Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical & Computer Engineering

Studies on Transmission Expansion planning

(Case study: Addis Ababa Transmission System)

By: Abrham Workie

Thesis submitted to Addis Ababa institute of Technology in partial fulfillment of the requirements for the award of the Degree of Master of Science in Power Engineering

Advisor: Prof. N.P. Singh

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DECLARATION

I, the undersigned, declare that this MSc thesis is my original work, has not been presented for fulfilment of degree in this or any other university, and all sources and materials used for the thesis have been acknowledged.

Name: Abrham Workie

Signature: ______________________________

Place: Addis Ababa

Date of submission: April, 2019 .

This thesis work has been submitted for examination with my approval as a university advisor.

Prof. N.P. Singh ______________________________
Signature

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ABSTRACT

Load forecasting is the prediction of demand for the future period and is an essential requirement for planning and expansion of power systems. In this thesis, load forecast for Addis Ababa Region Transmission System is obtained for the period of 2018 to 2022 and transmission system expansion planning is carried out to meet the forecasted load. Load forecasting is carried out using MS Excel software and following the general stochastic regression techniques. Two independent variables, namely - GDP and number of customers are considered as the main factors affecting the future load growth. Load forecasting is carried out using MS Excel software and following the general stochastic regression techniques. The load forecast for the year 2018 is 991.91MW, that for the year is 2019 is 1063.00MW, the same for the year 2020 is 1169.42MW, while the same for the years 2021 and 2022 is found to be 1206.13MW 1269.83MW, respectively.

Network modeling using ETAP software is done for expansion planning and simulation studies. All the necessary data are collected and power system network elements has been modeled using the software. The model includes the overall power system equipment of Addis Ababa area with their arrangement for analysis and simulation purpose. Simulation studies including Load flow analysis, short circuit analysis and transient stability analysis have been carried out using the ETAP software for the existing system and the proposed expanded system.

From the simulation results, it is found that 9 out of 35 transmission lines are overloaded, 42 out of 71 transformers are overloaded, while 16 out of 31 buses face under voltage problems while meeting the future load demands. It is further observed that that maximum transmission line overloading happens in the year 2022 on Minilik – Gefersa 132kV transmission line and maximum transformer overloading occurs for the load during 2022 on Sebeta I TR3. It is also found that the Addis south II bus is 86.4% below the nominal voltage range.

Simulation studies have been further carried out to test the performance of the expanded Addis Ababa Region Transmission System and compare the results with the existing transmission system to meet the future loads for the period 2018-2022. From the simulation results, it is observed that for the proposed expanded transmission system, the transmission lines overloading improves from 152.23% to 63.6% and transformer overloading improves from 335.14% to 82.8%. Also, with the proposed capacitor placement, the bus voltage improves to 97.13% while meeting the future loads.

Therefore, it is recommended that EEP may go for implementation of the proposed expansion plan.

Keywords: Load Forecasting, Transmission expansion planning, econometrics techniques, Load flow analysis, short circuit analysis, transient stability analysis.

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ABBREVIATIONS

AA – Addis Ababa

AAR – Addis Ababa Region

AARTS – Addis Ababa Region Transmission System

AC – Alternating Current

AI – Artificial Intelligence

ANCI – American National Standards Institute

ANN – Artificial Neural Network

CB – Mega Watt

DC – Direct Current

EEP – Ethiopian Electric Power

EEU – Ethiopian Electric Utility

EPG – Ethiopian Power Grid

ETAPS – Electrical Transient Analysis Program

FL – Fuzzy Logic

GA – Genetic Algorithm

GDP – Mega Volt Ampere

GGS – Ground Grid System

GIS – Geographic information system schematics

HV – High Voltage

IEC – International Electrical Code

KV – Kilo Volt

LF – Load Flow

LG – Line to Ground

LL – Line to Line

LLG – Line to Line to Ground

LLL – Line to Line to Line

LV – Low Voltage

MS – Microsoft

MV – Medium Voltage

MVA – Mega Volt Ampere

MW – Mega Watt

OLD – One-Line Diagrams

PF – Ethiopian Electric Power

SVR – Support Vector Regression

TEP – Ethiopian Electric Utility

TL – Transmission Line

TR - Transformer

UGS – Underground cable raceway systems

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Ethiopian power market was controlled and managed by sole company called Ethiopian Electric Power Corporation (EEPCO). In the last few years the company has been divided into two. They are Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). EEP is responsible in generating & transmitting to deliver power for EEU which is responsible for distributing and selling power to the end customer.

In Ethiopian Power Grid (EPG) there are 400kV, 230kV, 132kV, and 66kV and 45kV transmission/sub-transmission system voltage levels; 33kV and 15kV distribution system voltage levels. The 15kV is the voltage level where almost all customers are connected through distribution transformers.

The Addis Ababa region power grid is made up 22 substations. Out of the 22 substations three of them are 400kV, five of them are 230kV, fourteen of them are 132kV voltage. In 22 substations there are 71 transformers of 46 power transformers and 25 auto transformers with varies rating like 4/7.5/10/12/16/22/25/31.5/40/50/630MVA of power transformers to step down the voltage to distribution network and 63/125/250/MVA auto transformers to step down to suitable voltage for further transmission to other neighboring substations.

Substations are areas where different electrical equipment are arranged and function together. Switches, circuit breakers, transformers, power cables, etc. are available to receive power from the source or generation end and deliver it to the load end with a stepping down of voltage suitable to the load or generation end.

Power system expansion is a concern to be considered carefully in the electricity sector. Consumers need reliable service from the sector to be delivered when they need not when the service provider need. The electric service provider has a key indication parameter when and where the consumers need electricity through forecasting depending on the GDP growth rate, extrapolated number of consumers, and random load demand request.

In Addis Ababa region the demand not served from previous years are too much in addition to the demand to be served in the future related with the economic growth. At this time the load of Addis Ababa area is becoming more than the transmission system equipment capability so that different power system equipment fault is occurring in addition to frequently happening power interruption.

1.2 PROBLEM STATEMENT

Power consumption and power demand is always growing in every power sector. In the case of Ethiopian power network demand growth is undeniable and demand supply is under question. To supply the power demand, the work of proper forecasting of demand growth and proper follow up of expansion planning with implementation in a proper time frame is not done.

In power systems load forecasting is necessary to perform expansion planning. Because of lack of proper planning, a lot of power is lost in generation, transmission and distribution system. So that, there is a need of forecasting the load demand and make ready the necessary generation, transmission, and distribution infrastructures.

Addis Ababa is the capital city of the country and a preferred location for most of the industries in the country. Biggest electric power supply is directed towards the city. Due to this fact, Addis Ababa has been the load center of Ethiopian electric power system. In the near future Addis Ababa area will have load growth in respect with the growth seen in the housing development, industrial sectors, commercial buildings, etc.

This thesis focuses on load forecasting for Addis Ababa region for the year 2018-2022 and investigating the performance of the existing Addis Ababa Transmission System (AATS) to meet the load demands for the future period. Further, based on the performance of the existing system, it is proposed to carry out expansion planning of the existing AATS and perform simulation studies to investigate the performance of the proposed expanded transmission system and compare the results with those of the existing transmission system in order to supply the future load demands.

3 OBJECTIVES:

General Objective

The general objective of this thesis is to carry out load forecasting for in Addis Ababa Region and to investigate transmission network expansion planning of Addis Ababa Transmission system.

Specific Objectives

The specific objectives of this research include the following:

- To model Addis Ababa Transmission System using ETAP
- To review and analyze the performance of the existing Addis Ababa Transmission System.
- To review and analyze the load forecast of Addis Ababa Region.
- To review and analyze the problems of the existing Addis Ababa Transmission System.
- To carry transmission system expansion planning of Addis Ababa Transmission System.
- To analyze the performance of expanded Addis Ababa Transmission System.
- To compare the performance of the existing and proposed expanded transmission systems
- To draw conclusions based on the analysis of the simulation results
- To make recommendations to EEP to implement the findings of this thesis.

1.4 METHODOLOGY

Step by step procedures have been followed for successful completion of tasks. The followed method includes data collection, load forecasting, simulation and analysis, and performing transmission expansion.

Data required such as historical load data, transmission line data, transformer data, network topology, expected GDP growth rate, and number of consumer data has been collected from AAR and LDC planning department.

The load forecasting is performed using econometric load forecasting method. This technique relies on a technique that is statistically based and defined in econometric theory. The forecast focuses on the historical supplied power demand (actual load), GDP, and consumer number. Two variable regression analysis model formulated on MS Excel application built-in data analysis regression module is used.

Electrical power equipment modeling is mandatory on ETAP software for further simulation and analysis. Every necessary parameter like transmission line distance, impedance characteristics, voltage level, external grid characteristics, transformers capacity, circuit breakers data, load characteristics, etc. are inserted in the software with network topology which physically appeared in real time.

Using ETAP software all the necessary simulations like load flow analysis, short circuit analysis, and transient stability analysis are done on the modeled system; based on the collected network data and forecasted data. ETAP simulation results are obtained for further analysis and expansion planning. The simulation software uses the load forecast result of year 2018-2022 as an input.

After obtaining the analysis results, the results are subjected to further analysis and transmission expansion planning is performed. Load flow results which show overload transmission lines, overloaded transformers, and under voltage buses will be subjected to expansion planning. Circuit breakers which will be below the short circuit analysis report will also be subjected for change. And protection system settings will be obtained from the short circuit and transient stability study results.

Overload TL mitigation algorithm for TL expansion, Overload TR mitigation algorithm for TR expansion, and bus under voltage mitigation algorithm for capacitor placement are developed and used. Inception point to use the developed algorithms is load flow simulation result alerted operating condition.

In order to evaluate whether the proposed expansion can improve the network performance or not, simulation and analysis considering the proposed expansion is performed.

Finally, the outputs of the expansion work which meet the objective of the thesis are recorded. Conclusion and recommendation are made.

1.5 LITERATURE REVIEW

In this section previous works which are directly or indirectly related to the idea of this thesis work are examined. Works reviewed are generally categorized in to two as: load forecast techniques and transmission expansion planning techniques; from recently published journals, M.Sc. thesis and PhD. thesis works.

There are different methods of load forecasting, basic categories are parametric and artificial intelligence methods [3]. The parametric load forecasting techniques can be grouped in to three [8] and the soft computing (artificial intelligence) in to four [20] [3].

Parametric methods can be categorized again in to time series, econometric and end user load forecasting techniques. Artificial intelligence can be divided into Fuzzy logic, Artificial Neural networks (ANN), Support vector regression (SVR)

As the name indicates econometric technique is dependent on economic indexes like GDP, price, etc. [4]. Econometrics techniques is discussed [16] the first step to do on this technique is make a relationship between the load demand and variables affecting the load.

This class of model, like the time series model, uses historical data to predict the future. Econometric analysis however, attempts to go beyond time series models by explaining the causes of the identified trends. Econometric models assume relationships between the dependent variable (either energy or power) and independent variables (either economic e.g. GDP), technological (e.g. number and type of appliances; industrial processes), demographic (e.g. population) or other variables (e.g. weather) [4].

ED = f (Y, Pi, Pj, POP, T) is the basic relation function between the load demand and driving variables stated in [20]. Where ED is electricity demand, Y is output or income, Pi -own price, Pj – price of related fuels, POP – population and T is technology

The other category to be reviewed is transmission expansion planning. Transmission expansion planning used [4] an analytical algorithm which has been implemented for specific load condition with variations in generation and the power system operation condition will not be disturbed or compromised [5]. For that purpose, an economical factor has been measured that considers economic aspects of the line to be added for expansion. The prescribed analytical approach is also implemented for its feasibility check on a practical case study system. [4]. TEP can be classified according to the method adopted to build the expansion plans [4]. These methods can be classified into three types: mathematical, pure heuristic and meta-heuristic approaches in [4] detail models in these three classes are presented.

Mathematical models are focused on optimization processes, with cost minimization objective function subject to sets of constraints [5]. As the plan is usually obtained under large simplifications, as it is not possible to consider all details of the network on the problem model, it should be verified according to technical, environmental and financial points of view before any decision is taken.

Mathematical optimization methods can experience difficulties on solving large-scale TEP problems. We have to keep in mind that these problems are nonlinear and non-convex in nature.

The computational effort is huge and the obtained optimal solution can correspond to a local optimum due to intrinsic limitations of the searching process [5].

The solution of combinatorial optimization problems has to do with finding optimal solutions from a discrete set of feasible solutions. However, many of these problems cannot be solved to optimality in reasonable computation times, due to their dimension or to their characteristics. Reaching optimal solutions is also meaningless in many real situations, since one is often dealing with not precise data and rough simplifications of reality. So, the goal of approximate algorithms, or heuristics, is to produce good approximate solutions as quick as possible, without necessarily providing any guarantee of solution optimality.

Heuristic methods go step-by-step generating, evaluating, and selecting expansion options, with or without interacting with the planner (interactive or non-interactive) [5]. These methods are inventive techniques based on engineers' experience [5]. Taking advantage from this experience, the computational performance of heuristic methods is usually better than that of the mathematical methods.

It is possible to find good feasible solutions with a reasonable computational effort using heuristic algorithms. However, the quality of these solutions is not guaranteed, in the sense that it is not possible to prove that they are the best ones.

Meta-heuristic methods combine mathematical optimization with heuristic concepts. These methods have been subjected to deep research on recent years. Even when applied to large problems, meta-heuristic methods are able to identify quasi-optimal solutions with acceptable computational effort.

TEP problems are complex and computationally very demanding. The way these problems are approached is crucial for the feasibility of the methodology to be implemented. As explained in section above, one has to select only those projects that have significant implications in the transmission network, and avoid those who have a local nature.

Even though this thesis work took some ideas and methods from the above-mentioned works in the reviewed literature, it has some unique future. Load forecasting is handled as it is shown in the literature but considering only two independent variables that are GDP and consumer number only. In this thesis expansion algorithms developed doesn't consider any cost equation but in the literatures, there are cost index to optimize the cost effectiveness but cost.

1.6 SCOPE AND SIGNIFICANCE OF THE STUDY

Scope of the study includes forecasting load demand of Addis Ababa region transmission system using five years historical load data, GDP, and number of consumers and expansion planning of Addis Ababa region transmission system. Addis Ababa Region transmission system voltage levels included in this study are 400kV, 230kV, and 132kV while the loads are considered on the 66kV, 45kV, 33kV, and 15kV voltage level of the transformers.

The significance of the study includes the following:

To foresee the load growth of the region and to make preparations to serve the demand, To see how the system will respond if all loads are going to be peak,

To determine outstanding transmission expansion need and make decisions to coordinate further project works.

To see capabilities of circuit breakers and other power system elements during faults and recommend changes if necessary,

To suggest further studies on the gaps or problems faced when this thesis is conducted.

1.7 LIMITATION OF THE STUDY

This thesis is limited to the loads which have records in the past five years; and which is provided by the region office. Weather data is not integrated in the forecasting as an independent variable, the paper is limited not to consider the weather data as the peak load of the country is happening in different seasons which is not the bad weather time.

Cable overloading from load side, cable sizes, cable length and characteristics are delimitations to the distribution network side.

Protection systems like overload tripping, under voltage tripping, transformer over temperature tripping, etc. are not in the scope. Load shading and islanding are also out of scope.

Under voltage compensation is only limited to capacitors no other FACT devices.

1.8 THESIS ORGANIZATION

The research paper contains six chapters. The first chapter provide general introduction, statement of the problem, the research objective, general methodology, the scope and limitation of the study. The second chapter deals with modeling of Addis Ababa Region Transmission System (AARTS), describing the necessary data for modeling, and describing system structure of the region. The third chapter covers the load forecasting section of the research which describes load forecasting principles, applied methods, and obtained results. The fourth chapter is about the transmission expansion planning and performance analysis of the region network. Chapter five is about simulation studies and analysis of results. Conclusion, recommendation, and suggestion for future works are raised in the sixth chapter.

CHAPTER 2

MODELING OF ADDIS ABABA REGION TRANSMISSION SYSTEM

2.1 INTRODUCTION

In this chapter, Addis Ababa region transmission system modeling using ETAP software is presented. Description of Addis Ababa region transmission system network as well as its topology is presented in Section 2.2. The necessary data collected for transmission system substations, transmission lines and the transformers are provided in Section 2.3. A brief description of the ETAP software is presented in Section 2.4. Addis Ababa region transmission system modeling using ETAP software is carried out in Section 2.5.

2.2 ADDIS ABABA REGION TRANSMISSION SY`STEM DESCRIPTION

Addis Ababa region transmission system consists of 22 substations. Out of the 22 substations 3 of them are 400kV, 5 of them are 230kV, 14 of them are 132kV voltage levels as listed in Table 2-1.

Table 2-1 List of substations in Addis Ababa Region

S. No.	Substation	Operating Voltage Level (kV)
1	Sebeta II	400kV
2	Sululta	
3	Gelan	
4	Legetafo	230kV
5	Sebeta I	
6	Tor Hailoch	
7	Kaliti I	
8	Gefersa	
9	Minilik	132kV
10	Addis North	
11	Addis East II	
12	Nefas Silk	
13	Ayat	
14	Cotobie	
15	Kaliti II	

16	Kaliti North	
17	Kaliti GIS	
18	Yesu	
19	Weregenu	
20	Mekanisa	
21	Addis south II	
22	Addis Center	

Addis Ababa region network topology

As it is mentioned earlier, AARTS topology is a composition of 22 substations with different voltage levels, 31 buses with different voltage levels; 35 transmission lines with different voltage levels, length characteristics to interconnect each substation; 71 transformers with different voltage levels and ratings to step down the voltage and to feed specific loads. The network topology as a whole is shown in figure 2-1. All substations single line diagram is annexed.

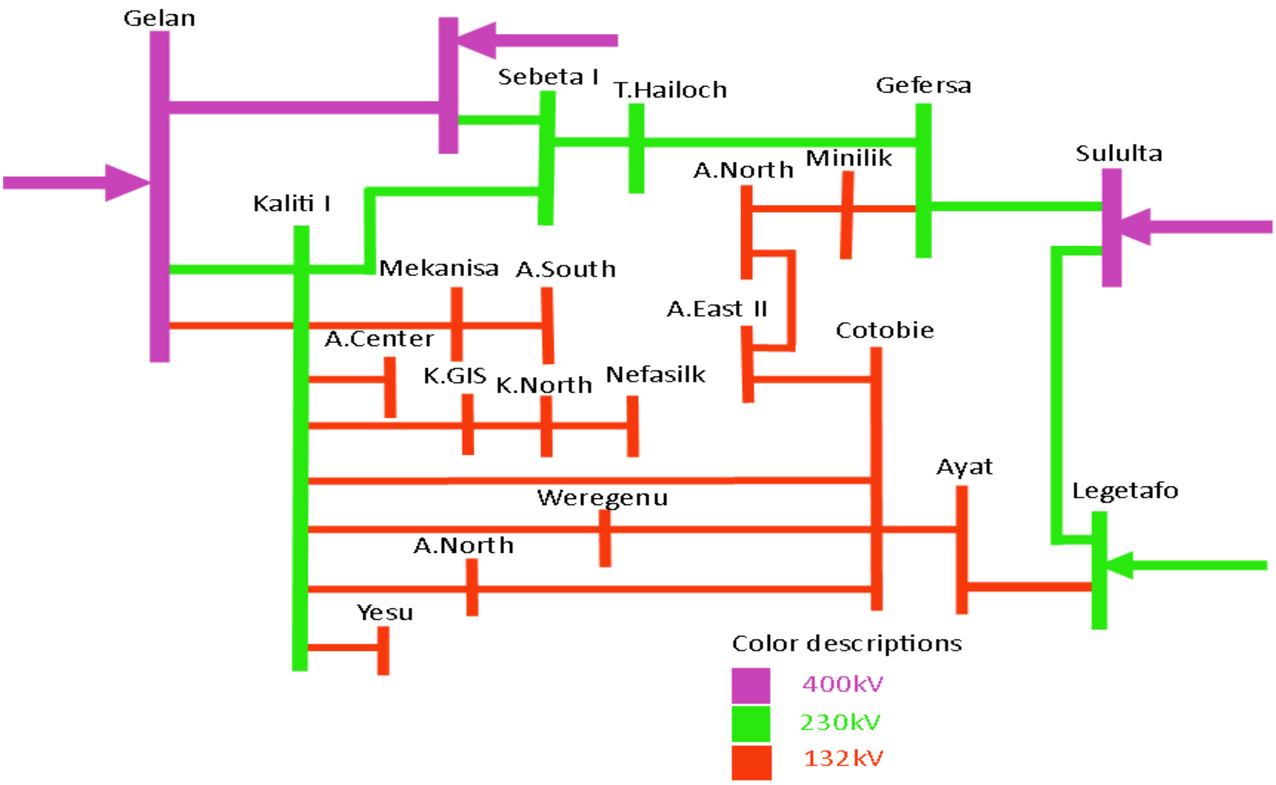


Figure 2-1 Addis Ababa Region transmission system network topology

2.3 TRANSMISSION SYSTEM DATA COLLECTION

Addis Ababa region office is the main source of historical data. Every data used in this thesis is gathered from these offices except the GDP data which is obtained from world wide website. Available transmissions data, transformers data, grid interconnection points and capacity are described in this section.

In Addis Ababa region there are 35 transmission lines. 4 transmission lines are 400kV voltage level, 10 transmission lines are 230kV voltage level, and 20 are 132KV transmission lines. In total 71 transformers there are available in the region. 25 auto transformer and 46 power transformers. From 46 power transformers 37 of them are 2 winding transformers and 9 of them are 3 winding transformers; all are connected at 132kV bus except 1 transformer which is connected at 230kV bus at Sebeta II substation. 8 auto transformers are with voltage level of 400/230kV and the remaining 17 auto transformers are with voltage level of 230kV/132kV.

Transmission line data

Transmission lines data which are necessary for modeling on ETAP software are transmission line length, voltage level, maximum capacity, impedance characteristics, tower height, arrangement or configuration of conductors, distance between conductors, type and manufacturer of transmission lines. All necessary data are obtained from the Ethiopian electric power (EEP) Addis Ababa region office and national grid load dispatch center. Other data like manufacturer is used from the software library.

Table 2-2 List of transmission lines in Addis Ababa Region Transmission System

Sl. No.	Transmission Lines	Line Capacity (A)
400kV Transmission Lines		
1	Sebeta II - Gelan 400kV Line 1	1050
230kV Transmission Lines		
2	Gefersa - Sululta 230kV Line 1	920
3	Gefersa - Sululta 230kV Line 2	920
4	Kaliti I - Legetafo 230kV Line 1	920
5	Legetafo - Sululta 230kV Line 2	920
6	Legetafo - Sululta 230kV Line 1	920
7	Sebeta II- Sebeta 230kV Line 1	920
8	Sebeta II- Sebeta 230kV Line 2	920
9	Gelan - Kaliti I 230kV Line 1	920

10	Gelan - Kaliti I 230kV Line 2	920
11	Sebeta I – Tor Hailoch 230kV Line 1	920
12	Tor Hailoch - Gefersa 230kV Line 1	920
132kV Transmission Lines		
13	Addis East – Addis North 132kVLine 1	490
14	Addis North - Minilik 132kV Line 1	490
15	Ayat - Legetafo 132kV Line 1	490
16	Cotobie - Addis East II 132kV Line 1	490
17	Cotobie - Ayat 132kV Line 1	490
18	Gelan - Kaliti I 132kV Line 1	490
19	Gelan - Kaliti I 132kV Line 2	490
20	Kaliti II - Nefas Silk 132kV Line 1	490
21	Kaliti North - Cotobie 132kV Line 1	490
22	Kaliti I - Addis Center 132kV Line 1	490
23	Kaliti I - Kaliti North 132kV Line 1	490
24	Kaliti I - Kaliti GIS 132kV Line 1	490
25	Kaliti I - Mekanissa 132kV Line 1	490
26	Kaliti I - Wereregenu 132kV Line 1	490
27	Kaliti I - Yesu 132kV Line 1	510
28	Kaliti I - Sebeta I 132kV Line 1	510
29	Kaliti I - Kaliti II 132kV Line 1	510
30	Kaliti I - Cotobie 132kV Line 1	510
31	Kaliti GIS - Kaliti II 132kV Line 1	510
32	Mekanisa - A.SII 132kV Line 1	510
33	Minilik - Gefersa 132kV Line 1	510
34	Sebeta II - Sebeta I Line 1	510
35	Sebeta II - Sebeta I Line 2	510

Transformer data

Transformer data required for ETAP simulation are transformer naming, rating, tap setting, connection bus related to the voltage level in the primary and secondary plus tertiary sides, impedance, and grounding. The entire mandatory data are obtained from related office.

Table 2-3 List of transformers in Addis Ababa Region transmission System

Sl No.	Station Name	Voltage Ratio (kV)	Rating (MVA)	Sl No.	Station Name	Voltage Ratio (kV)	Rating (MVA)	Sl No.	Station Name	Voltage Ratio (kV)	Rating (MVA)
1	SEBETA-II	400/230	250	5	KALITI-I	230/132	125	12	KALITI NORTH	132/15	31.5
		400/230	250			230/132	125			132/15	31.5
		400/230	250/250/80			230/132	125	13	MEKANISSA	132/15	50
		230/33	25			132/45/15	22/22/7.3			132/15	20
2	SULULTA	400/230	250/250/80			132/45/15	22/22/7.3	14	WOREGENU	132/15	32/40
		400/230	250/250/80	6	SEBETA I	230/132	125			132/15	32/40
		400/230	250/250/80			230/132	125	15	ADDIS SOUTH II	132/15	25
		230/132	63			230/132	125			132/15	25
		230/132	63			132/45/15	25/25/10	16	YESU	132/15	10
		132/33/15	50/25/25			132/45/15	12/12/4.0			132/15	25
		132/66	25			132/15	50	17	GELAN	400/230	500
3	GAFARSSA	230/132	125			132/15	50			400/230	500

		230/132	125	7	ADDIS CENTER	132/15	31.5			400/230	500
		230/132	125			132/15	31.5			230/132	125
		230/132	125	8	ADDIS EAST II	132/15	25			230/132	125
		132/66/15	25/20			132/15	25			230/132	125
		132/45	6	9	ADDIS NORTH	132/15	25			132/15	50
		132/33/15	30/15/15			132/15	25	18	NIFAS SILK	132/15	31.5
		132/45/15	20/25	10	COTOBIE	132/15	31.5			132/15	31.5
4	LEGATAFO	230/132	125			132/45/15	12/16	19	Torhailoch GIS	230/15	25
		230/132	125			132/33	12/16	20	Ayat GIS	132/15	25
		132/15	31.5	11	KALITI-II	132/45/15	25/25/10	21	Minilik GIS	132/15	25
		132/15	31.5			132/15	25	22	kaliti GIS	132/15	25
						132/15	25				

2.4 DESCRIPTION OF ETAP SOFTWARE

ETAP (**E**lectrical **T**ransient **A**nalysis **P**rogram) is a fully graphical Enterprise package that runs on Microsoft® Windows® 2003, 2008, 2012, XP, Vista, 7, and 8 operating systems. ETAP is the most comprehensive analysis tool for the design and testing of power systems available. Using its standard offline simulation modules, ETAP can utilize real-time operating data for advanced monitoring, real-time simulation, optimization, energy management systems, and high-speed intelligent load shedding. [7]

ETAP allows to easily create and edit graphical one-line diagrams (OLD), underground cable raceway systems (UGS), three-dimensional cable systems, advanced time-current coordination and selectivity plots, geographic information system schematics (GIS), as well as three-dimensional ground grid systems (GGS).

