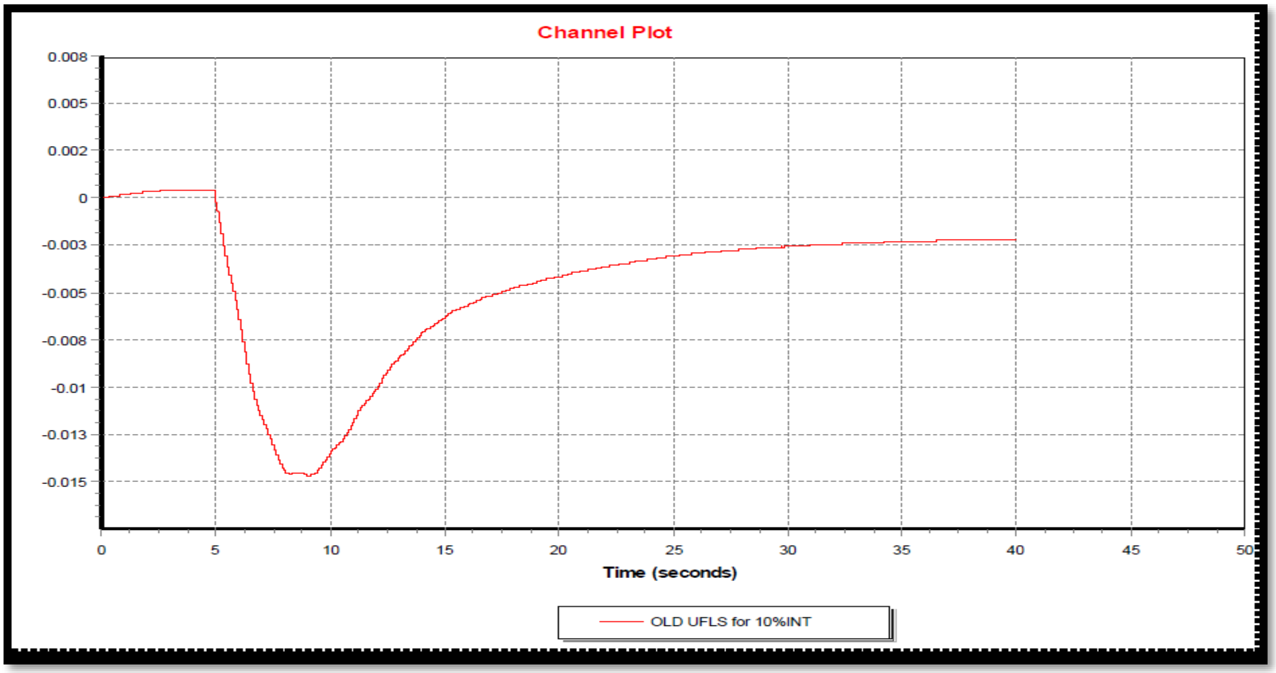


Chart 3-5: Frequency response for 10% generation loss and action of the existing UFLS scheme

For this case, under frequency relays did not tripped, since, the minimum frequency is 49.25HZ which is above the first stage 48.6HZ.

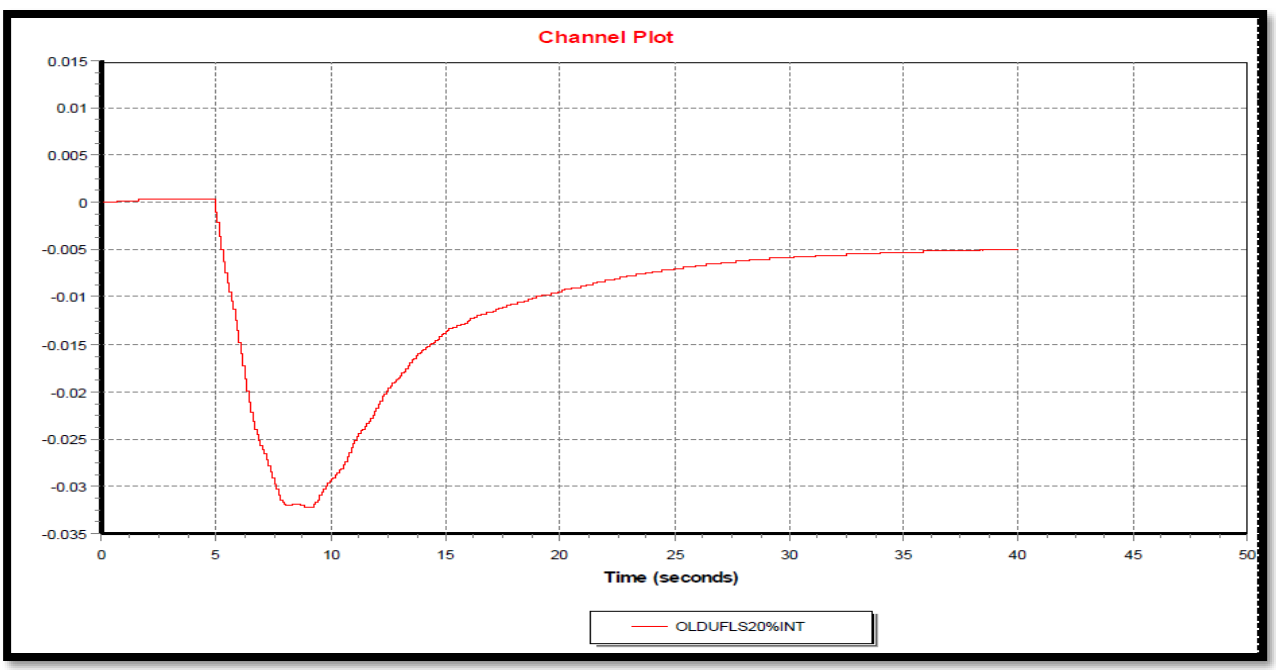


Chart 3-6: Frequency response for 20% generation loss and action of the existing UFLS scheme

For the above case under frequency relays did not tripped, since, the minimum frequency drop is 48.4HZ which is above the first stage under frequency set point of 48.6.

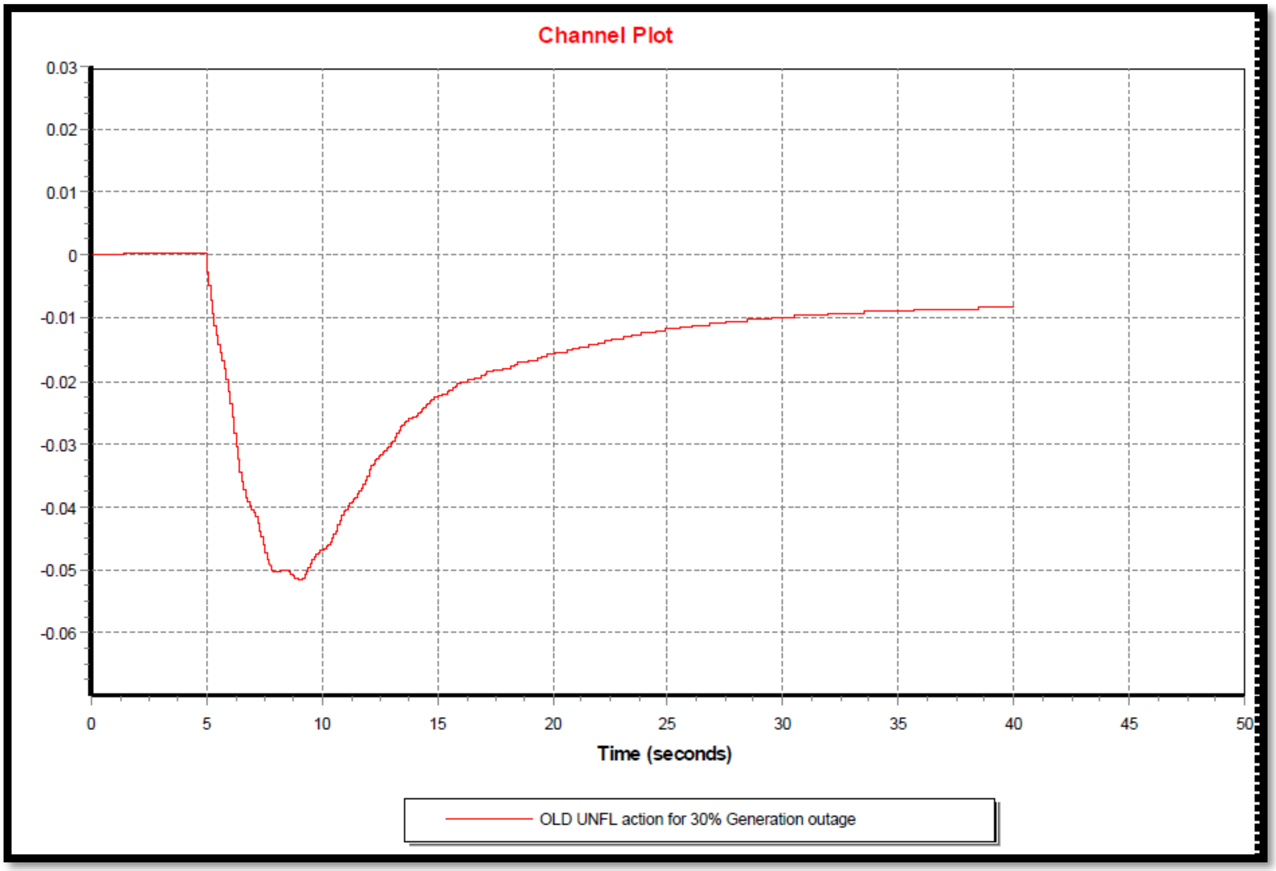


Chart 3-7: Frequency response for 30% generation loss and action of the existing UFLS scheme.

The minimum frequency reached to 47.6HZ, even after the action of both first and second stage UFLS. So, the existing UFLS system cannot able to recover the frequency for 30% Generation loss.

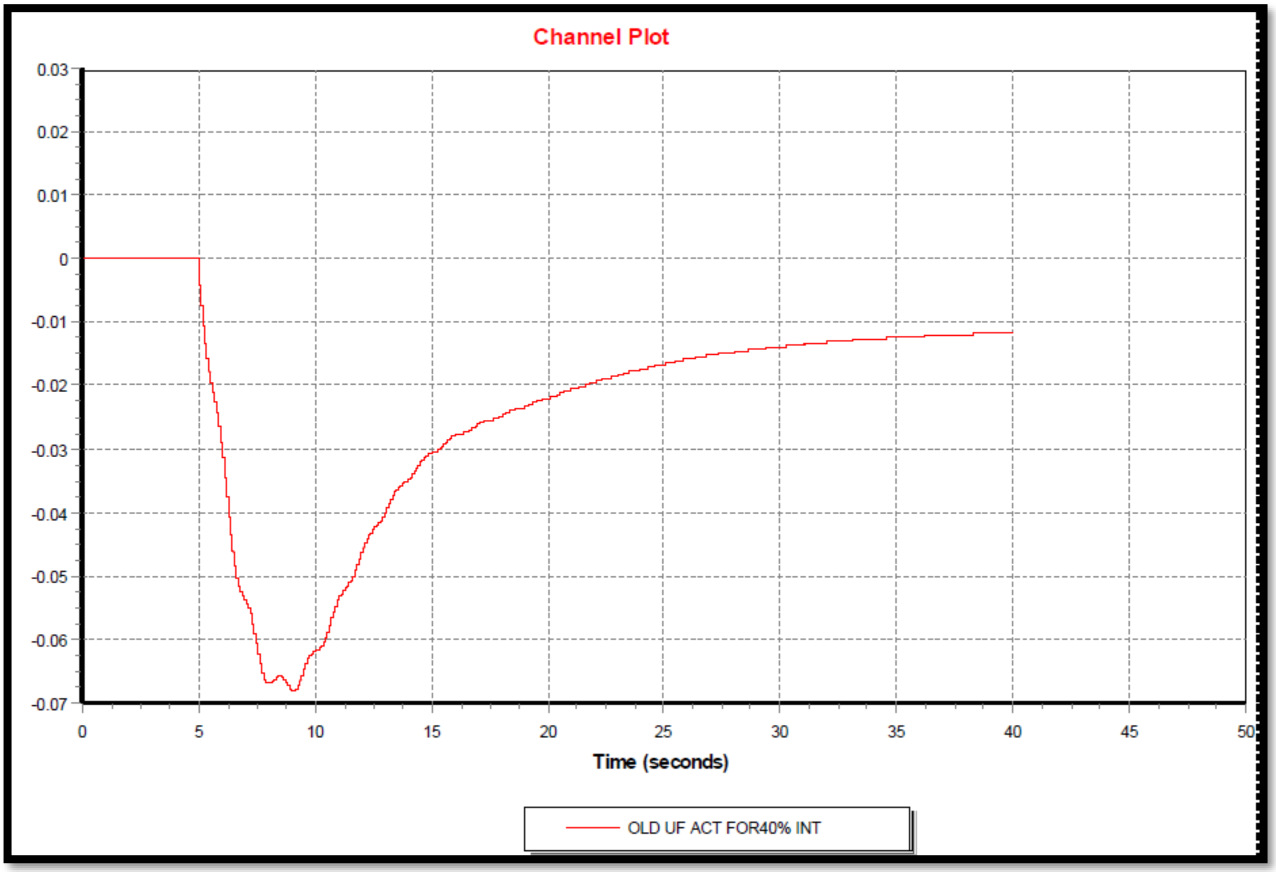


Chart 3-8: Frequency response for 40% generation loss and action of the existing UFLS scheme.

For this case also, the minimum frequency reached to 46.8HZ, even after the action of both first and second stage UFLS. So, the existing UFLS system cannot able to recover the frequency for 40% Generation loss.

3.7.4. Result Summary and Conclusion

Table 3-11: Result Summary

Loss of Generation (%)	Original Freq0uency before UFLS action	Result summery after Action of UFLS in HZ	Remark
10	49.25	49.32	System recovered frequency restored and the frequency can be restored to 50Hz by the action of AGC
20	48.35	48.45	System recovered frequency restored and the frequency can be restored to 50Hz by the action of AGC
30	46.75	47.45	Results in Cascade outage and Black out
40	46.4	46.8	Results in Cascade outage and Black out

As is observed from the frequency response of the existing system for different generation outage scenarios, for 30% and 40% generation loss the system frequency drops below 47.5Hz, which is the generator under frequency tripping point and most generators will trip by under frequency and system collapse will occur. Hence, it is possible to conclude that the existing under frequency load shedding cannot recover the system frequency drop for the generation loss of 30 and 40%, and need to be studied and upgraded.

CHAPTER-FOUR

4. SELECTION OF UFLS SCHEME

4.1.Selection Procedure for Conventional UFLS

The following design procedures shall be followed for conventional UFLS method and the same procedure is followed in the literatures [14], [18].

The conventional UFLS method is considered as reference to compare in the selection procedure with the AUFLS and to estimate the number of stages to be used later for AUFLS.

A. Over load calculation

In the power system following loss of generating units or sudden connection of industrial load the system frequency drops which results in over load on other generating units in the system. The anticipated overload can be used to determine the amount of load to be shed. The under-frequency relays should shed a load amount equivalent to the overload. By shedding the amount of load equal to the overload, the system generating units and tie lines can be preserved and kept synchronized avoiding system collapse[1][19].

The anticipated over load or the load excess ratio, L, is given by Equation (2.12)

$$L = \frac{TL - TG}{TG} \quad \text{Equation (4.1)}$$

Where: - *TL*: Total load in the system
TG: Total generation in the system
L: anticipated overload

Value of L greater than 50% is not recommended due to possible over shedding during small disturbances [8]. However, for Ethiopian National Grid bigger power plants like Gibe III contribute more than 45% of the generation and this case shall be analyzed on this thesis.

B. Calculating the amount of load to be shed

Equation (2.12) can be used for calculating the total amount of load to be shed in order to maintain the frequency above the threshold limit of 1%.

$$LD = \frac{LF - d(ff)}{1-d(ff)} \qquad \text{Equation (4.2)}$$

Where: -

LF $= \frac{L}{1+L}$ and $ff = 1 - \frac{f}{fn}$

LF: Overload Factor

ff :Frequency Factor

LD: Load to be shed

L : Overload

f : Minimum permissible frequency

f_n: Nominal frequency

d : Load reduction factor

The load reduction factor d value can be neglected for the system where the under-frequency load shedding is set to operate within one or two seconds.

Note that the constant d affects the per unit overload more rapidly than it affects the total system load; however, d does not have significant effect until the frequency has decayed appreciably. To design a conservative scheme, it is safest to assume that d equals zero [1].

C. Number of load shedding steps

The load can be shed in one single step in which a predetermined percentage of load is shed when the system frequency drops. But this approach leads to over shedding for small disturbances. The other way of load shedding is using two groups, one operating at lower frequency and the other at higher frequency each shedding half of the overload calculated.

The number of UFLS steps are dependent mainly on the rate of change of frequency, the system inertia, the relay and breaker operation time and the range between the lower acceptable limit of frequency and the minimum acceptable limit of frequency that is, generator under frequency tripping points.

The better way of shedding the load is to reduce small amount of load in several steps as far as the time coordination and the last set point is above the minimum frequency. Using smaller steps results in accurate load shedding. However, increasing the number of steps can cause overlap between successive steps [1][2].

Typically, 3 to 6 steps provide the best co-relation between the amount of load shed and the minimum amount of load to be shed[1][2]. Most utilities use between two and five load shedding steps [19].

D. Size of the load shed at each step

The size of load to be shed shall be equivalent to the expected overload. The load shedding blocks shall be sized based on the study result for the loss of power generating units and tripping of transmission lines that can cause loss of generation. Each step sheds only enough loads to handle the next, more serious contingencies.

After calculating the amount of load to be shed, load shedding steps are decided for shedding load from the system. But the load shedding steps are not adaptable to system faults. So, to have a general rule, small amount of load is shed in first step, large in intermediate steps and again small amount in final step [19].

E. Frequency Setting

The frequency set point for load shedding of each stage is done considering the normal operation range of frequency, the speed and accuracy of under frequency relays, breaker operation time and the number of stages selected for under frequency load shedding. The under-frequency set points shall be coordinated with the neighboring countries, so that each country having disturbance event shall respond not to lose the tie line and not to transfer the disturbance to the other region.

The frequency setting for the UFLS protection relays is done as follows:

- The first step set point should be just below the normal operating frequency band of the system, allowing the variation in tripping frequency of the relay.
- The rate of change of frequency in the range between the nominal frequency and the frequency of the first step is calculated. This will help us to calculate the actual

frequency at which load will be shed by the first step relays for the most severe expected overload considering under frequency relay tripping curves.

- Set the second step relays just below this frequency, allowing a safety margin that will tolerate any expected frequency drift for both sets of relays
- Calculate the actual frequency at which the second load shedding step will occur.
- Continue the above step till the selected frequency is above the minimum acceptable limit, that is the Generator UF tripping point

The following factors are considered for relay setting:

a) The threshold frequency

b) The number of load shedding steps

c) The operating speed of relays and breakers

d) The accuracy of the relays

Setting = Previous clearing frequency – safety margin [4] Safety margin considers inaccuracies of relays and breakers [19].

The time delay should be minimum, so that, the system can react quickly for disturbance and the resulting drop of frequency that can endanger the grid from collapse. However, the time is dependent on the type of relays or breakers used in the system.

The total amount of time required to clear the load is given by [19]:

Time = ROT + TDelay + BOT……………………………….…………………..Equation (4.3)[3]

Where: - Time : Total clearing time

ROT : Relay operating time

TDelay : Intentional time delay

BOT: Breaker operating time

4.2.Selection Procedure for Adaptive UFLS

AUFLS is used to determine the amount of load to be shed dynamically and uses the PSSE built-in model of the system to observe the network parameters following system disturbance. The result output of the dynamic simulation is dependent on the topology of the network and the system inertia which might be varying based on the availability of the generating units in the grid.

The following four steps are included in the design of AUFLS. And this are the procedures discussed in the literatures.

Step 1: Dynamic system modeling

The System under study is modeled for dynamic simulation and the generator, governor parameters and excitation system is properly tuned to represent the actual system under study. In addition, the dynamic model for regional interconnection shall be represented by equivalent dynamic model.

Step 2: Application of different disturbances to the system:

In this step, several generator outage events are applied to the simulated network. Events are classified in three categories which are small, medium and large disturbance on f-df/dt characteristic of an adaptive relay.

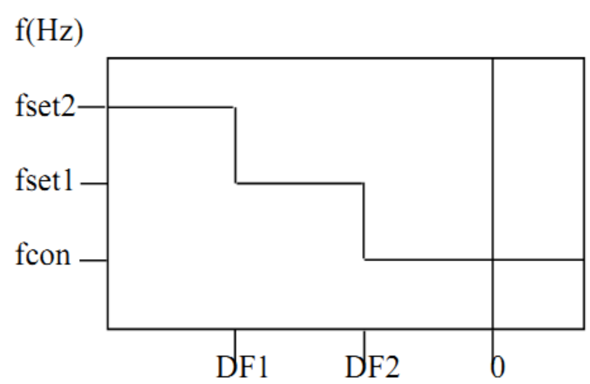


Figure 2.2: $\mathbf{f} - \frac{\mathbf{df}}{\mathbf{dt}}$ characteristic of an adaptive relay

- Small disturbances are in the region >DF2 for this region the generation outage is 25% of the total generation.
- Medium disturbance cases are in the region between DF1 and DF2 for this case the generation outage between 25% and 35% are considered.
- Large disturbance cases are in the region above DF2 for this case the Generation outage more than 35% of the total generation are considered.

The number of regions for the implementation of f-df/dt relay might vary based on the nature of power system and also the range between the normal operation range of frequency and the minimum allowable limit.

Step 3. Determine the values of DF1 and DF2.

The value of DF1 is different from one topology of the network to other, which is mainly because of the operational planning issues, scheduled maintenance on generating units, the system load, etc. Due to this fact the value of DF might vary for the same generation loss.

So, for N large disturbance cases under different network topology that can be categorized in the same region the Value of DF1 is calculated as follows: [14]

$$Min.\left(Max._{i=1}^{N} N \left|\frac{df}{dt}\right|\right) - 0.2 \quad \text{Equation (4.4)}$$

Where 0.2Hz/second is considered as safety margin, the under-frequency relays operate for all disturbance cases where |df/dt| is greater than |DF1|

DF2 is calculated in a similar way except for the type of disturbance.

For DF2, medium disturbances are used instead of large disturbances. In other words, N medium disturbances are applied to the above equation for different topology of the network.

Step 4: Determining frequency and time-delay settings:

The last stage of design is to determine the frequency and time delay settings. First, fset2 is determined. This parameter is frequency setting of relays for large disturbances.

This should be the maximum possible setting considering the output of the large disturbance events. However, too high frequency settings may endanger system security due to possibility of unnecessary load shedding and tripping of generating units by over frequency.

In some literatures the frequency setting is the same as that of the conventional method, however the load shedding is done using the defined values of DF1 and DF2 [19].

Step 5. The amount and the location of load to be shed

- The amount of load to be shed is defined based on the disturbance level and the result of the dynamic simulation for different disturbance events.
- Once, the quantity of load to be shed is decided, the buses are ranked according to their dV/dt value or voltage profile before the fault [13].

This ranking decides the order in which load will be shed. Thus, the bus with under voltage is ranked first and the load shedding starts from them and over voltage.

In the system where the voltage is suspected to rise after the loss of generation, like Ethiopian national grid, under voltage areas are selected for load shedding and other load areas that might aggravate the over voltage of the system shall be shed at last stage with proper over voltage protection coordination between the lines.

4.3.Proposed UFLS Scheme for Ethiopian National Grid

As discussed in Chapter 3. The existing under frequency protraction of the national grid is implemented long time ago where; Melka-wakena was the biggest power plant. Loss of more than 20% of generation cannot be recovered by the action of current UFLS scheme and this was the major cause of black in Ethiopia.

So, it is mandatory to revise the existing UFLS scheme for safe operation of the National grid.

The design procedure discussed in section 4.2 is used to propose new UFLS scheme for Ethiopian National Grid using both conventional and AUFLS scheme. The conventional method is considered to observe the number of stages and the time settings that can be suggested safely and later the same stages can be recommended for AUFLS scheme.

In addition, the load to be shed from each stage will be distributed to selected load areas throughout the country based on the voltage profile of different load buses. The voltage profile for substations is taken from the load flow analysis.

4.3.1. Selection of UFLS Using Conventional Method

The design of conventional UFLS scheme proposed here will consider the following outage cases. The conventional method is analyzed to observe the maximum load shedding stages between the first set point and the minimum acceptable frequency of the system.

- 33% generation loss and three stage UFLS scheme
- 45% generation loss and four stage UFLS shame
- 45% generation loss and five stage UFLS shame
- 50% generation loss and four stage UFLS scheme
- 55% generation loss and five stage UFLS scheme

The system load of 2200MW is considered for the design and design procedure for one of the sample case, that is, 33% generation loss three stage UFLS scheme, will be considered and the result for all scenarios will be summarized using the same design principle.

Design procedure for 33% Generation Loss three stage Conventional UFLS Scheme:

A. Anticipated over load

Considering loss of 33% of generation which is 726MW and using Equation (4.1) the anticipated over load (L) will be 0.5.

B. The amount of load to be shade

Considering the anticipated over load of L=0.5 and neglecting the damping factor d=0, so the total load to be shed can be found using equation (2.14) and the result is LD=0.33.

C. Number of load shedding steps

The under-frequency load shedding of Sudan is starting from 49.2Hz, whereas the Ethiopian UFLS scheme is starting from 48.6, due to this fact some time the under-frequency load shedding in Sudan will act for outage in Ethiopian grid. So, to harmonize the UFLS of both countries the first load shed point is taken to be 49.2HZ.

As it is discussed in chapter 2, the minimum allowable under frequency is 47.5Hz which is the UF tripping point of the generating units.

The three stage 33% UFLS stages shall have additional two stages between 49Hz and 47.5Hz.

D. The amount of load to be shed on each stage

Based on the study of the existing system, the amount of load to be shed will be distributed among the three stages as 100MW, 313MW, 313MW for each stage. The first stage of 100MW is selected, since; the minimum load that can reduce the frequency to 49.2Hz is 100MW. This is found from study and also from load rejection test of the national grid the frequency bias is 12MW/0.1HZ, so to make the frequency drop to 49.2Hz, approximately 100MW generation loss shall be there in the system. The load shed of the other stages is distributed evenly.

E. Under frequency load shedding set points

First stage set point

As discussed in item c, the frequency of the first stage is set at 49.2Hz and the second and the third under frequency set points will be defined using procedure mentioned under section

The system inertia H, power factor and rate of change of frequency are calculated using Equation (2.6) and the results are shown on Table 4-1.The inertia of Generating units is annexed under Input data **annex II**

Table 4-1: The Results for system inertia H, power factor and rate of change of frequency

No.	H in sec.	PF	R in Hz/Sec.
1.	3.17	0.567	2.22Hz/sec

Considering the relay operation time is 100ms and breaker operation time is 25ms, so, the frequency decrease to a value 2.22*0.125=0.277Hz (48.7Hz).

So, the actual frequency that the first stage will shade 100MW set is 48.7Hz.

Considering a safety margin of 0.2Hz, the second under frequency load shedding point will be 48.7-0.2=48.5HZ,

From the original disturbance after the action of the first stage load reduction the excess load L will become 0.37.The average rate of change of frequency R from 48.7HZ to 48.5Hz will be -1.6Hz/sec.

Considering the breaker and relay operating time it will take 0.125sec to operate for the second stage and the actual frequency that the second stage act is 48.5Hz-0.125sec*1.6Hz/sec =48.3HZ. This implies the actual frequency the load shedding of 313MW to be shed is 48.3Hz.

Considering safety margin of 0.2Hz the third stage is set at 48.3-0.2=48.1Hz, and this is the frequency set point for the last 313MW to be shed.

This sample is presented to show the steps followed to propose the conventional UFLS scheme and in similar manner the conventional load shedding is designed for the following outage cases and the results are summarized as follows:

Table 4-2: 45% five stages Conventional UFLS shame

Stage	Freq. Set point	Time delay	Amount of load to be shade in MW	Remark
1	49.20	0.1	100	
2	48.43	0.1	222.5	
3	48.12	0.1	222.5	
4	47.90	0.1	222.5	
5	47.63	0.1	222.5	

On this scheme the power deficit for the loss of 50% Generation for a system load of 2200MW is 990MW. So, the first stage shade 100MW, as this is the load that can drop the frequency to 49.2HZ and the rest deficit is evenly distributed to the three stages. The minimum frequency set point for this scheme is 47.63Hz which is above the minimum acceptable frequency of 47.5HZ.

Table 4-3: 50% four stages Conventional UFLS

Stage	Freq. Set point	Time delay	Amount of load to be shade	Remark
1	49.20	0.1	100	
2	48.40	0.1	333	
3	48.10	0.1	333	
4	47.85	0.1	333	

On this scheme the power deficit for the loss of 50% Generation for a system load of 2200MW is 1100MW. So, the first stage scheme 100MW, as this is the load that can drop the frequency to 49.2HZ and the rest deficit is evenly distributed to the three stages. However, the amount of load to be shed on the second, third and fourth stage is higher than the 45% five cases considered above, which might lead to unnecessary load shedding for some small disturbance cases.

The minimum frequency set point for this scheme is 47.85Hz which is above the minimum acceptable frequency of 47.5HZ.

Table 4-4: 50% five stages Conventional UFLS shame

Stage	**Freq. Set point**	**Time delay**	**Amount of load to be shade**	**Remark**
1	49.20	0.1	220	
2	48.39	0.1	220	
3	48.05	0.1	220	
4	47.77	0.1	220	
5	47.54	0.1	220	Very near to Generator

On this scheme the power deficit for the loss of 50% Generation for a system load of 2200MW is 1100MW. So, the first stage shade 100MW, as this is the load that can drop the frequency to 49.2HZ and the rest deficit is evenly distributed to the three stages. The amount of load to be shed on this case is lower than the 50% four stage UFLS scheme, but the last stage is almost on the lower acceptable frequency of 47.5HZ, So, this stage is not safe to apply and might lead the system to total blackout.

Result summary for conventional UFLS Scheme

As is observed the proposed conventional UFLS that can be safely implemented is five sages 45% generation loss. The 50% four stage is also feasible but the amount of load to be shed on second, third and fourth stages are higher and might lead to unnecessary load shading for minor disturbance cases.

4.3.2. Selection of Adaptive Under Frequency Load Shedding

AUFLS is discussed in section 4.2 and the same selection procedure is used for the proposal of new AUFLS scheme.

A. System model for Dynamic analysis

The system is modeled for dynamic analysis in PSSE software and all the data is updated to represent the current state of the national Grid.

PSSE software is used for the modeling and analysis of the system.

B. Application of Disturbance

In Ethiopian National Grid Operation, the loading of the network is different for different time of the day which makes the rate of change of frequency to be different for the same percentage of generation loss. The topology change is mainly for the following reasons:

- ✓ System load which is available within the day and the resulting unit commitment. On the current operation practice the day time and the peak load scenario of the grid does not have significant change on the inertia of the system where as the day time load is 80% of the peak load.
  The evening time load is around 60% of the peak load and the system topology is different than the day and night time topology of the grid.
- ✓ Operational planning issues which is to be done to effectively utilize the energy of the dams till the next rainy season
- ✓ Is the system isolated or the interconnection with Sudan and Djibouti is available? (particularly the presence of Sudan interconnection has significant impact on the system inertia)For this thesis the network topology for night time, day time and peak load scenarios will be studied for defining DF values.

As it is observed on the design of the conventional UFLS scheme, the maximum number of stages that can be defined between 49.2Hz and 47.5Hz safely is five for 45% Generation outage and is four for 50% generation outage.

For this thesis AUFLS with four regions that was recommended for conventional UFLS design will be considered and also 50% generation loss is analyzed as maximum outage case.

Determining the Rate of Change of Frequency (ROCOF) from the PSSE Simulation Output

Network Scenarios Considered for Disturbance Analysis

In this thesis three major scenarios are considered for disturbance analysis

- ✓ Peak load scenario: - peak load is 2200MW with regional interconnection to Sudan and

Djibouti

- ✓ Day time load scenario with load of 80% of the peak load which is 1760MW, with regional interconnection to Sudan and Djibouti.
- ✓ Light load scenario: - with system load of 60% of the peak load which is 1320MW.

For all scenarios, the system inertia is almost the same, since the generating units shall stay synchronized in the grid for voltage regulation, even though the demand is decreased. The system response for outage cases during evening time loading not significant, since there is enough reserve during this time both in Sudan and Ethiopian Grid.

So, on this thesis more attention is given for peak load and day time loading scenario of the system.

For the determination of the rate of change of frequency the PSSE result output (frequency vs time curve) is used as an input for under frequency relays.

The effective rate of change of frequency used by the relay is calculated by measuring the frequency and time for the first 3-5 cycles and taking the average. The same method is used in this thesis for determining the effective rate of change of frequency.

The rate of change of frequency for all disturbance category and events considered for the proposal of AUFLS scheme are presented as follows:

ROCOF for Outage Scenarios for Peak load scenario of the Network

For all disturbance cases considered which are 50%, 40%, 30%, 20% and 10% generation loss scenarios the system is operating smoothly and the disturbance is created on the 5th second. The system frequency response for the disturbance cases considered is as follow:

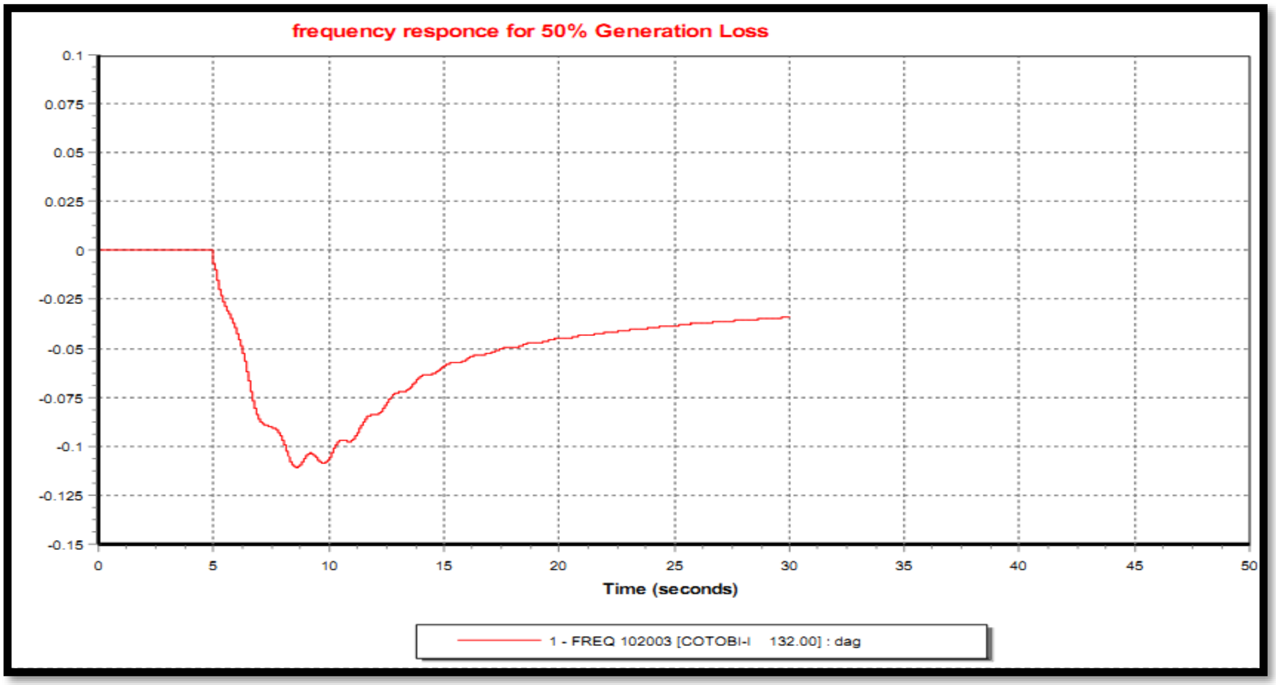


Chart 4-1: Frequency response for 50% generation loss

Table 4-5: Summary of frequency response for 50% generation loss

	F1(PU)	F2(pu)	Df(PU)	df(Hz)	Df/dt
R1	0	0.01563	0.01563	0.7815	3.9075
R2	0.01563	0.02474	0.00911	0.4555	2.2775
R3	0.02474	0.0301	0.00536	0.268	1.34
R4	0.0301	0.03506	0.00496	0.248	1.24
				Average	2.19125

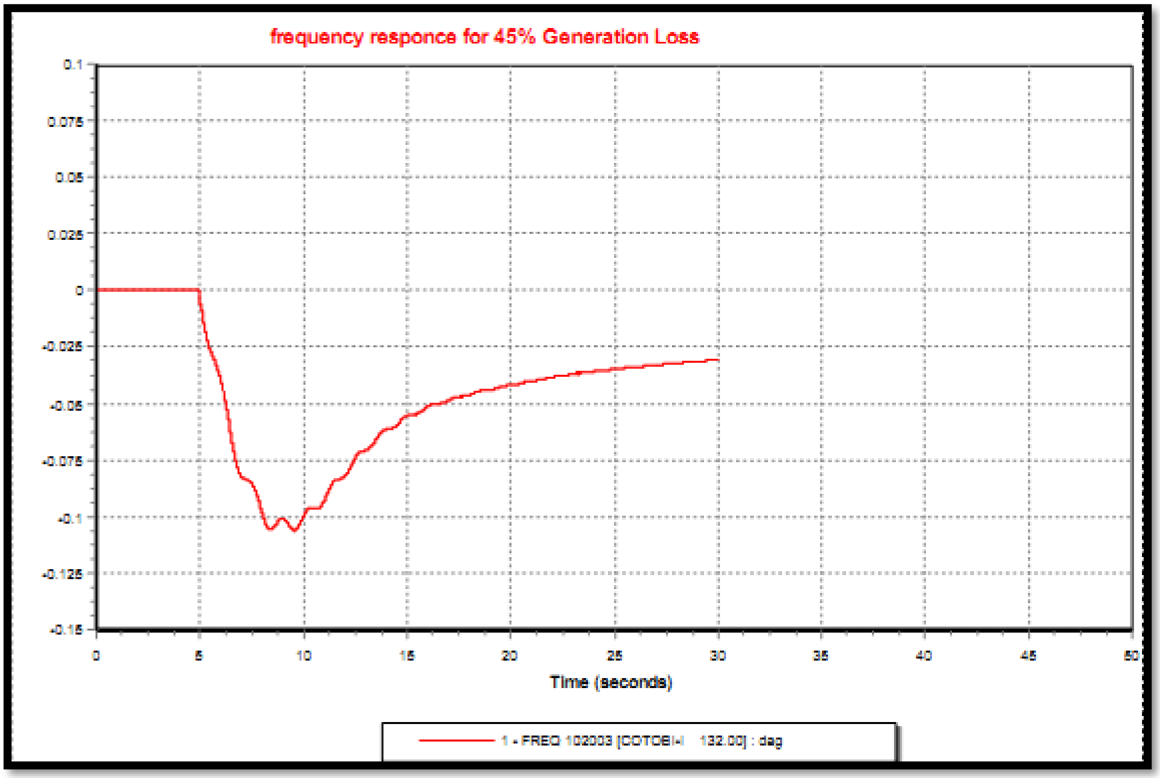


Chart 4-2: Frequency response for 45% generation loss

Table 4-6: Summary of frequency response for 45% generation loss

	F1(PU)	F2(pu)	Df(PU)	df(Hz)	Df/dt
R1	0	0.01488	0.01488	0.744	3.72
R2	0.01488	0.02366	0.00878	0.439	2.195
R3	0.02366	0.02885	0.00519	0.2595	1.2975
R4	0.02885	0.03353	0.00468	0.234	1.17
				Average	2.095625

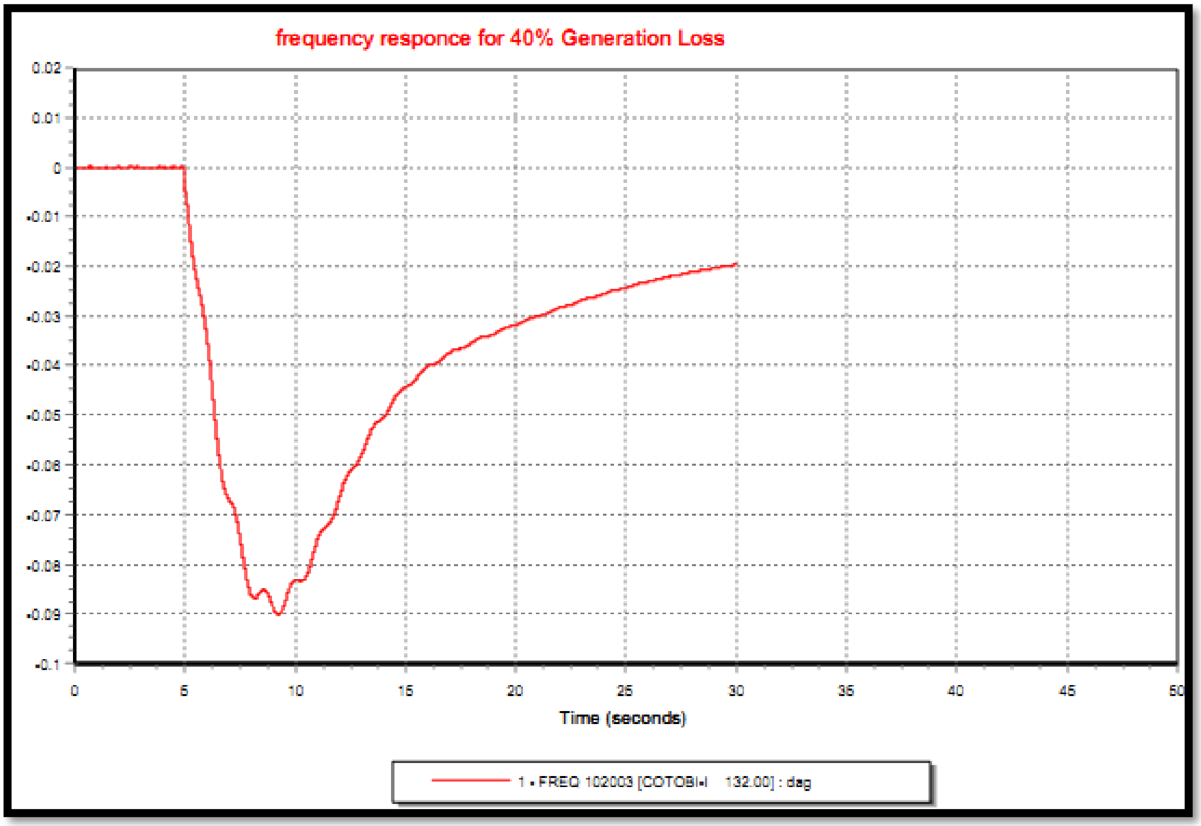


Chart 4-3: Frequency response for 40% generation loss

Table 4-7: Summary of frequency response for 40% generation loss

	F1(PU)	F2(pu)	Df(PU)	df(Hz)	Df/dt
R1	0	0.01229	0.01229	0.6145	3.0725
R2	0.01229	0.01962	0.00733	0.3665	1.8325
R3	0.01962	0.02429	0.00467	0.2335	1.1675
R4	0.02429	0.028555	0.004265	0.21325	1.06625
				Average	1.784688

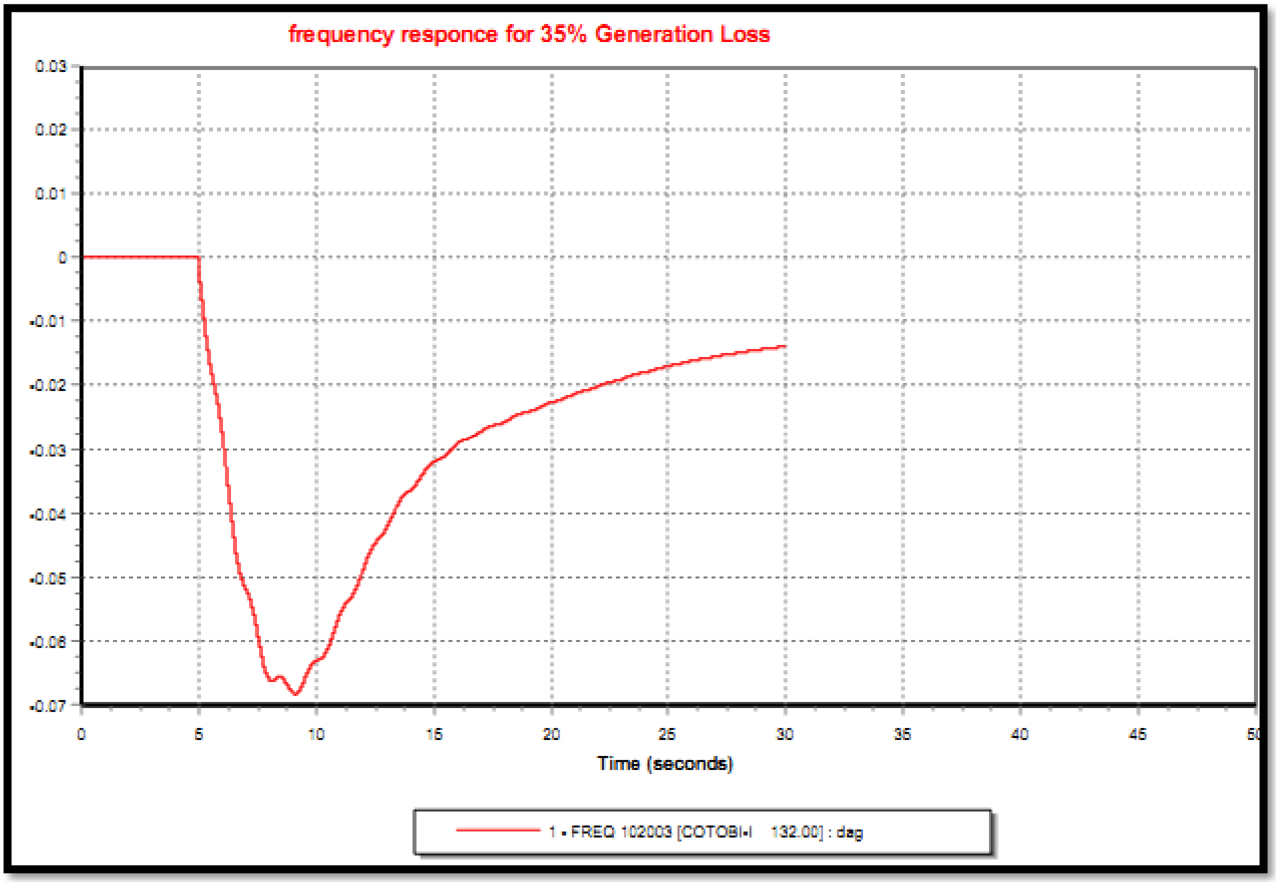


Chart 4-4: Frequency response for 35% generation loss

Table 4-8: Summary of frequency response for 35% generation loss

	F1(PU)	F2(pu)	Df(PU)	df(Hz)	Df/dt
R1	0	0.00894	0.00894	0.447	2.235
R2	0.00894	0.01489	0.00595	0.2975	1.4875
R3	0.01489	0.01903	0.00414	0.207	1.035
R4	0.01903	0.02279	0.00376	0.188	0.94
				Average	1.424375