The program has been designed to incorporate to three key concepts:

Virtual reality operation

Total integration of data

Simplicity in data entry

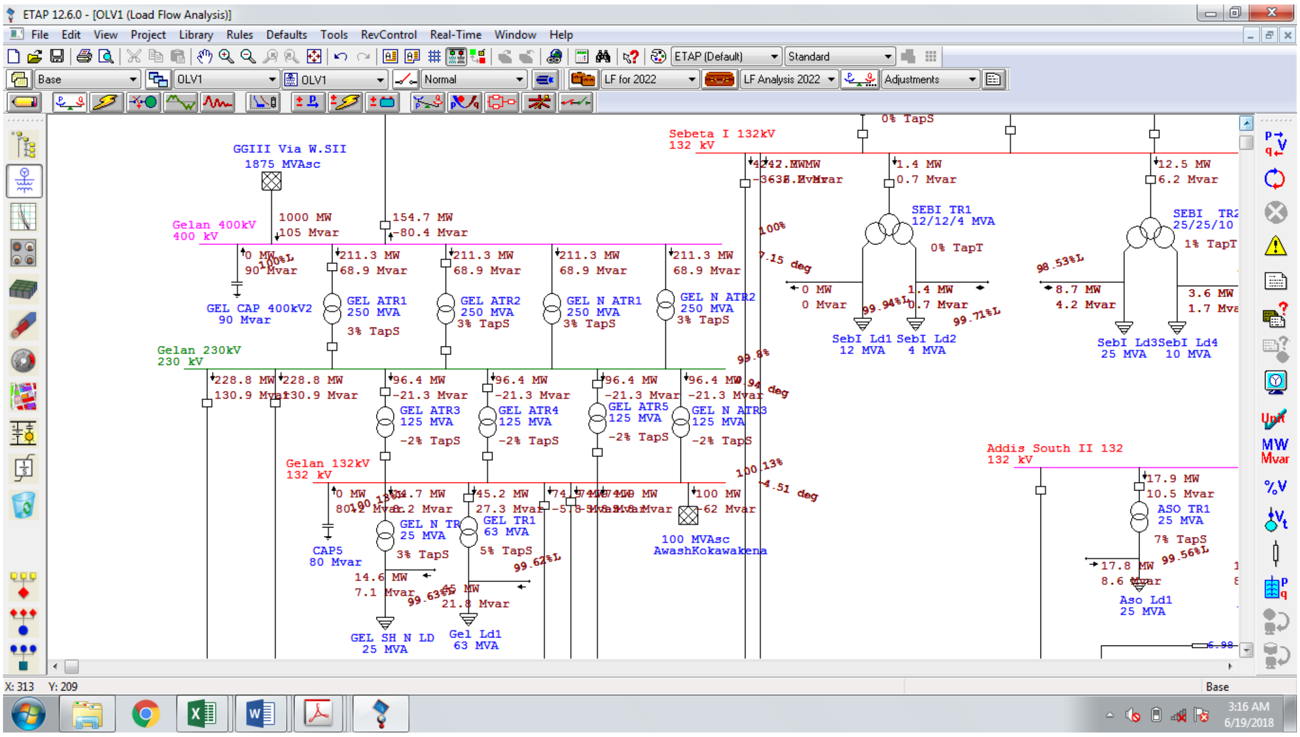


Figure 2-2 ETAP software snapshot

Virtual Reality Operation

The program operation emulates real electrical system operation as closely as possible. For example, when you open or close a circuit breaker, place an element out of service, or change the operating status of motors, the de-energized elements and sub-systems are indicated on the one-line diagram in gray. ETAP incorporates innovative concepts for determining protective device coordination directly from the one-line diagram.

Total Integration of Data

ETAP combines the electrical, logical, mechanical, and physical attributes of system elements in the same database. For example, a cable not only contains data representing its electrical properties and physical dimensions, but also information indicating the raceways through which it is routed. Thus, the data for a single cable can be used for load flow or short-circuit analyses (which require electrical parameters and connections) as well as cable ampacity derating calculations (which require physical routing data). This integration of the data provides consistency throughout the system and eliminates the need for multiple data entry for the same element, which can be a considerable time savings.

Simplicity in Data Entry

ETAP keeps track of the detailed data for each electrical apparatus. Data editors can speed up the data entry process by requiring the minimum data for a particular study. In order to achieve this, we have structured the property editors in the most logical manner for entering data for different types of analysis or design.

ETAP's one-line diagram supports a number of features to assist you in constructing networks of varying complexities. For example, each element can have individually varying orientations, sizes, and display symbols (IEC or ANSI). The one-line diagram also allows you to place multiple protective devices between a circuit branch and a bus.

ETAP provides you with a variety of options for presenting or viewing your electrical system. These views are called presentations. The location, size, orientation, and symbol of each element can be shown differently in each presentation. Additionally, protective devices and relays can be displayed (visible) or hidden (invisible) for any particular presentation. For example, one presentation can be a relay view where all protective devices are displayed. Another presentation may show a one-line diagram with some circuit breakers shown and the rest hidden (a layout best suited for load flow results).

Among ETAP's most powerful features are the composite network and motor elements. Composite elements allow to graphically nesting network elements within themselves down to an arbitrary depth. For example, a composite network can contain other composite networks, a feature that provides the capability to construct complex electrical networks while still maintaining a clean, uncluttered diagram that displays what we want to emphasize - yet the next level of system detail is within easy reach of the computer mouse. ETAP puts the power at fingertips.

ETAP is considered to be the foremost-integrated database for electrical systems, allowing having multiple presentations of a system for different analysis or design purposes.

2.5 TRANSMISSION SYSTEM MODELING USING ETAP

On ETAP it is possible to represent or model transmission lines with physical characters like the voltage drop, conductor type, operating frequency, configuration, and impedance. So that all available transmission lines are modeled, as if they are available in the real world. Transmission line editor is the one which gives this modeling and editing capability. Two standards can be used alternatively. Single line diagrams of every substation is annexed and is used to model all the substations in ETAP software.

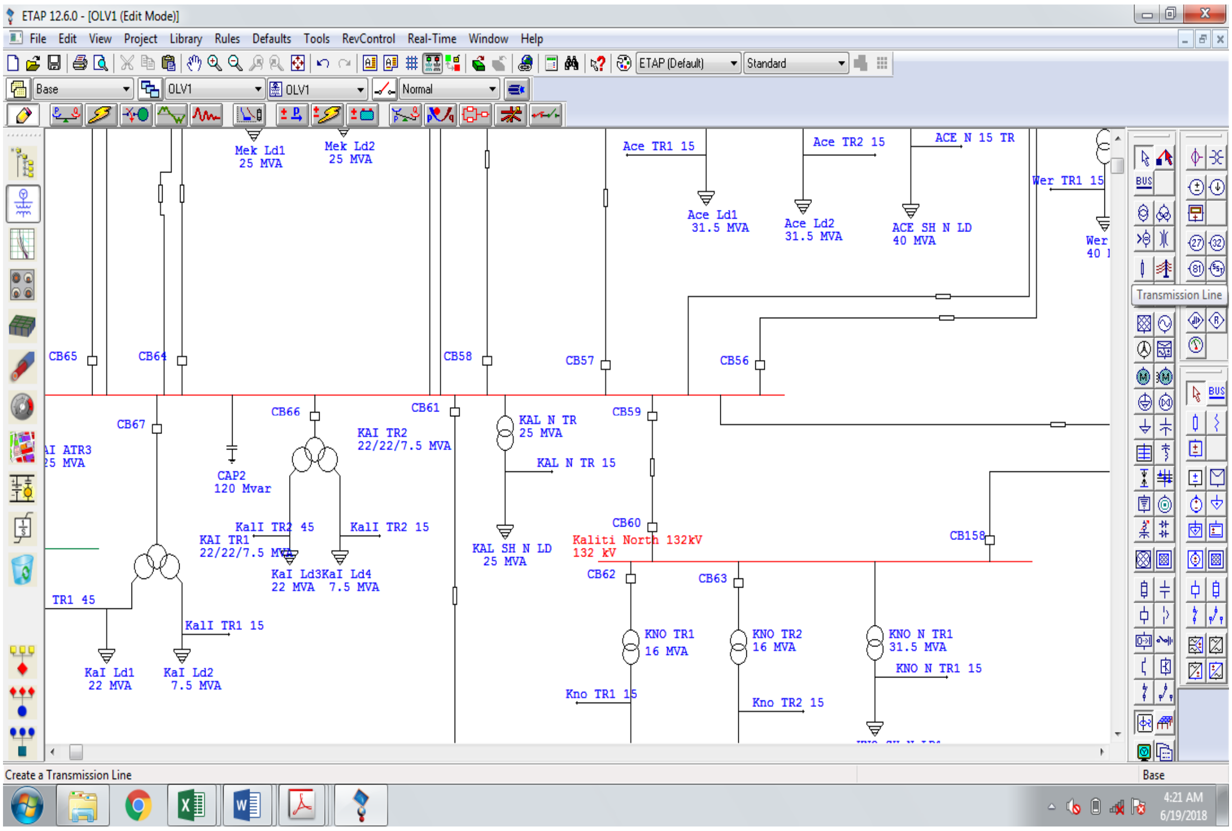


Figure 2-3 ETAP model overview

The same is true for Transformers and external grid representations.

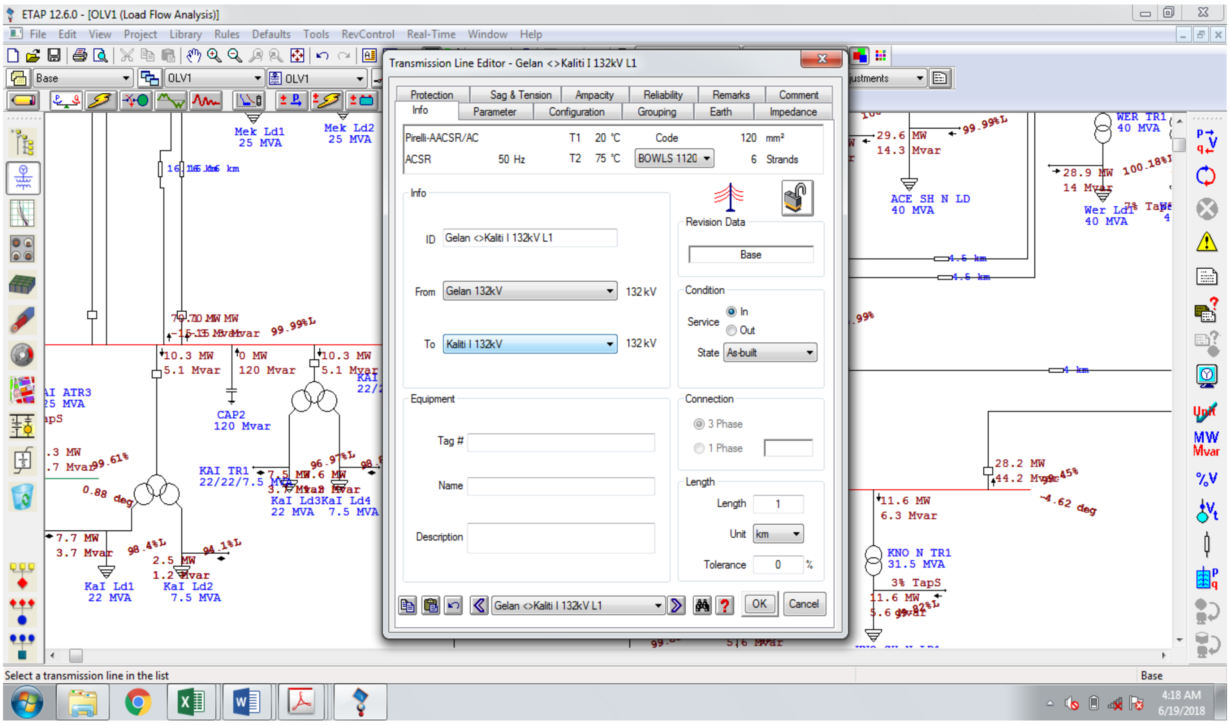


Figure 2-4 ETAP model overview

Transmission line modeling is a continuation of bus bar edition. Buses are modeled as if they exit in their voltage levels. For best visualization of the model done on the software Gelen substation which consist 400kV, 230kV, and 132kV buses with many auto transformers is presented as follows:

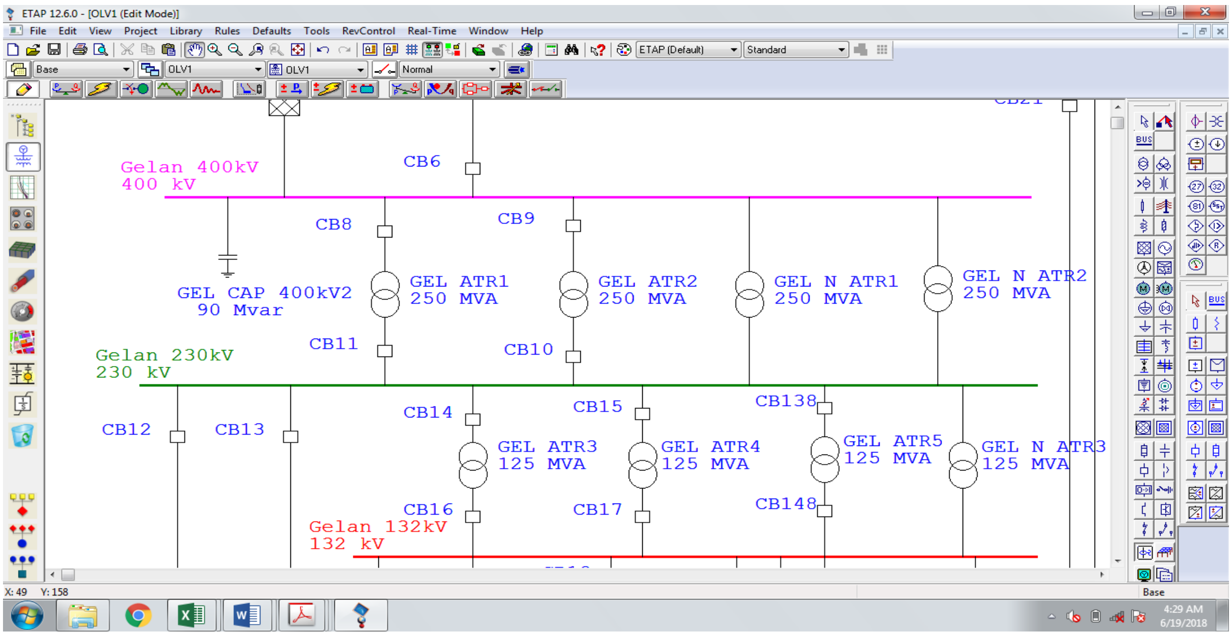


Figure 2-5 ETAP model Gelan substation view

CHAPTER 3

LOAD FORECASTING FOR ADDIS ABABA REGION

3.1 INTRODUCTION

In this Chapter, load forecasting for Addis Ababa Region using MS excel is carried out. A brief description of load forecasting techniques is provided in Section 3.2. The details of load forecasting for Addis Ababa Region using the econometrics method with two independent variables, GDP and number of consumers, for the year 2018, 2019, 2020, 2021 and 2022 is presented in Section 3.3.

3.2 LOAD FORECASTING TECHNIQUES

Load forecasting is a primary requirement for expansion planning studies. Load forecast results are needed for; transmission planning, generation planning, distribution planning, and operational planning.

Different load forecasts are required for the short, medium or long term and for different levels of the system (e.g. generation, transmission substations, distribution substations and at consumer terminals). Rigorous load forecasting may be necessary for a number of reasons, such as:

It is often essential for investors (like donor agencies, Independent Power Producers (IPPs), project shareholders and bankers) to be convinced of the reasonableness of future load growth before making a financial commitment.

Large consumers are often more optimistic about future growth than is justified by the prevailing economic climate. This may result in an over-estimate of load with a consequent over-investment.

In power markets where demand is going to saturation, decisions made depending on rough growth in the past may not be a good guide to growth in the future.

There are different methods of load forecasting. Basic categories are parametric and artificial intelligence methods [3]. The parametric load forecasting techniques can be grouped in to three [8] and the soft computing (artificial intelligence) in to four [20] [3].

Parametric methods can be categorized again in to time series, econometric and end user load forecasting techniques. Artificial intelligence can be divided into Fuzzy logic, Artificial Neural networks (ANN), Support vector regression (SVR)

3.2.1 Parametric Load forecasting

Time series

Time series technique is defined as “the long-term average growth and may be regarded in some way as an average increase in a time series”. Superimposed on this may be a seasonal variation. Seasonal in this sense is defined as “a cyclic variable that has roughly the same beginning and end values for a given period of time (similar to the properties of a sine wave)”. Such variations may be seen over a 24-hour period, a weekly period, an annual period, or even a longer period [8][9]

Econometric

As the name indicates this technique is dependent on economic indexes like GDP, price, etc. [4]. Econometrics techniques is discussed [16] the first step to do on this technique is make a relationship between the load demand and variables affecting the load.

This class of model, like the time series model, uses historical data to predict the future. Econometric analysis however, attempts to go beyond time series models by explaining the causes of the identified trends. Econometric models assume relationships between the dependent variable (either energy or power) and independent variables (either economic e.g. GDP), technological (e.g. number and type of appliances; industrial processes), demographic (e.g. population) or other variables (e.g. weather) [4].

ED = f (Y, Pi, Pj, POP, T) is the basic relation function between the load demand and driving variables stated in [20]. Where ED is electricity demand, Y is output or income, Pi -own price, Pj – price of related fuels, POP – population and T is technology.

Detail description about econometrics technique is presented in section 3.2.3 load forecasting (econometric) methodology used in this thesis.

End user

End user load forecasting approach is the approach to forecast future loads based on the statistical information gather from end users [4]. This technique takes in to account all the electrical devices which can have power demand and by doing survey to formulate the need. Such models usually begin by specifying uses for which energy is ultimately required, such as heating water, cooling buildings and cooking food.

$E = S \cdot N \cdot P \cdot H$ Where E is energy consumption of an appliance in kWh, S is a penetration level in terms of number of such appliances per customer, N is a number of customers, P is power required by the appliance in kW and H is hours of appliance use [20].

3.2.2 Soft computing (Artificial Intelligence)

“Soft computing is a collection of methodologies that aim to exploit the tolerance for imprecision and uncertainty to achieve tractability, robustness, and low solution cost. Its principal constituents are fuzzy logic, neuro-computing, and probabilistic reasoning. Soft computing is likely to play an increasingly important role in many application areas, including software engineering. The role model for soft computing is the human mind.” The quotation is from Lofty A. Zadeh the one who invented fuzzy logic and soft computing concept in 1994 [17].

Soft computing technique can be categorized as modern load forecasting techniques has different sub techniques to be described as follows according to [18]

- Fuzzy logic

- Artificial Neural networks (ANN)
- Support vector regression (SVR)

But Artificial intelligence according to [20] is divided in to four so that the naming is different with reference [18] they are

- Fuzzy Logic (FL)
- Artificial Neural networks (ANN)
- Wavelet network (same principle with SVR)
- Genetic algorithm

Fuzzy logic forecasting technique is used for short term load forecasting [18] for Adama University. It is stated in the paper that the input historical data passes through fuzzification module then ready to be collected and managed by fuzzy interference E-system so that the fuzzy rules are to be applied. For the output defuzzification module is necessary [18].

Artificial neural network (ANN) technique is the popular soft computing technique is multilayer feed-forward architecture. [19] Performed a detailed review of ANN on short term load forecast.

Support vector regression or wavelet network technique is used in load forecasting report literatures [22] [25].

3.2.3 Load forecasting (Econometric) methodology

The load forecast technique used in this study is econometric load forecasting method. This technique relies on a technique that is statistically based and defined in econometric theory. The study focuses on the historical supplied power demand (actual load). The forecast is done using two variable regression analysis model formulated on MS Excel application. Built-in MS Excel Data analysis regression module is used.

Statistical relationship between historical data with respect to country's GDP growth rate and number of customers is formulated in the following econometric equation.

$Y=a+b_1X_1+b_2X_2$

$\sum x_1y = \sum X_1Y-[(\sum X_1)(\sum Y)]/N$

$\sum x_2y = \sum X_2Y-[(\sum X_2)(\sum Y)]/N$

$\sum x_1x_2 = \sum X_1X_2-[(\sum X_1)(\sum X_2)]/N$

$\sum x_1^2 = \sum X_1^2-[\sum X_1]^2/N$

$\sum x_2^2 = \sum X_2^2-[\sum X_2]^2/N$

$b_1 = [(\sum x_2^2)(\sum x_1y)-(\sum x_1x_2)(\sum x_2y)]/[(\sum x_1^2)(\sum x_2^2)-(\sum x_1x_2)^2]$

$b_2 = [(\sum x_1^2)(\sum x_2y)-(\sum x_1x_2)(\sum x_2y)]/[(\sum x_1^2)(\sum x_2^2)-(\sum x_1x_2)^2]$

$a = (Y_{mean}) - b_1(X_{1\,mean}) - b_2(X_{2\,mean})$

Where: Y is peak load

a is constant

b_1, b_2 are coefficients for independent variables X_1, and X_2 respectively

X_1, X_2 are independent parameters which are GDP and No. of consumers

y, x_1, x_2 are intermediate variables to calculate the constant and the coefficients a, b_1, & b_2

N is number of data

Regression analysis is used to calculate constant (a) and coefficients (b_1 & b_2). After the constant and the coefficients are obtained the calculation formula will look like as follows:

Peak load = a + b_1 * GDP + b_2 * No. of consumers

Strong correlation between the dependent variable peak load and independent variables GDP and number of consumers can be determined by analyzing the statistical outputs. Statistical outputs to determine the strong relation are obtained from the calculation procedure on the model. There are three main statistical result outputs that help to determine the validity of relationships of the dependent and independent variables. They are R squared, P value, and coefficients. They are described as follows:

R^2 (R squared) – the R^2 statistic describes the correlation between dependent variable (historical peak load) and independent variable (GDP & No. of customers). If R^2 value is 1 it indicates perfect correlation while R^2 value 0 indicates no correlation.

P-values – the P value identify whether the independent variable are adding anything to regression. A P value for any specific variable that is close to zero indicates that it is very likely that the particular variable in the equation plays a significant role in the determination of dependent variable (peak load). When both independent variables are mandatory and p-values not in the specified range it is necessary to look at the Significance-F value for overall test and should be less than 0.05

Coefficients – the coefficients determine the impact of the independent variables (drivers) on historical peak load. Regression should only be accepted if the coefficients appear to be of the correct sign (positive or negative). If the independent variable has negative effect on the power consumption the coefficient will be managed as negative and if the variable have positive effect for power consumption coefficient should be managed as positive.

Regression results which have R^2 value over 0.7 (indicating good correlation) and p-value or significance-F value lower than 0.05 should be accepted. Those parameters need further calculation if we follow manual formulation. But can be obtained automatically in the Excel regression module.

The purpose with such a model is; it assumes that historical relationship will remain valid in the future. So that the analysis results are not only statistically correlated but also ensures the forecast results would be credible.

3.3 LOAD FORECAST FOR ADDIS ABABA REGION

Historical load data as it is shown in table 3.4(a) and (b) for the whole load centers of Addis Ababa region in a medium voltage of 15kV, 33kV, and 45kV is collected. As shown in the following diagram; the forecast is performed on individual loads. Sum up of the individual load forecast result is compared with forecast result performed on sum up of total load.

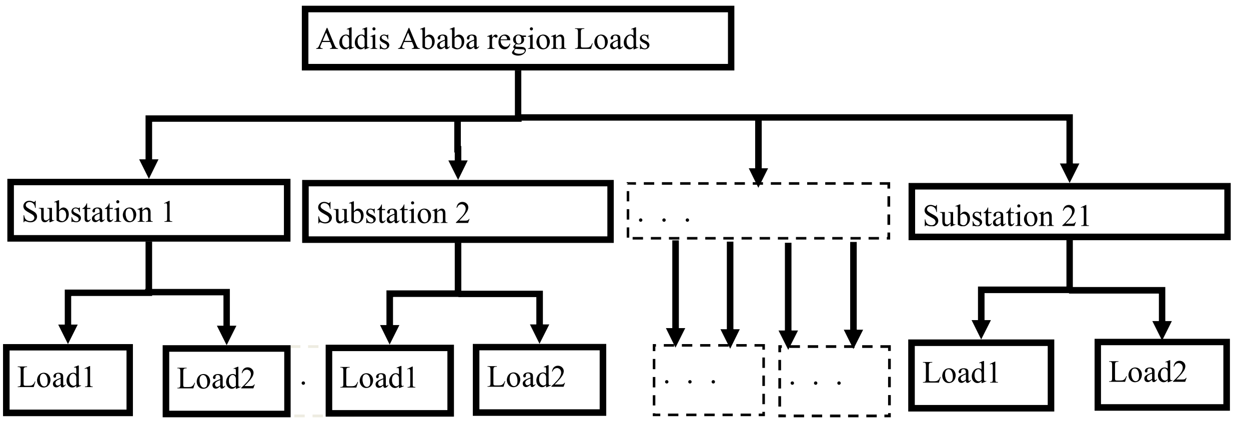


Figure 3-1 Load structure of Addis Ababa region

GDP growth rate for the past five years (historical) and for the next five years (forecasted) are collected from different statistical institutions worldwide. Number of consumers data for the year 2013, 2014, 2015, and 2016 is collected form distribution office and extrapolation is performed for the rest forecast years.

Network model including transmission lines, transformers, and circuit breaker data of AAR are collected and used for simulation purpose.

3.3.3 Historical load, GDP, and consumer data

Accordingly, the loads of the region are distributed thoroughly with the listed transformers which look like the following. Load data listed below is unified from the daily record through peak selection.