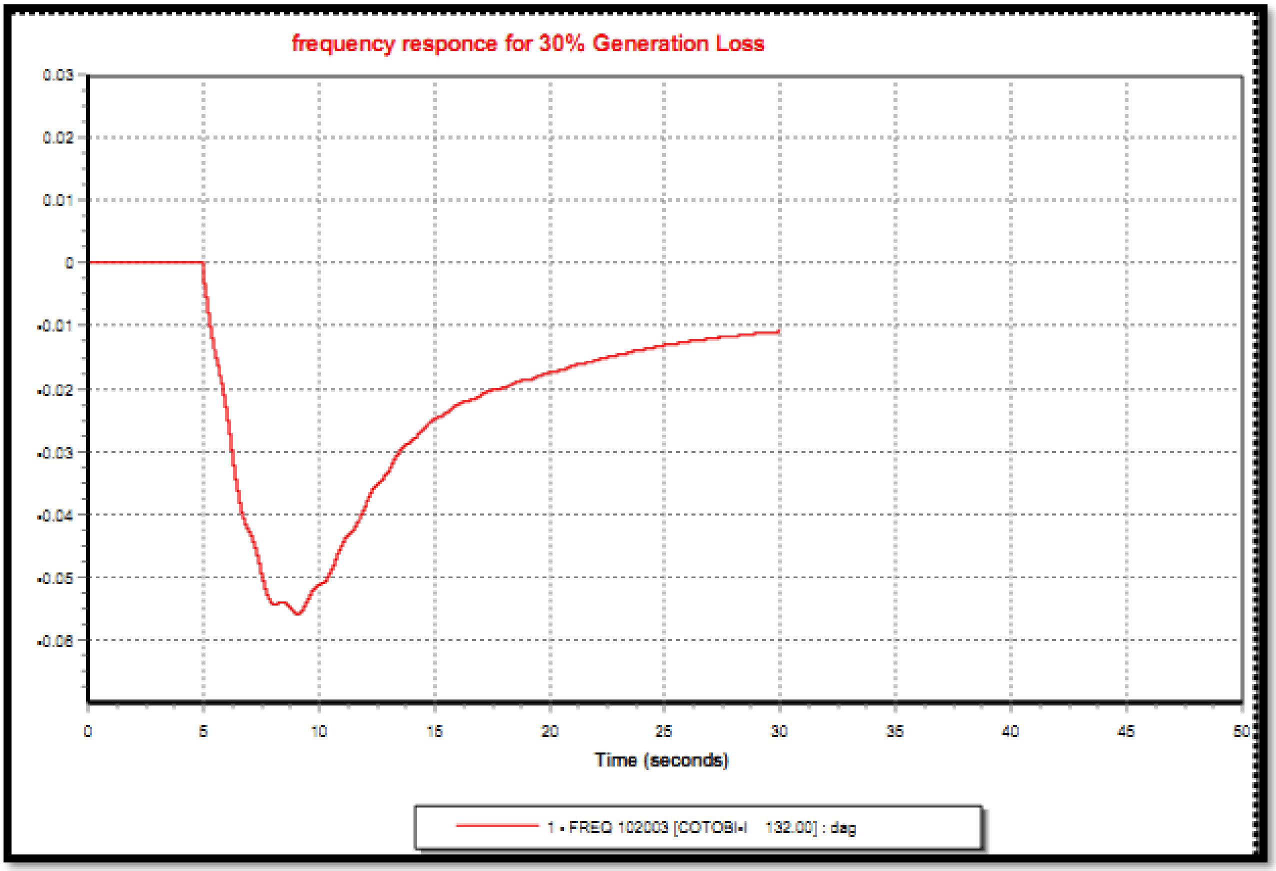


Chart 4-5: Frequency response for 30% generation loss

Table 4-9: Summary of frequency response for 30% generation loss

	F1(PU)	F2(pu)	Df(PU)	df(Hz)	Df/dt
R1	0	0.00732	0.00732	0.366	1.83
R2	0.00732	0.01234	0.00502	0.251	1.255
R3	0.01234	0.01584	0.0035	0.175	0.875
R4	0.01584	0.01905	0.00321	0.1605	0.8025
				Average	1.190625

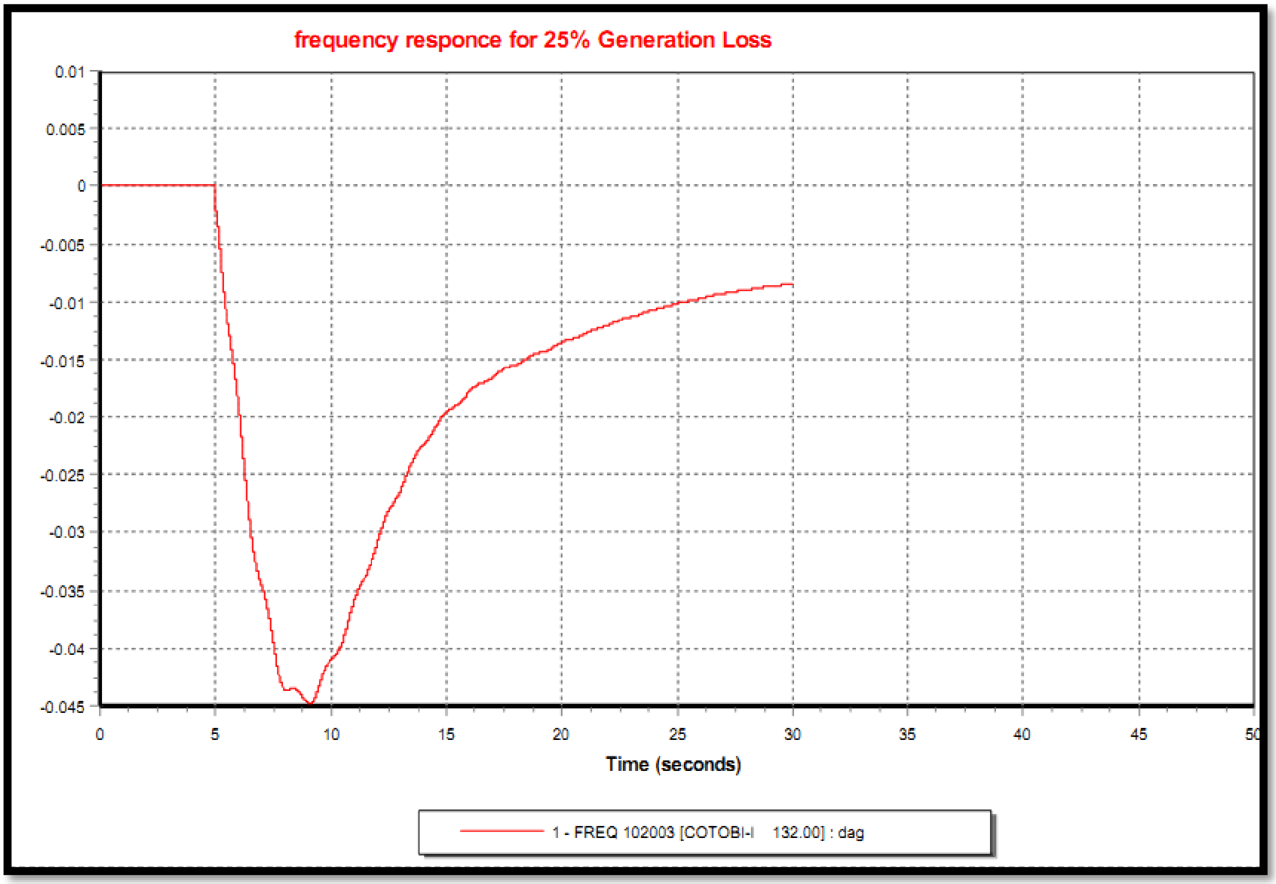


Chart 4-6: Frequency response for 25% generation loss

Table 4-10: Summary of frequency response for 25% generation loss

	F1(PU)	F2(pu)	Df(PU)	df(Hz)	Df/dt
R1	0	0.00576	0.00576	0.288	1.44
R2	0.00576	0.00989	0.00413	0.2065	1.0325
R3	0.00989	0.01281	0.00292	0.146	0.73
R4	0.01281	0.01548	0.00267	0.1335	0.6675
				Average	0.9675

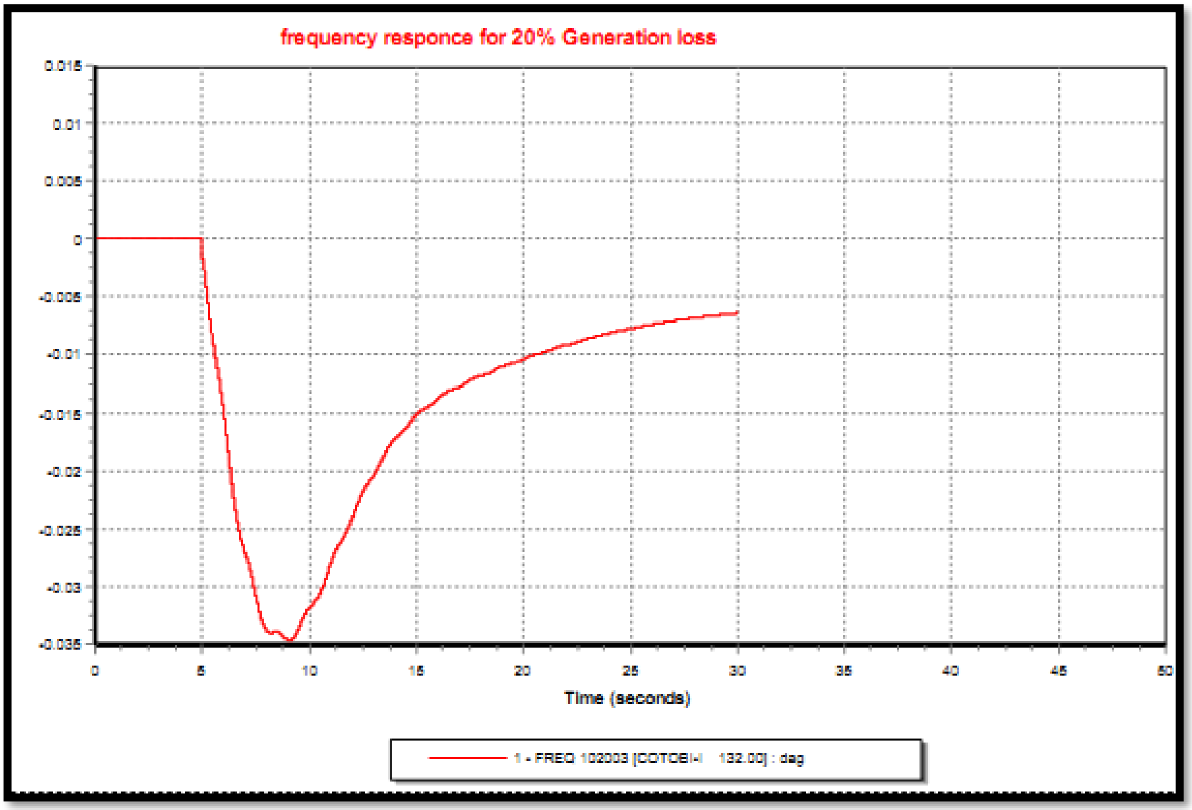


Chart 4-7: Frequency response for 20% generation loss

Table 4-11: Summary of frequency response for 20% generation loss

	F1(PU)	F2(pu)	Df(PU)	df(Hz)	Df/dt
R1	0	0.00433	0.00433	0.2165	1.0825
R2	0.00433	0.0075	0.00317	0.1585	0.7925
R3	0.0075	0.00997	0.00247	0.1235	0.6175
R4	0.00997	0.01222	0.00225	0.1125	0.5625
				Average	0.76375

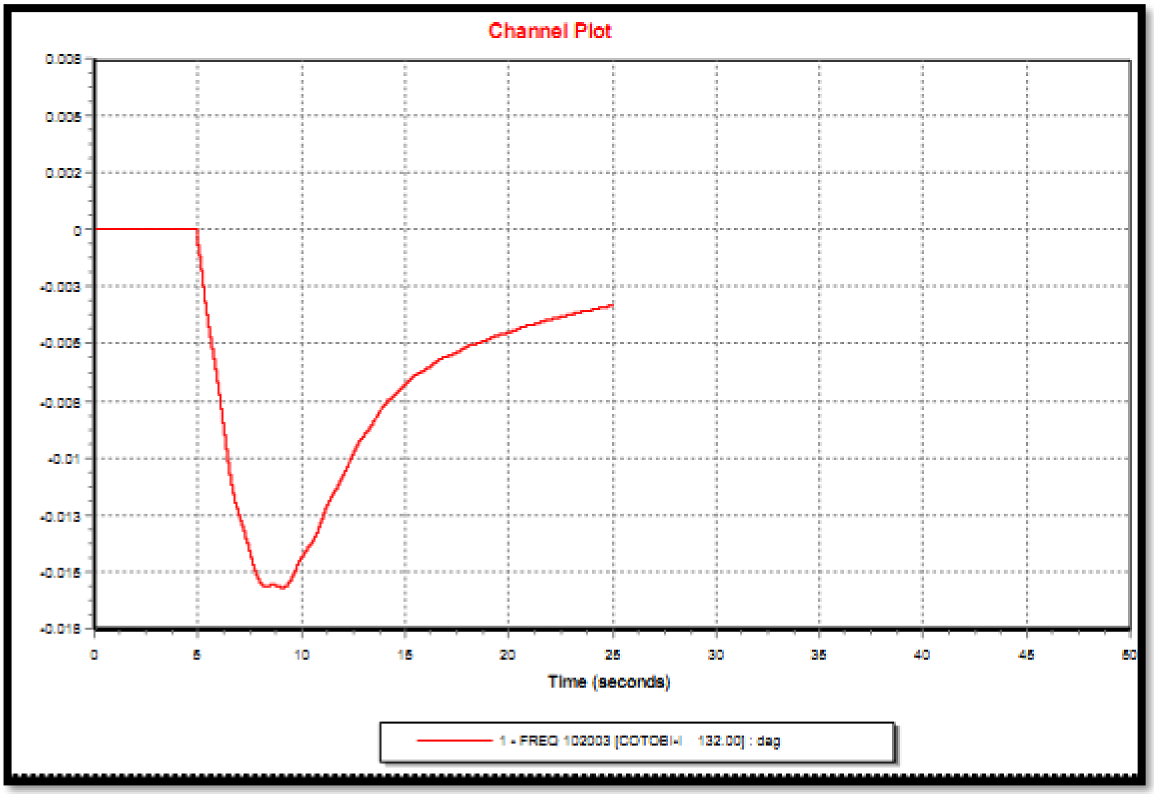


Chart 4-8: Frequency response for 10% generation loss

Table 4-12: Summary of frequency response for 10% generation loss

	F1(PU)	F2(pu)	Df(PU)	df(Hz)	Df/dt
R1	0	0.00205	0.00205	0.1025	0.5125
R2	0.00205	0.00349	0.00144	0.072	0.36
R3	0.00349	0.00481	0.00132	0.066	0.33
R4	0.00481	0.00593	0.00112	0.056	0.28
				Average	0.370625

Table 4-13: Summary of rate of change of frequency for peak load scenario of the system

Disturbance level	Percentage Loss of Generation	Mw. Lost	Max. Df/Dt In Hz/sec.	Average. Df/dt in Hz/sec.	Remark
Small	10	220	0.5125	0.37	
	20	440	1.08	0.76	
Medium	35	770	2.24	1.42	
	40	880	3.07	1.78	
Large	45	990	3.72	2.09	
	50	1100	3.91	2.19	

Table 4-14: Summary of rate of change of frequency for day time load scenario of the system

System load at day time of the day is 80% of the system peak which is 1760MW

Disturbance level	Percentage Loss of Generation	Mw. Lost	Max. Df/Dt In Hz/sec.	Average. Df/dt in Hz/sec.	Remark
Small	10	176	0.40	0.25	
	20	352	0.90	0.59	
Medium	35	616	1.83	1.19	
	40	704	2.24	1.42	
Large	45	792	3.07	1.78	
	50	880	3.72	2.09	

C. Define the values of DF1, DF2, DF3 and DF4

Based on the result of the disturbance analysis conducted under item B. DF1, DF2, DF3 and DF4 are defined as shown on Table.4.11.

Table 4-15: Values of DF1, DF2 and DF4

Relay Characteristic input	DF1(Hz/sec)	DF2(Hz/sec)	DF3(Hz/sec)	Remark
	0.39	1.22	1.9	

4.3.3. Determining the frequency set point and the time delay

The AUFLS is proposed to have four stages which are 49.2Hz, 49Hz, 48.4 and 48.1Hz which are taken from four stages conventional UFLS selection scheme.

As it is discussed under section 4.1, for conventional UFLS scheme selection the first stage of 49.2Hz is selected to harmonize to the Sudan UFLS scheme and the second and the third stages that shall be set is taken from four stages conventional UFLS considering the same time delay.

Considering safety margin of 0.2Hz, the second stage pickup at a frequency of 49.0Hz, the third stage pickup at 48.4Hz and the fourth stage pickup at frequency of 48.1Hz

The set point and load shedding amount for all proposed stages are shown on Table 4-16:

Table 4-16: Summary of set point and load shedding amount for all proposed stages

Freq. pickup (Hz)	STAGE 1	STAGE2	STAGE 3	STAGE 4
	Drop of Load for F=49.2Hz	DF1=0.39	DF2=1.22	DF3=1.9
49.2	100			
49.0		340		
48.4			440	
48.1				220

On stage one 100MW is disconnected to keep the tie line to scheduled value.

The second stage reduce a total of 440MW load is shed and this stage pickup at 49Hz and reduce the specified amount of load at DF1=0.39Hz/Sec.

The third stage reduce a total of 880MW including 440MW load reduction from the first and second stages. This stage picks up at 48.4Hz and reduces the specified amount of load at DF2=1.22Hz/sec.

The fourth stage reduce a total of 1100MW including 880MW load reduction from the first, second and third stages. This stage pickup at 48.1Hz and reduces the specified amount of load at DF3=1.9Hz/sec.

The load to be shed on each stage and the total load to be shed for each stage is summarized on Table 4-9:

Table 4-17: Minimum and the maximum load to be shed for each stage

Load shed(MW)	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
Load shed on this stage	100	340	440	220
Total		440	880	1100

4.3.4. Selecting the load feeders for load shedding

Under frequency load shedding schemes have been widely used, to restore power system stability post major disturbances. However, the analysis of recent blackouts suggests that voltage collapse and voltage-related problems are also important concerns in maintaining system stability. For this reason, both frequency and voltage need to be taken into account in load shedding schemes. The location for load shedding is selected based on the voltage before the disturbance.

The following steps are suggested for the selection of load shedding Locations:

- ✓ Rate all substations in each region based on their voltage from minimum to maximum and for ratting purpose distribution bus bar voltage is considered.

The 33 and 15KV distribution bus bars in the National Grid for peak our scenario of loading is ranked as follow: -

Table 4-18: The 33 and 15KV distribution bus bars loading in the National Grid for peak our scenario.

Bus ranking number	Bus Number	Bus Name	Base kV	Area Name	Zone Name	Voltage (pu)	Pload (MW)	Qload (Mvar)	Pload shed (MW)
1	807013	PAWIE	15	NORTH WEST	BENSHANGUL-G	0.7404	1.9813	0.9589	1.18878
2	807017	PAWIE	33	NORTH WEST	BENSHANGUL-G	0.7475	2.4204	1.2102	1.45224
3	805021	NEGELE-BORNA	15	SOUTH	OROMIA	0.7703	1.9103	0.9247	1.14618
4	805013	NEGLE-BORENA	33	SOUTH	OROMIA	0.7761	1.5894	0.7693	0.95364
5	805020	DILLA-2	15	SOUTH	S.N.N.P	0.7845	7.4172	3.3907	4.45032
6	805016	SHAKISO	15	SOUTH	OROMIA	0.8002	5.4217	1.946	3.25302
7	805044	AWASA	15	SOUTH	S.N.N.P	0.8092			0
8	805039	AWASA	33	SOUTH	S.N.N.P	0.8139	2.3268	1.1263	1.39608
9	807033	DANGLA	15	NORTH WEST	AMHARA	0.8142			0
10	807020	DANGLA	33	NORTH WEST	AMHARA	0.8148	2.6382	1.2769	1.58292
11	805009	DILLA	33	SOUTH	S.N.N.P	0.8229	1.2716	0.6154	0.76296
12	807036	BITCHENA	15	NORTH WEST	AMHARA	0.8287			0
13	807024	BITCHENA	33	NORTH WEST	AMHARA	0.8305	7.9584	3.8519	4.77504
14	805026	SHAKISO	33	SOUTH	S.N.N.P	0.837	2.9045	1.4058	1.7427
15	809018	HUMERA	15	NORTH	TIGRAY	0.8372	2.419	1.1708	1.4514
16	805022	YIRGALEM	15	SOUTH	S.N.N.P	0.8447	5.7218	1.0597	3.43308
17	806020	WOLDIA	15	NORTH EAST	AMHARA	0.847			0
18	806013	WOLDIA	33	NORTH EAST	AMHARA	0.8477	1.8747	0.9073	1.12482
19	805004	BALEROBE	15	SOUTH	OROMIA	0.8491			0
20	805003	BALEROBE	33	SOUTH	OROMIA	0.85	1.9073	0.9231	1.14438

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21	805030	SHASHEMENE	33	SOUTH	S.N.N.P	0.8556	0.3602	0.1743	0.21612
22	802016	MUGGER 33	33	CENTRAL	OROMIA	0.8569	6.9192	3.3489	4.15152
23	805045	SHASHEMENE-1	15	SOUTH	OROMIA	0.8573	4.5793	1.0649	2.74758
24	802051	ADAMI TULU	33	CENTRAL	OROMIA	0.8579	4.355	2.1086	2.613
25	805023	YIRGALEM	33	SOUTH	S.N.N.P	0.8594	2.1192	1.0257	1.27152
26	802003	FICHE	15	CENTRAL	OROMIA	0.861	3.7165	1.7989	2.2299
27	802061	ADAMI TULU	15	CENTRAL	OROMIA	0.8639			0
28	809004	HUMERA	33	NORTH	TIGRAY	0.8648	8.4228	4.0765	5.05368
29	802004	FITCHE	33	CENTRAL	OROMIA	0.8668	0.9649	0.467	0.57894
30	805011	H-MARIAM	33	SOUTH	OROMIA	0.867	5.9438	2.8729	3.56628
31	805043	AWASA MOBILE	15	SOUTH	S.N.N.P	0.8683	8.4768	4.1027	5.08608
32	805008	BOCU LUGUMA	33	SOUTH	OROMIA	0.8756	2.9422	1.4265	1.76532
33	805042	AWASA MOBILE	33	SOUTH	S.N.N.P	0.8764	3.2814	1.5862	1.96884
34	802009	ADDIS ALEM	15	CENTRAL	OROMIA	0.8766	6.8552	3.3186	4.11312
35	802022	GINCHI 15	15	CENTRAL	OROMIA	0.8794	1.3554	0.6583	0.81324
36	802021	MUGER	15	CENTRAL	OROMIA	0.8798	1.0541	0.5102	0.63246
37	802011	GINCHI 15	15	CENTRAL	OROMIA	0.8827	0.6777	0.3292	0.40662
38	809029	ABIADI MB	33	NORTH	TIGRAY	0.8834	5.7168	2.7669	3.43008
39	809028	ABIADI MB	15	NORTH	TIGRAY	0.8838	2.7615	1.3366	1.6569
40	803004	ALEMAYA-33	33	EAST	OROMIA	0.8861	3.4886	1.6885	2.09316
41	802025	AWASH-7KL	15	CENTRAL	OROMIA	0.8974	3.0228	1.463	1.81368
42	809008	SHIRE	15	NORTH	TIGRAY	0.8989	8.5258	4.1265	5.11548
43	809013	SHIRE	33	NORTH	TIGRAY	0.9013	5.5946	2.7078	3.35676