Table 3-1 Unified historical load

Substation		Device					Peak Load (MW)				
Substation Name	Substation ID	Type	Device ID	Voltage Level	MVA	Load ID	2013	2014	2015	2016	2017
Addis Center	ACE	2W-TR	ACE TR1	132/15	31.5	Ace Ld1	19.16	21.91	26.2	28.9	27.9
		2W-TR	ACE TR2	132/15	31.5	Ace Ld2	19.16	21.91	26.2	28.9	27.9
Addis East II	AEA	2W-TR	AEA TR1	132/15	25	Aea Ld1	16.02	18.31	21.9	24.35	24
		2W-TR	AEA TR2	132/15	25	Aea Ld2	16.02	18.31	21.9	24.35	24
Addis North	ANO	2W-TR	ANO TR1	132/15	25	Ano Ld1	13.9	15.89	19	21.13	22.95
		2W-TR	ANO TR2	132/15	25	Ano Ld2	15.36	17.56	21	23.35	25.37
Addis South II	ASO	2W-TR	ASO TR1	132/15	25	Aso Ld1	16.09	18.39	22	24.46	24.1
		2W-TR	ASO TR2	132/15	25	Aso Ld2	16.82	19.23	23	23.19	24.1
Ayat	AYA	2W-TR	AYA TR1	132/15	25	Aya Ld1			3.5	3.89	4.23
		2W-TR	AYA TR2	132/15	25	Aya Ld2			3.5	3.89	4.23
Cotobie	COT	3W-TR	COT TR1-S	45	16	Cot Ld1	9	10.28	12.3	13.68	14.86
			COT TR1-T	15	4	Cot Ld2	3.12	1.5	0	3.58	3.29
		2W-TR	COT TR2	132/15	31.5	Cot Ld3	16.82	19.23	23	25.57	27.78
		2W-TR	COT TR3	132/15	12	Cot Ld4	4.1	4.68	5.6	6.23	6.76
Gefersa	GEF	3W-	GEF	45	16	Gef	8.78	10.03	12	13.34	14.5

		TR	TR1-S			Ld1					
			GEF TR1-T	15	14	Gef Ld2	25.6	29.26	35	32.23	33.5
		3W-TR	GEF TR2-S	33	15	Gef Ld3	0.93	1.06	1.27	1.41	1.53
			GEF TR2-T	15	15	Gef Ld4	7.31	8.36	10	11.12	12.08
		2W-TR	GEF TR3	132/66	25	Gef Ld5	14.26	16.3	19.5	21.68	23.56
Gelan	GEL	2W-TR	GEL TR1	132/15	63	Gel Ld1	26.38	26.38	35.31	39.26	42.65
Kaliti I	KAI	3W-TR	KAI TR1-S	45	22	KaI Ld1	6.87	7.86	9.4	10.45	11.35
			KAI TR1-T	15	7.5	KaI Ld2	4.53	5.18	6.2	6.89	7.49
		3W-TR	KAI TR2-S	45	22	KaI Ld3	6.87	7.86	9.4	10.45	11.35
			KAI TR2-T	15	7.5	KaI Ld4	4.53	5.18	6.2	6.89	7.49

Table 3-2 Unified historical load

Substation		Device					Peak Load (MW)				
Substation Name	Substation ID	Type	Device ID	Voltage Level	MVA	Load ID	2013	2014	2015	2016	2017
Kaliti GIS	KGI	2W-TR	KGI TR1	132/15	25	Kgi Ld1			3.5	3.89	4.23
		2W-TR	KGI TR2	132/15	25	Kgi Ld2			3.5	3.89	4.23
Kaliti II	KII	3W-TR	KII TR1-S	132/15	25	KII Ld1	14.63	16.72	20	22.24	24.16
			KII TR1-	132/1	10	KII Ld2	2	5.95	7.12	7.92	8.6

			T	5							
		2W-TR	KII TR2	132/15	25	KII Ld3	11.34	12.96	15.5	17.23	18.72
		2W-TR	KII TR3	132/15	25	KII Ld4	15.58	17.81	21.3	23.68	25.73
Kaliti North	KNO	2W-TR	KNO TR1	132/15	16	Kno Ld1	10.53	12.04	14.4	16.01	17.39
		2W-TR	KNO TR2	132/15	16	Kno Ld2	10.53	12.04	14.4	16.01	17.39
Legetafo	LEG	2W-TR	LEG TR1	132/15	31.5	Leg Ld1	18.65	21.32	25.5	28.35	30.8
		2W-TR	LEG TR2	132/15	31.5	Leg Ld2	19.45	22.24	26.6	29.58	31
Mekanissa	MEK	2W-TR	MEK TR1	132/15	25	Mek Ld1	16.13	18.44	22.06	24.53	25.2
		2W-TR	MEK TR2	132/15	25	Mek Ld2	16.13	18.44	22.06	24.53	25.2
Minilik	MIN	2W-TR	MIN TR1	132/15	25	Min Ld1			4	4.45	4.83
		2W-TR	MIN TR2	132/15	25	Min Ld2			4	4.45	4.83
Nefasilk	NEF	2W-TR	NEF TR1	132/15	25	Nef Ld1	14.77	16.89	20.2	22.46	24.4
		2W-TR	NEF TR2	132/15	25	Nef Ld2	14.77	16.89	20.2	22.46	24.4
Sebeta I	SEBI	3W-TR	SEBI TR1-S	45	12	SebI Ld1	4.2	5.6	0	0	0
			SEBI TR1-T	15	4	SebI Ld2	3.2	3.5	3	3.34	3.62
		3W-TR	SEBI TR2-S	45	25	SebI Ld3	10.39	11.87	14.2	15.79	17.15
			SEBI TR2-T	15	10	SebI Ld4	5.05	5.77	6.9	7.67	8.34

		2W-TR	SEBI TR3	132/15	50	SebI Ld5	33.33	38.1	45.57	48.5	46.2
sebeta II	SEBII	2W-TR	SEBII TR1	230/33	25	SebII Ld1	9.29	10.62	12.7	14.12	15.34
Sululta	SUL	3W-TR	SUL TR1-S	33	25	Sul Ld1	2.93	3.34	4	4.45	7.32
			SUL TR1-T	15	25	Sul Ld2	17	18.73	22.4	21.8	23.6
		2W-TR	SUL TR2	132/15	25	Sul Ld3	17	12.54	15	16.68	18.12
Torhailoch	THA	2W-TR	THA TR1	132/15	25	Tha Ld1			3	3.34	3.62
		2W-TR	THA TR2	132/15	25	Tha Ld2			3	3.34	3.62
Weregenu	WER	2W-TR	WER TR1	132/15	40	Wer Ld1	24.5	23.41	28	31.13	35.6
		2W-TR	WER TR2	132/15	40	Wer Ld2	24.5	23.41	28	31.13	35.6
Yesu	YES	2W-TR	YES TR1	132/15	10	Yes Ld1	5.2	6.03	7.21	6	6.85
		2W-TR	YES TR2	132/15	10	Yes Ld2	5.2	6.03	7.21	6	6.85
						TOTAL	597.94	665.37	817.91	894.14	949.94

GDP growth rate data is collected from different statistical and economical institutions websites worldwide and this data is as follows:

GDP data are collected from World Bank web-portal http://www.worldbank.org/en/publication/global-economic-prospects#data.

Number of consumer data is obtained from the region's distribution office. The load wise consumer distribution data is filtered as needed and presented in table 3-3 (b).

Table 3-3 GDP data (a) and No. of Consumers data (b)

(a)

year	GDP %
2013	10.3
2014	10.3
2015	10.41
2016	7.96
2017	8.33
2018	7.96
2019	7.92
2020	7.91
2021	7.68
2022	7.1

(b)

year	Number of Consumers data
2013	2208000
2014	2208000
2015	2593500
2016	2782000
2017	3080000
2018	3150000
2019	3350000
2020	3650000
2021	3750500
2022	3922500

3.3.4 Load forecast results

The collected historical load data, GDP, and number of customers are presented in this chapter section 3.3.3. These data are arranged on Excel and load forecasting is conducted using the formula presented in section 3.2.3. Calculated load forecast results for future years are presented in Table 3-4. Calculated coefficients a, b_1, and b_2, are presented in Table 3-5, and regression statistics outputs are presented in Table 3-6. Individual load forecast results for every TR loads is presented in Table 3-7.

Table 3-4 Load forecast input and outputs results for total load

Year	Peak Load (MW)	GDP	Number of Consumers data
2013	597.94	10.3	2208000
2014	665.37	10.3	2,208,000.00
2015	817.91	10.41	2,593,500.00
2016	894.14	7.96	2,782,000.00
2017	928.44	8.33	3,080,000.00

2018	991.91	7.96	3,150,000.00
2019	1,063.00	7.92	3,350,000.00
2020	1,169.42	7.91	3,650,000.00
2021	1,206.13	7.68	3,750,500.00
2022	1,269.83	7.1	3,922,500.00

Table 3-5 Load forecast coefficient outputs

	Coefficients	Standard Error	t Stat	P-value
Intercept	-87.65728	677.818	-0.129	0.909
GDP	-4.684469	40.144	-0.117	0.918
Number of Consumers data	0.0003546	0.0001	2.753	0.111

Table 3-6 Regression Statistics outputs

Multiple R	0.960665632
R Square (R^2)	0.922878456
Adjusted R Square (R^2)	0.845756911
Standard Error	56.49867331
Observations (N)	5

Using the obtained results in Table 3-5, general load forecast formula becomes

Peak Load= - 87.65728 - 4.684496 * GDP + 0.0003546 * Number of consumers

Table 3-7 Individual TR load forecast result

Device					Peak Load (MW)									
Substation Name	Type	Device ID	Voltage Level	MVA	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Addis	2W-	ACE	132/15	31.5	19.	21.	26.	28.	27.	30.4	32.1	34.	35.	37.

Center	TR	TR1		MVA	16	91	20	90	90	6	9	76	73	49
	2W- TR	ACE TR2	132/15	31.5 MVA	19. 16	21. 91	26. 20	28. 90	27. 90	30.4 6	32.1 9	34. 76	35. 73	37. 49
Addis East II	2W- TR	AEA TR1	132/15	25 MVA	16. 02	18. 31	21. 90	24. 35	24. 00	26.0 3	27.5 9	29. 92	30. 80	32. 39
	2W- TR	AEA TR2	132/15	25 MVA	16. 02	18. 31	21. 90	24. 35	24. 00	26.0 3	27.5 9	29. 92	30. 80	32. 39
Addis North	2W- TR	ANO TR1	132/15	25 MVA	13. 90	15. 89	19. 00	21. 13	22. 95	24.1 0	25.9 4	28. 68	29. 64	31. 32
	2W- TR	ANO TR2	132/15	25 MVA	15. 36	17. 56	21. 00	23. 35	25. 37	26.6 4	28.6 7	31. 70	32. 76	34. 61
Addis South II	2W- TR	ASO TR1	132/15	25 MVA	16. 09	18. 39	22. 00	24. 46	24. 10	27.9 0	30.0 3	33. 21	34. 32	36. 26
	2W- TR	ASO TR2	132/15	25 MVA	16. 82	19. 23	23. 00	23. 19	24. 10	25.5 7	27.3 5	30. 05	30. 82	32. 02
Ayat	2W- TR	AYA TR1	132/15	25 MVA			3.5 0	3.8 9	4.2 3	5.38	6.58	8.4 0	8.9 4	9.8 1
	2W- TR	AYA TR2	132/15	25 MVA			3.5 0	3.8 9	4.2 3	5.38	6.58	8.4 0	8.9 4	9.8 1
Cotobie	3W- TR	COT TR1-S	45	16 MVA	9.0 0	10. 28	12. 30	13. 68	14. 86	15.6 0	16.7 9	18. 57	19. 19	20. 27
		COT TR1-T	15	4 MVA	3.1 2	1.5 0	0.0 0	3.5 8	3.2 9	3.02	2.46	1.5 4	1.6 1	2.0 5
	2W- TR	COT TR2	132/15	31.5 MVA	16. 82	19. 23	23. 00	25. 57	27. 78	29.1 7	31.4 0	34. 72	35. 88	37. 91
	2W- TR	COT TR3	132/15	12 MVA	4.1 0	4.6 8	5.6 0	6.2 3	6.7 6	7.10	7.64	8.4 5	8.7 4	9.2 3
Gefersa	3W- TR	GEF TR1-S	45	16 MVA	8.7 8	10. 03	12. 00	13. 34	14. 50	15.2 2	16.3 8	18. 12	18. 72	19. 78
		GEF TR1-T	15	14 MVA	25. 60	29. 26	35. 00	32. 23	33. 50	35.3 9	37.8 8	41. 71	42. 52	43. 52
	3W- TR	GEF TR2-S	33	15 MVA	0.9 3	1.0 6	1.2 7	1.4 1	1.5 3	1.61	1.73	1.9 2	1.9 8	2.0 9
		GEF	15	15	7.3	8.3	10.	11.	12.	12.6	13.6	15.	15.	16.

		TR2-T		MVA	1	6	00	12	08	8	5	10	60	48
	2W-TR	GEF TR3	132/66	25 MVA	14.26	16.30	19.50	21.68	23.56	24.73	26.62	29.44	30.42	32.14
Gelan	2W-TR	GEL TR1	132/15	63 MVA	26.38	26.38	35.31	39.26	42.65	45.23	49.04	54.76	56.72	60.09
Kaliti I	3W-TR	KAI TR1-S	45	22 MVA	6.87	7.86	9.40	10.45	11.35	11.92	12.83	14.19	14.67	15.49
		KAI TR1-T	15	7.5 MVA	4.53	5.18	6.20	6.89	7.49	7.86	8.46	9.36	9.67	10.22
	3W-TR	KAI TR2-S	45	22 MVA	6.87	7.86	9.40	10.45	11.35	11.92	12.83	14.19	14.67	15.49
		KAI TR2-T	15	7.5 MVA	4.53	5.18	6.20	6.89	7.49	7.86	8.46	9.36	9.67	10.22
Kaliti GIS	2W-TR	KGI TR1	132/15	25 MVA			3.50	3.89	4.23	5.38	6.58	8.40	8.94	9.81
	2W-TR	KGI TR2	132/15	25 MVA			3.50	3.89	4.23	5.38	6.58	8.40	8.94	9.81
Kaliti II	3W-TR	KII TR1-S	132/15	25 MVA	14.63	16.72	20.00	22.24	24.16	25.37	27.30	30.19	31.20	32.96
		KII TR1-T	132/15	10 MVA	2.00	5.95	7.12	7.92	8.60	9.58	10.77	12.57	13.14	14.10
	2W-TR	KII TR2	132/15	25 MVA	11.34	12.96	15.50	17.23	18.72	19.66	21.16	23.40	24.18	25.55
	2W-TR	KII TR3	132/15	25 MVA	15.58	17.81	21.30	23.68	25.73	27.02	29.08	32.15	33.23	35.11
Kaliti North	2W-TR	KNO TR1	132/15	16 MVA	10.53	12.04	14.40	16.01	17.39	18.26	19.66	21.74	22.47	23.73
	2W-TR	KNO TR2	132/15	16 MVA	10.53	12.04	14.40	16.01	17.39	18.26	19.66	21.74	22.47	23.73
Legetafo	2W-TR	LEG TR1	132/15	31.5 MVA	18.65	21.32	25.50	28.35	30.80	32.34	34.81	38.50	39.78	42.03
	2W-TR	LEG TR2	132/15	31.5 MVA	19.45	22.24	26.60	29.58	31.00	32.93	35.25	38.71	39.95	42.13
Mekaniss	2W-	MEK	132/15	25	16.	18.	22.	24.	25.	26.9	28.7	31.	32.	34.

a	TR	TR1		MVA	13	44	06	53	20	5	6	45	43	17
	2W-TR	MEK TR2	132/15	25 MVA	16.13	18.44	22.06	24.53	25.20	26.95	28.76	31.45	32.43	34.17
Minilik	2W-TR	MIN TR1	132/15	25 MVA			4.00	4.45	4.83	6.15	7.52	9.59	10.22	11.22
	2W-TR	MIN TR2	132/15	25 MVA			4.00	4.45	4.83	6.15	7.52	9.59	10.22	11.22
Nefasilk	2W-TR	NEF TR1	132/15	25 MVA	14.77	16.89	20.20	22.46	24.40	25.62	27.57	30.49	31.51	33.29
	2W-TR	NEF TR2	132/15	25 MVA	14.77	16.89	20.20	22.46	24.40	25.62	27.57	30.49	31.51	33.29
Sebeta I	3W-TR	SEBI TR1-S	45	12 MVA	4.20	5.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		SEBI TR1-T	15	4 MVA	3.20	3.50	3.00	3.34	3.62	3.46	3.44	3.40	3.41	3.47
	3W-TR	SEBI TR2-S	45	25 MVA	10.39	11.87	14.20	15.79	17.15	18.01	19.38	21.44	22.15	23.40
		SEBI TR2-T	15	10 MVA	5.05	5.77	6.90	7.67	8.34	8.75	9.42	10.42	10.76	11.37
	2W-TR	SEBI TR3	132/15	50 MVA	33.33	38.10	45.57	48.50	46.20	50.60	53.37	57.52	58.95	61.45
sebeta II	2W-TR	SEBII TR1	230/33	25 MVA	9.29	10.62	12.70	14.12	15.34	16.11	17.34	19.17	19.81	20.93
Sululta	3W-TR	SUL TR1-S	33	25 MVA	2.93	3.34	4.00	4.45	7.32	6.85	7.79	9.22	9.65	10.35
		SUL TR1-T	15	25 MVA	17.00	18.73	22.40	21.80	23.60	24.57	26.36	29.09	29.79	30.82
	2W-TR	SUL TR2	132/15	25 MVA	17.00	12.54	15.00	16.68	18.12	17.99	18.49	19.22	19.58	20.28
Torhailoch	2W-TR	THA TR1	132/15	25 MVA			3.00	3.34	3.62	4.61	5.64	7.20	7.66	8.41
	2W-TR	THA TR2	132/15	25 MVA			3.00	3.34	3.62	4.61	5.64	7.20	7.66	8.41
Weregen	2W-	WER	132/15	40	24.	23.	28.	31.	35.	36.0	38.5	42.	43.	45.

u	TR	TR1		MVA	50	41	00	13	60	9	6	26	57	87
	2W-TR	WER TR2	132/15	40 MVA	24.50	23.41	28.00	31.13	35.60	36.09	38.56	42.26	43.57	45.87
Yesu	2W-TR	YES TR1	132/15	10 MVA	5.20	6.03	7.21	6.00	6.85	7.00	7.62	8.58	8.73	8.86
	2W-TR	YES TR2	132/15	10 MVA	5.20	6.03	7.21	6.00	6.85	7.00	7.62	8.58	8.73	8.86
					597.94	665.37	817.91	894.14	949.94	1010.68	1088.70	1205.62	1245.21	1313.29
									Total Forecast result	1007.239	1083.156	1196.899	1235.6	1302.33
					Difference between total forecast result and sum of individual forecast results					3.45	5.54	8.72	9.61	10.97
									Error	0.34%	0.51%	0.72%	0.77%	0.84%

3.3.5 Comparison of Load forecasts

Comparison between 25 years' mater plan forecast result, (the percentage of load covering of AAR out of the total is calculated and the average percentage is considered 40.31% the whole Ethiopia load as Addis Ababa load) and which looks like the following Table:

Table 3-8 Load comparisons between AARTS and whole grid

Percentage Calculation load coverage			
Year	Total Ethiopia Load	Addis Ababa Load	%
2013	1437.09	597.94	41.61%
2014	1642.84	665.37	40.50%
2015	1964.91	817.91	41.63%
2016	2204.34	894.14	40.56%
2017	2491.45	928.44	37.27%

Average %	40.31%

Table 3-9 Forecast comparisons between 2012 and forecast result of this thesis

Year	Peak Demand (MW) Reference			Considering 40.31% of the total Ethiopia Load as Addis Ababa region load				
	Reference	High	Low	Reference	High	Low		
2013	1516	1719	1410	611.10	692.93	568.37	597.94	Actual historical Loads of Addis Ababa collected during data collection
2014	1992	2318	1810	802.98	934.39	729.61	665.37	
2015	2641	3095	2334	1064.59	1247.59	940.84	817.91	
2016	3335	3927	2899	1344.34	1582.97	1168.59	894.14	
2017	4107	4857	3528	1655.53	1957.86	1422.14	928.44	
2018	4795	5692	4091	1932.86	2294.45	1649.08	991.91	Forecast Results of this thesis for Addis Ababa
2019	5496	6557	4635	2215.44	2643.13	1868.37	1063.00	
2020	6219	7450	5163	2506.88	3003.10	2081.21	1169.42	
2021	6962	8370	5701	2806.38	3373.95	2298.07	1206.13	
2022	7848	9530	6289	3163.53	3841.54	2535.10	1269.83	

Master plan study [8] considers three cases which are reference case is the case where the country is growing continuously. High case is where the load demand from rural electrification, demand from the all customers are served and the low case is the base case that all the available generation and the upcoming expected generation is on hand and load factor of 57% is considered with other economic factors.

CHAPTER 4

TRANSMISSION SYSTEM EXPANSSION PLANNING AND PERFORMANCE ANALYSIS

4.1 INTRODUCTION

Theoretical concept and review of transmission system expansion planning (i.e. network modeling, load flow, short circuit, transient stability) is presented in this chapter. The purpose of this chapter is to visualize what type of data is relevant, which methodology on which basis should be selected, what kind of analysis to be performed for the final better expected result. To do the expansion planning three different algorithms are developed and are stated here in this section. The overall methodology used for the success of the objective of this thesis is shown in Figure 4-1 below.

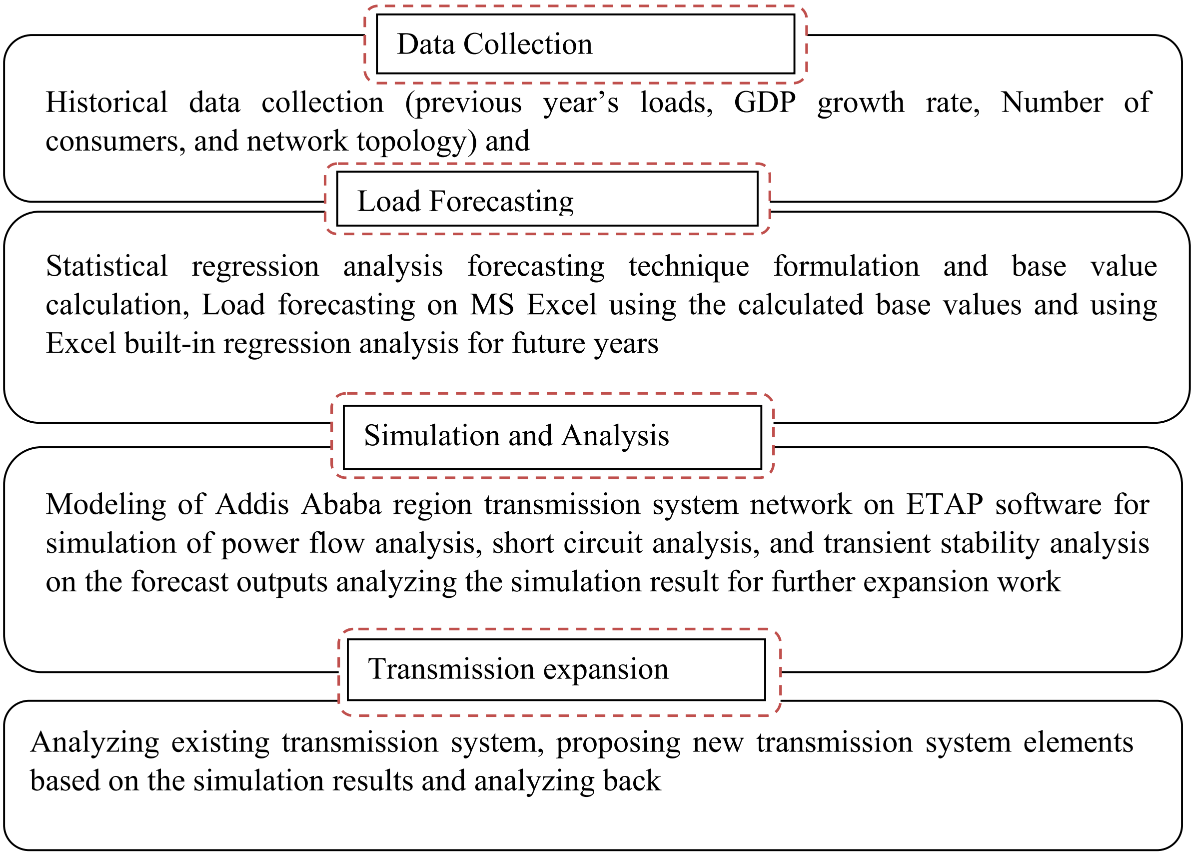


Figure 4-1 overall methodology chart

4.2 TRANSMISSION SYSTEM EXPANSION

Today, the transmission expansion planning for an existing power system under different constraints is one of the major challenges for power engineers. There are several reasons; one of the reasons is rapid growth in load and inadequate capacity addition. Hence, it is important and essential to implement an algorithm for the transmission expansion which works well and have a good feasibility under certain assumptions and available constraints. Transmission expansion planning used [4] an analytical algorithm which has been implemented for specific load condition with variations in generation and the power system operation condition will not be disturbed or compromised [5]. For that purpose, an economical factor has been measured that considers economic aspects of the line to be added for expansion. The prescribed analytical approach is also implemented for its feasibility check on a practical case study system. [4]

TEP can be classified according to the method adopted to build the expansion plans. [4]

These methods can be classified into three types: mathematical, pure heuristic and meta-heuristic approaches in [4] detail models in these three classes are presented.

Mathematical models are focused on optimization processes, with cost minimization objective function subject to sets of constraints [5]. As the plan is usually obtained under large simplifications, as it is not possible to consider all details of the network on the problem model, it should be verified according to technical, environmental and financial points of view before any decision is taken.

Mathematical optimization methods can experience difficulties on solving large-scale TEP problems. We have to keep in mind that these problems are nonlinear and non-convex in nature. The computational effort is huge and the obtained optimal solution can correspond to a local optimum due to intrinsic limitations of the searching process [5].

The solution of combinatorial optimization problems has to do with finding optimal solutions from a discrete set of feasible solutions. However, many of these problems cannot be solved to optimality in reasonable computation times, due to their dimension or to their characteristics. Reaching optimal solutions is also meaningless in many real situations, since one is often dealing with not precise data and rough simplifications of reality. So, the goal of approximate algorithms, or heuristics, is to produce good approximate solutions as quick as possible, without necessarily providing any guarantee of solution optimality.

Heuristic methods go step-by-step generating, evaluating, and selecting expansion options, with or without interacting with the planner (interactive or non-interactive) [5]. These methods are inventive techniques based on engineers' experience [5]. Taking advantage from this experience, the computational performance of heuristic methods is usually better than that of the mathematical methods.

It is possible to find good feasible solutions with a reasonable computational effort using heuristic algorithms. However, the quality of these solutions is not guaranteed, in the sense that it is not possible to prove that they are the best ones.

Meta-heuristic methods combine mathematical optimization with heuristic concepts. These methods have been subjected to deep research on recent years. Even when applied to large problems, meta-heuristic methods are able to identify quasi-optimal solutions with acceptable computational effort.

TEP problems are complex and computationally very demanding. The way these problems are approached is crucial for the feasibility of the methodology to be implemented. As explained in section above, one has to select only those projects that have significant implications in the transmission network, and avoid those who have a local nature.

4.3 TRANSMISSION SYSTEM EXPANSION PLANNING METHODS

After the load flow analysis results obtained, the results are subjected to further studies and analysis to perform transmission expansion planning. Load flow results which show overload transformers, overloaded transmission lines, and under voltage buses will be subjected to expansion planning. Circuit breakers which will be below the short circuit analysis report will also be subjected for change. And protection system settings will be obtained from the short circuit and transient stability study results.

Overload transmission line expansion algorithm, Overload transformer expansion algorithm, and Capacitor placement algorithm are algorithms used for TL expansion, TR expansion, and compensation device placement algorisms used respectively. The inception point is the simulation result. The simulation software uses the load forecast result of year 2018-2022 as input.

Three algorithms are developed to do the expansion work which are explained below

4.3.1 Overloaded transmission line problem solving algorithm

ETAP software Load flow analysis result for the year 2018, 2019, 2020, 2021, and 2022 are analyzed for the availability of overloaded transmission lines and list all. Using the algorithm shown in figure 4-2 transmission line expansion is performed and the output results are obtained. Overloaded is considered if a transformer is loaded 95 - 100% in the ETAP software.