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44	806018	COMBOL-II	33	NORTH EAST	AMHARA	0.909			0
45	809001	ADIGRAT	15	NORTH	TIGRAY	0.91	6.5641	3.1755	3.93846
46	807035	DABAT	15	NORTH WEST	AMHARA	0.9122			0
47	807027	DABAT	33	NORTH WEST	AMHARA	0.9123	8.8	4.2592	5.28
48	807022	DANGLA	15	NORTH WEST	AMHARA	0.9133	1.6353	0.7915	0.98118
49	801087	SEBETA1	15	ADDIS ABABA	ADDIS ABABA	0.9146	13.3002	6.4374	7.98012
50	802052	ASSELA	33	CENTRAL	OROMIA	0.9158	0.2649	0.1282	0.15894
51	802062	ASSELA	15	CENTRAL	OROMIA	0.9165			0
52	802077	BUTAJIRA	15	CENTRAL	S.N.N.P	0.9181	6.4915	3.1419	3.8949
53	806022	SHEWA-ROBIT	15	NORTH EAST	AMHARA	0.92			0
54	801016	SULULTA	33	ADDIS ABABA	OROMIA	0.9229	5.9462	2.8779	3.56772
55	801020	SULULTA	33	ADDIS ABABA	OROMIA	0.9229	55.8938	27.073	33.53628
56	807034	WORETA	15	NORTH WEST	AMHARA	0.9254			0
57	809034	ADIGRAT	15	NORTH	TIGRAY	0.9259	6.4575	3.1272	3.8745
58	807014	WORETA	33	NORTH WEST	AMHARA	0.926	1.1992	0.5804	0.71952
59	809006	MEKELE	15	NORTH	TIGRAY	0.9269	56.4934	27.343	33.89604
60	806014	SHEWA-ROBIT	33	NORTH EAST	AMHARA	0.9274	3.8874	1.8751	2.33244
61	806008	WOLDIA	15	NORTH EAST	AMHARA	0.9281	4.2499	2.0569	2.54994
62	807001	BAHIR DAR1	15	NORTH WEST	AMHARA	0.9296	5.086	2.9669	3.0516
63	801059	GELAN	15	ADDIS ABABA	ADDIS ABABA	0.93	25.9662	12.568	15.57972
64	801065	GELAN	15	ADDIS ABABA	ADDIS ABABA	0.9301	24.3708	6.6754	14.62248
65	801030	GEFERSA2	15	ADDIS ABABA	OROMIA	0.9302	53.4547	10.204	32.07282
66	801062	GELAN	15	ADDIS ABABA	ADDIS ABABA	0.9302			0

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67	809030	MEKELE MB	15	NORTH	TIGRAY	0.9318	9.4724	4.5846	5.68344
68	806019	DESSIE	15	NORTH EAST	AMHARA	0.9332	7.4547	3.6081	4.47282
69	808003	GAMBELA2	33	SOUTH WEST	GAMBELA	0.9362	0.8477	0.4103	0.50862
70	802074	DUKEM	15	CENTRAL	OROMIA	0.9369	1.5199	0.7357	0.91194
71	801008	BOLE-LEMI MB	15	ADDIS ABABA	ADDIS ABABA	0.9382	3.6026	0.5404	2.16156
72	801037	GEFERSA	15	ADDIS ABABA	OROMIA	0.9395	45.2614	21.921	27.15684
73	802080	BUTAJIRA33	33	CENTRAL	S.N.N.P	0.9399	3.3251	1.6094	1.99506
74	805029	HOSAINA	33	SOUTH	S.N.N.P	0.94	1.4834	1.6953	0.89004
75	805007	AWASA	15	SOUTH	S.N.N.P	0.9403	25.9813	12.575	15.58878
76	802069	DUKEM	15	CENTRAL	OROMIA	0.9407	1.2393	0.5998	0.74358
77	805036	ARBA MINCH	33	SOUTH	S.N.N.P	0.9415	2.8609	1.3846	1.71654
78	801014	BOLE-LEMI MB	33	ADDIS ABABA	ADDIS ABABA	0.9429			0
79	801025	COTOBIE-15B1	15	ADDIS ABABA	ADDIS ABABA	0.9441	8.2854	4.0101	4.97124
80	809033	ADWA	15	NORTH	TIGRAY	0.9442	8.3648	4.0469	5.01888
81	809036	MEKELE	15	NORTH	TIGRAY	0.9442			0
82	802002	DEBRE BERHAN	15	CENTRAL	AMHARA	0.9447	2.8079	1.359	1.68474
83	809002	ADWA	15	NORTH	TIGRAY	0.945	13.3605	6.4672	8.0163
84	805046	ALABA	15	SOUTH	S.N.N.P	0.9465			0
85	809025	MEKELLE	33	NORTH	TIGRAY	0.9473	1.6953	0.8205	1.01718
86	805015	SAWLA	33	SOUTH	S.N.N.P	0.9474	2.4371	3.7086	1.46226
87	802073	DUKEM	15	CENTRAL	OROMIA	0.9475	0.7455	0.3608	0.4473
88	805012	HOSAINA	15	SOUTH	S.N.N.P	0.9479	6.3479	3.0724	3.80874
89	807032	GONDAR2	15	NORTH WEST	AMHARA	0.9491			0

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90	801029	GEFARSA-3	15	ADDIS ABABA	OROMIA	0.9495	0.4132	-0.371	0.24792
91	807007	GONDAR2	33	NORTH WEST	AMHARA	0.9497	1.5808	0.7652	0.94848
92	806017	DESSIE	33	NORTH EAST	AMHARA	0.9525			0
93	808006	METU	15	SOUTH WEST	OROMIA	0.9527	6.5695	3.1795	3.9417
94	802079	WOLKITE	33	CENTRAL	S.N.N.P	0.9529	5.9961	2.902	3.59766
95	805005	ALABA	15	SOUTH	S.N.N.P	0.9531	6.7814	3.2822	4.06884
96	808022	JIMMA OLD	15	SOUTH WEST	OROMIA	0.9532	14.0926	6.8208	8.45556
97	802013	MUGER	15	CENTRAL	OROMIA	0.9535	3.6208	1.7523	2.17248
98	807004	DABAT	15	NORTH WEST	AMHARA	0.9537	3.1219	1.511	1.87314
99	801028	GEFERSA	15	ADDIS ABABA	OROMIA	0.9545	36	18	21.6
100	801004	SULULTA-15	15	ADDIS ABABA	OROMIA	0.9546		0	0
101	805006	ARBA MINCH	15	SOUTH	S.N.N.P	0.9551	20.841	10	12.5046
102	808026	MIZAN	15	SOUTH WEST	OROMIA	0.9553	3.1259	1.5129	1.87554
103	808001	DEMBI DO	15	SOUTH WEST	OROMIA	0.9555	2.6066	1.2616	1.56396
104	801076	SEBETA1	15	ADDIS ABABA	ADDIS ABABA	0.9555			0
105	809023	ADIGRAT	33	NORTH	TIGRAY	0.9557	0.9939	0.4811	0.59634
106	808004	METU	33	SOUTH WEST	OROMIA	0.9558	0.7205	0.3487	0.4323
107	805047	WOLAYTA SODO	15	SOUTH	S.N.N.P	0.956	9.6814	4.6859	5.80884
108	805028	WOLAYTA SODO	33	SOUTH	OROMIA	0.9566	1.3563	0.6564	0.81378
109	808018	TEPI	15	SOUTH WEST	S.N.N.P	0.9567	2.8291	0.9505	1.69746
110	802001	D BEREHAN-33	33	CENTRAL	AMHARA	0.9567	6.3365	3.0668	3.8019
111	808011	AGARO	15	SOUTH WEST	OROMIA	0.9568	7.2123	3.4907	4.32738
112	801003	COTOBIE-15B1	15	ADDIS ABABA	ADDIS ABABA	0.9569	0		0

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113	808017	MIZAN	33	SOUTH WEST	S.N.N.P	0.957	1.0172	0.4923	0.61032
114	801038	GEFERSA	15	ADDIS ABABA	OROMIA	0.9575			0
115	802010	DERBA-33	33	CENTRAL	OROMIA	0.958	2.1365	0.0842	1.2819
116	802078	WOLISO	15	CENTRAL	OROMIA	0.9582	7.3835	3.5736	4.4301
117	809014	SHIRE-33-2	15	NORTH	TIGRAY	0.9584	0	0	0
118	807003	BITCHENA	15	NORTH WEST	AMHARA	0.9584	1.338	0.6476	0.8028
119	805025	KEY AFER 33	33	SOUTH	S.N.N.P	0.9584	1.6318	0.7898	0.97908
120	801013	BOLE ARABSA	15	ADDIS ABABA	ADDIS ABABA	0.9587	49.0594	16.275	29.43564
121	801026	ADDIS NORTH	15	ADDIS ABABA	ADDIS ABABA	0.9589			0
122	802067	DEBRE-ZEIT1	15	CENTRAL	OROMIA	0.9592	4.0663	1.9654	2.43978
123	801002	B.WRGENU	15	ADDIS ABABA	ADDIS ABABA	0.9593			0
124	801074	GEDJA	15	ADDIS ABABA	ADDIS ABABA	0.9593			0
125	801050	YESU	15	ADDIS ABABA	OROMIA	0.9599			0
126	802081	WOLISO-33	33	CENTRAL	OROMIA	0.96	2.5074	1.2136	1.50444
127	801005	ADDIS-EAST 2	15	ADDIS ABABA	ADDIS ABABA	0.9603	5.5629	2.3099	3.33774
128	808021	TEPI	33	SOUTH WEST	S.N.N.P	0.9604	0	0	0
129	801010	LEGETAFO	15	ADDIS ABABA	ADDIS ABABA	0.9605	0.3842	0.2163	0.23052
130	801077	SABATA-II33	33	ADDIS ABABA	OROMIA	0.9606			0
131	805002	BALEROBE	15	SOUTH	OROMIA	0.961	6.3576	1.2715	3.81456
132	805014	SHASHEMENE-1	15	SOUTH	OROMIA	0.9611	15.3354	3.8339	9.20124
133	801031	TORHAYLO GIS	15	ADDIS ABABA	ADDIS ABABA	0.9611	36.4502	8.9006	21.87012
134	801012	AYAT GIS	15	ADDIS ABABA	ADDIS ABABA	0.9611	36.4786	17.656	21.88716

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135	801011	COTTEBEI	33	ADDIS ABABA	ADDIS ABABA	0.9611			0
136	804009	FINCHA-SUG 2	15	WEST	OROMIA	0.9613	2.8584	1.3835	1.71504
137	802082	WOLKITE	15	CENTRAL	S.N.N.P	0.9613	4.9554	2.3984	2.97324
138	805048	HOSAINA	15	SOUTH	S.N.N.P	0.9613			0
139	805017	WOLAYTA SODO	15	SOUTH	S.N.N.P	0.9614	6.934	3.3561	4.1604
140	809024	WUKRO	33	NORTH	TIGRAY	0.9621	0.9906	0.4953	0.59436
141	808008	DEMBI DO	33	SOUTH WEST	GAMBELA	0.9623	1.2716	0.6154	0.76296
142	807018	WORETA	15	NORTH WEST	AMHARA	0.9627	3.2954	1.595	1.97724
143	801088	SEBETA1	15	ADDIS ABABA	ADDIS ABABA	0.9627	4.0264	1.9488	2.41584
144	808002	GAMBELA1	15	SOUTH WEST	GAMBELA	0.9628	3.7086	1.7949	2.22516
145	801049	NEFASILK	15	ADDIS ABABA	ADDIS ABABA	0.9628	4.2762	2.0695	2.56572
146	809011	WUKRO	15	NORTH	TIGRAY	0.963	6.5272	3.1592	3.91632
147	806009	KEMISS33	33	NORTH EAST	AMHARA	0.9633	2.5268	0.9616	1.51608
148	802040	GOBESSA	33	CENTRAL	OROMIA	0.9636	2.8127	1.3595	1.68762
149	804004	ASSOSA	15	WEST	BENSHANGUL-G	0.9643	2.702	0.6199	1.6212
150	807016	GONDAR2	15	NORTH WEST	AMHARA	0.9647	13.5034	6.5357	8.10204
151	801001	ADDIS-EAST1	15	ADDIS ABABA	ADDIS ABABA	0.9652	0	0	0
152	801007	SULULTA-33	33	ADDIS ABABA	OROMIA	0.9653	17.359	3.8339	10.4154
153	801006	COTOBIE-15B2	15	ADDIS ABABA	ADDIS ABABA	0.9657	45.3322	21.841	27.19932
154	804001	ASSOSA	33	WEST	BENSHANGUL-G	0.9662	0.1971	0.4292	0.11826
155	801032	MINILIK GIS	15	ADDIS ABABA	ADDIS ABABA	0.9662	39.2971	5.4313	23.57826
156	804015	FINCHA-SUG 2	15	WEST	OROMIA	0.9663	2.8584	1.3835	1.71504

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157	801027	GEFARSA 33	33	ADDIS ABABA	OROMIA	0.9666	47.1636	22.827	28.29816
158	808013	BONGA	15	SOUTH WEST	S.N.N.P	0.9673	2.2484	1.0883	1.34904
159	801067	EIZ	33	ADDIS ABABA	OROMIA	0.9673			0
160	801072	ADDIS-W1	15	ADDIS ABABA	ADDIS ABABA	0.9674			0
161	807002	BAHIR DAR2-1	15	NORTH WEST	AMHARA	0.968	15.8811	7.6935	9.52866
162	806002	AKISTA	33	NORTH EAST	AMHARA	0.9685	10.49	0.6251	6.294
163	805001	W SODO-II	15	SOUTH	S.N.N.P	0.9686	4.2383	2.0514	2.54298
164	806005	LALIBELA	15	NORTH EAST	AMHARA	0.969	3.2742	1.5847	1.96452
165	806007	SHEWA-ROBIT	15	NORTH EAST	AMHARA	0.9695	3.6132	0.1059	2.16792
166	805040	YADOT	15	SOUTH	OROMIA	0.9696	0.604	0.2922	0.3624
167	806010	KEMISS15	15	NORTH EAST	AMHARA	0.9696	2.9727	0.4573	1.78362
168	804017	GIDA-AYANA	33	WEST	OROMIA	0.9703	4.3126	2.0872	2.58756
169	807023	B.DAR2	33	NORTH WEST	AMHARA	0.9704	0.5662	0.4246	0.33972
170	809005	MAYCHEW	15	NORTH	TIGRAY	0.9709	4.747	2.2975	2.8482
171	808035	JIMMA OLD	15	SOUTH WEST	OROMIA	0.9709			0
172	806026	SEMERA	33	NORTH EAST	AFAR	0.971	5.9231	2.8667	3.55386
173	801047	KALTI-NORTH	15	ADDIS ABABA	ADDIS ABABA	0.9712	0.2331	0.1128	0.13986
174	805024	RAMO33	33	SOUTH	OROMIA	0.9712	7.6376	3.6942	4.58256
175	801041	ADDIS SOUTH	15	ADDIS ABABA	ADDIS ABABA	0.9713			0
176	802032	ADAMI TULU	15	CENTRAL	OROMIA	0.9715	0.7433	0.3598	0.44598
177	802007	CHANCHO	33	CENTRAL	OROMIA	0.9723	0	0	0
178	805018	YADOT	33	SOUTH	OROMIA	0.9725	0.2966	0.1436	0.17796

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179	806001	ALEM-KETEMA	33	NORTH EAST	AMHARA	0.9725	1.594	0.7715	0.9564
180	801048	MEKANISA	15	ADDIS ABABA	ADDIS ABABA	0.9726			0
181	801068	KALITI2	15	ADDIS ABABA	ADDIS ABABA	0.973			0
182	801092	MEKANISA	15	ADDIS ABABA	ADDIS ABABA	0.9734			0
183	801054	KALITI GIS	15	ADDIS ABABA	ADDIS ABABA	0.9737	24.6394	8.7746	14.78364
184	801055	EIZ	33	ADDIS ABABA	OROMIA	0.9739	10.8626	1.917	6.51756
185	801066	KALITI1	15	ADDIS ABABA	ADDIS ABABA	0.9739			0
186	801039	ADDIS CENTER	15	ADDIS ABABA	ADDIS ABABA	0.9744			0
187	802012	HORMAT	15	CENTRAL	OROMIA	0.975	9.4728	4.5848	5.68368
188	805037	W.SODO	16	SOUTH	S.N.N.P	0.9766			0
189	804002	GHIMBI	15	WEST	OROMIA	0.9768	4.0264	0.8477	2.41584
190	808020	BONGA	33	SOUTH WEST	S.N.N.P	0.9773	0	0	0
191	804006	GHIMBI	33	WEST	OROMIA	0.9782	3.8146	0	2.28876
192	808025	JIMMA OLD	33	SOUTH WEST	OROMIA	0.9782	4.2383	2.0514	2.54298
193	806006	SEKOTA	15	NORTH EAST	AMHARA	0.979	2.0799	1.0067	1.24794
194	802075	DEBRE-ZEIT2	15	CENTRAL	OROMIA	0.9797	17.2137	10.65	10.32822
195	804018	NEKEMPTE	15	WEST	OROMIA	0.9811	7.2611	3.5144	4.35666
196	804003	MENDI	33	WEST	OROMIA	0.9812	1.3775	-0.318	0.8265
197	807008	GONDER1	15	NORTH WEST	AMHARA	0.9814	4.2121	2.0386	2.52726
198	806025	DITCHETO	33	NORTH EAST	AFAR	0.9819	2.2867	1.1091	1.37202
199	801046	KALITI2	15	ADDIS ABABA	ADDIS ABABA	0.9826	1.9813	0.9589	1.18878
200	808027	AGARO	33	SOUTH WEST	OROMIA	0.9827			0
201	801045	KALITI1	15	ADDIS ABABA	ADDIS ABABA	0.9832	69.7163	12.26	41.82978

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202	802068	DEBRE-ZEIT2	15	CENTRAL	OROMIA	0.9836	18.8208	11.637	11.29248
203	806015	WOLDIYA MOB	15	NORTH EAST	AMHARA	0.9843	3.1574	1.5282	1.89444
204	801093	ADDIS CENTER	15	ADDIS ABABA	ADDIS ABABA	0.985	1.715	0.8301	1.029
205	802035	ASSELA	15	CENTRAL	OROMIA	0.9855	4.4503	2.154	2.67018
206	806016	WOLDIYA MOB	33	NORTH EAST	AMHARA	0.9857	6.3149	3.0564	3.78894
207	807006	FINOTE-SELAM	15	NORTH WEST	AMHARA	0.9858	1.3628	0.6596	0.81768
208	802066	MODJO	15	CENTRAL	OROMIA	0.9861	6.5411	3.1659	3.92466
209	803043	GODE33	33	EAST	SOMALE	0.9868	0	0	0
210	802047	NURAERA	15	CENTRAL	OROMIA	0.9877	4.0795	1.1434	2.4477
211	802046	NAZERETH-II	15	CENTRAL	OROMIA	0.9887	45.6658	19.232	27.39948
212	804021	NEKEMPTE	33	WEST	OROMIA	0.989	2.6528	1.2876	1.59168
213	802039	ELALA-GEDA	15	CENTRAL	OROMIA	0.9896	8.0521	3.9007	4.83126
214	808010	ABA	15	SOUTH WEST	OROMIA	0.9907	1.8013	0.8718	1.08078
215	802076	DEBRE-ZEIT2	15	CENTRAL	OROMIA	0.9916	1.5007	0.9294	0.90042
216	803001	ASEBE TEFERI	15	EAST	OROMIA	0.9921	5.0649	2.6489	3.03894
217	802031	AMIBARA	15	CENTRAL	OROMIA	0.9929			0
218	802027	AMIBARA	33	CENTRAL	AFAR	0.9931	1.0488	0.5076	0.62928
219	802049	NURAERA-33	33	CENTRAL	OROMIA	0.9936	1.372	0.5717	0.8232
220	801053	GELAN	15	ADDIS ABABA	ADDIS ABABA	0.9936	38.9314	18.843	23.35884
221	802057	NAZRETH2 MB	15	CENTRAL	OROMIA	0.9937	9.4724	4.5846	5.68344
222	808028	JIMMA	15	SOUTH WEST	OROMIA	0.9943			0
223	808034	JIMMA	15	SOUTH WEST	OROMIA	0.9943			0
224	804014	FINCHA II	15	WEST	OROMIA	0.9944	1.3949	0.6746	0.83694

Bus ranking number	Bus Number	Bus Name	Base kV	Area Name	Zone Name	Voltage (pu)	Pload (MW)	Qload (Mvar)	Pload shed (MW)
225	802053	MOJO II MOB	15	CENTRAL	OROMIA	0.9949	7.284	3.5287	4.3704
226	808016	JIMMA	15	SOUTH WEST	OROMIA	0.9953	1.486	0.7192	0.8916
227	802048	WONJI PULP	15	CENTRAL	OROMIA	0.9955	10.8894	16.107	6.53364
228	808012	B.BEDELE	15	SOUTH WEST	OROMIA	0.9958	3.9099	1.8924	2.34594
229	807009	METEMA	33	NORTH WEST	EXPORT	0.996	2.0169	0.9762	1.21014
230	802019	HORMAT	33	CENTRAL	OROMIA	0.9963	0.4842	0.2316	0.29052
231	809017	MEHONI	15	NORTH	TIGRAY	0.9973	4.2278	1.6636	2.53668
232	801042	AKAKI 1	15	ADDIS ABABA	ADDIS ABABA	0.9975			0
233	802017	GEBRE-GURCHA	33	CENTRAL	OROMIA	0.9982	6.8874	3.3335	4.13244
234	809012	ALAMATA2	15	NORTH	TIGRAY	0.9985	2.0424	0.9892	1.22544
235	809031	ALAMATA2	15	NORTH	TIGRAY	0.9985			0
236	809032	ALAMATA2	15	NORTH	TIGRAY	0.9985			0
237	809015	MEHONI33	33	NORTH	TIGRAY	0.999	0	0	0
238	802091	HOLETA	33	CENTRAL	OROMIA	0.9999			0
239	803010	DIRE DAW	15	EAST	DIRE DAWA	1	0	0	0
240	807026	FINOTE SELAM	33	NORTH WEST	AMHARA	1	0	0	0
241	804008	FINCHA-SUG 1	15	WEST	OROMIA	1	0	0	0
242	804019	GIDAMI33	33	WEST	BENSHANGUL-G	1	0	0	0
243	801069	ADDIS CENTER	15	ADDIS ABABA	ADDIS ABABA	1	5.9444	2.8754	3.56664
244	801078	BLACK-LION	15	ADDIS ABABA	ADDIS ABABA	1	37.0448	17.951	22.22688
245	801009	SHEGOLE	15	ADDIS ABABA	OROMIA	1	44	21	26.4
246	809035	WELKAYT	33	NORTH	TIGRAY	1			0
247	805019	YIRGALEM	15	SOUTH	S.N.N.P	1			0
248	802093	HOLETA-33	33	CENTRAL	OROMIA	1			0
249	809003	ALAMATA1	15	NORTH	TIGRAY	**1.001**	8.7098	4.2156	5.22588
250	801071	GELAN	15	ADDIS	ADDIS ABABA	**1.0014**	8.7326	4.230	5.23956

Bus ranking number	Bus Number	Bus Name	Base kV	Area Name	Zone Name	Voltage (pu)	Pload (MW)	Qload (Mvar)	Pload shed (MW)
				ABABA				8	
251	802023	AMIBARA	15	CENTRAL	OROMIA	**1.0031**	1.4866	0.719 5	0.89196
252	804011	GHEDO	33	WEST	OROMIA	**1.005**	0.1059	0.051 3	0.06354
253	808023	AGARO	33	SOUTH WEST	OROMIA	**1.0056**	0.4344	0.210 3	0.26064
254	807005	DEBRE MARKOS	15	NORTH WEST	AMHARA	**1.0057**	10.0843	4.880 7	6.05058
255	809026	ALAMATA	33	NORTH	TIGRAY	**1.0058**	0.9906	0.495 3	0.59436
256	808024	B.BEDELE	33	SOUTH WEST	OROMIA	**1.0058**	2.1192	1.025 7	1.27152
257	807025	DEBREMARKOS	33	NORTH WEST	AMHARA	**1.0066**	0.4578	0.221 6	0.27468
258	801043	AKAKI-SP	15	ADDIS ABABA	ADDIS ABABA	**1.0066**	19.27	9.327	11.562
259	804010	GHEDO	15	WEST	OROMIA	**1.0075**	0.6358	0.307 7	0.38148
260	803005	ASEBE-33	33	EAST	OROMIA	**1.0077**	0.9536	0.635 8	0.57216
261	804013	FINCHA II	33	WEST	OROMIA	**1.0085**	3.5215	1.703 6	2.1129
262	808015	G.GIBE NEW	33	SOUTH WEST	OROMIA	**1.0085**			0
263	806023	GASHENA	33	NORTH EAST	AMHARA	**1.0087**	4.3448	0.228 7	2.60688
264	803019	HURSO	15	EAST	OROMIA	**1.0098**	0.445	0.215 5	0.267
265	803026	DIRE DAW	33	EAST	DIRE DAWA	**1.0111**	5.5099	2.666 8	3.30594
266	806024	GASHENA-15	15	NORTH EAST	AMHARA	**1.0112**			0
267	802029	AWSH-7KL	15	CENTRAL	AFAR	**1.012**			0
268	802030	AWSH-7KL	15	CENTRAL	AFAR	**1.012**			0
269	803006	BABILE	15	EAST	OROMIA	**1.0122**	1.9814	0.960 6	1.18884
270	803036	HURSO	15	EAST	SOMALE	**1.0131**	0	0	0
271	803037	HURSO	15	EAST	SOMALE	**1.0131**	0	0	0
272	803015	HURSO	33	EAST	OROMIA	**1.0138**	0	0	0
273	802044	METAHARA	15	CENTRAL	OROMIA	**1.0154**	3.5678	1.728 4	2.14068
274	807010	MOTA	33	NORTH	AMHARA	**1.0155**	2.5619	1.240	1.53714

Bus ranking number	Bus Number	Bus Name	Base kV	Area Name	Zone Name	Voltage (pu)	Pload (MW)	Qload (Mvar)	Pload shed (MW)
				WEST				1	
275	806003	COMBOL-1	15	NORTH EAST	AMHARA	**1.0155**	10.7338	5.195	6.44028
276	803011	DIRE DAW	15	EAST	DIRE DAWA	**1.016**	0	0	0
277	807011	NEFASMEWCHA	15	NORTH WEST	AMHARA	**1.0165**			0
278	806004	DESSIE	15	NORTH EAST	AMHARA	**1.0168**	9.12	4.4148	5.472
279	806021	DESSIE	15	NORTH EAST	AMHARA	**1.0177**	6.8061	3.2917	4.08366
280	807012	NEFAS MEWCHA	33	NORTH WEST	AMHARA	**1.018**	4.7423	0.5128	2.84538
281	809019	ADWA	33	NORTH	TIGRAY	**1.0193**	0.5023	0.2431	0.30138
282	807015	BAHIR DAR-2	15	NORTH WEST	AMHARA	**1.0245**	5.6971	2.7593	3.41826
283	803041	JIJIGA2	15	EAST	SOMALE	**1.0257**	11.253	5.4464	6.7518
284	803012	FIK	33	EAST	OROMIA	**1.0312**	0.9906	0.4953	0.59436
285	803002	ADIGALA	33	EAST	EXPORT	**1.0326**	0.445	-0.911	0.267
286	803018	HARAR3	15	EAST	HARARI	**1.0359**	9.5046	2.3206	5.70276
287	803014	HARAR3	33	EAST	HARARI	**1.0362**	0.4344	0.2103	0.26064
288	802083	HOLETA-33	33	CENTRAL	OROMIA	**1.0363**	0	0	0
289	802092	HOLETA-33	33	CENTRAL	OROMIA	**1.0363**			0
290	803007	BEDESSA	15	EAST	OROMIA	**1.0387**	2.1192	0.4239	1.27152
291	803009	DIRE DAW	15	EAST	DIRE DAWA	**1.0406**	22.0396	7.4172	13.22376
292	803003	ALEMAYA	15	EAST	OROMIA	**1.0412**	4.0139	1.9427	2.40834
293	803008	CHELENKO	15	EAST	OROMIA	**1.0413**	1.8013	0.8718	1.08078
294	803040	JIJIGA	33	EAST	SOMALE	**1.0417**	1.0597	1.3033	0.63582
295	803023	BEDESA	33	EAST	OROMIA	**1.043**	0.6358	0.1059	0.38148
296	803013	HARAR	15	EAST	HARARI	**1.0436**	4.6622	2.2565	2.79732

- ✓ The over voltage bus bars are filtered and the bus bars with the nominal and under voltage are selected for load shedding first and if the amount of load to be shed is not enough over voltage areas will be considered as last option.
- ✓ The total amount of load of the selected substations is 1776MW added and compared with the maximum load to be shed that is, the maximum outage considered is 50% generation loss which will be 1100MW. This maximum load to be shed is lower and it is 60% of the load available. So, the load shedding can be managed by the filtered substations only.
- ✓ Assume that the maximum load to be shed from each substation is 60% of the load available and the rest is left for very sensitive areas like, Hospitals, public service areas, Government palaces …etc. so the maximum load to be shed is shown on the lookup table 4-19 under column load shading.
- ✓ The load shedding for each stage of proposed AUFLS scheme is done staring from substations ranked from top to down till all the stages are covered.

For the proposed AUFLS scheme the lines to be participated on each stage are selected from the lookup table and summarized as follows:

Table 4-19: Proposed AUFLS scheme and ranking of load bus bars for each stage

F-pickup(HZ)	Stage 1	Stage 2	Stage 3	Stage 4
49.2	1-48			
49.0		49-99		
48.4			99-153	
48.1				153-208

The effective power to be shed might not be exactly what is calculated for AUFLS scheme, but it is equivalent.

Table 4-20: Proposed AUFLS scheme and participation of lines to shed load on each stage

f-Pick up(Hz)	**S1**	**s2**	**S3**	**S4**
49.2	94.73748			
49.0		457		
48.4			879	
48.1				1110.0

After ranking the load bud bars the effective load shedding is not exactly the same as that of the proposed however it is near the proposed value as shown on table 4.21

The proposed AUFLS scheme is simulated and analyzed for its effectiveness on the next chapter.

CHAPTER-FIVE

5. SIMULATION STUDY AND ANALYSIS OF RESULTS

5.1.Analysis of the Simulation results

The response of the existing UFLS scheme is analyzed in chapter three for different disturbance cases and it is observed that the current UFLS scheme cannot help the system for medium and big generation loss and it is proposed new AUFLS scheme for National Grid. The proposed UFLS scheme shall be analyzed for its effectiveness in restoring the system frequency following disturbance cases mainly loss of generating units.

The proposed AUFLS scheme is proposed in chapter 4 and the summery is shown on Table 5.1. The load to be shade is also selected as per the ranking table 4-20 on chapter 4.

Table 5-1: Summary of the proposed AUFLS scheme

Freq. pickup (Hz)	STAGE 1	STAGE2	STAGE 3	STAGE 4
	Drop of Load for F=49.2Hz	DF=0.39	DF=1.22	DF=1.9
49.2	100			
49.0		340		
48.4			440	
48.1				220

For all simulation cases to be analyzed the system is operating smoothly and the disturbance is applied on the 5th second of the time line.

In this chapter the following cases are selected for observation and analysis:

- ✓ System response for stage one AUFLS
- ✓ System response for small disturbance cases: for 20% generation loss
- ✓ System response for medium disturbance cases: for 30 and 40% generation loss
- ✓ System response for big disturbance cases: from 45 and 50% generation loss

5.2.System frequency response for first stage AUFLS

On this stage the under-frequency relay act at 49.2Hz and reduce 100MW from the demand based on the voltage sensitivity table 4-20 as discussed in chapter 4, this frequency is selected to keep the tie line flow to Sudan and also to recover the system frequency to its acceptable limit of 1%.

The frequency reaches 49.2Hz for a minimum of 100MW generation loss, which is defined by study and the frequency bias of the National grid is tested and it set at 12MW/0.1HZ, this means the frequency drops by 0.1HZ for 12MW generation and we can say that, for the frequency to drop to 49.2HZ or by 0.8HZ, the minimum Generation loss is 100MW. The system is simulated for 100MW generation loss and the action of the first stage UFLS at 49.2HZ.

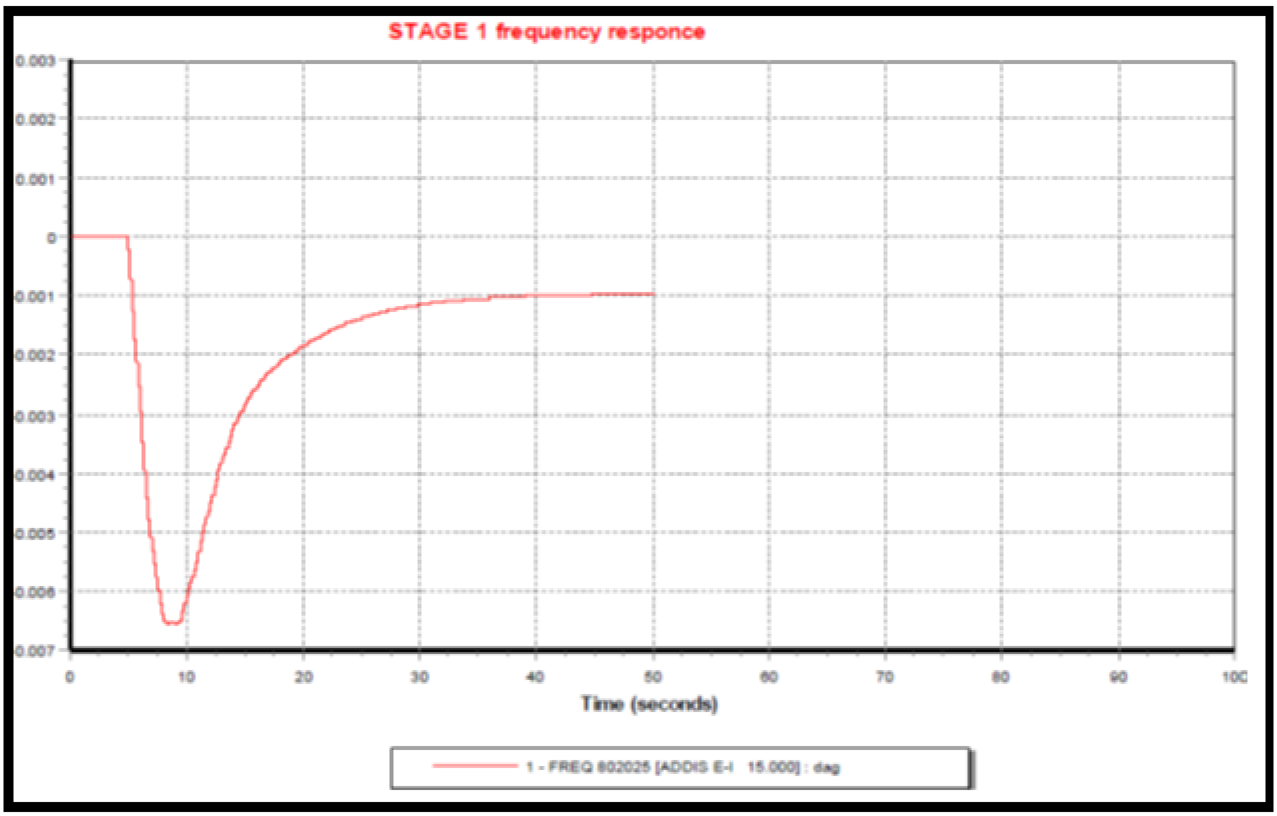

Chart5-1:System response for 100MW loss and action of first stage UFLS scheme.

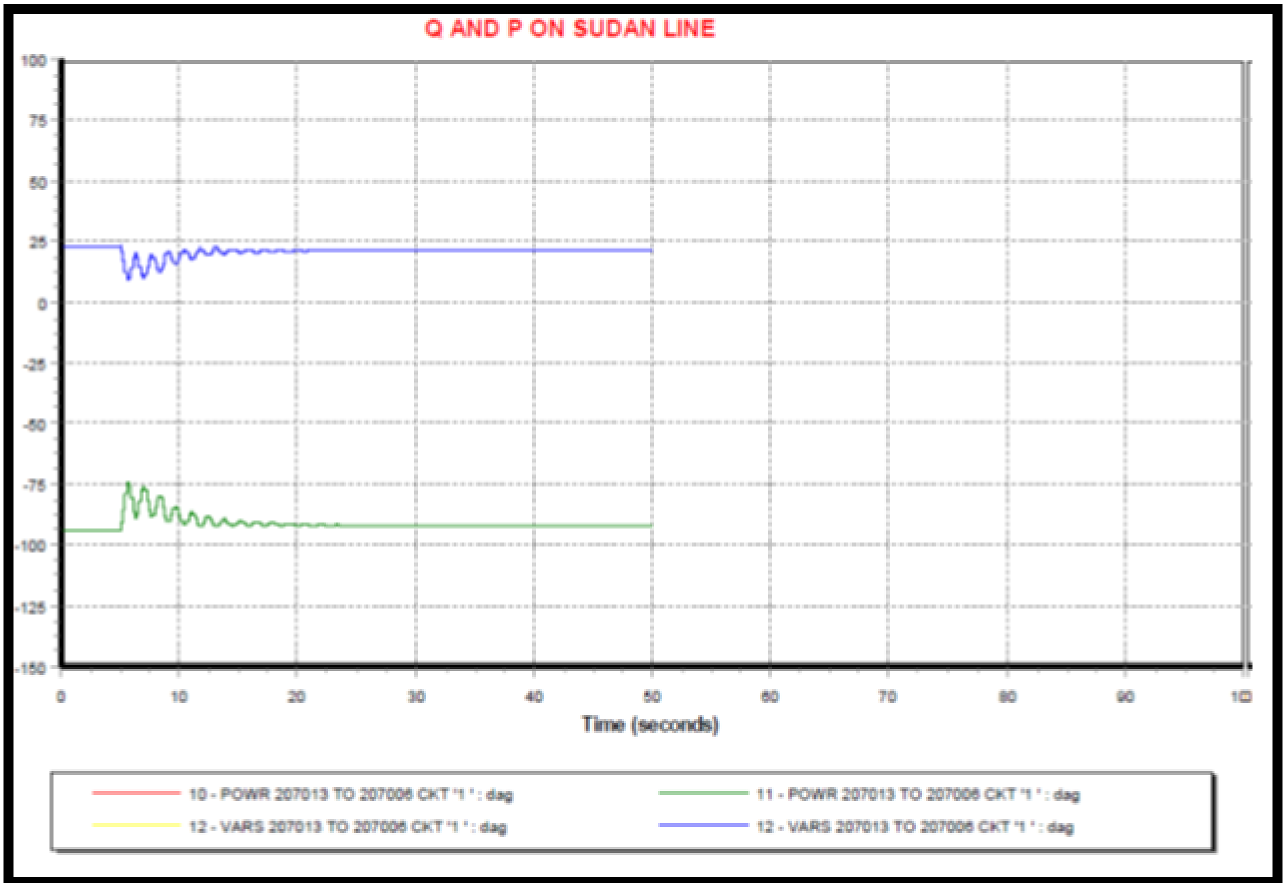

Chart 5-2: Active (P) and Reactive (Q) Tie line flow of Sudan 230KVline after 100MW loss/49.68HZ.

As it is observed the minimum frequency drop after the action of the first stage is 0.0625PU which is drop of 0.3HZ. The system frequency recovers to 49.7HZ which is within the acceptable range of 1% (from 50.5 to 49.5HZ).

The tile line flow drops from the scheduled value of 95MW to 75MW and returned to the scheduled value with in 3seconds.after the action of the first stage UFLS.

5.3.System response for proposed small disturbance region of the AUFLS scheme (Stage 2 operation of UFLS relay)

On this stage the maximum generation loss of 20% is analyzed and compared with the system frequency repose without the action of AUFLS scheme.

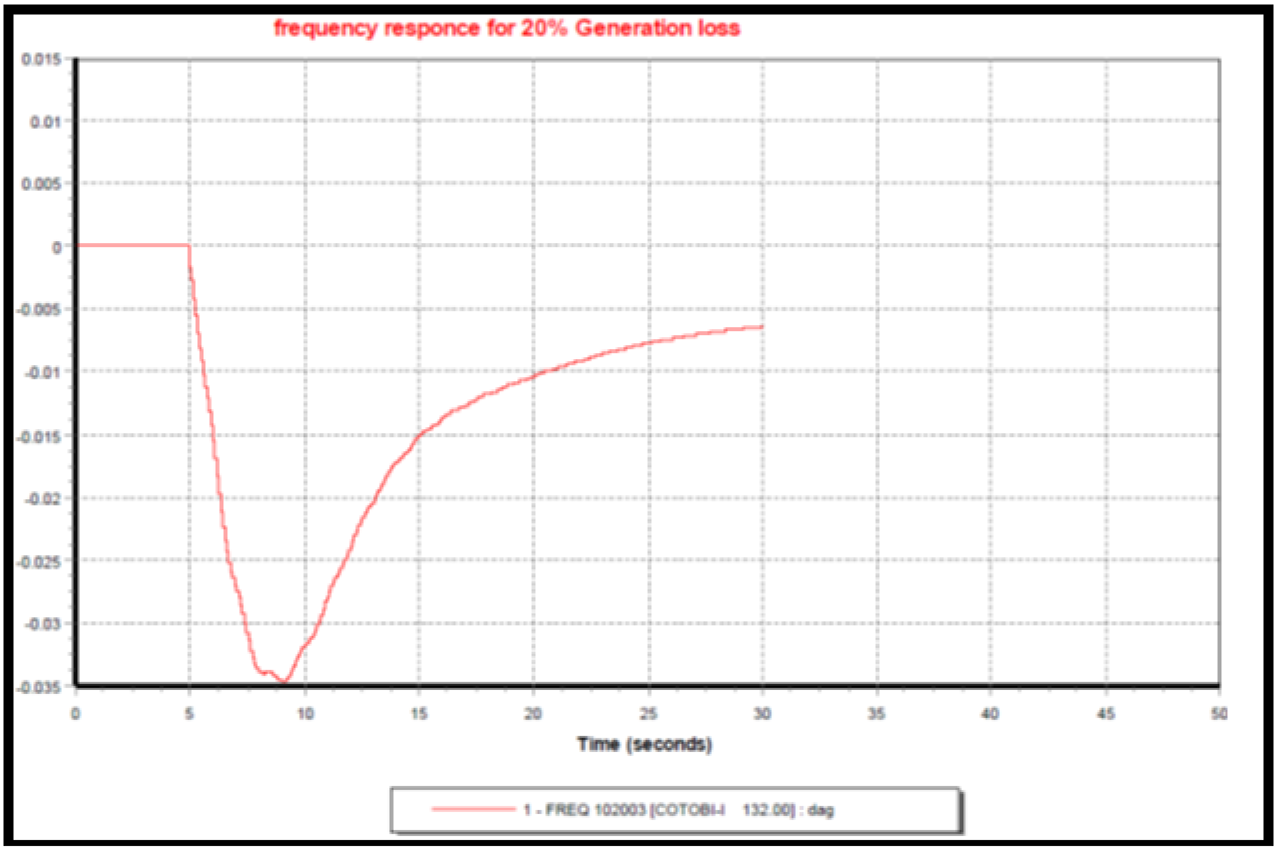

Chart 5-3: System frequency response for 20% generation loss without the action of the UFL scheme

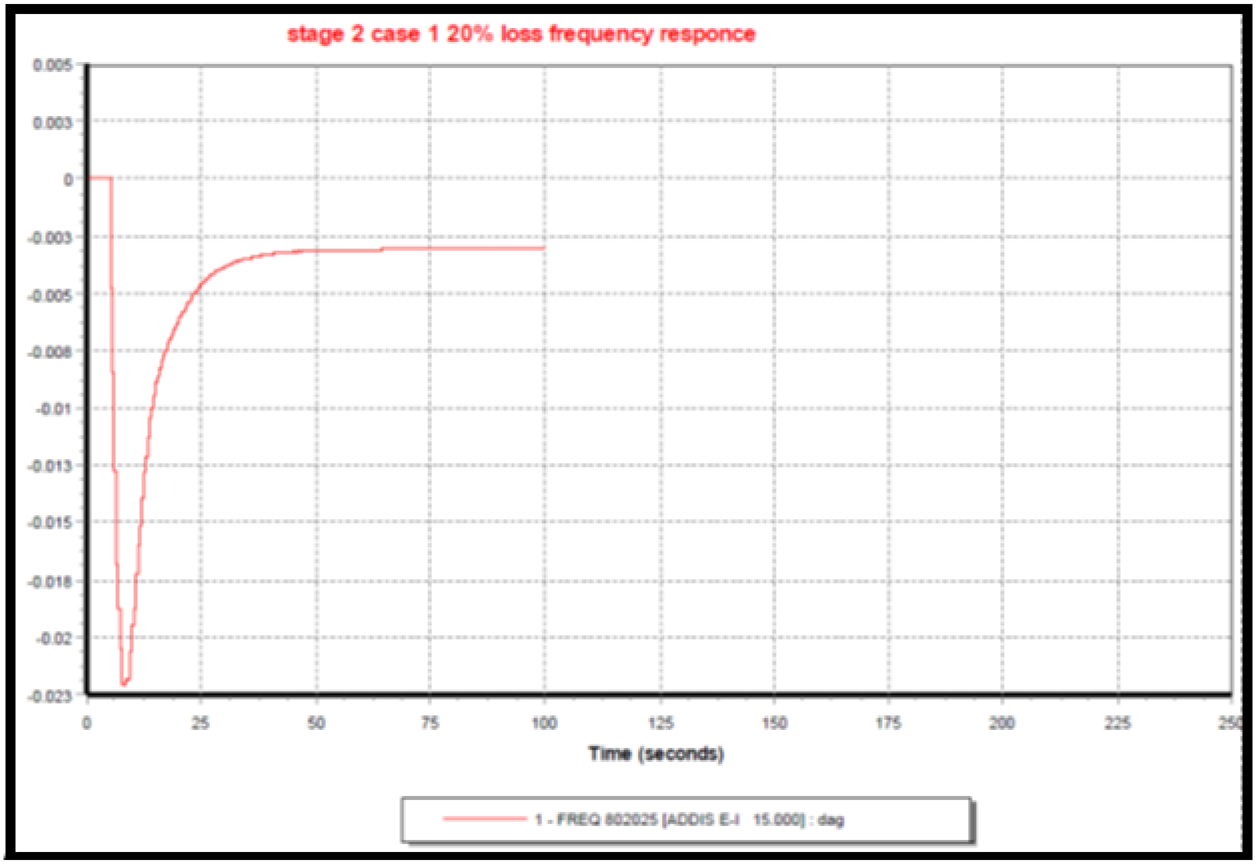

Chart 5-4: System frequency response after the action of stage 2 at DF=0.39Hz/Sec**.**

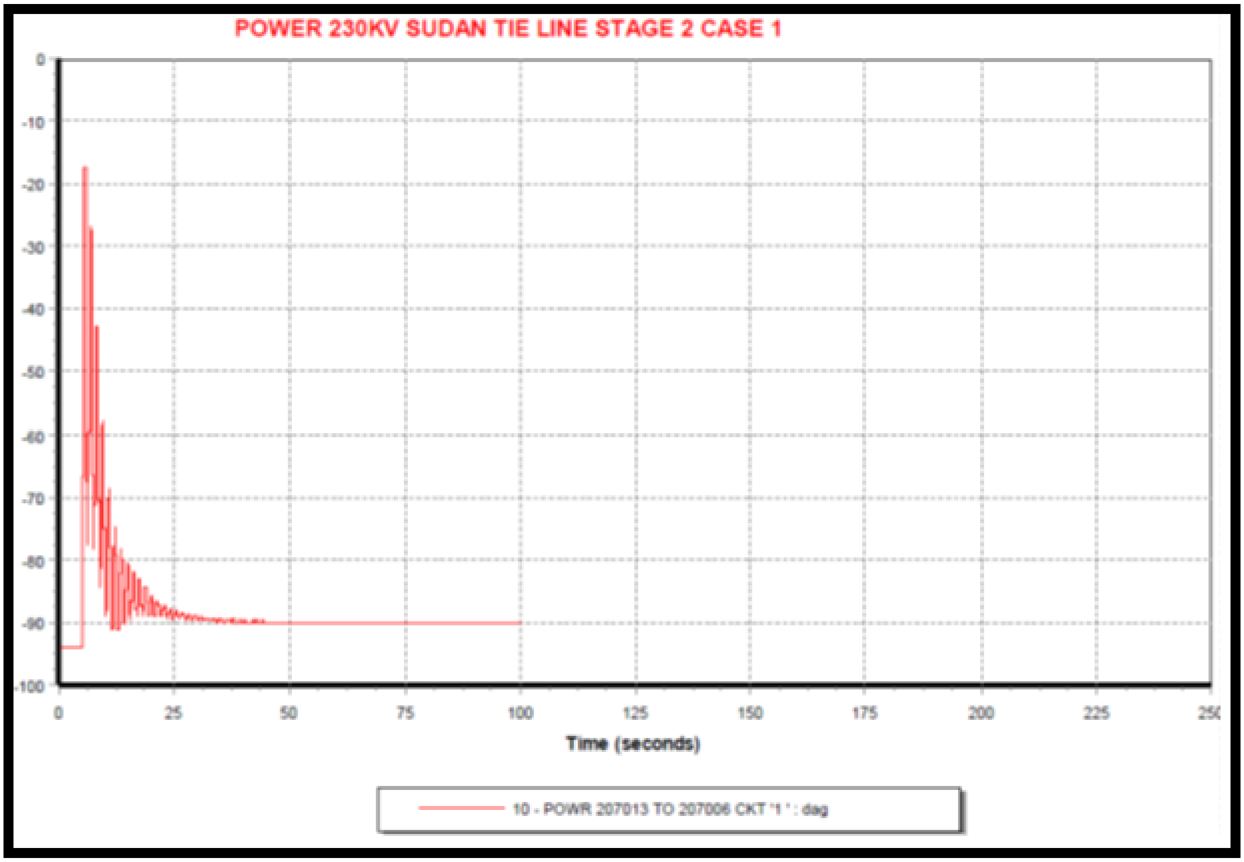

Chart 5-5: Tie line flow on Sudan 230KV line after 20% generation loss

The total generation loss considered is 20% which is 440MW and at it is shown the system frequency drops to0.035PU/ 48.25Hz without the action of UFLS whereas after the action of stage two UFLS the minimum frequency is 0.022PU/48.9HZ and the frequency recovers normal operation range of 1%/49.5HZ.