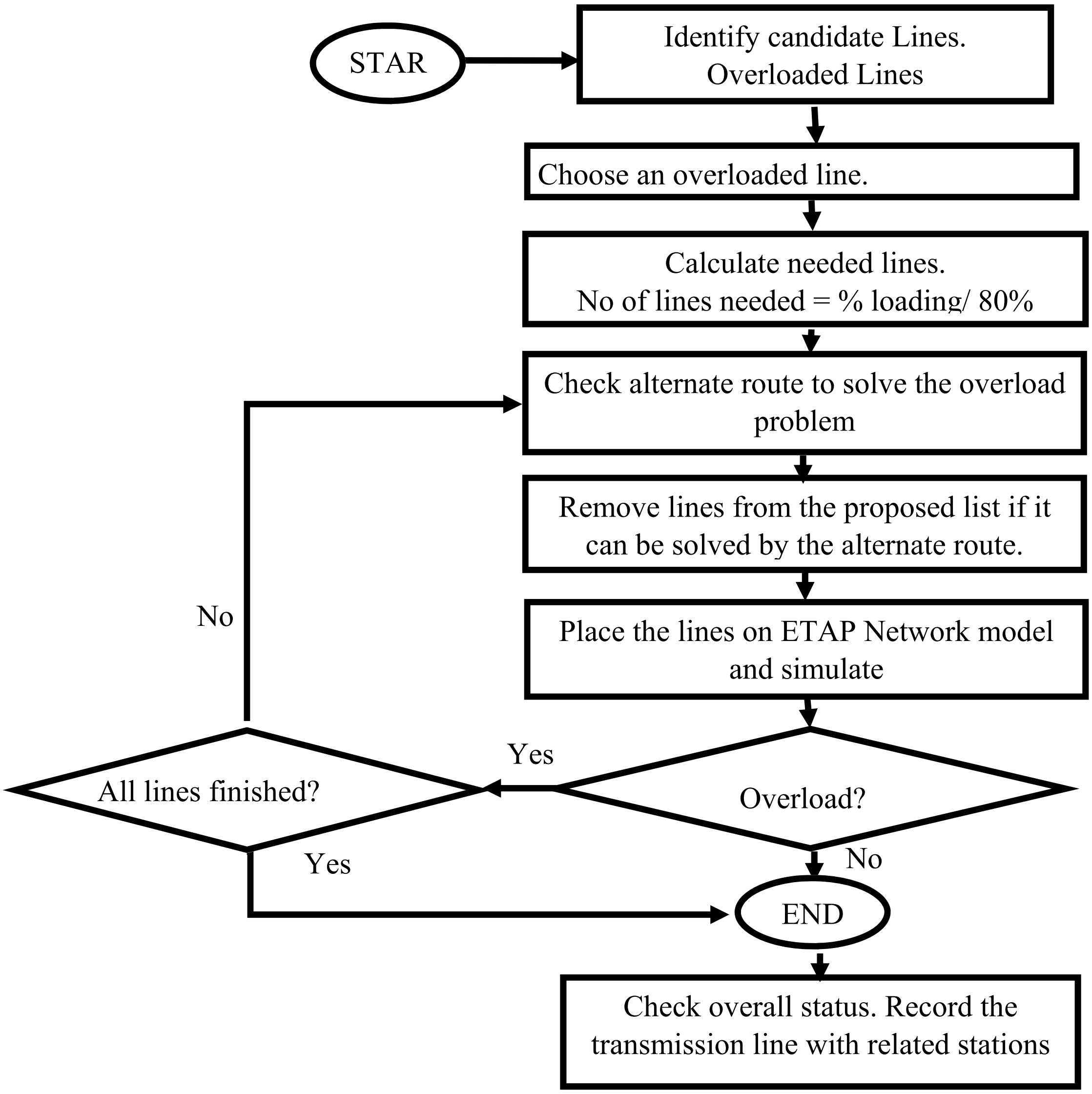


Figure 4-2 Overloaded transmission line mitigation flow chart

4.3.2 Overloaded transformers problem solving algorithm

Same to the overloaded transmission algorithm, load flow analysis result for the year 2018, 2019, 2020, 2021, and 2022 are analyzed for the availability of overloaded transformers and list all transformers. Using the algorithm shown in the figure 4-3 transformer addition and load sharing in the substation are performed and the output results are obtained.

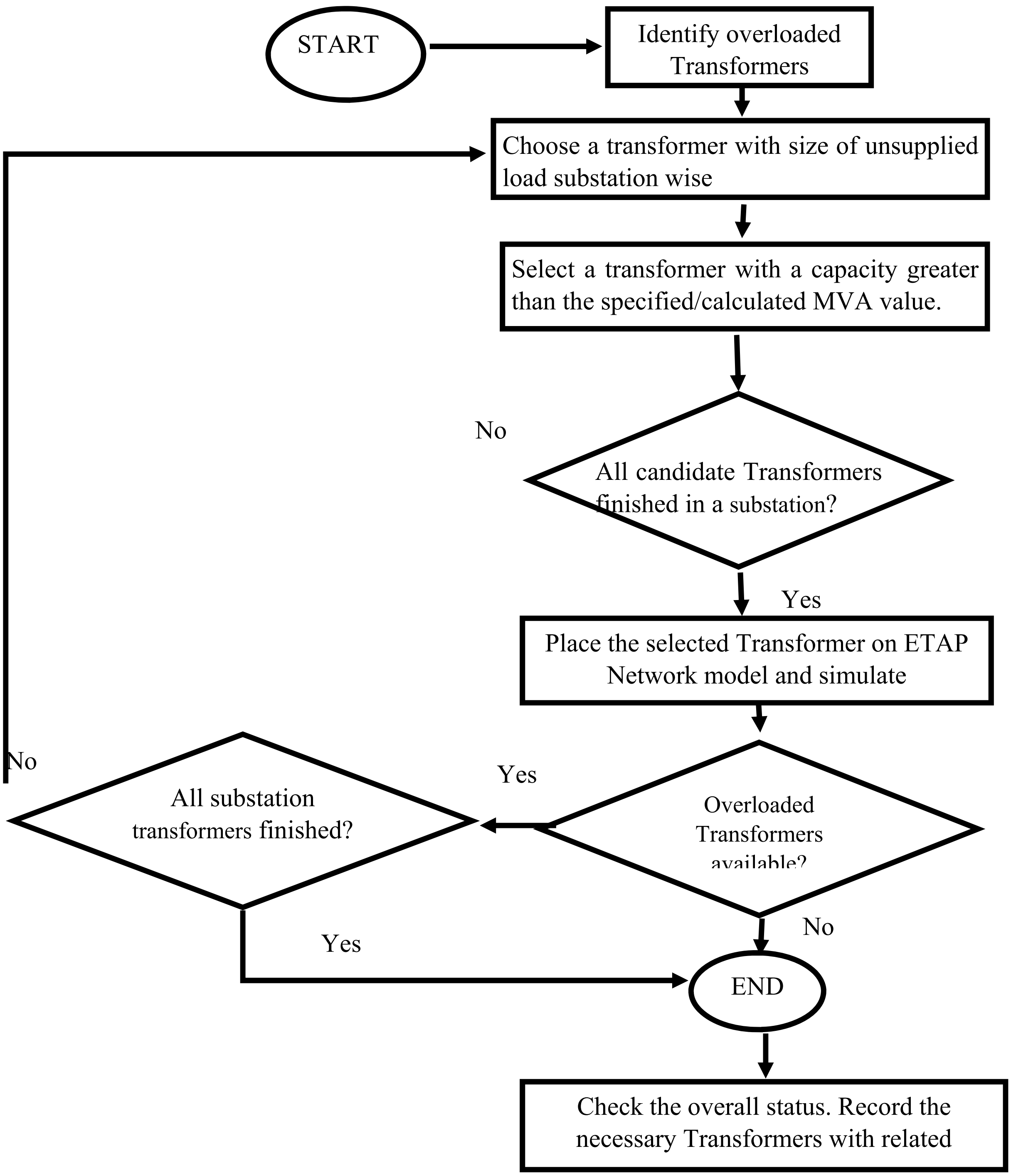


Figure 4-3 Overloaded transformers mitigation flow chart

After necessary transformer addition load sharing from the old transformer to the new should be done. The techniques used here is simple to understand but not to implement on the software for simulation purpose because it needs to manage the whole loads where overload is happened.

Old transformers are forced to carry there 80% capacity because we need the transformers to have reserved serving capacity for inconsistent power demand. So that the remaining demand is going to be supplied by the newly added transformer.

If we have two transformers in a substation already overloaded, let the old TR's are A and B with MW capacity of MW_A and MW_B respectively. Let the new addition is C with capacity MVA_C. Let the forecasted load demand from transformer A and B to be L_A and L_B for both old transformers.

The transformers load sharing will look like MW_A*0.8 for transformer A and MW_B*0.8 for transformer B, and the remaining unsupplied load which is $(L_A+L_B) - (MW_A*0.8+ MW_B*0.8)$ is going to be new loading for new TR C.

The scenario will be changed if the new transformer is more than one and no need of load sharing between the old the new if the new transformer to be added is auto transformer.

4.3.3 Bus Under-Voltage problem solving algorithm

Figure 4-4 illustrates the algorithm which is developed and used to mitigate under voltage problems in the bus. The buses to be subjected for under voltage condition are voltage levels above 132kV not less.

The technique is to see how to enhance the bus voltages where there are under voltages by means of capacitor placement. This is achieved by means of controlling the reactive power flowing in the bus. The ultimate location to place capacitors is selected in a simple logic as it is mentioned in the algorithm; human intervention is used to just see where may be the best to control the reactive power.

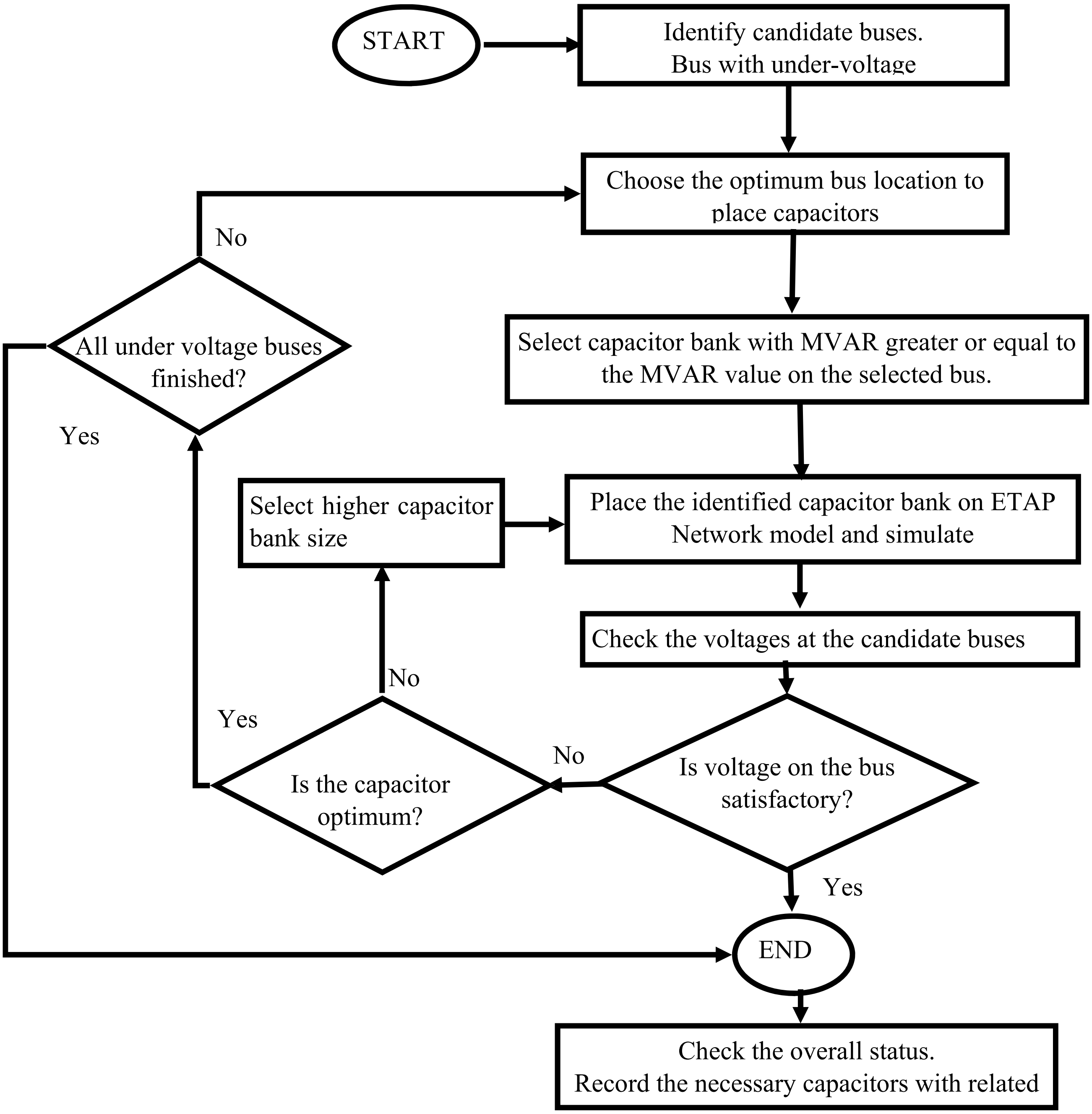


Figure 4-4 under voltage buses mitigation flow chart

4.4 TRANSMISSION NETWORK PERFORMANCE ANALYSIS

4.4.1 Load flow analysis

The objective of any load flow program is to produce the following information:

• Critical alerts report for overloading transformers' and transmission lines, and under voltage of buses. Annexed in alert complete (critical alerts report) results of 2018, 2019, 2020, 2021, and 2022 forecast years.

• Branch loading which shows capacity of every elements and loading in respected rating and in percentage (%). Annexed in branch loading (Branch Loading summary report) results of 2018, 2019, 2020, 2021, and 2022.

• Voltage magnitude and phase angle at each bus. Annexed in Load flow results of 2018, 2019, 2020, 2021, and 2022.

• Real and reactive power flowing in each element. Annexed in Load flow results of 2018, 2019, 2020, 2021, and 2022.

• Reactive power loading on each generator. Annexed in Load flow results of 2018, 2019, 2020, 2021, and 2022.

The above objectives are achieved by supplying the load-flow program with the following information:

• Branch list of the system connections i.e., the impedance of each element, sending-end and receiving-end node number. Lines and transformers are represented by their π-equivalent models. Annexed in branch (branch connections) of 2018, 2019, 2020, 2021, and 2022.

• Voltage magnitude and phase-angle at one bus, which is the reference point for the rest of the system. (Data's collected from AAR office are all used)

• Real power generated and voltage magnitude at each generator bus. (Generation capabilities which can feed AAR transmission system are all used)

• Real and reactive power demanded at each load bus. (Forecasted loads result presented in table - 4.2 are used)

In a power system, power flows from generating station to the load through different branches of the network.

The flow of active and reactive power is known as load flow or power flow. Load flow analysis is an important tool used by power engineers for planning and determining the steady state operation of a power system. Power flow studies provide a systematic mathematical approach to determine the various bus voltages, phase angles, active and reactive power flows through different branches, generators, transformer settings and load under steady state conditions. The power system is modeled by an electric circuit which consists of generators, transmission network and distribution network [1].

The main information obtained from the load flow analysis comprises magnitudes and phase angles of load buses, reactive powers and voltage phase angles at generator buses, real and reactive power flows on transmission lines together with power at the reference bus; other variables being specified [2] [3].

In power system network there are different power system elements. As already noted, a typical power system is comprised of enormous number of elements. The elements may vary from a small lamp switch to a giant generator. However, the main elements [26][27] are

Generation facilities

Transmission facilities such as substations (transformer, circuit breaker, isolator switches, capacitor, reactor, etc.), and network (lines, cable)

Distribution facilities (Loads)

Generation facilities are the power source of the network for the consumers or loads. But to have access for the generated power, transmission facilities are mandatory through substations and networks like transformers, lines and cables.

Power system planning is a process in which the aim is to decide on new as well as upgrading existing system elements, to adequately satisfy the loads for a foreseen future. [26]

The elements may be

Generation facilities

Substations or substation elements like transformers

Transmission lines and/or cables

Capacitors/Reactors

Load flow studies are the most common of all power system analysis calculations. They are used in planning studies to determine if and when specific elements will become overloaded. Major investment decisions begin with reinforcement strategies based on load flow analysis. In operating studies, load flow analysis is used to ensure that each generator runs at the optimum operating point; demand will be met without overloading facilities; and maintenance plans can precede without undermining the security of the system.

In a power system, power flows from generating station to the load through different branches of the network.

The flow of active and reactive power is known as load flow or power flow [1]. Load flow analysis is an important tool used by power engineers for planning and determining the steady state operation of a power system. Power flow studies provide a systematic mathematical approach to determine the various bus voltages, phase angles, active and reactive power flows through different branches, generators, transformer settings and load under steady state conditions. The power system is modeled by an electric circuit which consists of generators (power source), transmission network and distribution network (loads).

The main information obtained from the load flow analysis comprises [2], magnitudes and phase angles of load bus; voltages, reactive powers and voltage phase angles at generator buses, real and reactive power flows on transmission lines together with power at the reference bus; losses on transmission lines and distribution cables; other variables being specified [3].

Applied load Flow setup

Using ETAP software and all necessary data collected form AAR office, system modeling and load flow setup is made as it is presented in Table 4-1. Load flow analysis is done for forecasted loads of 2018, 2019, 2020, 2021, and 2022. The result is annexed (load flow result, branch loading summary, bus loading report, branch losses summary report, equipment cable and overload heater losses summary report)

Table 4-1 General load flow setup

Study ID	LF Analysis 2018	LF Analysis 2019	LF Analysis 2020	LF Analysis 2021	LF Analysis 2022
Study Case ID	LF for 2018	LF for 2019	LF for 2020	LF for 2021	LF for 2022
Data Revision	Base	Base	Base	Base	Base
Configuration	Normal	Normal	Normal	Normal	Normal
Loading Cat	2018	2019	2020	2021	2022
Generation Cat	Design	Design	Design	Design	Design
Diversity Factor	Normal Loading	Normal Loading	Normal Loading	Normal Loading	Normal Loading
Buses	107	107	107	107	107
Branches	137	137	137	137	137
Generators	0	0	0	0	0
Power Grids	5	5	5	5	5
Loads	77	77	77	77	77

Load-MW	963.713	1031.024	1146.571	1176.509	1242.477
Load-Mvar	195.734	236.818	322.669	331.582	391.123
Generation-MW	963.713	1031.024	1146.571	1176.509	1242.477
Generation-Mvar	195.734	236.818	322.669	331.582	391.123
Loss-MW	45.656	42.68	42.249	41.908	42.8
Loss-Mvar	335.376	336.176	364.213	361.944	385.65
Mismatch-MW	0	0	0	0	0
Mismatch-Mvar	0	0	0	0	0

4.4.2 Short circuit analysis

The fault analysis of a power system is required in order to provide information for the selection of switchgear, setting of relays and stability of system operation. A power system is not static but changes during operation (switching on or off of generators and transmission lines) and during planning (addition of generators and transmission lines). Thus, fault studies need to be routinely performed.

An electrical system should be designed so that the occurrence of the short circuit becomes minimal. When short circuit occurs, removing its effects by isolating the smallest possible portion of the system around the faulted area in order to retain service to the rest of the system.

One of the major parts of system protection is orientated towards short-circuit detection. Interrupting equipment at all voltage levels that is capable of withstanding the fault currents and isolating the faulted area requires considerable investments.

Short circuit phenomena

Electrical power systems are systems composed of a wide range of power equipment used for generating, transmitting, and distributing electrical power to consumers. Complexity of these systems indicates that breakdowns and faults are unavoidable, no matter how carefully these systems have been designed. An electrical system can be designed with zero failure rates, however that is economically unjustifiable. From the perspective of short-circuit analysis, system faults manifest themselves as insulation breakdowns. These breakdowns lead to one or more phenomena: [30]

Currents of excessive magnitudes that usually cause equipment damage

Undesirable power flow

Under-voltage

Excessive over-voltages

Cause conditions that could harm human beings

Types of short circuits

The majority of short circuit studies in power systems address one or more of the following four kinds of short circuits [30]

- Line-to-line fault (LL). Any two phases shorted together.

- Double line-to-ground fault (LLG). Any two phases connected together and then to ground.

- Single line-to-ground fault (LG). Any one, but only one, phase shorted to ground.

- Three-phase fault (LLL). May or may not involve ground. All three phases shorted together.

Fault types are graphically presented in Figure 4-5.

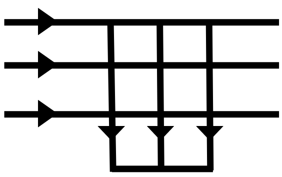
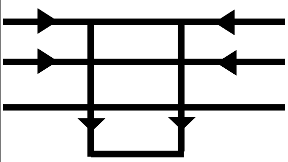
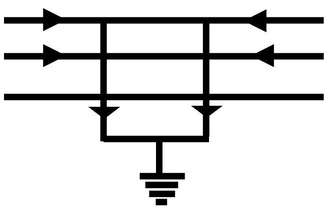
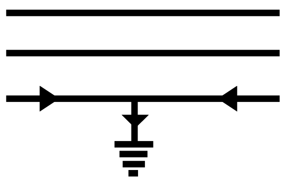
			
Three Phase Fault (LLL)	Line to Line Fault (LL)	Double Line to Ground Fault (LLG)	Single Line-to-Ground Fault (LG)

Figure 4-5 Fault types

Other types of fault conditions that may be of interest include the "series faults" and they refer to one of the following types of system unbalances:

Two lines open. Any two of the three phases may be open.

One line open. Any one of the three phases may be open.

Unequal impedances. Unbalanced line impedance discontinuity.

Series faults are of interest when assessing the effects of snapped overhead phase wires, failures of cable joints, blown fuses, failure of breakers to open all poles, unintentional breaker energization across one or two poles and other situations that result in the flow of unbalanced currents.

Symmetrical components

Theory of the symmetrical components prescribes that for a three-phase electrical system, it needs to be established for the assessment of imbalanced short circuit current conditions. The first part is the positive sequence system, that is determined by a balanced set of voltages and currents of equal magnitude, following the phase sequence of a, b, and c.

The second part is the negative sequence system, that is similar to the positive sequence system, but is determined by a balanced set of voltages and currents with a reverse phase sequence of a, c, and b.

Lastly, the zero-sequence system is defined by a group of voltages and currents that are in phase with each other and not displaced by 120 degrees, as it is the case with the other two systems. Electrical connectivity of the zero-sequence system can be different from the positive and negative sequence systems. This is due to the fact that it is influenced by the power transformer winding connections and system neutral grounding; components that are not important when ascertaining the topology of the positive and the negative sequence networks [29]

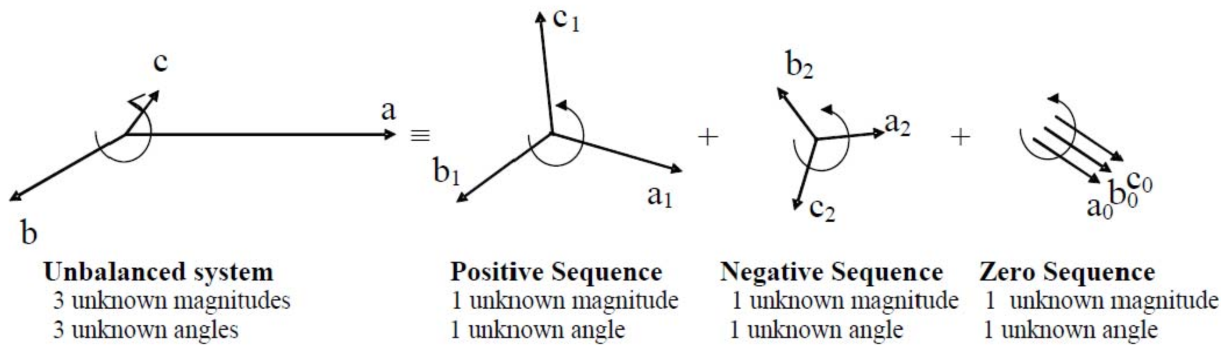


Figure 4-6 Sequence system representation

$$a = a_1 + a_2 + a_0$$

$$b = b_1 + b_2 + b_0$$

$C = C_1 + C_2 + C_0$

Standards for short circuit current calculations

There are a lot of standards for short circuit calculation and equipment rating in AC systems operating at 50 Hz or 60 Hz. They cover 3-phase, line-to-ground, line-to-line, and line-to-line-to-ground faults.

IEC 60909 and the associated standards classify short circuit currents according to their magnitudes (maximum and minimum) and fault distances from the generator (far and near). Maximum short circuit currents determine equipment ratings, while minimum currents dictate protective device settings. Near-to-generator and far-from-generator classifications determine whether or not to model the AC component decay in the calculation, respectively.

IEC 61363 Standard calculates the short circuit current as a function of time and displays its instantaneous values using the machine's sub transient reactance and time constants. This provides an accurate evaluation of the short circuit current for sizing protective devices and coordinating relays for isolated systems such as ships and offshore platforms.

Certain analytical techniques are defined by industry standards that adhere to specific guidelines and are specifically accommodated to address the problems of AC and DC current decay in practical multi-machine systems that are in conformity with established, practices accepted by the power industry. They are also associated to and accord with adopted, existing switchgear rating structures. Typical industry standards are:

International standard, IEC 60909

North American ANSI

IEC 60909 - International standard

Standard IEC 60909 (published in 1988) distinguishes four duty types resulting in four different calculated short circuit currents:

- The initial short-circuits current I"k
- The peak short-circuits current Ip
- The breaking short-circuits current Ib
- The steady-state fault current Ik

Loading conditions before the fault are considered with due attention in IEC 60909. In order to account for system loads leading to higher voltages before the fault, the standard advocates that voltages before the fault at the fault location point can be different from 1.00 per unit. This means that a load flow solution is not required in order to calculate short circuit currents. IEC 60909 suggests impedance correction factors for the generators. These correction factors can also be applicable to their step-up transformers

ANSI standards – North American standard

IEEE standards covering short circuit current calculations for low voltage electrical systems (below 1000 V), are:

- IEEE Standard 242-1986
- IEEE Standard 241-1990
- IEEE Standard C37.13-1990
- IEEE Standard 141-1993

IEEE standards dealing with short circuit current calculations for medium and high voltage electrical networks are:

IEEE Standard 141-1993

IEEE Standard C37.5-1979

IEEE Standard 241-1990

IEEE Standard 242-1986.

IEEE Standard C37.010-1979

Three types of fault currents are determined, depending on the time frame of interest considered from the origin of the fault, as first-cycle fault currents, also called momentary fault currents, are the currents at 1/2 cycle after fault initiation. These currents pertain to the duty circuit breakers face when “closing against” or withstanding fault currents. These currents usually contain DC offset and are computed on the assumption of no AC decay in the contributing sources. Bearing in mind that low voltage circuit breakers operate in the first cycle, their breaking ratings are compared to these currents.

Short circuit analysis results

The main reasons for performing short-circuit studies are as follows:

- Defining system protective device settings and that is done by quantities that describe the system under fault conditions.

- Verification of the adequacy of existing interrupting equipment.

- Assessment of the effect that different kinds of short circuits of varying severity may have on the overall system voltage profile. These calculations identify areas in the system for which faults can result in unacceptable voltage depressions.

- Defining effects of the fault currents on various system components such as cables, overhead lines, buses, transformers, capacitor banks and reactors during the time the fault persists. Mechanical stresses from the resulting fault currents are compared with the corresponding short-term withstand capabilities of the system equipment.

- Compliance with codes and regulations governing system design and operation.

- Design and sizing of system layout, neutral grounding, and substation grounding.

The accuracy of the calculated short circuit currents depends on the modeling accuracy, system configuration and equipment impedances. Other factors include modeling of the electrical machines, generators, grounding point of the system, other system components and different operating conditions.

Using ETAP software short circuit analysis is done on loading scenario of 2022 with faults on all buses are studied and annexed (short circuit summary report, sequence impedance summary report, short circuit report considering faults at each bus).