The tie line flow reduced from scheduled value of 95MW to 21MW and returned back to the scheduled value after the action of UFLS with in 5seconds.

5.4.System response for proposed medium 1 disturbance region of the AUFLS scheme (Stage 3 operation of UFLS relay)

On this stage the maximum generation loss in this region, i.e. 30% or 660MW is analyzed and compared with the system frequency repose without the action of AUFLS scheme.

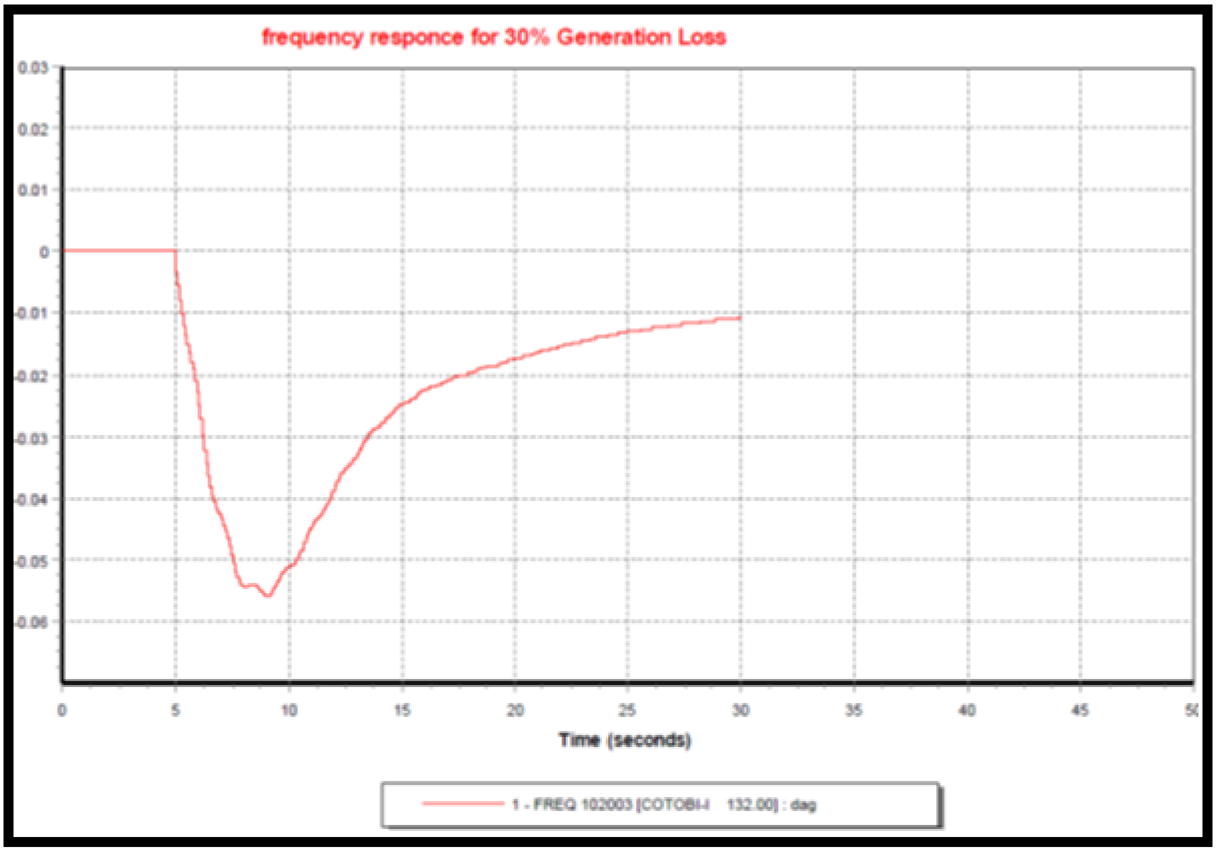

Chart 5-6: System frequency response for 30% generation loss without the action of the UFL scheme.

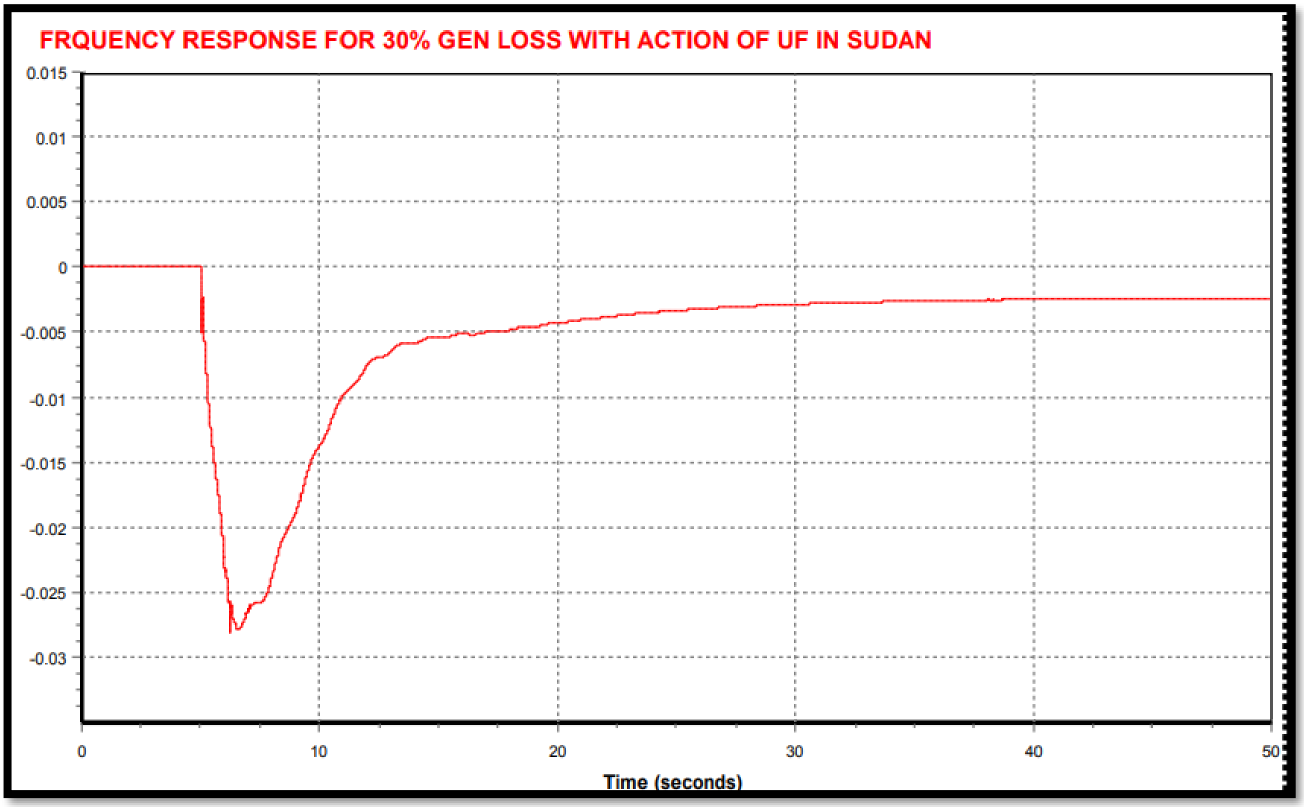

Chart 5-7:System frequency response after the action of stage 3 at DF=0.77/Sec**.**

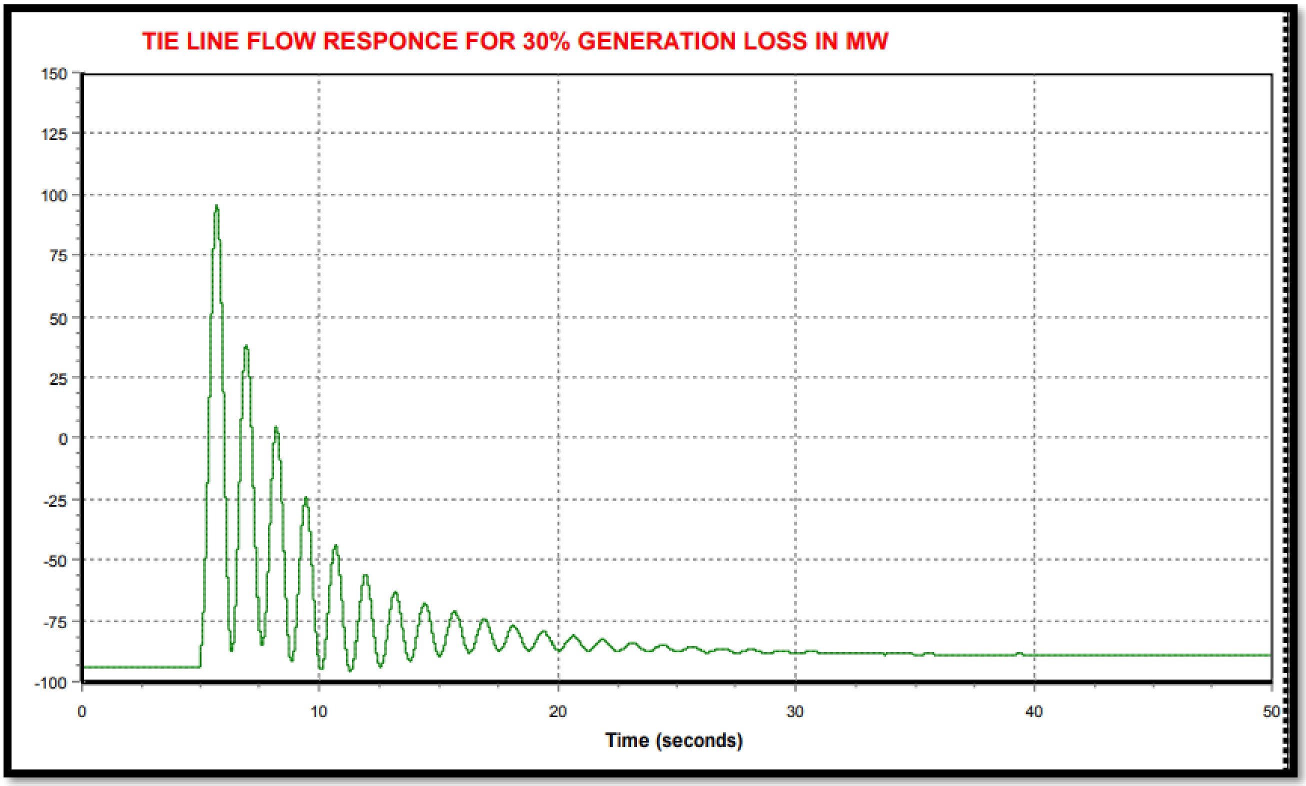

Chart 5-8:Tie line flow on Sudan 230KV line after 30% generation loss.

The total generation loss considered is 30% which is 660MW and at it is shown the system frequency drops to0.053PU/ 47.35Hz without the action of UFLS whereas after the action of stage three UFLS the minimum frequency is 0.02875PU/48.5Hz, which is above the last allowed frequency of 47.5Hz. then the frequency returned back to normal operation range of 0.01PU/49.5HZ within 7 seconds the tie line flow reduced from scheduled value of 94MW to 0 MW and the power flow change direction then 94MW flows from Sudan to Ethiopia, gradually the flow reduces and returned back to the scheduled value after the action of UFLS with in 7seconds.

5.5.System response for proposed medium 2 disturbance region of the AUFLS scheme (Stage 4 operation of UFLS relay)

On this stage the maximum generation loss in this region, i.e. 40% or 880MW is analyzed and compared with the system frequency response without the action of AUFLS scheme.

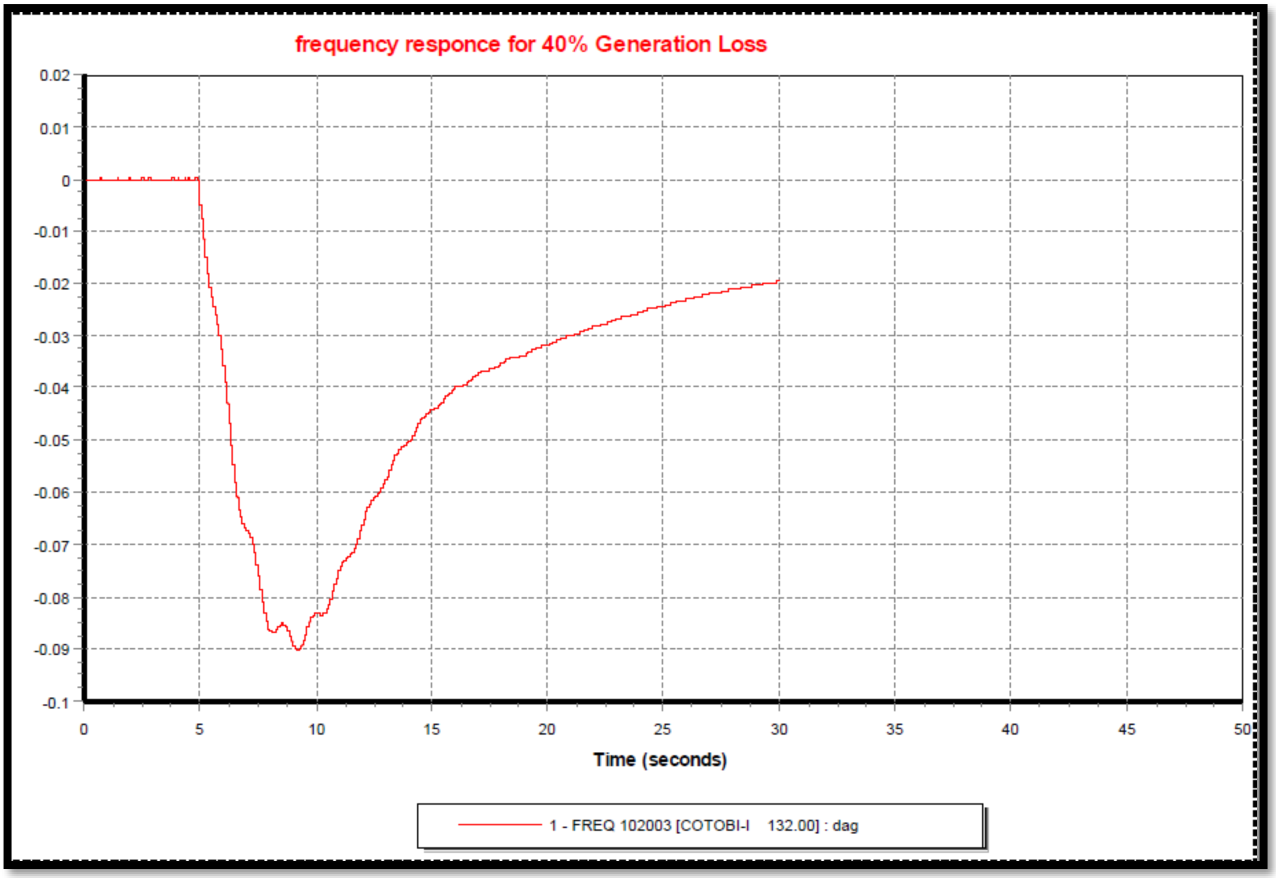

Chart 5-9:System frequency response for 40% generation loss without the action of the UFL scheme.

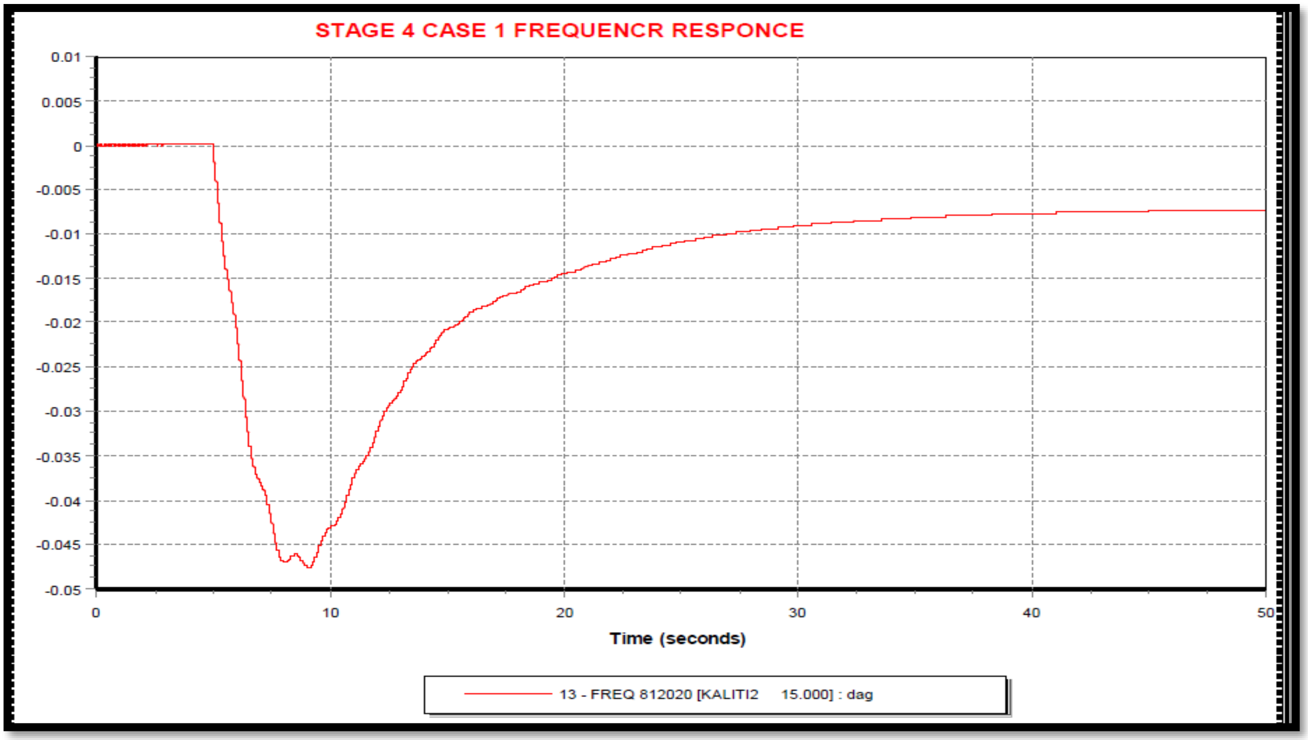

Chart 5-10:System frequency response after the action of stage 4.

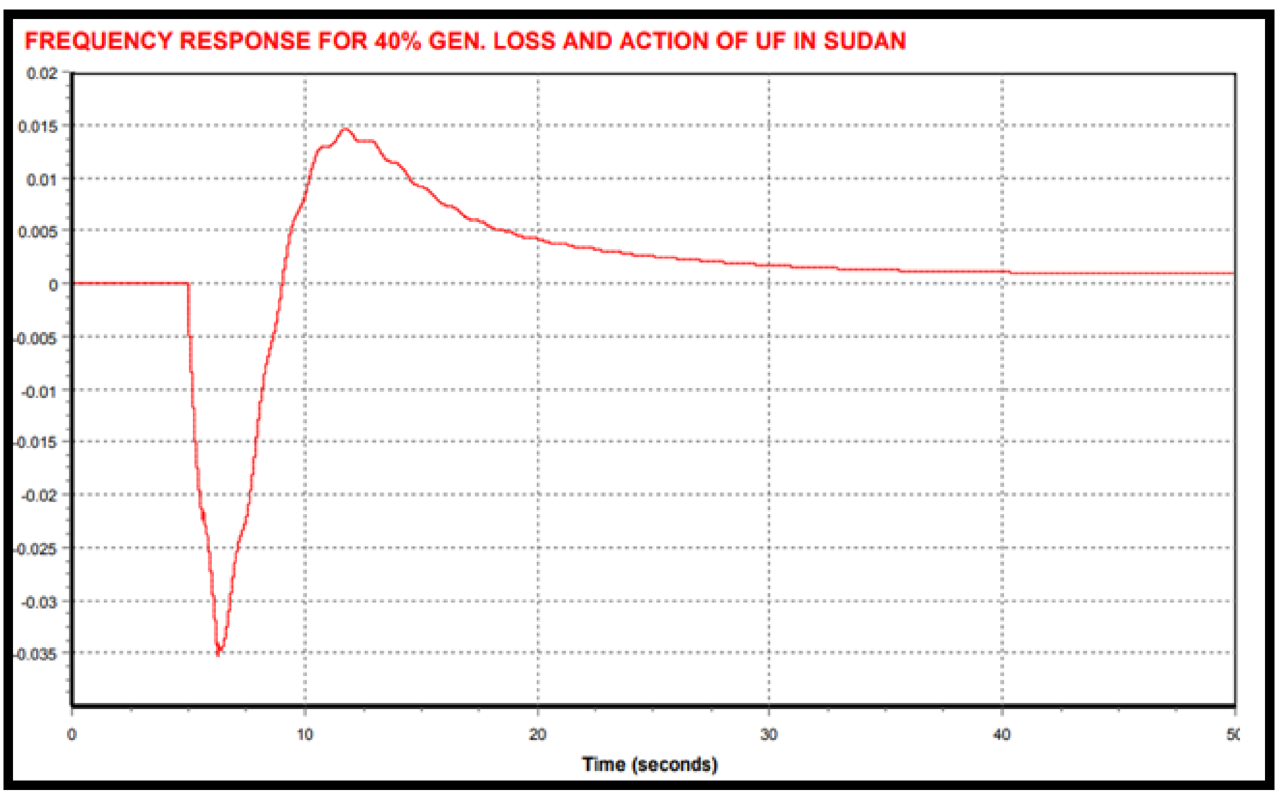

Chart 5-11:System frequency responseof 40% generation loss after the action of the UFL scheme.