Sequence impedance summary is presented in Table 4-2 and short circuit summary report is presented in Table 4-3

Table 4-2 Sequence impedance result of short circuit analysis

Sequence Impedance Summary Report										
Bus		**Positive Seq. Imp. (ohm)**			**Negative Seq. Imp. (ohm)**			**Zero Seq. Imp. (ohm)**		
ID	kV	Resistance	Reactance	Impedance	Resistance	Reactance	Impedance	Resistance	Reactance	Impedance
Addis Center 132kV	132	5.887	14.329	15.492	5.887	14.329	15.492	7.558	22.993	24.204
Addis East II 132kV	132	3.044	10.408	10.844	3.044	10.408	10.844	2.965	8.282	8.797
Addis North 132kV	132	3.459	11.322	11.839	3.459	11.322	11.839	3.845	9.834	10.559
Addis South II 132	132	7.897	16.928	18.679	7.897	16.928	18.679	10.991	33.311	35.077
Ayat 132kV	132	2.454	10.027	10.323	2.454	10.027	10.323	1.411	5.273	5.458
Cotobie 132kV	132	2.027	9.163	9.385	2.027	9.163	9.385	0.790	2.340	2.470
Gefersa 132kV	132	2.044	10.654	10.848	2.044	10.654	10.848	0.244	1.063	1.091
Gefersa 230kV	230	4.854	23.614	24.108	4.854	23.614	24.108	5.487	23.542	24.173
Gelan 132kV	132	1.697	8.927	9.087	1.697	8.927	9.087	0.383	1.670	1.714
Gelan 230kV	230	4.117	23.924	24.275	4.117	23.924	24.275	0.300	7.015	7.021
Gelan 400kV	400	9.823	56.983	57.823	9.823	56.983	57.823	12.424	77.040	78.036
Kaliti GIS 132kV	132	2.348	9.750	10.029	2.348	9.750	10.029	1.130	3.188	3.382
Kaliti I 132kV	132	1.653	8.852	9.005	1.653	8.852	9.005	0.334	1.268	1.311
Kaliti I 230kV	230	4.162	23.962	24.320	4.162	23.962	24.320	0.325	7.060	7.068
Kaliti II 132kV	132	2.684	10.186	10.533	2.684	10.186	10.533	0.831	2.665	2.791
Kaliti North 132kV	132	2.040	9.346	9.566	2.040	9.346	9.566	1.051	3.419	3.576
Legetafo 132kV	132	2.499	10.662	10.950	2.499	10.662	10.950	0.585	4.877	4.912
Legetafo 230kV	230	4.992	24.100	24.612	4.992	24.100	24.612	6.635	25.730	26.572
Mekanisa 132kV	132	6.422	15.020	16.335	6.422	15.020	16.335	8.474	25.741	27.099
Minilk 132kV	132	3.178	11.288	11.726	3.178	11.288	11.726	2.963	8.405	8.912
Nefasilk 132kV	132	3.570	11.331	11.880	3.570	11.331	11.880	2.340	7.206	7.576
Sebeta I 132kV	132	2.190	11.080	11.295	2.190	11.080	11.295	0.393	1.941	1.981
Sebeta I 230kV	230	4.626	23.548	23.998	4.626	23.548	23.998	2.933	16.067	16.333
Sebeta II 230kV	230	4.314	23.457	23.851	4.314	23.457	23.851	0.330	7.910	7.917
Sebeta II 400kV	400	11.568	61.479	62.558	11.568	61.479	62.558	18.331	105.516	107.096
Sululta 132kV	132	1.533	16.628	16.698	1.533	16.628	16.698	0.540	2.042	2.112
Sululta 230kV	230	4.632	23.421	23.875	4.632	23.421	23.875	6.556	25.606	26.432
Sululta 400kV	400	13.614	88.651	89.691	13.614	88.651	89.691	29.324	390.011	391.111
T.Hailoch 230kV	230	4.851	23.689	24.180	4.851	23.689	24.180	4.832	21.722	22.253
Weregenu 132kV	132	2.307	9.662	9.934	2.307	9.662	9.934	1.498	4.712	4.944
Yesu 132kV	132	1.948	9.234	9.437	1.948	9.234	9.437	0.837	2.781	2.905

Table 4-3 short circuit summary report fault currents

Short-Circuit Summary Report																
3-Phase, LG, LL, LLG Fault Currents																
Bus		**3-Phase Fault**			**Line-to-Ground Fault**				**Line-to-Line Fault**				***Line-to-Line-to-Ground**			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
Addis Center 132kV	132	5.41	10.18	5.15	4.56	8.58	4.56	4.56	4.69	8.817	4.69	4.69	5.181	9.749	5.181	5.181
Addis East II 132kV	132	7.73	15.94	7.18	8.253	17.01	8.253	8.253	6.7	13.8	6.7	6.7	8.159	16.82	8.159	8.159
Addis North 132kV	132	7.08	14.42	6.6	7.35	14.97	7.35	7.35	6.13	12.49	6.13	6.13	7.381	15.03	7.381	7.381
Addis South II 132	132	4.49	8.129	4.31	3.478	6.3	3.478	3.478	3.89	7.04	3.89	3.89	4.259	7.714	4.259	4.259
Ayat 132kV	132	8.12	17.75	7.52	9.635	21.06	9.635	9.635	7.03	15.37	7.03	7.03	9.243	20.21	9.243	9.243
Cotobie 132kV	132	8.93	19.86	8.23	11.85	26.34	11.85	11.85	7.74	17.2	7.74	7.74	11.92	26.51	11.92	11.92
Gefersa 132kV	132	7.73	17.85	7.13	11.04	25.49	11.04	11.04	6.69	15.45	6.69	6.69	11.78	27.2	11.78	11.78
Gefersa 230kV	230	6.06	13.51	5.41	6.054	13.5	6.054	6.054	5.25	11.7	5.25	5.25	6.102	13.61	6.102	6.102
Gelan 132kV	132	9.23	21.27	8.49	12.65	29.16	12.65	12.65	7.99	18.42	7.99	7.99	12.9	29.75	12.9	12.9
Gelan 230kV	230	6.02	14.02	5.51	7.893	18.38	7.893	7.893	5.21	12.14	5.21	5.21	7.923	18.45	7.923	7.923
Gelan 400kV	400	4.39	10.09	4.08	3.935	9.037	3.935	3.935	3.81	8.738	3.81	3.81	4.214	9.677	4.214	4.214
Kaliti GIS 132kV	132	8.36	18.24	7.75	10.74	23.42	10.74	10.74	7.24	15.79	7.24	7.24	10.64	23.21	10.64	10.64
Kaliti I 132kV	132	9.31	21.52	8.56	13.02	30.1	13.02	13.02	8.06	18.64	8.06	8.06	13.6	31.44	13.6	13.6
Kaliti I 230kV	230	6.01	13.96	5.5	7.873	18.3	7.873	7.873	5.2	12.09	5.2	5.2	7.898	18.36	7.898	7.898
Kaliti II 132kV	132	7.96	16.97	7.41	10.54	22.48	10.54	10.54	6.89	14.7	6.89	6.89	10.49	22.38	10.49	10.49
Kaliti North 132kV	132	8.76	19.53	8.09	11.08	24.7	11.08	11.08	7.59	16.92	7.59	7.59	10.88	24.25	10.88	10.88
Legetafo 132kV	132	7.66	17.17	7.11	9.388	21.06	9.388	9.388	6.63	14.87	6.63	6.63	9.215	20.67	9.215	9.215
Legetafo 230kV	230	5.94	13.24	5.31	5.783	12.9	5.783	5.783	5.14	11.47	5.14	5.14	5.943	13.26	5.943	5.943
Mekanisa 132kV	132	5.13	9.542	4.9	4.212	7.83	4.212	4.212	4.44	8.263	4.44	4.44	4.897	9.105	4.897	4.897
Minilk 132kV	132	7.15	14.92	6.65	7.774	16.23	7.774	7.774	6.19	12.92	6.19	6.19	7.649	15.97	7.649	7.649
Nefasilk 132kV	132	7.06	14.34	6.62	8.026	16.31	8.026	8.026	6.11	12.42	6.11	6.11	7.699	15.65	7.699	7.699
Sebeta I 132kV	132	7.42	17.17	6.92	10.24	23.68	10.24	10.24	6.43	14.87	6.43	6.43	10.46	24.2	10.46	10.46
Sebeta I 230kV	230	6.09	13.71	5.51	6.812	15.34	6.812	6.812	5.27	11.87	5.27	5.27	6.562	14.78	6.562	6.562
Sebeta II 230kV	230	6.12	14.01	5.59	7.888	18.05	7.888	7.888	5.3	12.14	5.3	5.3	7.876	18.02	7.876	7.876
Sebeta II 400kV	400	4.06	9.172	3.76	3.282	7.413	3.282	3.282	3.52	7.943	3.52	3.52	3.791	8.562	3.791	3.791
Sululta 132kV	132	5.02	12.58	3.27	7.088	17.75	7.088	7.088	4.35	10.89	4.35	4.35	7.546	18.9	7.546	7.546
Sululta 230kV	230	6.12	13.79	5.38	5.909	13.32	5.909	5.909	5.3	11.94	5.3	5.3	6.114	13.78	6.114	6.114
Sululta 400kV	400	2.83	6.657	2.58	1.337	3.142	1.337	1.337	2.45	5.765	2.45	2.45	2.521	5.925	2.521	2.521
T.Hailoch 230kV	230	6.04	13.48	5.42	6.206	13.85	6.206	6.206	5.23	11.67	5.23	5.23	6.157	13.74	6.157	6.157
Weregenu 132kV	132	8.44	18.4	7.81	10.14	22.1	10.14	10.14	7.31	15.93	7.31	7.31	9.854	21.48	9.854	9.854
Yesu 132kV	132	8.88	20	8.2	11.55	26.01	11.55	11.55	7.69	17.32	7.69	7.69	11.46	25.81	11.46	11.46

I"k – Initial symmetrical current (kA, rms)

Ip – Peak current (kA)

Ib – Breaking current (kA, rms)

Ik – Steady State Current (kA, rms)

*Line-to-Line-to-Ground (LLG) fault current is the largest of all fault currents.

Based on Table 4-3 the circuit breaker data could be selected and if the breaker needs change the work could be easy.

4.4.3 Transient stability analysis

Transient stability is a property of a power system that ensures the system remains in electromechanically equilibrium throughout any normal or abnormal conditions.

Because of the power stability is a condition of electromechanical phenomenon, it is thus defined as the ability of designated synchronous machines in the system to remain in synchronism with one another following disturbance such as fault and fault removal at various location in the system to maintain torque to carry load following these disturbances.

Transient stability analysis results

Using ETAP software transient stability is studied. Running for 20sec; and event to happen at 10.00sec; three phase faults at Gelan 400kV bus. Analysis result is annexed (screen shoot of TS study at 10.00sec, 10.065sec and 10.071sec with different graphs).

Table 4-4 Transient stability analysis

Device ID: Gelan 400kV													
Device Type: Bus													
Time (s)	V Ang. (Deg.)	Freq. (Hz)	MW	Mvar	V/Hz (%)	Bus V (%)	Time (s)	V Ang. (Deg.)	Freq. (Hz)	MW	Mvar	V/Hz (%)	Bus V (% Nom.)
9.68	-33.77	50	0	-69.23	87.7	87.71	9.7	-33.76	50	0	-69.235	87.71	87.71
9.72	-33.77	50	0	-69.23	87.7	87.71	9.74	-33.77	50	0	-69.23	87.71	87.71
9.76	-33.78	50	0	-69.22	87.7	87.7	9.78	-33.79	50	0	-69.218	87.7	87.7
9.8	-33.8	50	0	-69.21	87.7	87.69	9.82	-33.82	50	0	-69.205	87.7	87.69
9.84	-33.82	50	0	-69.2	87.7	87.69	9.86	-33.83	50	0	-69.196	87.69	87.68
9.88	-33.83	50	0	-69.2	87.7	87.68	9.9	-33.83	50	0	-69.196	87.69	87.68
9.92	-33.83	50	0	-69.2	87.7	87.69	9.94	-33.83	50	0	-69.203	87.69	87.69

9.96	-33.82	50	0	-69.21	87.7	87.69	9.98	-33.82	50	0	-69.213	87.7	87.69
10	-33.81	50	0	-69.22	87.7	87.7	10.001	0	50	0	0	0	0
10.02	0	49.5	0	0	0	0	10.041	0	49.03	0	0	0	0
10.06	0	48.6	0	0	0	0	10.081	0	48.23	0	0	0	0

Fault clearing time selection

Using Table 4-4 as a reference clearing time in second are selected as shown in Table 4-5 and simulation has been done to see how the system will respond. Results are obtained and presented in Figure 4-7 to Figure 4-10. So that the fault clearing time to be chosen should be less than 0.065sec (65miliseconds)

Table 4-5 Transient stability analysis clearing time selection

Fault Location	Fault type	Happening time	Clearing time	System state
Galan 400kV bus	3-phase fault	10.000 sec	10.065	stable
			10.071	unstable

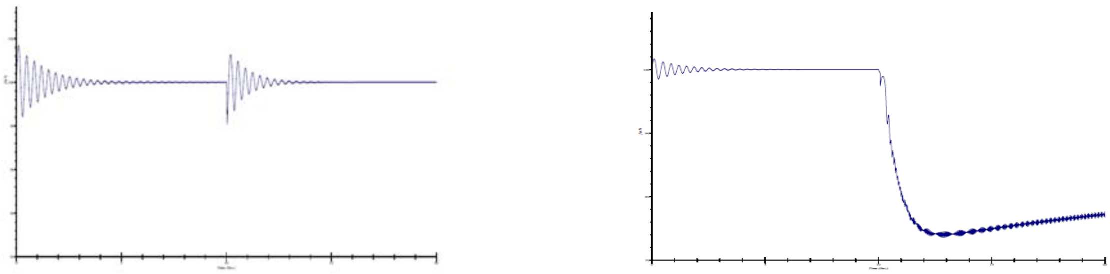


Figure 4-7 graph of bus frequency at stable condition and unstable condition

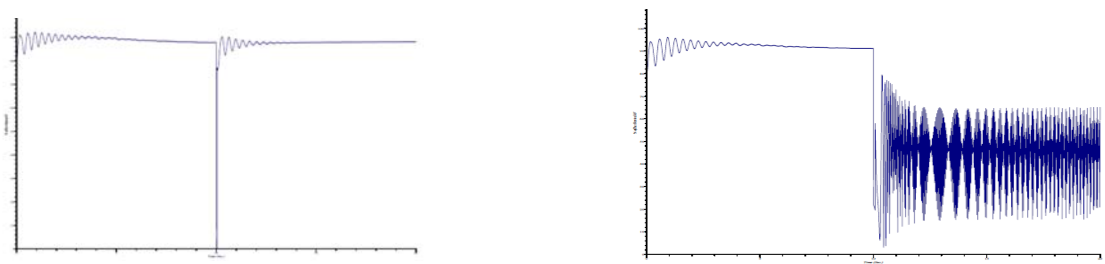
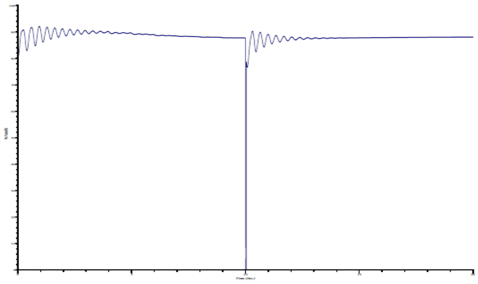


Figure 4-8 Graph of bus voltage at stable condition and unstable condition



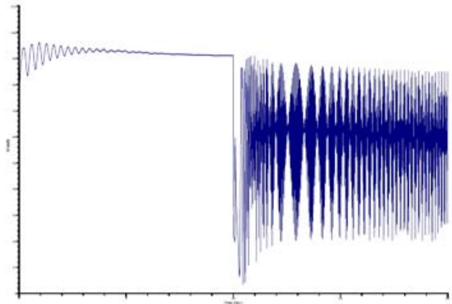
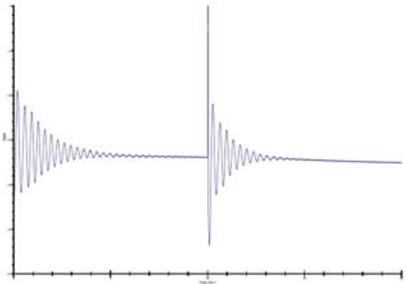


Figure 4-9 graph of bus voltage/HZ at stabl



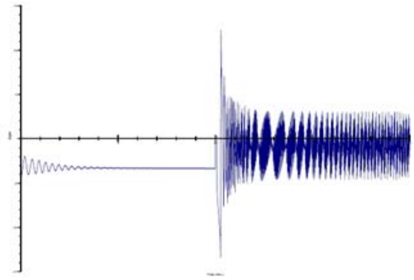


Figure 4-10 graph of bus voltage angle at stable condition and unstable condition

4.4.4 Analysis of network upgrading in the region

The coming new loads which could be considered as additional loads are as presented in Table 4-6. But, the related transmission line and / or auto transformer where the new additions are going to be connected should be considered during the time of addition. The time line is not specified when the loads will be active.

All circuit breakers are already upgraded with proper breaker rating. All the CB's with their rating is presented in Table 4-7.

Table 4-6 Upcoming Substations in the region

Sl. No.	Substation name	Region	Voltage level	MVA	TR Qt.
1	Addis East I	Addis Ababa	132/15	50	3
2	Bole Lemi (mobile) GIS	Addis Ababa	132/33/15	50	2
3	Bole Arabsa Mobile	Addis Ababa	230/15	50	2
4	Addis West	Addis Ababa	132/15	50	2

Table 4-7 CB data in Addis Ababa Region

SF6 CIRCUIT BREAKER	ALSTOM 132kV CB	ALSTOM 230kV CB	ABB 400kV CB
Rated voltage	132kV	230kV	400kV
Rated lightening impulse withstand voltage	750 kV	1250kV	1800kV
Rated Frequency	50 Hz	50HZ	50HZ
Rated current	3150A	4000A	5000A
Rated duration of short -circuit	3second	3 second	3 second
Rated short braking current	40kA	50kA	63kA
DC component of short -circuit braking current	50%	50%	50%
First -pole to clear factor	1.3	1.3	1.3
Rated line churching braking current	63A	160A	500A
Rated operating sequence	O-o.3s-CO-180s-CO	O-o.3s-CO-3min-CO	O-o.3s-CO-3min-CO

CHAPTER 5

SIMULATION STUDIES AND ANALYSIS OF RESULTS

5.1 INTRODUCTION

Load forecasting is done on MS Excel using the general stochastic regression techniques with two independent variables. On MS Excel the general formula is used and the built-in data analysis regression module is used for comparison and correctness. Load forecasting has been done for all the sub-transmission substations power transformers low voltage load feeders which reside in AARTS individually and result is obtained.

Network modeling using ETAP software is done for simulation purpose. All the necessary collected data are used and power system network elements has been modeled on the software. The model shows the overall power system equipment of Addis Ababa area with their arrangement for analysis and simulation purpose.

The simulation studies conducted are load flow, short circuit, and transient stability. In this chapter load flow simulation result analysis, network performance analysis before expansion and after expansion has been discussed.

The load flow analysis report which is annexed in appendix A is analyzed for critical and marginal network disturbing conditions. ETAP software is capable of generating a critical load flow conditions in a tab called alert view. Output alert view compiled for whole year is as follows.

5.2 PERFORMANCE ANALYSIS OF THE EXISTING SYSTEM

5.2.1 Transmission lines operating conditions

Transmission line loading in reference with the allowable current carrying capacity is presented in Table 5-1. Highlighted are critical and warning conditions, not highlighted rows are normal operating conditions.

Table 5-1: TL loading (percentage)

ID	Allowable	LF Analysis 2018	LF Analysis 2019	LF Analysis 2020	LF Analysis 2021	LF Analysis 2022
AddisEast-AddisNorth 132kVL1	510 A	38	41	49	55.1	61.7
Addis North-Minilk 132kVL1	510 A	85.4	91.3	105.3	114.2	123.9

Ayat - Legetafo 132kV L1	510 A	35.6	36.6	44.9	47.2	53.2
Cotobie - AddisEasII 132kV L1	510 A	28.7	29	22.6	17	13
Cototobie - Ayat 132kV L1	510 A	35.9	34.2	41.2	42.4	49.4
Gefersa - Sululta 230kV L1	920 A	55.8	54.3	51.3	49	48.8
Gefersa - Sululta 230kV L2	920 A	55.8	54.3	51.3	49	48.8
Gelan -Kaliti I 132kV L1	490 A	118	121.4	125.5	125.9	128.8
Gelan -Kaliti I 132kV L2	490 A	118	121.4	125.5	125.9	128.8
Gelan -Kaliti I 230kV L1	890 A	57.6	57.5	56.5	55.9	55.8
Gelan -Kaliti I 230kV L2	890 A	57.6	57.5	56.5	55.9	55.8
Kaliti I – Kaliti II 132kV L1	490 A	67.1	72.1	78.9	81.3	85
Kaliti II - N.Silk 132kV L1	490 A	55.5	59.8	64.8	66.6	69.4
KalitiNorth-Cotobie 132kVL1	490 A	40.9	39.9	40.2	38.3	39.9
KalitiI - Cotobie 132kV L1	490 A	54.7	54.1	54.9	53	55
Kaliti I - Addis Center 132kV L1	490 A	63.7	66.1	69.7	71.3	73.6
Kaliti I – KalitiNorth 132kV L1	490 A	76.2	77.1	80	79.1	82.1
Kaliti I - KalitiGIS 132kV L1	490 A	73.2	79.6	88.7	91.8	96.6
Kaliti I - Legetafo 230kV L2	890 A	52.6	51.1	49.8	49.1	49
Kaliti I - Mekanisa 132kV L1	490 A	109.2	114.4	122.1	125	129.1
Kaliti I - Weregenu 132kV L1	490 A	78.7	79.8	82.7	82.1	84.9
Kaliti I - Yesu 132kV L1	490 A	14.7	16.3	18.7	19	19
Kaliti I-Sebeta I 132kV L1	490 A	86.6	90	96.1	97.6	102.3
KalitiGIS – Kaliti II 132kV L1	490 A	62.2	66.1	71.2	73.2	76
Legetafo - Sululta 230kV L1	920 A	18	20.2	22.7	24.1	24.7
Legetafo - Sululta 230kV L2	920 A	18	20.2	22.7	24.1	24.7
Mekanisa–AddisSouthII132kV L1	490 A	54.3	57	61	62.4	64.3

Minilik-Gefersa 132kV L1	490 A	101.3	110.4	129.5	140.1	152.1
Sebeta I-Torhailoch 230kV L1	920 A	132.2	129	121.4	117.6	114.6
Sebeta II-Sebeeta I 230kV L1	1050 A	76.1	75.5	74.1	73.4	73.3
Sebeta II-Sebeta I 230kV L2	1050 A	76.1	75.5	74.1	73.4	73.3
Sebeta II-Gelan 400kV L1	1000 A	52.9	52.9	53.5	53.9	54
TorHailoch-Gefersar 230kV L1	920 A	130.5	126.9	118.6	114.4	111.2
Wereregnu - Cotobie 132kV L1	490 A	19.8	19.6	20.9	20.7	22

From Table 5-1 it is possible to identify TL which can be candidates for TL expansion. The setting for overloading conditions is given for the software as 100% critical and 95% as marginal alerting.

5.2.2 Transformers operating conditions

Transformer loading in reference with the allowable MVA capacity of TR's is presented in Table 5-2. Highlighted are critical and warning conditions, not highlighted rows are normal operating conditions. The name ID is created for TR identification.

Table 5-2: TR loading (percentage)

Name ID	Allowable	LF Analysis 2018	LF Analysis 2019	LF Analysis 2020	LF Analysis 2021	LF Analysis 2022
ACE TR1	31.5 MVA	108.1	110.7	114.9	117.2	119.7
ACE TR2	31.5 MVA	108.1	110.7	114.9	117.2	119.7
AEA TR1	25 MVA	120.4	124.1	130.5	134	137.8
AEA TR2	25 MVA	120.4	124.1	130.5	134	137.8
ANO TR1	25 MVA	114.3	119.8	129.3	134.1	139.4
ANO TR2	25 MVA	114.3	119.8	129.3	134.1	139.4
ASO TR1	25 MVA	115.7	119.8	126	128.7	131.7
ASO TR2	25 MVA	106.7	109.9	115.1	116.8	117.8

AYA TR1	50 MVA	12.2	14.8	19	20.2	22.1
AYA TR2	50 MVA	12.2	14.8	19	20.2	22.1
COT TR1-P	16 MVA	112.5	112.9	113.6	116.8	122.4
COT TR1-S	12 MVA	119.7	125	133.2	136.6	140.4
COT TR1-T	4 MVA	74.6	59.4	36.1	37.6	46.8
COT TR2	31.5 MVA	107.7	112.5	120	123.2	126.9
COT TR3	12 MVA	68.1	71.4	76.6	78.8	81.5
GEF ATR1	125 MVA	43.6	47	54	57.8	62.1
GEF ATR2	125 MVA	43.6	47	54	57.8	62.1
GEF ATR3	125 MVA	43.6	47	54	57.8	62.1
GEF ATR4	125 MVA	43.6	47	54	57.8	62.1
GEF TR1-P	25 MVA	217.8	229.5	251.7	261	268.9
GEF TR1-S	15 MVA	105.1	110.9	121.5	127	133.4
GEF TR1-T	15 MVA	247.1	259.5	283.4	292.5	298.4
GEF TR2-P	24 MVA	65.5	69.4	76.5	80.1	84.5
GEF TR2-S	12 MVA	14.7	15.6	17.2	18	19
GEF TR2-T	12 MVA	114.2	120.8	132.9	139.1	146.4
GEF TR3	25 MVA	116.6	127.3	141.9	145.8	155.7
GEL ATR1	250 MVA	168.6	171.7	174.3	174.3	176.6
GEL ATR2	250 MVA	168.6	171.7	174.3	174.3	176.6
GEL ATR3	125 MVA	97.9	100.8	104.5	105.4	107.5
GEL ATR4	125 MVA	97.9	100.8	104.5	105.4	107.5
GEL ATR5	125 MVA	97.9	100.8	104.5	105.4	107.5
GEL TR1	63 MVA	85	91.2	100.1	102.9	106.6
KAI ATR1	125 MVA	97.7	100.6	104.4	105.3	107.4
KAI ATR2	125 MVA	97.7	100.6	104.4	105.3	107.4
KAI ATR3	125 MVA	97.7	100.6	104.4	105.3	107.4
KAI TR1-P	22 MVA	88.8	92.8	99.1	101.8	105.1

KAI TR1-S	22 MVA	54.8	57.4	61.4	63.1	65.2
KAI TR1-T	7.5 MVA	93.2	96.7	102.2	104.5	107.2
KAI TR2-P	22 MVA	92.2	96.7	103.6	106.5	110.2
KAI TR2-S	22 MVA	53.6	56	59.8	61.3	63.3
KAI TR2-T	7.5 MVA	106.6	111.7	119.6	122.9	127.1
KGI TR1	50 MVA	12.1	14.6	18.7	19.8	21.7
KGI TR2	50 MVA	12.1	14.6	18.7	19.8	21.7
KII TR1-P	25 MVA	131.4	138.8	150.1	154.5	160
KII TR1-S	25 MVA	96	99.9	106	108.6	111.7
KII TR1-T	20 MVA	37.7	41.1	46	47.8	50
KII TR2	20 MVA	79.4	83	88.7	91	94
KII TR3	20 MVA	156.7	163.3	173.6	177.9	183.1
KNO TR1	16 MVA	134.7	140.6	149.9	153.8	158.5
KNO TR2	16 MVA	134.7	140.6	149.9	153.8	158.5
LEG ATR1	125 MVA	32.7	37.4	41.7	44	44.8
LEG ATR2	125 MVA	32.7	37.4	41.7	44	44.8
LEG TR1	20 MVA	179.8	188.1	199.7	205	210.1
LEG TR2	20 MVA	182.7	190.2	200.6	205.7	210.5
MEK TR1	25 MVA	114.2	117.5	122.7	125.2	128
MEK TR2	25 MVA	114.2	117.5	122.7	125.2	128
MIN TR1	50 MVA	13.8	16.9	21.7	23.2	25.3
MIN TR2	50 MVA	13.8	16.9	21.7	23.2	25.3
NEF TR1	50 MVA	59.7	63.4	67.6	69.4	71.5
NEF TR2	50 MVA	59.7	63.4	67.6	69.4	71.5
SEBI TR2-P	12 MVA	245.5	261.7	290.4	298.5	316.2
SEBI TR2-S	4 MVA	471.6	498	546.7	565	593
SEBI TR2-T	4 MVA	241.7	260.4	291.7	296	316.9
SEBI ATR1	125 MVA	46.2	48.9	54.9	56.5	60.5

SEBI ATR2	125 MVA	46.2	48.9	54.9	56.5	60.5
SEBI ATR3	125 MVA	46.2	48.9	54.9	56.5	60.5
SEBI TR1-P	25 MVA	15.7	15.4	15.2	15.3	15.5
SEBI TR1-S	12 MVA	0	0	0	0	0
SEBI TR1-T	8 MVA	48.4	47.4	46.9	47.3	48
SEBI TR3	22 MVA	271.6	286.5	312.4	320.4	337.9
SEBII ATR1	250 MVA	86.7	86	84.9	84.7	84.5
SEBII ATR2	250 MVA	86.7	86	84.9	84.7	84.5
SEBII ATR3	250 MVA	86.7	86	84.9	84.7	84.5
SEBII TR1	30 MVA	62.3	66.4	74.6	77.7	81.3
SUL ATR1	250 MVA	75.8	76.5	76.2	75.2	77.6
SUL ATR2	250 MVA	75.8	76.5	76.2	75.2	77.6
SUL ATR3	250 MVA	75.8	76.5	76.2	75.2	77.6
SUL ATR4	63 MVA	44.8	48.2	52.5	54	56.7
SUL ATR5	63 MVA	44.8	48.2	52.5	54	56.7
SUL TR1-P	50 MVA	68.4	74.8	83.1	85.6	90
SUL TR1-S	25 MVA	29.5	33.8	39.5	41.3	44.7
SUL TR1-T	25 MVA	104.5	112.7	122.7	125.6	130.9
SUL TR2	50 MVA	41.4	42.8	44.9	45.7	47.7
THA TR1	50 MVA	10.4	12.6	16.2	17.3	18.8
THA TR2	50 MVA	10.4	12.6	16.2	17.3	18.8
WER TR1	20 MVA	199.8	206.4	216.9	221.6	226.8
WER TR2	20 MVA	199.8	206.4	216.9	221.6	226.8
YES TR1	10 MVA	80.7	88.6	99.9	101.2	100.7
YES TR2	10 MVA	80.7	88.6	99.9	101.2	100.7

From Table 5-2 it is possible to identify TR's which can be candidates for TR expansion. The setting for overloading of TR's is 100% for critical conditions and 95% for marginal conditions.