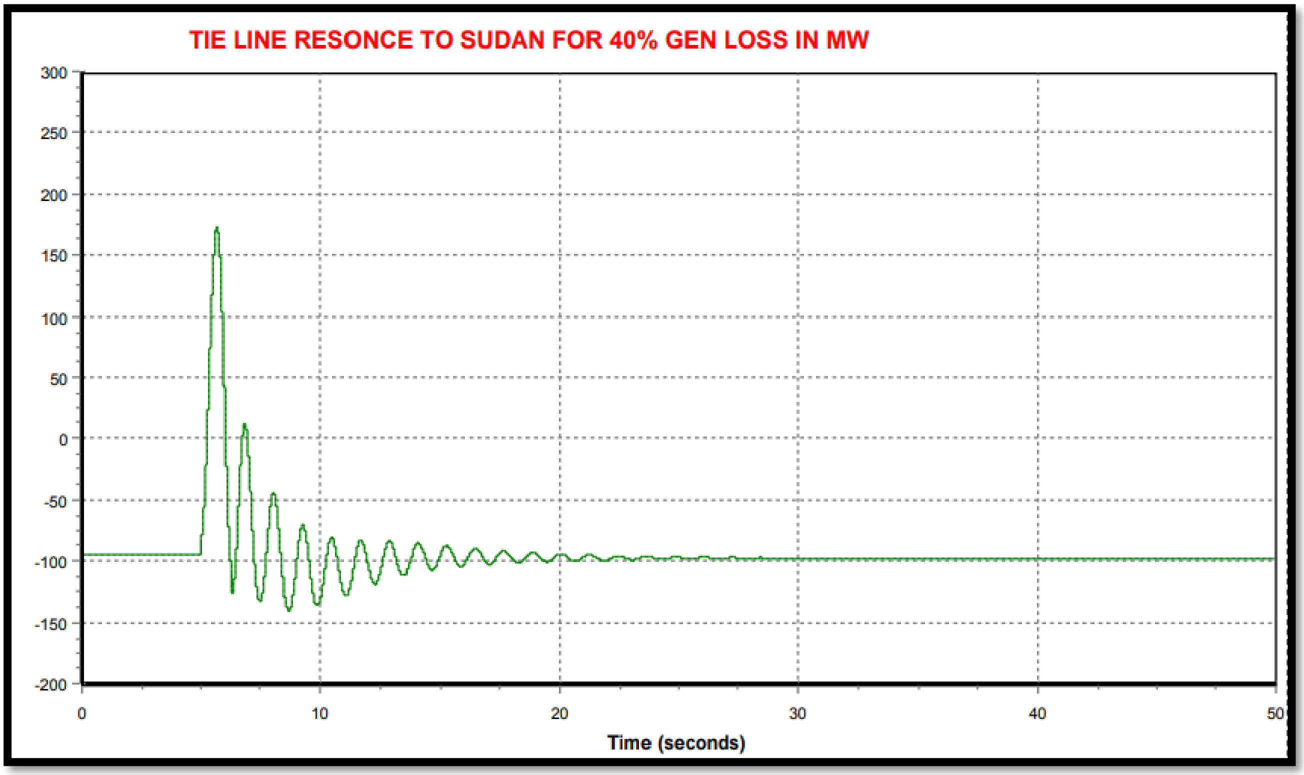

Chart 5-12:Tie line flow on Sudan 230KV line after 40% generation loss.

The total generation loss considered is 40% which is 880MW and as it is observed that the system frequency drops to 0.047PU/ 4.5Hz without the action of UFLS. Whereas after the action of stage four UFLS the minimum frequency is 0.035PU/48.25Hz, which is higher than acceptable lower limit of 47.5Hz. The frequency recovers to normal operation range of 0.01PU/49.5Hz within 7seconds.

The tie line flow reduced from scheduled value of 95MW to 0 MW and the power flow change direction then 165MW flows from Sudan to Ethiopia gradually the flow reduces and returned back to the scheduled value after the action of AUFLS with in 7seconds.

5.6.System response for proposed big disturbance region of the AUFLS scheme (Stage 5 operation of UFLS relay)

On this stage the maximum generation loss in this region, i.e. 45 %(990MW) is and 50% (1100MW) simulation cases are analyzed and compared with the system frequency response for the same outage scenario without the action of AUFLS scheme.

Case 1. System response to 45% generation loss

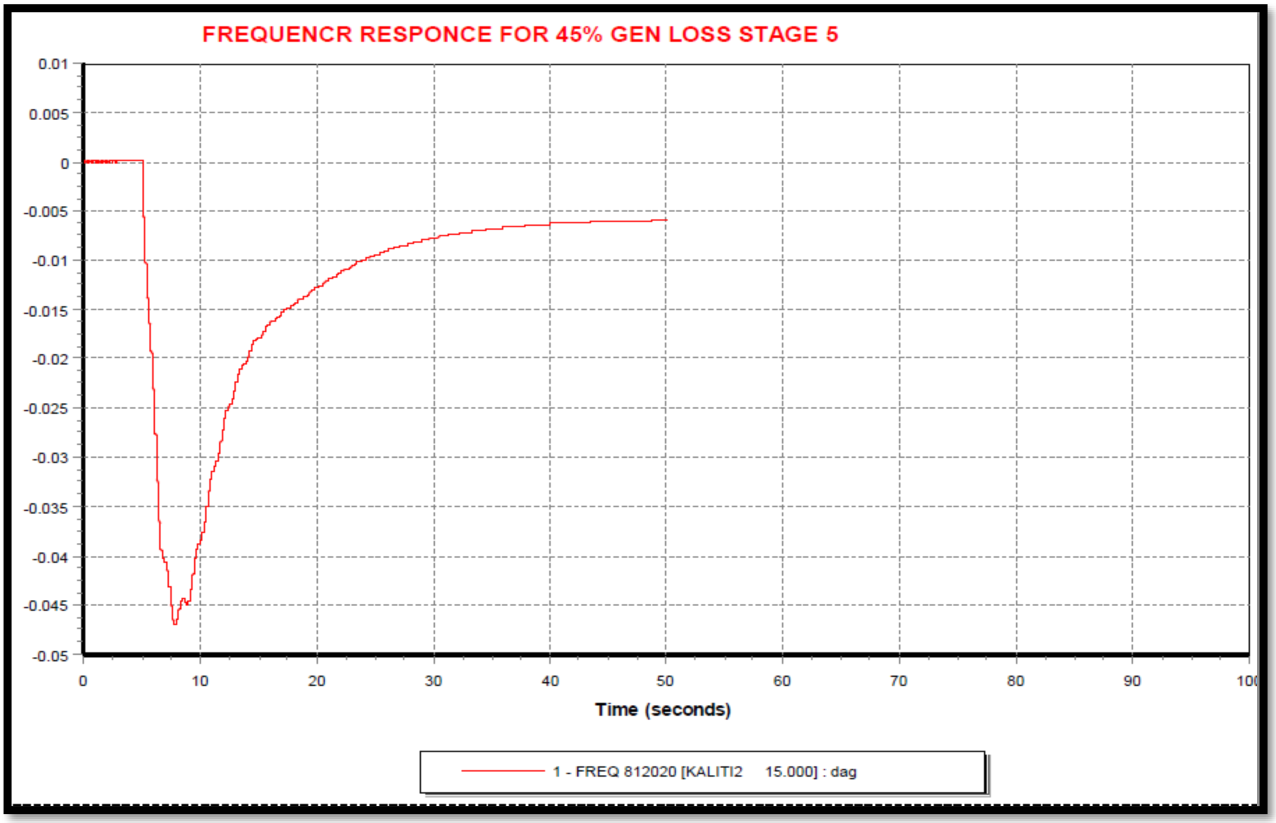

Chart 5-13:System frequency response for 45% generation loss without the action of the UFL scheme.

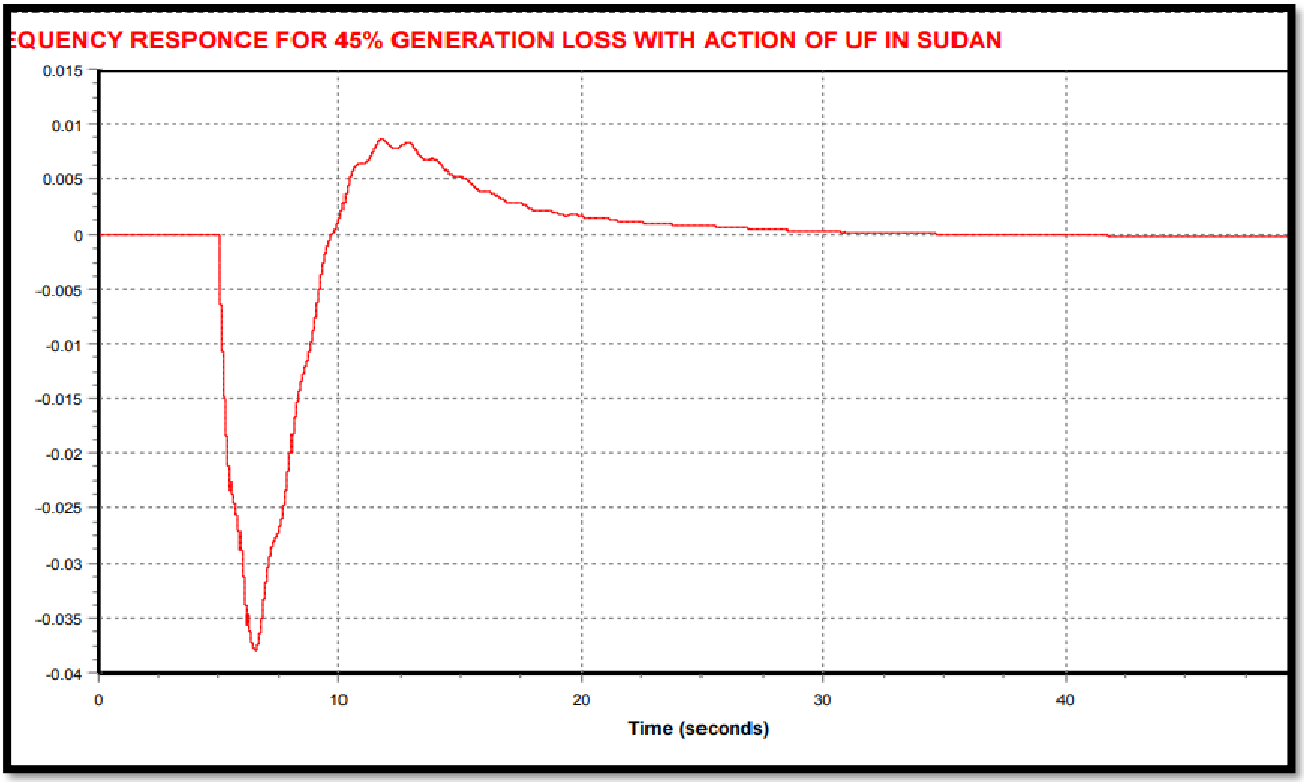

Chart 5-14:System frequency responseof 45% generation loss after the action of the UFL scheme.

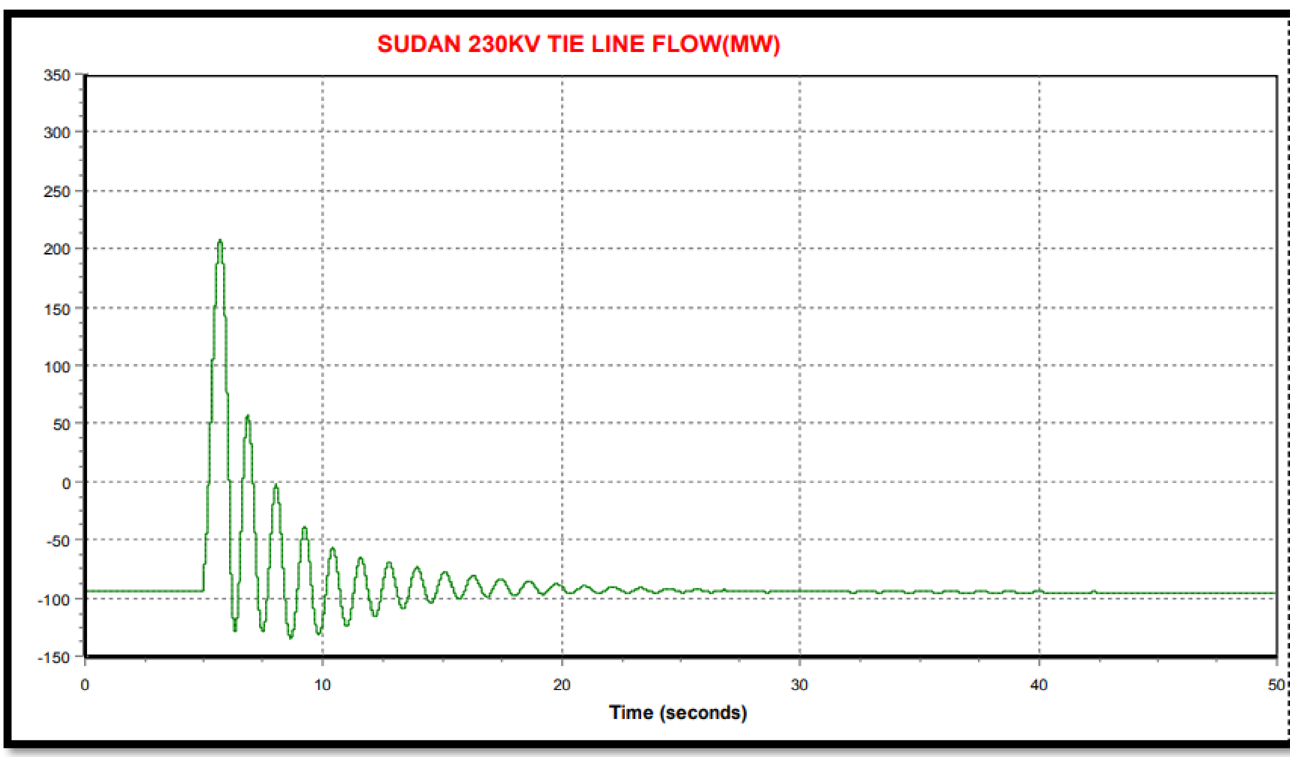

Chart 5-15:Tie line flow on Sudan 230KV line after 45% generation loss.

The total generation loss considered is 45% which is 990MW and at it is shown the system frequency drops to 1.06PU/ 44.7Hz without the action of UFLS whereas after the action of stage five UFLS the minimum frequency observed is 0.0385PU/48.0Hz, which is above the minimum acceptable lower limit of 47.5Hz. The frequency recovers to normal operation of 0.01PU/49.5Hz within 7seconds.

The tie line flow reduced from scheduled value of 95MW to 0 MW and the power flow change direction then 200MW flows from Sudan to Ethiopia, gradually the flow reduces and returned back to the scheduled value after the action of UFLS with in 7seconds.

Case 2.System response to 50% generation loss

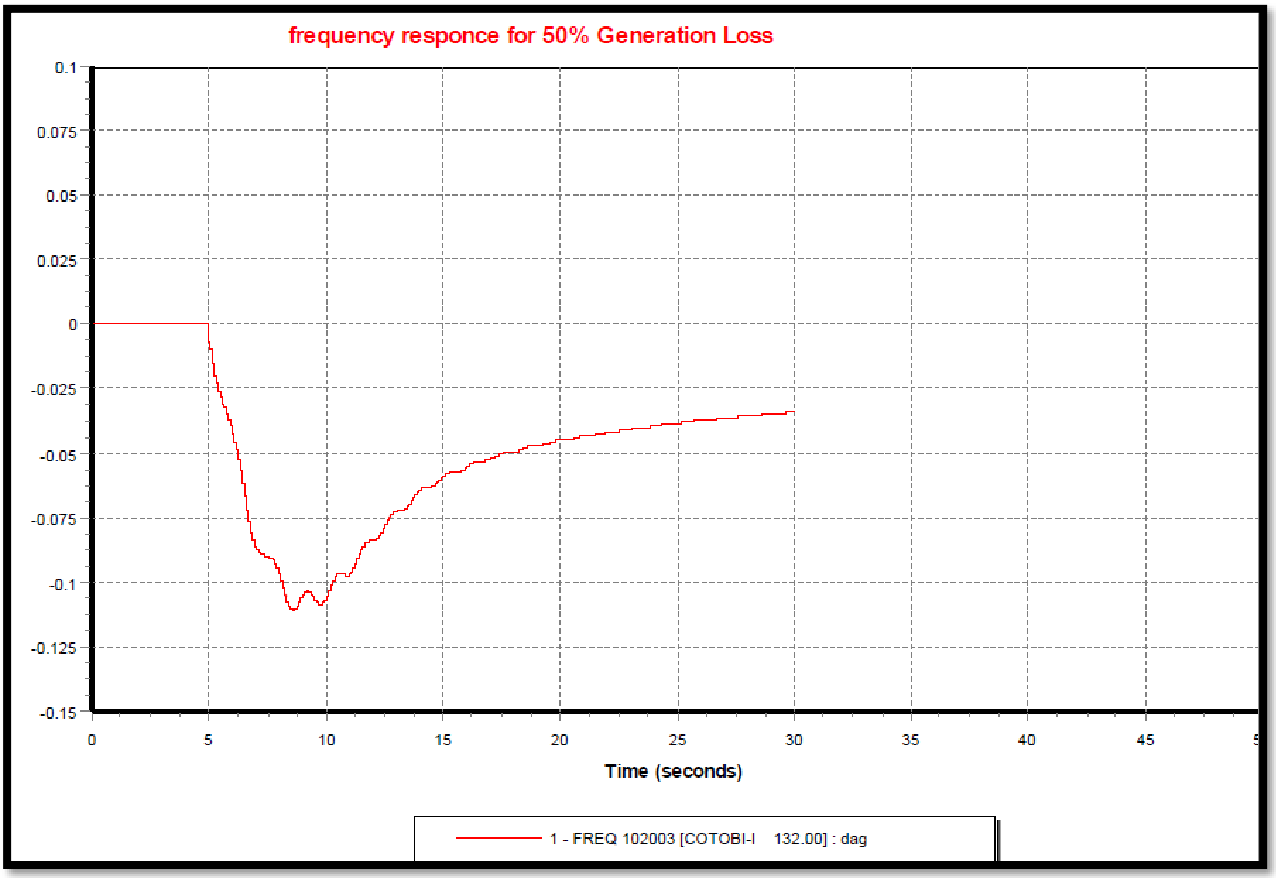

Chart 5-16: System frequency response for 50% generation loss without the action of the UFL scheme.

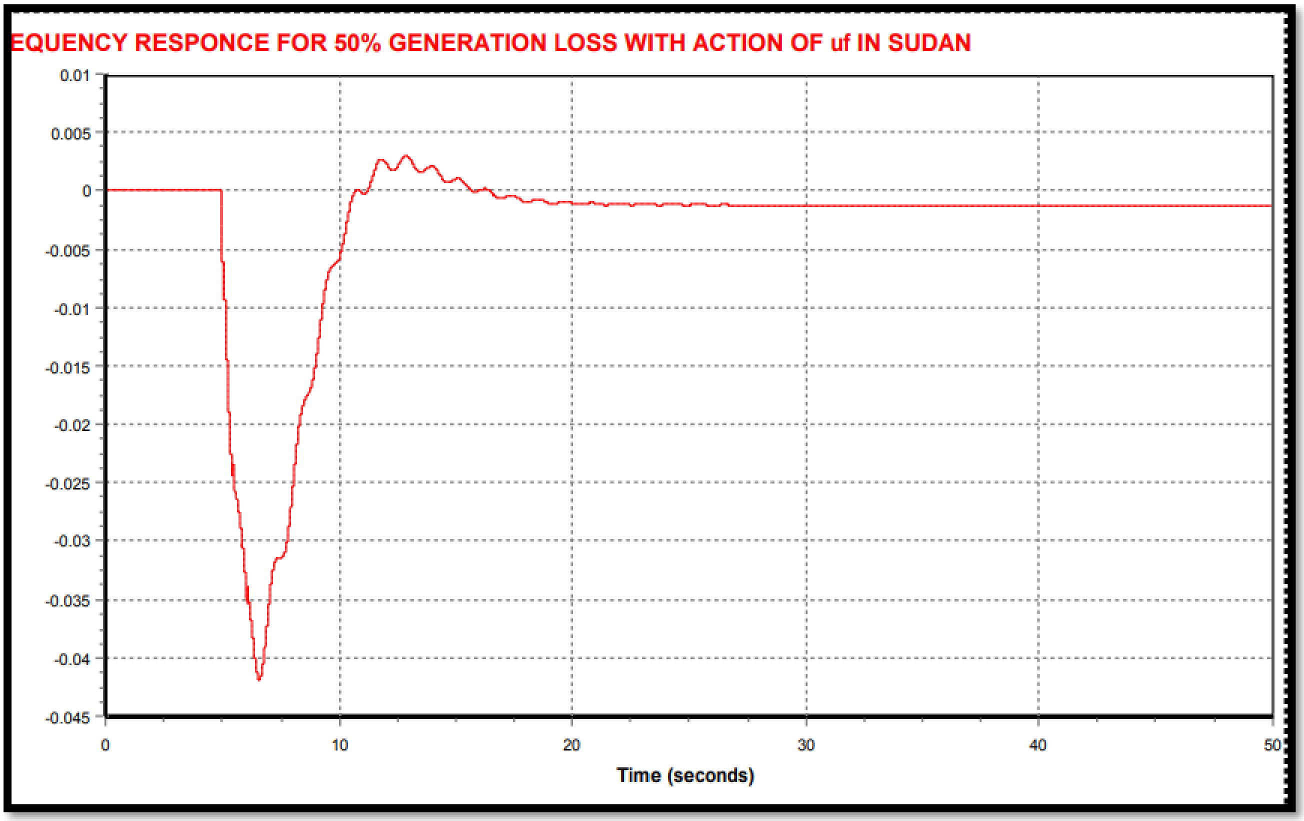

Chart 5-17: System frequency response after the action of 50% generation loss.

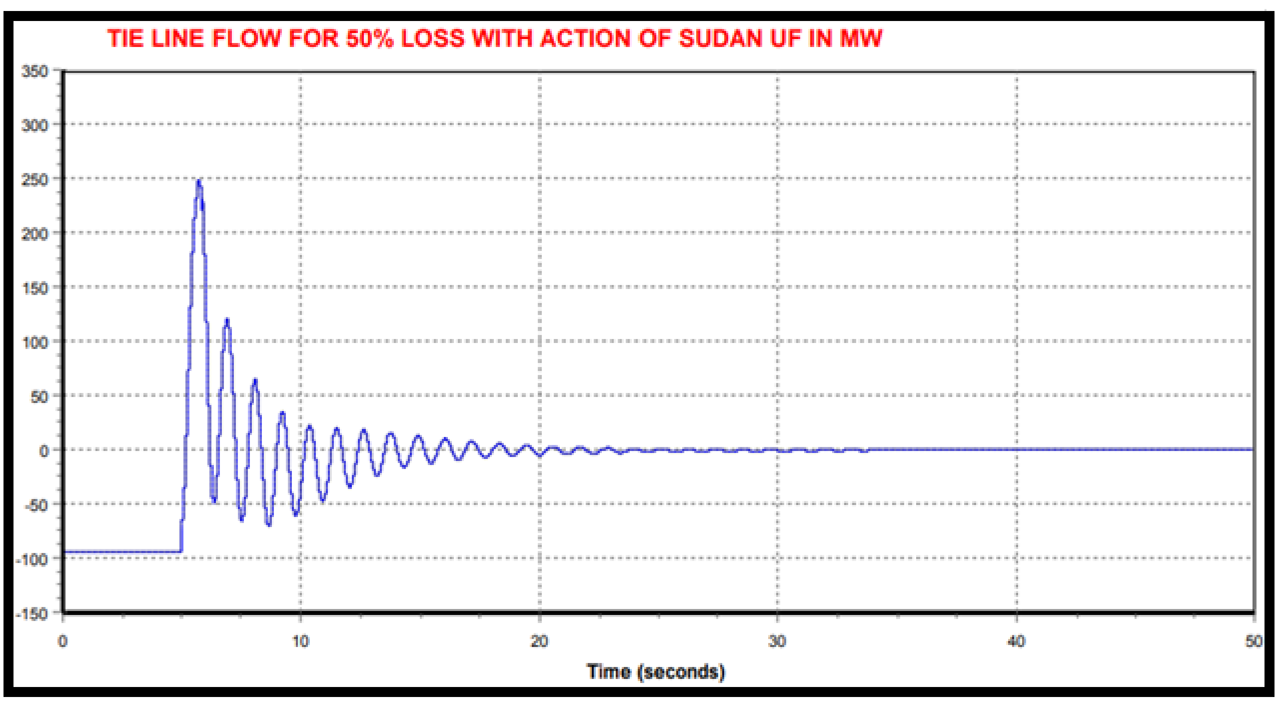

Chart 5-18: Tie line flow on Sudan 230KV line after 50% generation loss.

The total generation loss considered is 50% which is 1100MW and as it is observed that the system frequency drops to 1.06PU/ 44.7Hz without the action of UFLS whereas, after the action of stage five UFLS the minimum frequency observed is 0.042PU/47.9Hz, which is stillabove the acceptable minimum limit of 0.01PU/47.5Hz.

So it is possible to conclude from the simulation result that the designed AUFLS scheme can support the grid to recover the system frequency up to 50% generation loss.

5.7.Voltage response of the proposed AUFLS scheme

The voltage of selected areas that are exposed to over voltage are analyzed for the voltage before, during and after the occurrence of disturbance and the result is summarized on Table 5-3.

The worst scenario of 50% generation loss among the tested case is simulated for voltage response analysis.

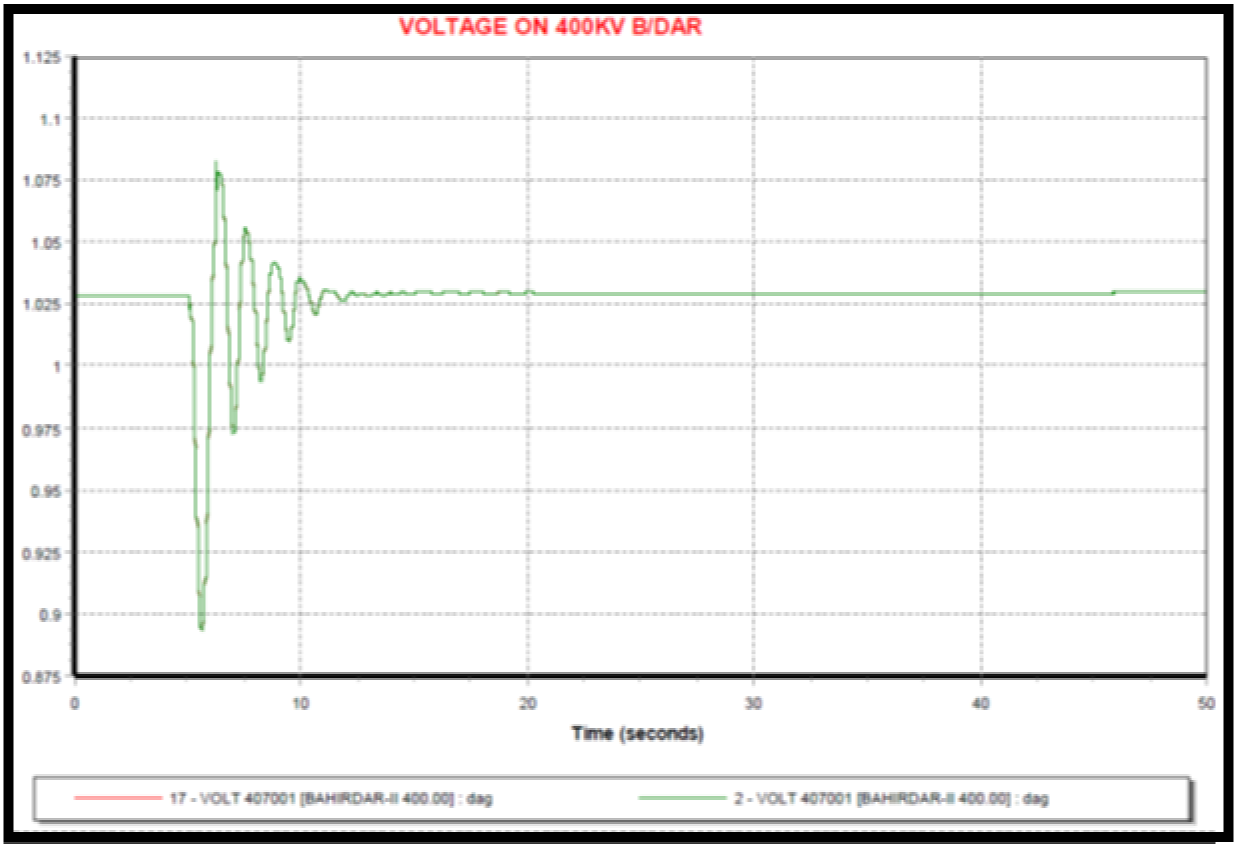

Chart 5-19: Voltage response on B/Dar 400kv bus after 50% generation loss.

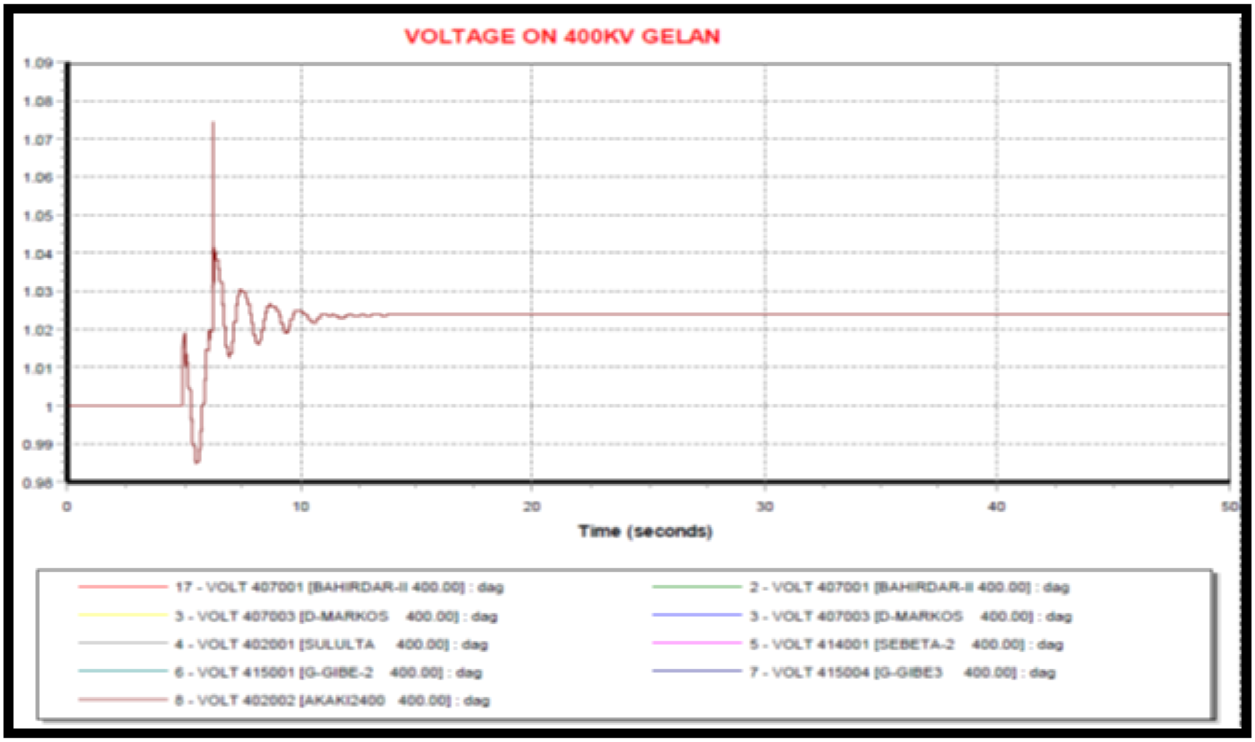

Chart 5-20: Voltage response on Gelan 400kv bus after 50% generation loss.

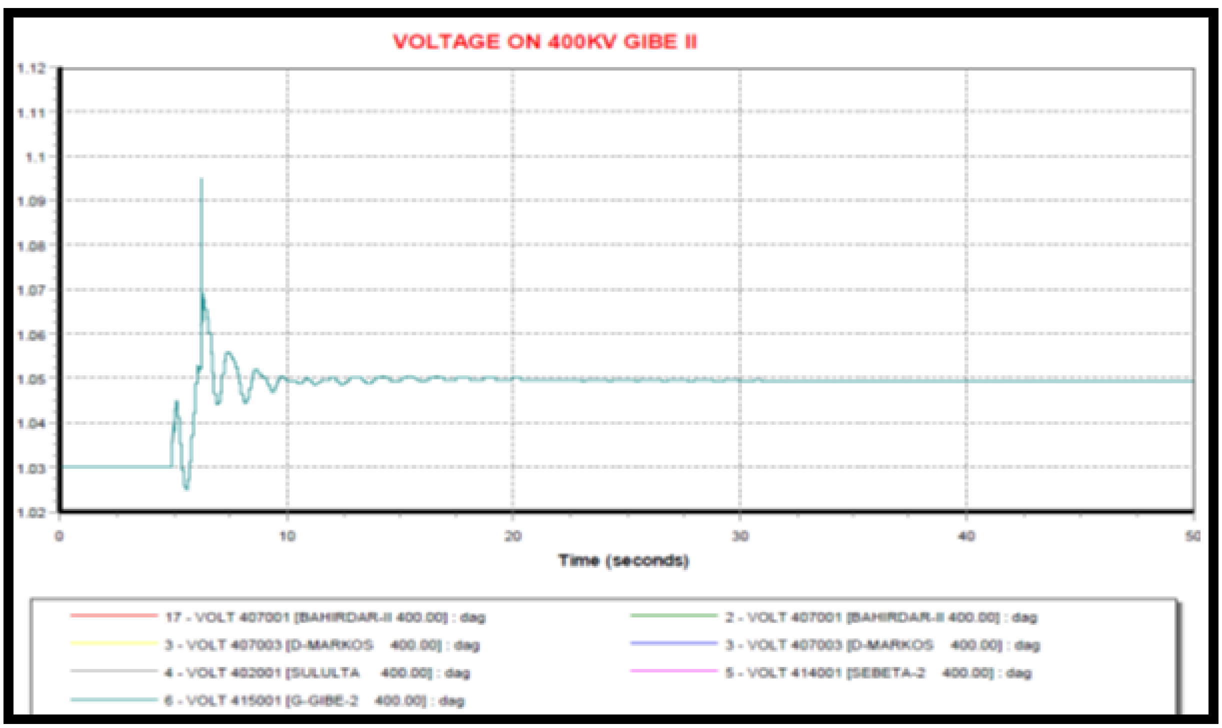

Chart 5-21: Voltage response on Gibe II 400kv bus after 50% generation loss.

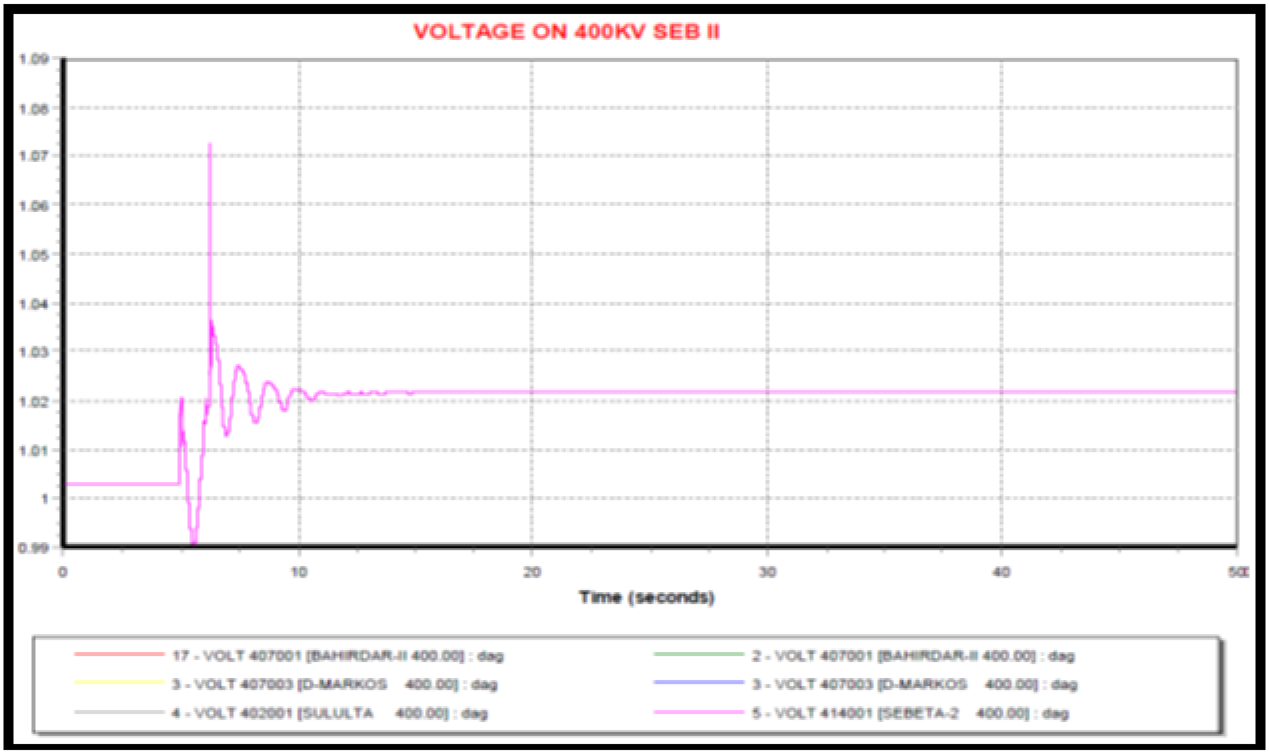

Chart 5-22: Voltage response on Sebeta II 400kv bus after 50% generation loss.

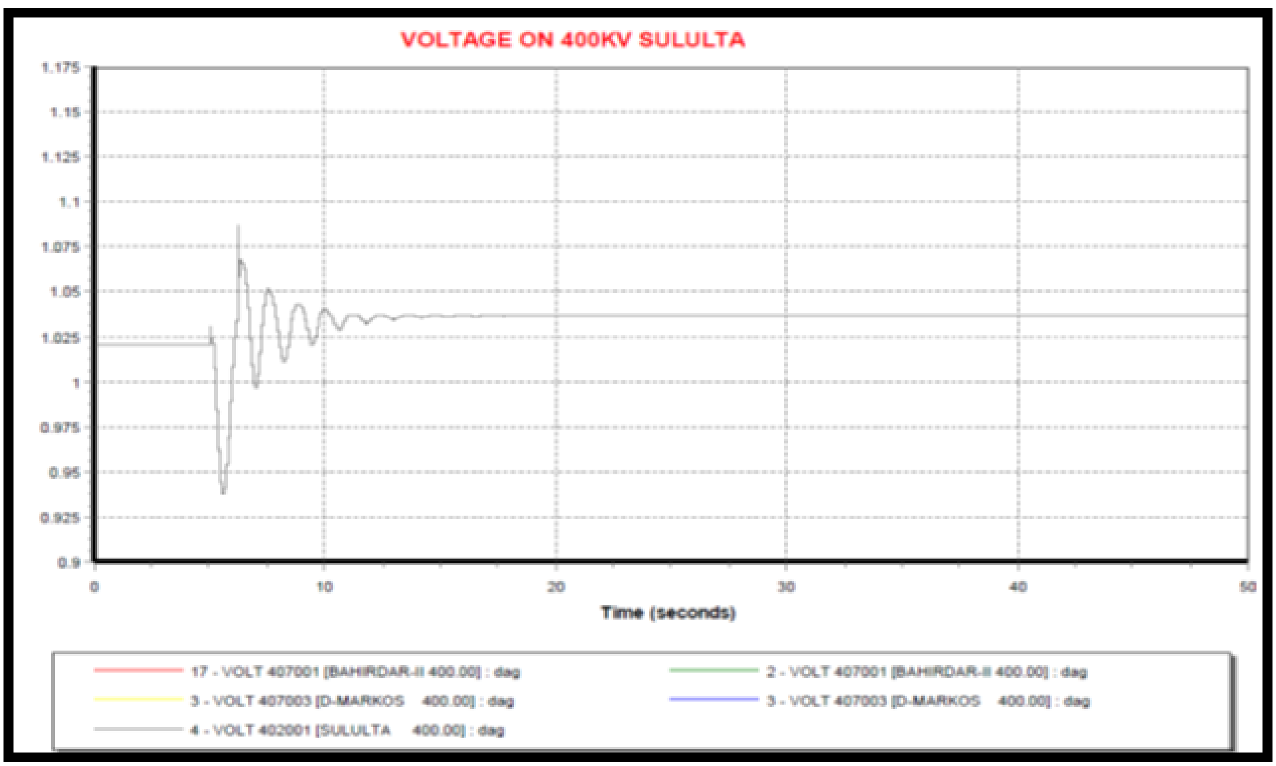

Chart 5-23: Voltage response on Sululta 400kv bus after 50% generation loss.

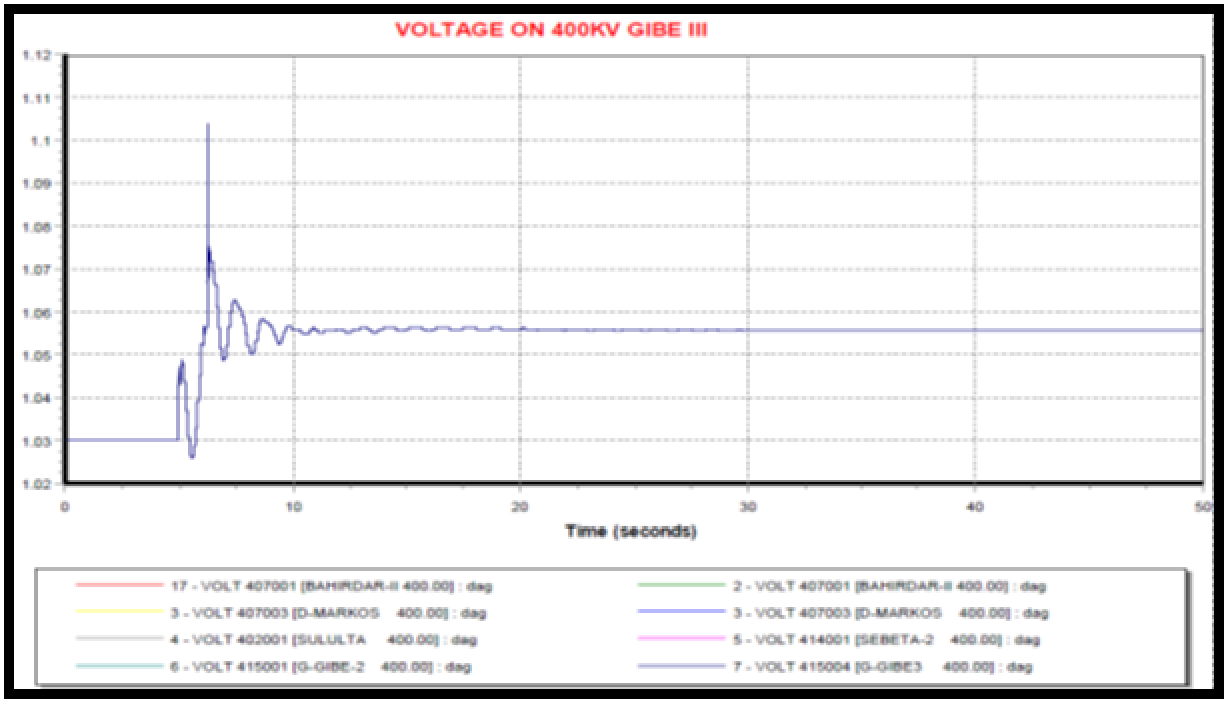

Chart 5-24: Voltage response on Gibe III 400kv bus after 50% generation loss.

Table 5-2: Summary of voltage response of the selected areas before, during and after the occurrence of disturbance.

substation Name	**Voltage level(KV)**	**voltage before fault(PU)**		**voltage during fault(PU)**		**voltage after fault(PU)**	
		PU	KV	PU	KV	PU	KV
BAHIR DAR	400	1.03	412	1.075	**430**	1.03	412
D/MARKOS	400	1.04	416	1.1	**440**	1.05	420
GELAN	400	1	400	1.074	**429.6**	1.025	410
GIBE II	400	1.03	412	1.095	**438**	1.05	420
GIBE III	400	1.03	412	1.14	**456**	1.055	422
SEBETA II	400	1.009	403.6	1.072	**428.8**	1.023	409.2
SULULTA	400	1.0249	409.96	1.074	**429.6**	1.04	416

The voltage during the occurrence of disturbance is much higher than the nominal value, so the over voltage protection between high voltage transmission lines shall be well coordinated in order to isolate the selected lines without affecting the stability of the system.

CHAPTER-SIX

6. CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORKS

6.1.Conclusions

The Ethiopian national grid uses only two stages of under frequency protection which are set at 48.6Hz and 48.0Hz and both acts with a time delay of 0.2 seconds. The total amount of load reduced by both stages is 20% of the load at the time of disturbance. On this thesis it is proved that the current under frequency load shedding protection is not supporting the grid for generation outage above 20%. That's way there is frequent blackout on the power grid.

New AUFLS is designed based on the frequency response of the system for different generation outage scenarios and using commonly used design procedures which consider the rate of change of frequency.

The AUFLS scheme proposed is simulated on PSSE for its effectiveness and it is found that, it optimally recovers the system frequency to normal range of operation for system disturbance case up to 50% generation loss.

6.2.Recommendations

The under-frequency tripping point of generating units is not set uniformly. Some generating units are set to trip before the UFLS scheme, which aggravate the system over load and the drop-in frequency during system disturbance.

The existing under frequency loads shedding Mincom relays not support more than four stages of frequency settings and shall be replaced by latest digital relays that can support more load shedding stages to avoid possible system overload and risk of over-shedding.

So, the under-frequency tripping of generating units shall be revised and set at the same point or below the UFLS scheme.

The regional interconnection shall support each other not only for normal operation but also during system disturbance. However, the 230KV tie line to Sudan set to trip for small change of schedule following minor system disturbance. So, the tie line protection system shall be studied and revised to tolerate disturbance cases that might not risk the stability of the system.

The speed droop setting of the generator speed governor of the national grid is not studied and tuned properly, due to this fact some generating units not participate for primary regulation during system disturbances. Whereas, other generating units participate above their limit and trips by over load. So, load rejection test shall be conducted on the system and speed droop settings of generator speed governors shall be tuned based on the test result

EEP completed live line installation of more than 3000Km OPGW for smooth data and voice communication between different substations and the National Control Center, in addition the New National Dispatch Center project if on progress. So, a centralizes AUFLS having central server that calculate the amount of load to be shed and also determined the location of load shedding based on the information collected from the site shall be included on the new National Control Center project.

6.3.Suggestion for Future Work

The under-frequency upgrading is not the only way to avoid the system black out and the system voltage change following the disturbance cases and also after the operation of UFLS schemes shall be studied.

In the future the voltage stability of the overall system shall be studied to avoid risk of system collapse particularly during light load times where the system voltage is operating above the nominal.

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