5.2.3 Buses operating conditions

The bus loading in reference with the respected voltage level is presented in Table 5-3. Highlighted are critical and warning conditions, not highlighted rows are with normal operating conditions.

Table 5-3: Bus bar voltages

Bus ID	Nominal kV	LF Analysis 2018	LF Analysis 2019	LF Analysis 2020	LF Analysis 2021	LF Analysis 2022
Addis Center 132kV	132	125.336	123.667	121.724	121.376	120.066
Addis East II 132kV	132	126.913	125.442	123.935	123.93	122.881
Addis North 132kV	132	128.151	126.808	125.799	126.164	125.477
Addis South II 132	132	120.483	118.532	116.166	115.679	114.179
Ayat 132kV	132	127.27	125.905	124.17	124.018	122.718
Cotobie 132kV	132	127.613	126.131	124.422	124.24	123.036
Gefersa 132kV	132	132.435	131.48	131.408	132.325	132.246
Gefersa 230kV	230	227.595	226.61	225.898	226.197	225.06
Gelan 230kV	230	223.603	222.053	220.417	220.196	219.052
Kaliti GIS 132kV	132	128.378	126.784	124.96	124.673	123.453
Kaliti I 132kV	132	129.315	127.803	126.098	125.851	124.694
Kaliti I 230kV	230	223.327	221.771	220.133	219.914	218.766
Kaliti II 132kV	132	127.314	125.651	123.737	123.416	122.144
Kaliti North 132kV	132	128.637	127.118	125.389	125.15	123.968
Legetafo 132kV	132	127.117	125.912	124.224	124.122	122.761
Mekanisa 132kV	132	121.658	119.768	117.493	117.037	115.579
Minilk 132kV	132	129.557	128.321	127.601	128.15	127.66
Nefasilk 132kV	132	126.602	124.882	122.903	122.557	121.248
Sebeta I 132kV	132	132.626	131.725	131.769	131.929	131.831
Sebeta I 230kV	230	228.152	227.234	226.872	227.582	226.442
Sebeta II 230kV	230	230.4	229.701	229.984	231.069	230.199
Sululta 132kV	132	131.951	132.52	131.974	132.043	132.65

Sululta 230kV	230	229.764	229.113	228.9	229.232	228.609
T.Hailoch 230kV	230	227.693	226.722	226.11	226.536	225.394
Weregenu 132kV	132	127.738	126.206	124.446	124.211	123.001
Yesu 132kV	132	129.252	127.733	126.018	125.77	124.613

From Table 5-3 it is possible to identify buses which can be candidates for capacitor placement. The setting for under voltage conditions is inserted in the software as below 98% bus loading as marginal and below 95% as critical conditions.

5.3 EXPANSION PLANNING ANALYSIS OF AARTS

From the Alert view (operating conditions) the whole report is exported in excel, for the purpose of further analysis. Only power system elements with the overload or under voltage conditions are selected and presented in this section and is analyzed further for candidate selection. It is prepared in different tables in excel sheet and is presented here the final under voltage buses, overloaded TLs, and overloaded TRs.

5.3.1 Transmission line expansion planning analysis

Overloaded Transmission lines

Nine transmission lines are identified as the loading is more than 100% with respected rating. Identified TL are totally 9 out of 35 which are available in AAR and is listed out in Table 5-4 with respect to forecasted years.

Table 5-4: Summarized TL overloads in different years

Device ID	Type	Condition	Rating /Limit	Unit	2022 in %	2021 in %	2020 in %	2019 in %	2018 in %
Addis North - Minilk 132kV L1	Line	Overload	510	Amp	123.96	114.12	111.23	0	0
Gelan - Kaliti I 132kV L1	Line	Overload	490	Amp	129.42	126.56	124.44	120.97	118.58
Gelan - Kaliti I 132kV L2	Line	Overload	490	Amp	129.48	126.57	124.44	120.97	118.58
Kaliti I – Kaliti GIS 132kV L1	Line	Overload	490	Amp	96.873	0	0	0	0
Kaliti I - Mekanisa 132kV L1	Line	Overload	490	Amp	129.36	125.30	122.91	114.95	109.34
Kaliti I - Sebeta I 132kV L1	Line	Overload	490	Amp	105.66	99.96	135.47	111.52	96.27
Minilik - Gefersa 132kV L1	Line	Overload	490	Amp	152.23	140.03	119.66	127.27	133.65
Sebebeta I - Torhailoch 230kV L1	Line	Overload	920	Amp	114.88	117.82	116.81	125.12	131.93

Torhailoch - Gefersa 230kV L1	Line	Overload	920	Amp	111.57	114.79	95.76	0	0

Expansion planning for transmission overload mitigation

The proposed algorithm for TL problem solving becomes effective at this stage and after the application of the algorithm final analysis result is shown in Table 5-5 and Table 5-6. It is identified that there are nine overloaded transmission lines individually but there are definite relations between each transmission lines so that the algorithm application will result relation between those.

Table 5-5: TL overloading analysis for proper candidate selection

Device ID	Analysis
Addis North - Minilk 132kV L1	transmission line for Gefersa Addis North could solve this problem
Gelan - Kaliti I 132kV L1	one additional transmission line with operation optimization could solve the problem
Gelan - Kaliti I 132kV L2	
Kaliti I – Kaliti GIS 132kV L1	One additional transmission line from kaliti I to kaliti II the problem will be solved
Kaliti I - Mekanisa 132kV L1	One transmission line could solve the problem
Kaliti I - Sebeta I 132kV L1	one transmission line could solve the problem
Minilik - Gefersa 132kV L1	transmission line for Gefersa Addis North could solve this problem
Sebebeta I - Torhailoch 230kV L1	alternate route for Sebeta I to Gefersa could solve the problem
Torhailoch - Gefersa 230kV L1	

The following Table 5-5 shows list of TL after application of transmission expansion algorithm developed in Chapter 4.

Table 5-6: TL overloading mitigation analyses

Year	overloaded Line	Action summary	Comment
2018	A.North - Minilk 132kV L1	Alternate transmission line for Gefersa<> Addis	Addis North <> Minilik become overloaded @2020 and Minilik

	Minilik - Gefersa 132kV L1	North can solve this two transmission overloaded problem	Gefersa will be overloaded @2018 so the action should be taken early.
	Gelan - Kaliti I 132kV L1	One additional transmission line can solve the problem	Gelan<>Kaliti I transmission line is saturating because of the third auto transformer 230/132kV if this down the overload will be cleared and Auto transformer at kaliti I will be overloaded again.
	Gelan - Kaliti I 132kV L2		
	Kaliti I - Mekanisa 132kV L1	One additional transmission line can solve the problem	
	Kaliti I- Sebeta I 132kV L1	One additional transmission line can solve the problem	
	Sebeta I<>T.hail 230kV L1	Alternate transmission line for Sebeta I<>Gefersa can solve this two transmission overloaded problem	Sebeta I <> T. Hailoch become overloaded @2020 and T. Hailoch<>Gefersa will be overloaded @2018 so the action should be taken early.
	T.Hail<>Gefersa 230kV L1		
2022	Kaliti I <> KGIS 132kV L1	Alternate transmission line for Kaliti I<>Kaliti II can solve this transmission overloaded problem	

It is identified that out of nine candidate overloaded transmission lines only 7 transmission line addition can solve the overload problems. List of proposed TL is presented in Table 5-7.

Table 5-7: Proposed TL's to overcome TL overloading

	Additional Transmission Line	Rate	Capacity	Line Length (km)	Year to implement
1	Gefersa <> Addis North	132kV	510A	11.11	2018
2	Gelan <> Kaliti I	132kV	490A	1	
3	Kaliti I <> Mekanisa	132kV	490A	16.16	
4	Kaliti I <> Sebeta I	132kV	490A	24.14	

5	Sebeta I <> Gefersa	230kV	920A	10.6	
6	Kaliti I <> Kaliti II	132kV	490A	6.9	2022
7	Kaliti I <> Weregenu	132kV	490A	4.5	2022

After all expansion works are finished with the first 6 transmission line addition, transformer addition and capacitor placement, simulation result shows one overloaded line and the last expansion is proposed. The overload happens because; before any expansion the voltage was dropped too much so that the transformers can't be loaded according the setting so that the transmission line will not be overloaded while the premier problem voltage drop is resolved.

5.3.2 Transformer expansion planning analysis

Overloaded transformers

Transformers are the next to be analyzed, the initial is having all the overloaded TR list. And implementing the algorithm it will result the needed load serving conditions. TR loadings are shown below in the Table 5-8

Table 5-8: List of Overloaded TRs

					2022		2021		2020		2019		2018	
Device ID	Type	Condition	Rating	Unit	Operating (MW)	% Operating	Operating	% Operating	Operating	% Operating	Operating	% Operating	Operating	% Operating
ACE TR1	Transformer	Overload	31.5	MVA	37.61391	119.4092	36.83403	116.9334	36.41998	115.619	34.99889	111.1076	33.90451	107.6334
ACE TR2	Transformer	Overload	31.5	MVA	37.61391	119.4092	36.83403	116.9334	36.41998	115.619	35.0012	111.1149	33.90659	107.64
AEA TR1	Transformer	Overload	25	MVA	34.33395	137.3358	33.37671	133.5068	32.93881	131.7552	31.17309	124.6924	29.90469	119.6188
AEA TR2	Transformer	Overload	25	MVA	34.33395	137.3358	33.37671	133.5068	32.93881	131.7552	31.17309	124.6924	29.90469	119.6188
ANO TR1	Transformer	Overload	25	MVA	34.73553	138.9421	33.40638	133.6255	32.79976	131.199	30.10673	120.4269	28.25919	113.0368
ANO TR2	Transformer	Overload	25	MVA	34.73553	138.9421	33.40638	133.6255	32.79976	131.199	30.10673	120.4269	28.25919	113.0368
ASO TR1	Transformer	Overload	25	MVA	32.86299	131.452	32.11924	128.477	31.68973	126.7589	30.05752	120.2301	28.79772	115.1909
ASO TR2	Transformer	Overload	25	MVA	29.38905	117.5562	29.13825	116.553	28.9384	115.7536	27.58804	110.3522	26.56797	106.2719
COT TR1	Transformer	Overload	16	MVA	19.51073	121.942	18.62056	116.3785	18.29197	114.3248	18.13305	113.3316	17.93005	112.0628
COT TR2	Transformer	Overload	31.5	MVA	39.82391	126.4251	38.66996	122.7618	38.04689	120.7838	35.59592	113.0029	33.80629	107.3216
GEF TR1	Transformer	Overload	25	MVA	67.21417	268.8567	65.21278	260.8511	64.29131	257.1653	57.8539	231.4156	53.70959	214.8384
GEF TR2	Transformer	Overload	12	MVA	17.51771	145.9809	16.64076	138.673	16.25561	135.4634	14.58322	121.5268	13.4857	112.3808
GEF TR3	Transformer	Overload	25	MVA	38.83927	155.3571	36.37382	145.4953	35.58289	142.3315	31.50411	126.0165	29.20822	116.8329
GEL ATR1	Transformer	Overload	250	MVA	441.7164	176.6866	435.9312	174.3725	432.7075	173.083	426.4005	170.5602	423.5621	169.4249
GEL ATR2	Transformer	Overload	250	MVA	441.7164	176.6866	435.9312	174.3725	432.7075	173.083	426.4005	170.5602	423.5621	169.4249
GEL ATR3	Transformer	Overload	125	MVA	134.6378	107.7102	132.017	105.6136	130.2075	104.166	125.8281	100.6625	7.962547	106.1673
GEL ATR4	Transformer	Overload	125	MVA	134.6378	107.7102	132.017	105.6136	130.2075	104.166	125.8281	100.6625	32.72064	130.8826
GEL ATR5	Transformer	Overload	125	MVA	134.6378	107.7102	132.017	105.6136	130.2075	104.166	125.8281	100.6625	31.2132	156.066
GEL TR1	Transformer	Overload	63	MVA	67.02195	106.384	64.73544	102.7547	63.3989	100.6332				
KAI ATR1	Transformer	Overload	125	MVA	134.5735	107.6588	131.9025	105.522	130.054	104.0432	125.5864	100.4691	21.45483	134.0927
KAI ATR2	Transformer	Overload	125	MVA	134.5735	107.6588	131.9025	105.522	130.054	104.0432	125.5864	100.4691	21.45483	134.0927
KAI ATR3	Transformer	Overload	125	MVA	134.5735	107.6588	131.9025	105.522	130.054	104.0432	125.5864	100.4691	36.04751	180.2376
KAI TR1	Transformer	Overload	22	MVA	23.06314	104.8324	22.34631	101.5741	22.93412	104.246	34.83144	139.3258		
KAI TR2	Transformer	Overload	22	MVA	24.19181	109.9628	23.39112	106.3233	37.73707	150.9483	32.79327	163.9663	36.62201	183.1101
KII TR1	Transformer	Overload	25	MVA	39.92012	159.6805	38.54644	154.1857	34.92016	174.6008	22.58754	141.1721	28.4351	113.7404
KII TR3	Transformer	Overload	20	MVA	36.53546	182.6773	35.51102	177.5551	24.12362	150.7726	22.58754	141.1721	28.4351	113.7404
KNO TR1	Transformer	Overload	16	MVA	25.28957	158.0598	24.54504	153.4065	24.12362	150.7726	37.7851	188.9255	29.1822	243.185
KNO TR2	Transformer	Overload	16	MVA	25.28957	158.0598	24.54504	153.4065	40.18378	200.9189	38.19999	190.9999	59.84777	272.0353
LEG TR1	Transformer	Overload	20	MVA	41.63277	208.1639	40.64655	203.2328	40.37423	201.8712	29.49479	117.9792	26.04314	104.1726
LEG TR2	Transformer	Overload	20	MVA	41.71775	208.5887	40.78917	203.9458	30.86032	123.4413	29.49479	117.9792	39.79503	198.9752
MEK TR1	Transformer	Overload	25	MVA	31.9318	127.7272	31.24118	124.9647	30.86032	123.4413	31.60911	263.4092	39.79503	198.9752
MEK TR2	Transformer	Overload	25	MVA	31.9318	127.7272	31.24118	124.9647	34.85204	290.4337	63.44201	288.3728	122.5853	98.06821
SEBI TR2	Transformer	Overload	12	MVA	38.05304	317.1087	36.13823	301.1519	69.1935	314.5159	27.78726	111.149	122.5853	98.06821
SEBI TR3	Transformer	Overload	22	MVA	73.76895	335.3134	71.10284	323.1947	30.80342	123.2137	41.45277	207.2638	122.5853	98.06821
SUL TR1	Transformer	Overload	25	MVA	32.69272	130.7709	31.37606	125.5042	43.65055	218.2527	41.45277	207.2638	122.2709	97.8167
WER TR1	Transformer	Overload	20	MVA	45.23244	226.1622	44.20842	221.0421	43.65055	218.2527	7.284658	97.12878	122.2709	97.8167
WER TR2	Transformer	Overload	20	MVA	45.23244	226.1622	44.20842	221.0421	10.04938	100.4938	21.35392	97.06326	122.2709	97.8167
YES TR1	Transformer	Overload	10	MVA	10.0499	100.499	10.10139	101.0139	10.04938	100.4938				
YES TR2	Transformer	Overload	10	MVA	10.0499	100.499	10.10139	101.0139	21.93635	99.71068				

Expansion planning for transformer overloading mitigation

Further transformer addition analysis is conducted considering the loading of year 2022 because if we consider the loading of before years it will need expansion again in the recent year. And as it is mentioned earlier the excel sheet is too big to show here so it is annexed in (Appendix B). But for better understanding it is attached for few transformers in Table 5-9

Transformers capacity reside in one substation in MVA is considered to evaluate how much MVA to be covered by additional TR with respect to the load forecast demand power in MW with 0.8 PF.

Table 5-9: TR addition calculations (Appendix E)

Device ID	Condition	Rating	Unit	Total Demand @2022	Load in MW	Demand in MVA consider .8 PF	Available MVA (Existing Capability)	MVA Required to supply the forecasted Load	Additional Tra sformers to supply the needed load	@subsation
ACE TR1	Overload	31.5	MVA	37.49	74.97	93.72	63.00	30.72	132kV	Addis Center
ACE TR2	Overload	31.5	MVA	37.49					1x40MVA	
AEA TR1	Overload	25	MVA	32.39	64.77	80.97	50.00	30.97	132kV	Addis East II
AEA TR2	Overload	25	MVA	32.39					1x40MVA	
ANO TR1	Overload	25	MVA	31.32	65.93	82.41	50.00	32.41	132kV	Addis North
ANO TR2	Overload	25	MVA	34.61					1x40MVA	
ASO TR1	Overload	25	MVA	36.26	68.28	85.36	50.00	35.36	132kV	Addis South

ASO TR2	Overload	25	MVA	32.02					1x40MVA	
COT TR1	Overload	16	MVA	20.27					132kV	
COT TR2	Overload	31.5	MVA	37.91	58.18	72.73	47.50	25.23	1x40MVA	Cotobie
GEF TR1	Overload	25	MVA	19.78					132kV	
GEF TR2	Overload	12	MVA	16.48					2x40MVA	
GEF TR3	Overload	25	MVA	32.14	111.93	139.91	62.00	77.91		Gefersa

Considering the systematic TR addition calculation and algorithm implementation presented in chapter 4 methodology section the final transformers necessary in the study year is listed in the Table 5-10.

Table 5-10: Proposed TRs to overcome TR overloading

Substation		Substation		Substation		Substation	
Addis Center	132kV	Cotobie	132kV	Kaliti I	230/132kV ATR	Mekanisa	132kV
	1x40MVA		1x40MVA		1x125MVA		1x40MVA
Addis East II	132kV	Gefersa	132kV		132kV	Nefas Silk	132kV
	1x40MVA		2x40MVA		1x25MVA		1x40MVA
Addis North	132kV	Gelan	400/230kV ATR	Kaliti II	132kV	Sebeta I	132kV
	1x40MVA		2X250MVA		2x40MVA		1x63MVA
Addis South	132kV		230/132kV ATR	Kaliti North	132kV	Sululta	132kV 1x31.5MVA

	1x40MVA		1X125MVA		1x31.5MVA	Weregenu	132kV
			132kV	Legetafo	132kV		2x40MVA
			1x25MVA		2x40MVA	Yesu	132kV
							1x10MVA

All Transformers to be deployed @2018 except Gelan TR @2020, Kaliti I TR @ 2019 and yesu TR @2020

Load sharing between old TR and new TR

After the transformers expansion, load sharing between the old transformers and new transformer is mandatory. It is done in such a way that old transformers will have to supply 80% of total capacity and the remaining will be loaded to the new transformer. If newly added TRs are two or more; sharing will be managed equally. To manage the sharing of loads on sheet is prepared and sample is presented in Table 511 as well as annexed in appendix E. This sharing is necessary for simulation after addition or expansion in the ETAP software.

Table 5-11: TR load sharing after new TR addition

Peak Load (MW)					proposed MW loading for old TRs					proposed MW Loading for New TRs				
2018	2019	2020	2021	2022	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022
30.46	32.19	34.76	35.73	37.49	22.68	22.68	22.68	22.68	22.68	15.57	19.03	24.17	26.11	29.61
30.46	32.19	34.76	35.73	37.49	22.68	22.68	22.68	22.68	22.68					
26.03	[illegible]	29.92	[illegible]	32.39	[illegible]	[illegible]	18.00	[illegible]	18.00	[illegible]	19.19	23.85	25.60	28.77
[illegible]	[illegible]	29.92	[illegible]	32.39	[illegible]	[illegible]	18.00	[illegible]	[illegible]					
[illegible]	[illegible]	28.68	[illegible]	31.32	[illegible]	[illegible]	18.00	[illegible]	18.00	[illegible]	[illegible]	24.38	26.40	29.93
26.64	28.67	31.70	[illegible]	34.61	[illegible]	[illegible]	18.00	[illegible]	18.00					
27.90	30.03	33.21	34.32	36.26	18.00	18.00	18.00	18.00	18.00	17.47	21.38	27.26	29.14	32.28

60.93 = 45.36 + 15.57

5.3.3 Bus Bar expansion planning analysis (Capacitor Placement)

Under voltage buses

Under voltage is the phenomenon happening when load is too much. Since we are discussing about the forecasted loads in the future, the loading will be considered maximum to be in the safe side as a planner. Under voltage problem in thesis will be solved in a capacitor placement to minimize total expansion cost.

Like the overload problem, under voltage problem solving is started from selecting buses with critically subjected to under voltage. Is shown in the following Table 5-12

Table 5-12: List of under voltage buses for all forecast years

	Type	Condition	Rating	Unit	2022		2021		2020		2019		2018	
					Operating	% Operating	Operating	% Operating	Operating	% Operating	Operating	% Operating	Operating	% Operating
Addis Center	Bus	Under Voltage	132	kV	119.94	90.86	121.26	91.86	122.08	92.48	123.91	93.87	125.06	94.75
Addis East II 132kV	Bus	Under Voltage	132	kV	122.65	92.92	123.71	93.72	124.53	94.34	125.73	95.25	126.50	95.84
Addis North II	Bus	Under Voltage	132	kV	125.26	94.90	125.95	95.42	126.70	95.98	127.14	96.32	127.44	96.55
Addis South	Bus	Under Voltage	132	kV	114.06	86.41	115.57	87.55	116.51	88.26	118.76	89.97	120.22	91.08
Ayat 132kV	Bus	Under Voltage	132	kV	122.31	92.66	123.63	93.66	124.57	94.37	126.17	95.58	127.23	96.39
Cotobie 132kV	Bus	Under Voltage	132	kV	122.80	93.03	124.02	93.95	124.85	94.58	126.39	95.75	127.38	96.50
Gefersa 230kV	Bus	Under Voltage	230	kV	224.75	97.72								
Gelan 132kV	Bus	Under Voltage	132	kV	125.13	94.79	126.28	95.67	127.01	96.22	128.58	97.41		

Gelan 230kV	Bus	Under Voltage	230	kV	218.98	95.21	220.14	95.71	220.81	96.00	222.36	96.68	223.24	97.06
Kaliti GIS 132kV	Bus	Under Voltage	132	kV	123.32	93.42	124.55	94.36	125.33	94.94	127.03	96.24	128.10	97.05
Kaliti I 132kV	Bus	Under Voltage	132	kV	124.56	94.37	125.73	95.25	126.47	95.81	128.05	97.01	129.03	97.75
Kaliti II 230kV	Bus	Under Voltage	230	kV	218.70	95.09	219.86	95.59	220.53	95.88	222.08	96.56	222.96	96.94
Kaliti II 132kV	Bus	Under Voltage	132	kV	122.01	92.44	123.30	93.41	124.10	94.01	125.90	95.38	127.04	96.24
Kaliti North	Bus	Under Voltage	132	kV	123.81	93.80	125.00	94.70	125.77	95.28	127.37	96.49	128.37	97.25
Legetafo 132kV	Bus	Under Voltage	132	kV	122.20	92.57	123.58	93.62	124.60	94.40	126.18	95.59	127.27	96.41
Legetafo 230kV	Bus	Under Voltage	230	kV	225.24	97.93								
Mekanisa 132kV	Bus	Under Voltage	132	kV	115.46	87.47	116.93	88.58	117.84	89.27	120.00	90.91	121.39	91.97
Minilk 132kV	Bus	Under Voltage	132	kV	127.45	96.55	127.94	96.92	128.63	97.44	128.67	97.48	128.72	97.52
Nefasilk 132kV	Bus	Under Voltage	132	kV	121.12	91.76	122.44	92.76	123.26	93.38	125.13	94.79	126.33	95.70

T.Hailoch 230kV	Bus	Under Voltage	230	kV	225.02	97.83								
Weregenu 132kV	Bus	Under Voltage	132	kV	122.82	93.05	124.04	93.97	124.84	94.58	126.46	95.80	127.48	96.58
Yesu 132kV	Bus	Under Voltage	132	kV	124.48	94.30	125.65	95.19	126.39	95.75	127.98	96.96	128.97	97.71

Expansion planning with Capacitor placement for under voltage mitigation

From Table 5-12 ultimate summarized under voltage buses are identified and is listed below in Table 5-13. Buses with under voltage condition considering voltage under 95% bus nominal. Total of 16 buses are identified with condition of under voltage.

Table 5-13: List of under voltage buses with critical condition for all forecast years

	Type	Condition	Rating	Unit	under voltage occurred @year
Addis Center 132kV	Bus	Under Voltage	132	kV	2018
Addis East II 132kV	Bus	Under Voltage	132	kV	2020
Addis North 132kV	Bus	Under Voltage	132	kV	2022
Addis South II 132	Bus	Under Voltage	132	kV	2018
Ayat 132kV	Bus	Under Voltage	132	kV	2020
Cotobie 132kV	Bus	Under Voltage	132	kV	2020
Gelan 132kV	Bus	Under Voltage	132	kV	2022
Kaliti GIS 132kV	Bus	Under Voltage	132	kV	2020
Kaliti I 132kV	Bus	Under Voltage	132	kV	2022
Kaliti II 132kV	Bus	Under Voltage	132	kV	2020

Kaliti North 132kV	Bus	Under Voltage	132	kV	2021
Legetafo 132kV	Bus	Under Voltage	132	kV	2020
Mekanisa 132kV	Bus	Under Voltage	132	kV	2018
Nefasilk 132kV	Bus	Under Voltage	132	kV	2019
Weregenu 132kV	Bus	Under Voltage	132	kV	2020
Yesu 132kV	Bus	Under Voltage	132	kV	2022

Analyzing buses with under voltage conditions including their source buses, further bus feeders, and further buses which can have direct impact on the candidate buses are presented in following Table 5-14

Table 5-14: List of candidate buses to place capacitor banks

Year	Candidate Buses	Source Bus	Source Bus connection which have effect	Further bus affecting	Maximum Under V. %	Minimum Under V. %
2018	Addis Center 132kV	Kaliti I 132kV	Gelan 132kV		90.8641	94.74564
	Mekanisa	Kaliti I 132kV	Gelan 132kV		87.46875	91.96562
	Addis South II 132kV	Mekanisa 132 kV	Kaliti 132kV		86.40854	91.07747
2019	Nefasilk 132kV	Kaliti II 132kV	Kaliti 132kV		91.76	94.79
2020	Addis East II 132kV	Cotobie 132kV	Kaliti 132kV		92.92	94.34
	Ayat 132kV	Cotobie 132kV	Kaliti 132kV		92.66	94.37
	Cotobie 132kV	Kaliti I 132kV			93.03	94.58
	Kaliti GIS 132kV	Kaliti I 132kV			93.42	94.94
	Kaliti II 132kV	Kaliti I 132kV			92.44	94.01
	Legetafo 132kV	Ayat 132kV	Cotobie 132kV	Kaliti I 132kV	92.57	94.40
	Weregenu 132kV	Kaliti I 132kV			93.05	94.58

2021	Kaliti North 132kV	Kaliti I 132kV			93.80	94.70
2022	Addis North 132kV	Addis East 132kV	Cotobie 132kV	Kaliti I 132kV	94.90	
	Gelan 132kV	Gelan 230kV			94.79	
	Kaliti I 132kV	Gelan 132kV			94.37	
	Yesu 132kV	Kaliti I 132kV			94.30	

The ultimate under voltage problem with the source buses feeding the candidate buses are listed in Table 5-14. Kaliti I substation 132kv bus bar is the one which have big effect on all the candidate buses but the bus itself face under voltage @2022 so step by step placing capacitor banks and implementation of algorithm solves the under voltage problem as it is presented in the following section.

After implementation of developed mitigation algorithm which is presented in chapter 4 methodology section, unified recorded capacitor banks need to overcome under voltage problems on buses are shown in the following table 5-15. Step by step placement of capacitor banks and simulation results in every step is annexed in appendix E.

Table 5-15: Proposed capacitor banks

Total Paced capacitors vs buses		
Bus	Placed Capacitor	Placement Year
Kaliti I 132kV	6x20Mvar=120Mvar	2018
Gelan 132kV	4x20Mvar=80Mvar	2018
Mekanisa 132kV	4x20MVAR=80Mvar	2018
Addis center 132 kV	2x20Mvar=40Mvar	2018
Addis South II 132 kV	2x20MVAR=40Mvar	2020

5.4 PERFORMANCE ANALYSIS OF THE EXPANDED SYSTEM

5.4.1 Transmission line operating conditions

Result of transmission lines after expansion is shown in Table 5-16. This result shows that there are no transmission lines which are over loaded in reference with the setting mentioned (100% loading as critical and 95% loading as marginal). No transmission line is even loaded around 80%.

Table 5-16: TL loading (percentage)

ID	Allowable	LF Analysis 2018	LF Analysis 2019	LF Analysis 2020	LF Analysis 2021	LF Analysis 2022
A.East<>A.Nor 132kV L1	510 A	22.6	20.6	24.4	25.5	30.3
A.Nor <> Minilk 132kV L1	510 A	32.8	32.8	35.2	36.6	39.5
Ayat <> Legt 132kV L1	510 A	16.4	17.8	21.8	21.6	28.4
Cot <> A.EasII 132kV L1	510 A	30.2	36.1	42.5	43.7	47
Cot <> Ayat 132kV L1	510 A	26.1	27.2	28.3	26.9	29.7
Gef <> Sululta 230kV L1	920 A	44.9	41.5	37.7	37.2	31.4
Gef <> Sululta 230kV L2	920 A	44.9	41.5	37.7	37.2	31.4
GEF<>ANO 132kV N L1	490 A	41.9	43.8	48.8	51.2	55.5
GEL<>KALI 132kV N L1	490 A	59.2	59.5	62.4	63.5	66.3
Gelan <>Kaliti I 132kV L1	490 A	59.2	59.5	62.4	63.5	66.3
Gelan <>Kaliti I 132kV L2	490 A	59.2	59.5	62.4	63.5	66.3
Gelan <>Kaliti I 230kV L1	890 A	70	70.3	71	71.2	73.5
Gelan <>Kaliti I 230kV L2	890 A	70	70.3	71	71.2	73.5
KAI <> KII 132kV L1	490 A	39.2	42	46.1	47.9	50.6
KAI <> KII 132kV N L1	490 A	39.2	42	46.1	47.9	50.6
Kal II <> N.Silk 132kV L1	490 A	52.7	57.1	63.2	65.4	70
kal N<>Cot 132kVL1	490 A	37	40.1	43.4	44.1	46
Kall <> cot 132kV L1	490 A	49.2	53	57.1	58	60.3
KALI <> WER 132kV N L1	490 A	51.4	54.6	58.9	60.6	62.9
KALI<>MEK 132kV N L1	490 A	55.1	57.2	60.8	61.7	64.5
KALI<>SEBI 132kV N L1	490 A	31.2	37.5	44.7	45.5	49.3
Kaliti I <> A. C 132kV L1	490 A	55.7	58.8	63.6	65.3	69.3
Kaliti I <> Ka N 132kV L1	490 A	65.9	70.3	75.3	76.8	79.4
Kaliti I <> KGIS 132kV L1	490 A	45.2	49.3	55.5	58	61.7
Kaliti I <> Legt 230kV L2	890 A	55.9	49.9	41.7	39.8	33.1
Kaliti I <> Mek 132kV L1	490 A	55.1	57.2	60.8	61.7	64.5
Kaliti I <> Wer 132kV L1	490 A	51.4	54.6	58.9	60.6	62.9
Kaliti I <> Yesu 132kV L1	490 A	14.5	18.2	26.1	27.2	28.4
Kaliti I<>Seb I 132kV L1	490 A	31.2	37.5	44.7	45.5	49.3
KGIS <> KII 132kV L1	490 A	34.6	36.3	39	40.1	42.2
Legt <> Sululta 230kV L1	920 A	15	11.4	9.4	10.2	10.9
Legt <> Sululta 230kV L2	920 A	15	11.4	9.4	10.2	10.9
Mek <> A.SII 132kV L1	490 A	49.2	52.3	57.8	59.4	63.1
Minilik<>Gef 132kV L1	490 A	46.4	49.3	55.7	58.7	63.6
Seb I<>T.hail 230kV L1	920 A	54	50.8	46.1	44.9	40.3
Seb II<>Seb I 230kV L1	1050 A	59.5	58.4	56.5	55.9	53.5
Seb II<>Seb I 230kV L2	1050 A	59.5	58.4	56.5	55.9	53.5
SEBI<>GEF 230kV N L1	920 A	53.5	50.2	45.3	44	39.3
SebII<>Gelan 400kV L1	1000 A	29.8	28.1	26.2	25.8	25.1
T.Hail<>Gefr 230kV L1	920 A	52.1	48.6	43.4	42	36.8
Wer <> Cot 132kV L1	490 A	27.8	31.4	34.6	34.6	36.9

5.4.2 Transformer operating conditions

Result of transformers after expansion is shown in Table 5-17. This result shows that there is no transformer which are over loaded in reference with the setting mentioned (100% loading as critical and 95% loading as marginal) (as it is clearly seen in the table three TR's are in marginal operating condition. This indicates that every time the load should be forecasted and expansion should be planned in regular manner.

Table 5-17: TR loading (percentage)

ID	Allowable	LF Analysis 2018	LF Analysis 2019	LF Analysis 2020	LF Analysis 2021	LF Analysis 2022
ACE N TR	40 MVA	44.6	54.5	70.5	76.4	86.9
ACE TR1	31.5 MVA	84.8	85.4	84.7	83.8	84.7
ACE TR2	31.5 MVA	84.8	85.4	84.7	83.8	84.7
AEA N TR	40 MVA	46	54.9	69.5	75	84.8
AEA TR1	25 MVA	84.2	84.6	84	83.2	84.2
AEA TR2	25 MVA	84.2	84.6	84	83.2	84.2
ANO N TR	40 MVA	42.2	53.9	70.6	76.8	87.6
ANO TR1	25 MVA	84	84.1	83.4	84.2	83.8
ANO TR2	25 MVA	84	84.1	83.4	84.2	83.8
ASO N TR	40 MVA	50.3	61.4	79.3	84.9	95.8
ASO TR1	25 MVA	83.4	83.8	84.3	83.3	84
ASO TR2	25 MVA	83.4	83.8	84.3	83.3	84
AYA TR1	50 MVA	11.9	14.7	19	20	21.9
AYA TR2	50 MVA	11.9	14.7	19	20	21.9
COT N TR	40 MVA	25.9	35.6	50	56.4	68.4
COT TR1-P	16 MVA	92.4	93.1	92.7	91.9	91.6
COT TR1-S	12 MVA	94.9	95.6	95.2	94.4	94
COT TR1-T	4 MVA	74.9	75.5	75.1	74.5	74.2
COT TR2	31.5 MVA	84.4	85	84.7	83.9	85.1
COT TR3	12 MVA	63.5	68.7	75.4	76.3	76.1
GEF ATR1	125 MVA	37.7	40.6	45.6	47.6	50.8
GEF ATR2	125 MVA	37.7	40.6	45.6	47.6	50.8
GEF ATR3	125 MVA	37.7	40.6	45.6	47.6	50.8
GEF ATR4	125 MVA	37.7	40.6	45.6	47.6	50.8
GEF N TR1	40 MVA	40.4	50.6	65.3	70.2	76.6
GEF N TR2	40 MVA	40.4	50.6	65.3	70.2	76.6
GEF TR1-P	25 MVA	94.8	95	94.4	93.8	93.6
GEF TR1-S	15 MVA	82.6	82.8	82.3	81.7	81.6
GEF TR1-T	15 MVA	73.4	73.6	73.2	72.7	72.5
GEF TR2-P	24 MVA	32.5	33.1	33.8	33.8	34.3
GEF TR2-S	12 MVA	14.9	16	17.6	18.1	19.1
GEF TR2-T	12 MVA	49.6	49.7	49.4	49	49
GEF TR3	25 MVA	83.4	83.6	83.1	84.1	83.9
GEL ATR1	250 MVA	81.7	83.2	85.8	86.4	88.8
GEL ATR2	250 MVA	81.7	83.2	85.8	86.4	88.8
GEL ATR3	125 MVA	76.2	76.2	77.2	77.6	79.7
GEL ATR4	125 MVA	76.2	76.2	77.2	77.6	79.7
GEL ATR5	125 MVA	76.2	76.2	77.2	77.6	79.7
GEL N ATR1	250 MVA	81.7	83.2	85.8	86.4	88.8
GEL N ATR2	250 MVA	81.7	83.2	85.8	86.4	88.8
GEL N ATR3	125 MVA	76.2	76.2	77.2	77.6	79.7
GEL N TR	63 MVA	0	6.5	17	20.7	27.1
GEL TR1	63 MVA	84.8	84.4	84.3	83.6	84.9
KAI ATR1	125 MVA	72.9	78.1	85.2	86.7	93.6
KAI ATR2	125 MVA	72.9	78.1	85.2	86.7	93.6
KAI ATR3	125 MVA	72.9	78.1	85.2	86.7	93.6
KAI TR1-P	22 MVA	52.1	52.6	52.5	52.1	51.9
KAI TR1-S	22 MVA	38.7	39	39	38.6	38.5
KAI TR1-T	7.5 MVA	37.1	37.5	37.4	37.1	37
KAI TR2-P	22 MVA	52.2	52.7	52.6	52.1	52
KAI TR2-S	22 MVA	38.1	38.5	38.4	38.1	38
KAI TR2-T	7.5 MVA	39	39.4	39.3	39	38.9
KAL N TR	63 MVA	0	3.6	10.9	6	18.6
KALI N ATR	125 MVA	72.9	78.1	85.2	86.7	93.6

KAI TR2-T	7.5 MVA	39	39.4	39.3	39	38.9
KAL N TR	63 MVA	0	3.6	10.9	6	18.6
KALI N ATR	125 MVA	72.9	78.1	85.2	86.7	93.6
KALII N TR1	40 MVA	14.3	19.1	26	28.7	32.7
KALII N TR2	40 MVA	14.3	19.1	26	28.7	32.7
KGI TR1	50 MVA	11.9	14.6	18.5	19.9	21.7
KGI TR2	50 MVA	11.9	14.6	18.5	19.9	21.7
KII TR1-P	25 MVA	54.7	55.2	54.9	54.4	54.5
KII TR1-S	25 MVA	37.9	38.3	38.1	37.8	37.6
KII TR1-T	20 MVA	19.9	20.1	20	19.8	20.1
KII TR2	25 MVA	84.2	83.4	83.1	83.8	83.5
KII TR3	25 MVA	84.2	83.4	83.1	83.8	83.5
KNO N TR1	31.5 MVA	18.3	24.5	33.2	36.6	41.7
KNO TR1	16 MVA	83.5	84.2	84	83.3	83
KNO TR2	16 MVA	83.5	84.2	84	83.3	83
LEG ATR1	125 MVA	23.8	28.2	36.2	38.9	44.4
LEG ATR2	125 MVA	23.8	28.2	36.2	38.9	44.4
LEG N TR1	40 MVA	28.3	35.2	45.9	49	56
LEG N TR2	40 MVA	28.3	35.2	45.9	49	56
LEG TR1	31.5 MVA	84.2	83.3	83.2	84.1	83.9
LEG TR2	31.5 MVA	84.2	83.3	83.2	84.1	83.9
MEK N TR	40 MVA	51.1	62.5	79.3	83.9	95.8
MEK TR1	25 MVA	84.2	83.2	83.9	83	83.8
MEK TR2	25 MVA	84.2	84.7	83.9	83	83.8
MIN TR1	50 MVA	13.9	17	21.5	23.1	25.2
MIN TR2	50 MVA	13.9	17	21.5	23.1	25.2
NEF N TR	40 MVA	43.2	55.4	72.4	78.6	89.4
NEF TR1	50 MVA	40.9	41.2	41	40.6	41.2
NEF TR2	50 MVA	40.9	41.2	41	40.6	41.2
SEBI TR2-P	25 MVA	55.5	55.7	55.7	55.4	55.5
SEBI TR2-S	25 MVA	38.5	38.8	38.8	38.6	38.7
SEBI TR2-T	10 MVA	40.4	39.9	40	39.7	39.8
SEBI ATR1	125 MVA	28.1	31.7	37.1	38.3	41.7
SEBI ATR2	125 MVA	28.1	31.7	37.1	38.3	41.7
SEBI ATR3	125 MVA	28.1	31.7	37.1	38.3	41.7
SEBI N TR	63 MVA	9.2	14.7	22.7	25.8	30.9
SEBI TR1-P	25 MVA	6.5	6.4	6.4	6.5	6.4
SEBI TR1-S	12 MVA	0	0	0	0	0
SEBI TR1-T	8 MVA	20.1	19.9	19.9	20.2	19.8
SEBI TR3	50 MVA	83.9	83.1	83.1	82.7	82.8
SEBII ATR1	250 MVA	70.1	69	66.9	66.2	63.6
SEBII ATR2	250 MVA	70.1	69	66.9	66.2	63.6
SEBII ATR3	250 MVA	70.1	69	66.9	66.2	63.6
SEBII TR1	30 MVA	61.9	66.5	74.3	76.4	81.1
SUL ATR1	250 MVA	61.2	55.1	51	51.7	46
SUL ATR2	250 MVA	61.2	55.1	51	51.7	46
SUL ATR3	250 MVA	61.2	55.1	51	51.7	46
SUL ATR4	63 MVA	47.5	50.7	55.6	56.6	59
SUL ATR5	63 MVA	47.5	50.7	55.6	56.6	59
SUL N TR	31.5 MVA	29.8	38.5	51.5	54.5	60
SUL TR1-P	50 MVA	55.7	57.5	60.8	61.6	63.7
SUL TR1-S	25 MVA	30	33.5	40.2	41.9	44.8
SUL TR1-T	25 MVA	79.7	79.8	79.5	79.2	80.4
SUL TR2	50 MVA	41.8	41.9	41.8	41.6	41.5
THA TR1	50 MVA	10.4	12.7	16.2	17.1	18.8
THA TR2	50 MVA	10.4	12.7	16.2	17.1	18.8
WER N TR1	40 MVA	20.5	27.5	38.3	42.3	48.5
WER N TR2	40 MVA	20.5	27.5	38.3	42.3	48.5
WER TR1	40 MVA	85.1	84.3	84.1	84.8	84.5
WER TR2	40 MVA	85.1	84.3	84.1	84.8	84.5
YES N TR	40 MVA	0	9.3	31.4	34.5	37.9
YES TR1	10 MVA	80.9	83.9	83.7	83	82.7
YES TR2	10 MVA	80.9	83.9	83.7	83	82.7

5.4.3 Bus loading operating conditions

Result of capacitors after expansion is shown in Table 5-18. This result shows that there are no buses which are under voltage in reference with the setting mentioned (less than 95% loading as critical and less than 98% loading as marginal). Eight buses got in marginal under voltage operating conditions. Note more than 0.5% deviation from the marginal setting 98%.

Table 5-18: Bus loading (percentage)

Bus ID	Nominal kV	LF Analysis 2018	LF Analysis 2019	LF Analysis 2020	LF Analysis 2021	LF Analysis 2022
		Voltage	Voltage	Voltage	Voltage	Voltage
Addis Center 132kV	132	98.1	98.42	98.04	97.52	97.16
Addis East II 132kV	132	98.11	98.33	97.99	97.53	97.28
Addis North 132kV	132	98.87	98.95	98.54	98.1	97.9
Addis South II 132	132	98.56	98.77	98.18	97.62	97.13
Ayat 132kV	132	98.34	98.71	98.54	98.13	97.98
Cotobie 132kV	132	98.7	99.09	98.88	98.45	98.27
Gefersa 132kV	132	100.39	100.49	100.2	99.85	99.77
Gefersa 230kV	230	99.02	99.15	99.05	98.86	98.91
Gelan 230kV	230	99.98	100.16	100.02	99.8	99.87
Kaliti GIS 132kV	132	99.46	99.91	99.75	99.31	99.14
Kaliti I 132kV	132	99.9	100.39	100.28	99.87	99.74
Kaliti I 230kV	230	99.84	100.01	99.86	99.64	99.69
Kaliti II 132kV	132	99.02	99.44	99.25	98.79	98.6
Kaliti North 132kV	132	99.46	99.92	99.78	99.35	99.2
Legetafo 132kV	132	98.11	98.51	98.41	98.05	97.95
Mekanisa 132kV	132	99.03	99.32	98.84	98.32	97.91
Minilk 132kV	132	99.32	99.38	98.98	98.56	98.39
Nefasilk 132kV	132	98.51	98.89	98.63	98.16	97.92
Sebeta I 132kV	132	99.77	100.17	100.19	99.92	100.02
Sebeta I 230kV	230	99.23	99.33	99.2	99.02	99.17
Sebeta II 230kV	230	99.85	99.9	99.76	99.62	99.98
Sululta 132kV	132	100.48	99.63	100.45	100.28	100.13
Sululta 230kV	230	99.65	99.98	100.18	100.1	100.12
T.Hailoch 230kV	230	99.07	99.19	99.07	98.88	98.97
Weregenu 132kV	132	99.13	99.57	99.4	98.96	98.79
Yesu 132kV	132	99.85	100.33	100.2	99.78	99.65

5.5 COMPARISON OF PERFORMANCE OF THE EXISTING AND EXPANDED SYSTEM

As it is clearly seen on previous sections the performance analysis is carried on for all forecast years before and after transmission system expansion. Problems were observed on TL, TR and buses during simulation of the existing system to supply the forecasted load. Overloading is a problem on TL and TR whereas under voltage is on buses. After transmission system expansion is carried on, the problems seen on TL, TR and buses are resolved.

Transmission lines overloading, under bus voltages and transformers overloading the existing and the expanded system is compared in Tables 5-19, 5-20 and 5-21, respectively.

Table 5-19: TL loading (percentage)

Device ID	Type	Rating (A)	Condition	2022 in %	2021 in %	2020 in %	2019 in %	2018 in %
Addis North - Minilk 132kV L1	Line	510	Before	123.96	114.12	111.23	0	0
			After	39.5	36.6	35.2	32.8	32.8
Gelan - Kaliti I 132kV L1	Line	490	Before	129.42	126.56	124.44	120.97	118.58
			After	66.3	63.5	62.4	59.5	59.2
Gelan - Kaliti I 132kV L2	Line	490	Before	129.48	126.57	124.44	120.97	118.58
			After	66.3	63.5	62.4	59.5	59.2
Kaliti I – Kaliti GIS 132kV L1	Line	490	Before	96.873	0	0	0	0
			After	61.7	58	55.5	49.3	45.2
Kaliti I - Mekanisa 132kV L1	Line	490	Before	129.36	125.3	122.91	114.95	109.34
			After	64.4	61.7	60.8	57.2	55.1
Kaliti I - Sebeta I 132kV L1	Line	490	Before	105.66	99.96	135.47	111.52	96.27
			After	48.8	45.5	44.7	37.5	33.5
Minilik - Gefersa 132kV L1	Line	490	Before	152.23	140.03	119.66	127.27	133.65
			After	64.1	58.7	55.7	49.3	41.5
Sebebeta I - Torhailoch 230kV L1	Line	920	Before	114.88	117.82	116.81	125.12	131.93
			After	40.4	44.9	46.1	53.1	50.8
Torhailoch - Gefersa 230kV L1	Line	920	Before	111.57	114.79	95.76	0	0
			After	51.2	48.6	43.4	42	36.9

Table 5-20: Bus voltages (percentage)

	Type	Condition	Rating (kV)	2022 Bus loading in % After	2022 Bus loading in % Before	2021 Bus loading in % After	2021 Bus loading in % Before	2020 Bus loading in % After	2020 Bus loading in % Before	2019 Bus loading in % After	2019 Bus loading in % Before	2018 Bus loading in % After	2018 Bus loading in % Before
Addis Center 132kV	Bus	UV	132	96.96	90.86	97.52	91.86	98.04	92.48	98.42	93.87	98.51	94.75
Addis East II 132kV	Bus	UV	132	97.12	92.92	97.53	93.72	97.99	94.34	98.33	95.25	98.14	95.84
Addis North 132kV	Bus	UV	132	97.78	94.90	98.10	95.42	98.54	95.98	98.95	96.32	98.51	96.55
Addis South II 132	Bus	UV	132	96.93	86.41	97.62	87.55	98.18	88.26	98.77	89.97	98.95	91.08
Ayat 132kV	Bus	UV	132	97.81	92.66	98.13	93.66	98.54	94.37	98.71	95.58	98.59	96.39
Cotobie 132kV	Bus	UV	132	98.08	93.03	98.45	93.95	98.88	94.58	99.09	95.75	98.97	96.50
Gelan 132kV	Bus	UV	132	99.82	94.79	99.80	95.67	100.02	96.22	100.16	97.41		
Kaliti GIS 132kV	Bus	UV	132	98.94	93.42	99.31	94.36	99.75	94.94	99.91	96.24	99.83	97.05
Kaliti I 132kV	Bus	UV	132	99.53	94.37	99.87	95.25	100.28	95.81	100.39	97.01	100.27	97.75
Kaliti II 132kV	Bus	UV	132	98.39	92.44	98.79	93.41	99.25	94.01	99.44	95.38	99.39	96.24
Kaliti North 132kV	Bus	UV	132	99.00	93.80	99.35	94.70	99.78	95.28	99.92	96.49	99.81	97.25
Legetafo 132kV	Bus	UV	132	97.80	92.57	98.05	93.62	98.41	94.40	98.51	95.59	98.35	96.41
Mekanisa 132kV	Bus	UV	132	97.71	87.47	98.32	88.58	98.84	89.27	99.32	90.91	99.42	91.97
Nefasilk 132kV	Bus	UV	132	97.70	91.76	98.16	92.76	98.63	93.38	98.89	94.79	98.88	95.70
Weregenu 132kV	Bus	UV	132	98.58	93.05	98.96	93.97	99.40	94.58	99.57	95.80	99.47	96.58
Yesu 132kV	Bus	UV	132	99.44	94.30	99.78	95.19	100.20	95.75	100.33	96.96	100.22	97.71

Table 5-21: TR loading (percentage)

Device ID	Type	Condition	Rating (MVA)	2022 loading in % After	2022 loading in % Before	2021 loading in % After	2021 loading in % Before	2020 loading in % After	2020 loading in % Before	2019 loading in % After	2019 loading in % Before	2018 loading in % After	2018 loading in % Before
ACE TR1	TR	Overload	31.5	84.30	119.41	83.80	116.93	84.70	115.62	85.40	111.11	84.10	107.63
ACE TR2	TR	Overload	31.5	84.30	119.41	83.80	116.93	84.70	115.62	85.40	111.11	84.10	107.64
AEA TR1	TR	Overload	25	84.00	137.34	83.20	133.51	84.00	131.76	84.60	124.69	84.20	119.62
AEA TR2	TR	Overload	25	84.00	137.34	83.20	133.51	84.00	131.76	84.60	124.69	84.20	119.62
ANO TR1	TR	Overload	25	83.60	138.94	84.20	133.63	83.40	131.20	84.10	120.43	83.40	113.04
ANO TR2	TR	Overload	25	83.60	138.94	84.20	133.63	83.40	131.20	84.10	120.43	83.40	113.04
ASO TR1	TR	Overload	25	83.60	131.45	83.30	128.48	84.30	126.76	83.80	120.23	84.10	115.19
ASO TR2	TR	Overload	25	83.60	117.56	83.30	116.55	84.30	115.75	83.80	110.35	84.10	106.27
COT TR1	TR	Overload	16	73.90	121.94	74.50	116.38	75.10	114.32	75.50	113.33	75.30	112.06
COT TR2	TR	Overload	31.5	84.80	126.43	83.90	122.76	84.70	120.78	85.00	113.00	84.80	107.32

GEF TR1	TR	Overload	25	72.40	268.86	72.70	260.85	73.20	257.17	73.60	231.42	72.60	214.84
GEF TR2	TR	Overload	12	48.90	145.98	49.00	138.67	49.40	135.46	49.70	121.53	49.00	112.38
GEF TR3	TR	Overload	25	83.80	155.36	84.10	145.50	83.10	142.33	83.60	126.02	84.00	116.83
GEL ATR1	TR	Overload	250	88.80	176.69	86.40	174.37	85.80	173.08	83.20	170.56	82.30	169.42
GEL ATR2	TR	Overload	250	88.80	176.69	86.40	174.37	85.80	173.08	83.20	170.56	82.30	169.42
GEL ATR3	TR	Overload	125	82.30	107.71	77.60	105.61	77.20	104.17	76.20	100.66	81.90	106.17
GEL ATR4	TR	Overload	125	82.30	107.71	77.60	105.61	77.20	104.17	76.20	100.66	81.90	130.88
GEL ATR5	TR	Overload	125	82.30	107.71	77.60	105.61	77.20	104.17	76.20	100.66	81.90	156.07
GEL TR1	TR	Overload	63	84.50	106.38	83.60	102.75	84.30	100.63				
KAI ATR1	TR	Overload	125	98.30	107.66	86.70	105.52	85.20	104.04	78.10	100.47	81.50	134.09
KAI ATR2	TR	Overload	125	98.30	107.66	86.70	105.52	85.20	104.04	78.10	100.47	81.50	134.09
KAI ATR3	TR	Overload	125	98.30	107.66	86.70	105.52	85.20	104.04	78.10	100.47	81.50	180.24
KAI TR1	TR	Overload	22	36.90	104.83	37.10	101.57	37.40	104.25	37.50	139.33		
KAI TR2	TR	Overload	22	38.70	109.96	39.00	106.32	39.30	150.95	39.40	163.97	39.30	183.11
KII TR1	TR	Overload	25	20.00	159.68	19.80	154.19	20.00	174.60	20.10	141.17	20.00	113.74
KII TR3	TR	Overload	20	83.10	182.68	83.80	177.56	83.10	150.77	83.40	141.17	83.30	113.74
KNO TR1	TR	Overload	16	84.20	158.06	83.30	153.41	84.00	150.77	84.20	188.93	84.00	243.19
KNO TR2	TR	Overload	16	84.20	158.06	83.30	153.41	84.00	200.92	84.20	191.00	84.00	272.04
LEG TR1	TR	Overload	20	83.60	208.16	84.10	203.23	83.20	201.87	83.30	117.98	83.10	104.17
LEG TR2	TR	Overload	20	83.60	208.59	84.10	203.95	83.20	123.44	83.30	117.98	83.10	198.98
MEK TR1	TR	Overload	25	83.50	127.73	83.00	124.96	83.90	123.44	83.20	263.41	83.40	198.98
MEK TR2	TR	Overload	25	83.50	127.73	83.00	124.96	83.90	290.43	84.70	288.37	83.40	98.07
SEBI TR2	TR	Overload	12	39.70	317.11	39.70	301.15	40.00	314.52	39.90	111.15	39.80	98.07
SEBI TR3	TR	Overload	22	84.10	335.31	82.70	323.19	83.10	123.21	83.10	207.26	84.30	98.07
SUL TR1	TR	Overload	25	80.30	130.77	79.20	125.50	79.50	218.25	79.80	207.26	79.50	97.82
WER TR1	TR	Overload	20	84.20	226.16	84.80	221.04	84.10	218.25	84.30	97.13	84.20	97.82

WER TR2	TR	Overload	20	84.20	226.16	84.80	221.04	84.10	100.49	84.30	97.06	84.20	97.82
YES TR1	TR	Overload	10	82.40	100.50	83.00	101.01	83.70	100.49				
YES TR2	TR	Overload	10	82.40	100.50	83.00	101.01	83.70	99.71				

CHAPTER 6

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORKS

6.1 INTRODUCTION

In this thesis, load forecasts for the Addis Ababa region for the period 2018-2022 have been obtained and simulation studies including load flow, short circuit, and transient stability analysis are carried out to test the performance of the existing Addis Ababa region transmission system and the expanded system to meet the forecasted load. Further, the simulation results are analyzed, conclusions are drawn, recommendations based on the findings of this thesis are made and suggestions for future work are presented as follows.

6.2 CONCLUSIONS

Addis Ababa region transmission system is analyzed from the capacity of load supplying point of view. The region's load is collected for the past five years and forecasting is conducted for the future five years. Econometrics technique is used to obtain future five-year loads. Peak load, GDP, and number of consumers are basic pillars to perform the future five-year loads.

Load forecast result is subjected to perform three analyses namely, load flow analysis, short circuit analysis, and transient stability analysis.

Load flow analysis result has been subjected to further analysis to identify power system elements which are under abnormal operation condition. Basic abnormal conditions are over loaded transmission lines, overloaded transformers, and under voltage buses. Three different algorithms are used to make a suggestion on the power system elements that can make the operation conditions normal. And as a result, transmissions lines are proposed to overcome transmission line overloading, transformers are proposed substation wise to overcome transformer overloading, and capacitor banks are proposed to overcome under voltage problems on buses.

Short circuit analysis result is obtained has been used to show how the breaking and making capacity of every circuit breaker on every bus.

Transient stability analysis result is used to show how the protection system should act during abnormal condition. The protection device acting time to clear the fault happened is obtained and presented for one bus.

After all analysis and proposals, the actual power system elements subject to study, with the proposed elements obtained in this study simulation has been performed and expected results are obtained and presented. If the proposed transmission lines, transformers, and capacitor banks are deployed as per the proposed timing the outstanding power flow problems of overloading, and under voltage could be solved for the coming five years.

6.3 RECOMMENDATIONS

Data collection was the worst part of this thesis. My first recommendation goes to data management system in the respected data source; mainly Addis Ababa region transmission system office. There should be structured, organized, and computerized data base system to collect all necessary data of power system elements with their detail information, peak load in MW, MVAR or ampere, number of consumers with detail information, and historical problems happening in the past.

It is strongly recommended that, the region office to perform load forecasting, analysis studies, and analyze results for best demand supply management and urge to follow the proposals presented in this thesis.

And finally, the expansion shall be done in a specified time line. But since there are updates in every data like the forecasted GDP, forecasted number of consumers, and new historical data is coming year by year; the region should follow the forecast and implement the expansion as it is mentioned in the following tables; Table 6-1 for TR expansion, Table 6-2 for capacitor placement, and Table 6-3 for TL expansion.

Table 6-1 Summarized proposed TR's vs. substations

<table>
<tr><td colspan="8">Additional Transformers to overcome Overloading of Transformers</td></tr>
<tr><td>Substation</td><td></td><td>Substation</td><td></td><td>Substation</td><td></td><td>Substation</td><td></td></tr>
<tr><td rowspan="2">Addis Center</td><td>132kV</td><td rowspan="2">Cotobie</td><td>132kV</td><td rowspan="4">Kaliti I</td><td>230/132kV ATR</td><td rowspan="2">Mekanisa</td><td>132kV</td></tr>
<tr><td>1x40MVA</td><td>1x40MVA</td><td>1x125MVA</td><td>1x40MVA</td></tr>
<tr><td rowspan="2">Addis East II</td><td>132kV</td><td rowspan="2">Gefersa</td><td>132kV</td><td>132kV</td><td rowspan="2">Nefas Silk</td><td>132kV</td></tr>
<tr><td>1x40MVA</td><td>2x40MVA</td><td>1x25MVA</td><td>1x40MVA</td></tr>
<tr><td rowspan="2">Addis North</td><td>132kV</td><td rowspan="6">Gelan</td><td>400/230kV ATR</td><td rowspan="2">Kaliti II</td><td>132kV</td><td rowspan="2">Sebeta I</td><td>132kV</td></tr>
<tr><td>1x40MVA</td><td>2X250MVA</td><td>2x40MVA</td><td>1x63MVA</td></tr>
<tr><td rowspan="2">Addis South</td><td>132kV</td><td>230/132kV ATR</td><td rowspan="2">Kaliti North</td><td>132kV</td><td>Sululta</td><td>132kV 1x31.5MVA</td></tr>
<tr><td>1x40MVA</td><td>1X125MVA</td><td>1x31.5MVA</td><td rowspan="2">Weregenu</td><td>132kV</td></tr>
<tr><td></td><td></td><td>132kV</td><td rowspan="2">Legetafo</td><td>132kV</td><td>2x40MVA</td></tr>
<tr><td></td><td></td><td>1x25MVA</td><td>2x40MVA</td><td rowspan="2">Yesu</td><td>132kV</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>1x10MVA</td></tr>
</table>

All Transformers to be deployed @2018 except Gelan TR @2020, Kaliti I TR @ 2029 and yesu TR @2020

Table 6-2 Summarized proposed capacitor banks vs. substations bus bar

Capacitors to overcome Under voltage problems		
Bus	Placed Capacitor	Placement Year
Kaliti I 132kV	6x20Mvar=120Mvar	2018
Gelan 132kV	4x20Mvar=80Mvar	2018
Mekanisa 132kV	4x20MVAR=80Mvar	2018
Addis center 132 kV	2x20Mvar=40Mvar	2018
Addis South II 132 kV	2x20MVAR=40Mvar	2020

Table 6-3 Summarized proposed TL's vs. substations

Transmission Lines to overcome Line overloading			
Additional Transmission Line	Rate	Capacity	Year to implement
Gefersa <> Addis North	132kV	510A	
Gelan <> Kaliti I	132kV	490A	
Kaliti I <> Mekanisa	132kV	490A	2018
Kaliti I <> Sebeta I	132kV	490A	
Sebeta I <> Gefersa	230kV	920A	
Kaliti I <> Kaliti II	132kV	490A	2022
Kaliti I <> Weregenu	132kV	490A	2022

6.4 SUGGESTIONS FOR FUTURE WORK

In this thesis, Load forecasting is done considering two economic indices. It is suggested to carry out load forecasting affected by other factors and compare these results. Further, transmission system expansion planning may be carried out using those load forecasts.

It is further suggested to carry out contingency analysis of the expanded Addis Ababa region transmission system and to investigate the performance of the circuit breakers capabilities in the region.

Based on the transient stability studies carried out in this thesis, protection coordination of Addis Ababa region transmission system may also be investigated and economic aspect of implementing the proposed expansion plan may be studied.

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Appendix A - Alert (Operating) Conditions

Project:	Loadforecast	ETAP		Page:	1
Location:	Addis Ababa	12.6.0H		Date:	13-06-2018
Contract:	1			SN:	
Engineer:	Abrham Workie	Study Case:	LF for 2018	Revision:	Base
Filename:	LoadForecast			Config.:	Normal

The study is conducted on Addis Ababa region only

Alert Summary Report

	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
ACE TR1	Transformer	Overload	31.500	MVA	34.052	108.1	3-Phase
ACE TR2	Transformer	Overload	31.500	MVA	34.054	108.1	3-Phase
Addis Center 132kV	Bus	Under Voltage	132.000	kV	125.336	95.0	3-Phase
Addis South II 132	Bus	Under Voltage	132.000	kV	120.483	91.3	3-Phase
AEA TR1	Transformer	Overload	25.000	MVA	30.098	120.4	3-Phase
AEA TR2	Transformer	Overload	25.000	MVA	30.098	120.4	3-Phase
ANO TR1	Transformer	Overload	25.000	MVA	28.574	114.3	3-Phase
ANO TR2	Transformer	Overload	25.000	MVA	28.574	114.3	3-Phase
ASO TR1	Transformer	Overload	25.000	MVA	28.923	115.7	3-Phase
Aso TR1 15	Bus	Under Voltage	15.000	kV	13.944	93.0	3-Phase
ASO TR2	Transformer	Overload	25.000	MVA	26.683	106.7	3-Phase
Aso TR2 15	Bus	Under Voltage	15.000	kV	14.038	93.6	3-Phase
Cable28	Cable	Overload	231.928	Amp	333.692	143.9	3-Phase
COT TR1	Transformer	Overload	16.000	MVA	17.995	112.5	3-Phase
Cot TR1 15	Bus	Under Voltage	15.000	kV	14.147	94.3	3-Phase
Cot TR1 45	Bus	Under Voltage	45.000	kV	41.844	93.0	3-Phase
COT TR2	Transformer	Overload	31.500	MVA	33.929	107.7	3-Phase
GEF TR1	Transformer	Overload	25.000	MVA	54.456	217.8	3-Phase
GEF TR2	Transformer	Overload	12.000	MVA	13.703	114.2	3-Phase
GEF TR3	Transformer	Overload	25.000	MVA	29.139	116.6	3-Phase
GEL ATR1	Transformer	Overload	250.000	MVA	421.560	168.6	3-Phase
GEL ATR2	Transformer	Overload	250.000	MVA	421.560	168.6	3-Phase
Gelan <>Kaliti I 132kV L1	Line	Overload	490.000	Amp	578.380	118.0	3-Phase
Gelan <>Kaliti I 132kV L2	Line	Overload	490.000	Amp	578.410	118.0	3-Phase
KAI TR2	Transformer	Overload	7.500	MVA	7.997	106.6	3-Phase
Kaliti I <> Mek 132kV L1	Line	Overload	490.000	Amp	536.936	109.6	3-Phase
KII TR1	Transformer	Overload	25.000	MVA	32.862	131.4	3-Phase
KII TR1 15	Bus	Under Voltage	15.000	kV	12.625	84.2	3-Phase
KII TR1 45	Bus	Under Voltage	45.000	kV	41.526	92.3	3-Phase
KII TR2 15	Bus	Under Voltage	15.000	kV	12.570	83.8	3-Phase
KII TR3	Transformer	Overload	20.000	MVA	31.349	156.7	3-Phase
KNO TR1	Transformer	Overload	16.000	MVA	21.544	134.7	3-Phase
KNO TR2	Transformer	Overload	16.000	MVA	21.544	134.7	3-Phase
LEG TR1	Transformer	Overload	20.000	MVA	35.962	179.8	3-Phase
Leg TR1 15	Bus	Under Voltage	15.000	kV	14.178	94.5	3-Phase
LEG TR2	Transformer	Overload	20.000	MVA	36.535	182.7	3-Phase

The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Leg TR2 15	Bus	Under Voltage	15.000	kV	14.147	94.3	3-Phase
MEK TR1	Transformer	Overload	25.000	MVA	28.559	114.2	3-Phase
Mek TR1 15	Bus	Under Voltage	15.000	kV	14.119	94.1	3-Phase
MEK TR2	Transformer	Overload	25.000	MVA	28.559	114.2	3-Phase
Mek TR2 15	Bus	Under Voltage	15.000	kV	14.119	94.1	3-Phase
Mekanisa 132kV	Bus	Under Voltage	132.000	kV	121.658	92.2	3-Phase
Minilik<>Gef 132kV L1	Line	Overload	490.000	Amp	496.725	101.4	3-Phase
Seb I<>T.hail 230kV L1	Line	Overload	920.000	Amp	1216.265	132.2	3-Phase
SEBI TR2	Transformer	Overload	12.000	MVA	29.458	245.5	3-Phase
SebI TR1 45	Bus	Over Voltage	33.000	kV	44.961	136.2	3-Phase
SEBI TR3	Transformer	Overload	22.000	MVA	59.749	271.6	3-Phase
SUL TR1	Transformer	Overload	25.000	MVA	26.126	104.5	3-Phase
T.Hail<>Gefr 230kV L1	Line	Overload	920.000	Amp	1200.378	130.5	3-Phase
WER TR1	Transformer	Overload	20.000	MVA	39.954	199.8	3-Phase
Wer TR1 15	Bus	Under Voltage	15.000	kV	14.049	93.7	3-Phase
WER TR2	Transformer	Overload	20.000	MVA	39.954	199.8	3-Phase
Wer TR2 15	Bus	Under Voltage	15.000	kV	14.049	93.7	3-Phase

The study is conducted on Addis Ababa region only

Marginal Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Ace TR1 15	Bus	Under Voltage	15.000	kV	14.457	96.4	3-Phase
Ace TR2 15	Bus	Under Voltage	15.000	kV	14.457	96.4	3-Phase
Addis East II 132kV	Bus	Under Voltage	132.000	kV	126.913	96.1	3-Phase
Addis North 132kV	Bus	Under Voltage	132.000	kV	128.151	97.1	3-Phase
Ayat 132kV	Bus	Under Voltage	132.000	kV	127.270	96.4	3-Phase
Cotobie 132kV	Bus	Under Voltage	132.000	kV	127.613	96.7	3-Phase
Gef TR1 15	Bus	Under Voltage	15.000	kV	14.569	97.1	3-Phase
Gef TR1 45	Bus	Under Voltage	45.000	kV	44.049	97.9	3-Phase
GEL ATR3	Transformer	Overload	125.000	MVA	122.390	97.9	3-Phase
GEL ATR4	Transformer	Overload	125.000	MVA	122.390	97.9	3-Phase
GEL ATR5	Transformer	Overload	125.000	MVA	122.390	97.9	3-Phase
Gelan 230kV	Bus	Under Voltage	230.000	kV	223.603	97.2	3-Phase
KAI ATR1	Transformer	Overload	125.000	MVA	122.075	97.7	3-Phase
KAI ATR2	Transformer	Overload	125.000	MVA	122.075	97.7	3-Phase
KAI ATR3	Transformer	Overload	125.000	MVA	122.075	97.7	3-Phase
KalI TR1 15	Bus	Under Voltage	15.000	kV	14.374	95.8	3-Phase
KalI TR1 45	Bus	Under Voltage	45.000	kV	42.932	95.4	3-Phase
KalI TR2 15	Bus	Under Voltage	15.000	kV	14.351	95.7	3-Phase
KalI TR2 45	Bus	Under Voltage	45.000	kV	42.911	95.4	3-Phase
Kaliti GIS 132kV	Bus	Under Voltage	132.000	kV	128.378	97.3	3-Phase
Kaliti I 132kV	Bus	Under Voltage	132.000	kV	129.315	98.0	3-Phase
Kaliti I 230kV	Bus	Under Voltage	230.000	kV	223.327	97.1	3-Phase
Kaliti II 132kV	Bus	Under Voltage	132.000	kV	127.314	96.4	3-Phase
Kaliti North 132kV	Bus	Under Voltage	132.000	kV	128.638	97.5	3-Phase
Legetafo 132kV	Bus	Under Voltage	132.000	kV	127.117	96.3	3-Phase
Nefasilk 132kV	Bus	Under Voltage	132.000	kV	126.602	95.9	3-Phase
SebI TR2 45	Bus	Under Voltage	45.000	kV	43.693	97.1	3-Phase
Sul TR1 15	Bus	Under Voltage	15.000	kV	14.678	97.9	3-Phase
Weregenu 132kV	Bus	Under Voltage	132.000	kV	127.738	96.8	3-Phase
Yesu 132kV	Bus	Under Voltage	132.000	kV	129.252	97.9	3-Phase

The study is conducted on Addis Ababa region only

Alert Summary Report

	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
ACE TR1	Transformer	Overload	31.500	MVA	34.862	110.7	3-Phase
Ace TR1 15	Bus	Under Voltage	15.000	kV	14.195	94.6	3-Phase
ACE TR2	Transformer	Overload	31.500	MVA	34.865	110.7	3-Phase
Ace TR2 15	Bus	Under Voltage	15.000	kV	14.195	94.6	3-Phase
Addis Center 132kV	Bus	Under Voltage	132.000	kV	123.667	93.7	3-Phase
Addis South II 132	Bus	Under Voltage	132.000	kV	118.532	89.8	3-Phase
AEA TR1	Transformer	Overload	25.000	MVA	31.032	124.1	3-Phase
AEA TR2	Transformer	Overload	25.000	MVA	31.032	124.1	3-Phase
ANO TR1	Transformer	Overload	25.000	MVA	29.951	119.8	3-Phase
ANO TR2	Transformer	Overload	25.000	MVA	29.951	119.8	3-Phase
ASO TR1	Transformer	Overload	25.000	MVA	29.940	119.8	3-Phase
Aso TR1 15	Bus	Under Voltage	15.000	kV	13.633	90.9	3-Phase
ASO TR2	Transformer	Overload	25.000	MVA	27.480	109.9	3-Phase
Aso TR2 15	Bus	Under Voltage	15.000	kV	13.740	91.6	3-Phase
Cable28	Cable	Overload	231.928	Amp	353.158	152.3	3-Phase
COT TR1	Transformer	Overload	16.000	MVA	18.058	112.9	3-Phase
Cot TR1 15	Bus	Under Voltage	15.000	kV	13.984	93.2	3-Phase
Cot TR1 45	Bus	Under Voltage	45.000	kV	41.281	91.7	3-Phase
COT TR2	Transformer	Overload	31.500	MVA	35.449	112.5	3-Phase
GEF TR1	Transformer	Overload	25.000	MVA	57.378	229.5	3-Phase
GEF TR2	Transformer	Overload	12.000	MVA	14.497	120.8	3-Phase
GEF TR3	Transformer	Overload	25.000	MVA	31.836	127.3	3-Phase
GEL ATR1	Transformer	Overload	250.000	MVA	429.160	171.7	3-Phase
GEL ATR2	Transformer	Overload	250.000	MVA	429.160	171.7	3-Phase
GEL ATR3	Transformer	Overload	125.000	MVA	125.966	100.8	3-Phase
GEL ATR4	Transformer	Overload	125.000	MVA	125.966	100.8	3-Phase
GEL ATR5	Transformer	Overload	125.000	MVA	125.966	100.8	3-Phase
Gelan <>Kaliti I 132kV L1	Line	Overload	490.000	Amp	595.232	121.5	3-Phase
Gelan <>Kaliti I 132kV L2	Line	Overload	490.000	Amp	595.262	121.5	3-Phase
KAI ATR1	Transformer	Overload	125.000	MVA	125.714	100.6	3-Phase
KAI ATR2	Transformer	Overload	125.000	MVA	125.714	100.6	3-Phase
KAI ATR3	Transformer	Overload	125.000	MVA	125.714	100.6	3-Phase
KalI TR1 15	Bus	Under Voltage	15.000	kV	14.184	94.6	3-Phase
KalI TR1 45	Bus	Under Voltage	45.000	kV	42.348	94.1	3-Phase
KalI TR2 15	Bus	Under Voltage	15.000	kV	14.158	94.4	3-Phase
KalI TR2 45	Bus	Under Voltage	45.000	kV	42.325	94.1	3-Phase

The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Kaliti I <> Mek 132kV L1	Line	Overload	490.000	Amp	562.352	114.8	3-Phase
KII TR1	Transformer	Overload	25.000	MVA	34.695	138.8	3-Phase
KII TR1 15	Bus	Under Voltage	15.000	kV	12.425	82.8	3-Phase
KII TR1 45	Bus	Under Voltage	45.000	kV	40.836	90.7	3-Phase
KII TR2 15	Bus	Under Voltage	15.000	kV	12.372	82.5	3-Phase
KII TR3	Transformer	Overload	20.000	MVA	32.665	163.3	3-Phase
KNO TR1	Transformer	Overload	16.000	MVA	22.498	140.6	3-Phase
KNO TR2	Transformer	Overload	16.000	MVA	22.498	140.6	3-Phase
LEG TR1	Transformer	Overload	20.000	MVA	37.623	188.1	3-Phase
Leg TR1 15	Bus	Under Voltage	15.000	kV	13.915	92.8	3-Phase
LEG TR2	Transformer	Overload	20.000	MVA	38.036	190.2	3-Phase
Leg TR2 15	Bus	Under Voltage	15.000	kV	13.892	92.6	3-Phase
MEK TR1	Transformer	Overload	25.000	MVA	29.380	117.5	3-Phase
Mek TR1 15	Bus	Under Voltage	15.000	kV	13.827	92.2	3-Phase
MEK TR2	Transformer	Overload	25.000	MVA	29.380	117.5	3-Phase
Mek TR2 15	Bus	Under Voltage	15.000	kV	13.827	92.2	3-Phase
Mekanisa 132kV	Bus	Under Voltage	132.000	kV	119.768	90.7	3-Phase
Minilik<>Gef 132kV L1	Line	Overload	490.000	Amp	541.356	110.5	3-Phase
Nefasilk 132kV	Bus	Under Voltage	132.000	kV	124.882	94.6	3-Phase
Seb I<>T.hail 230kV L1	Line	Overload	920.000	Amp	1186.798	129.0	3-Phase
SEBI TR2	Transformer	Overload	12.000	MVA	31.400	261.7	3-Phase
SebI TR1 45	Bus	Over Voltage	33.000	kV	44.657	135.3	3-Phase
SEBI TR3	Transformer	Overload	22.000	MVA	63.022	286.5	3-Phase
SUL TR1	Transformer	Overload	25.000	MVA	28.175	112.7	3-Phase
T.Hail<>Gefr 230kV L1	Line	Overload	920.000	Amp	1167.685	126.9	3-Phase
WER TR1	Transformer	Overload	20.000	MVA	41.287	206.4	3-Phase
Wer TR1 15	Bus	Under Voltage	15.000	kV	13.752	91.7	3-Phase
WER TR2	Transformer	Overload	20.000	MVA	41.287	206.4	3-Phase
Wer TR2 15	Bus	Under Voltage	15.000	kV	13.752	91.7	3-Phase

The study is conducted on Addis Ababa region only

Marginal Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Addis East II 132kV	Bus	Under Voltage	132.000	kV	125.442	95.0	3-Phase
Addis North 132kV	Bus	Under Voltage	132.000	kV	126.808	96.1	3-Phase
Aea TR1 15	Bus	Under Voltage	15.000	kV	14.531	96.9	3-Phase
Aea TR2 15	Bus	Under Voltage	15.000	kV	14.531	96.9	3-Phase
Ayat 132kV	Bus	Under Voltage	132.000	kV	125.905	95.4	3-Phase
Cable45	Cable	Overload	267.609	Amp	265.744	99.3	3-Phase
Cot TR2 15	Bus	Under Voltage	15.000	kV	14.510	96.7	3-Phase
Cotobie 132kV	Bus	Under Voltage	132.000	kV	126.131	95.6	3-Phase
Gef TR1 15	Bus	Under Voltage	15.000	kV	14.431	96.2	3-Phase
Gef TR1 45	Bus	Under Voltage	45.000	kV	43.655	97.0	3-Phase
Gef TR2 15	Bus	Under Voltage	15.000	kV	14.668	97.8	3-Phase
Gelan 132kV	Bus	Under Voltage	132.000	kV	128.333	97.2	3-Phase
Gelan 230kV	Bus	Under Voltage	230.000	kV	222.053	96.5	3-Phase
KAI TR1	Transformer	Overload	7.500	MVA	7.256	96.7	3-Phase
KAI TR2	Transformer	Overload	22.000	MVA	21.271	96.7	3-Phase
Kaliti GIS 132kV	Bus	Under Voltage	132.000	kV	126.784	96.0	3-Phase
Kaliti I 132kV	Bus	Under Voltage	132.000	kV	127.803	96.8	3-Phase
Kaliti I 230kV	Bus	Under Voltage	230.000	kV	221.771	96.4	3-Phase
Kaliti II 132kV	Bus	Under Voltage	132.000	kV	125.651	95.2	3-Phase
Kaliti North 132kV	Bus	Under Voltage	132.000	kV	127.118	96.3	3-Phase
KII TR3 15	Bus	Under Voltage	15.000	kV	14.492	96.6	3-Phase
Kno TR1 15	Bus	Under Voltage	15.000	kV	14.592	97.3	3-Phase
Kno TR2 15	Bus	Under Voltage	15.000	kV	14.592	97.3	3-Phase
Legetafo 132kV	Bus	Under Voltage	132.000	kV	125.912	95.4	3-Phase
Minilk 132kV	Bus	Under Voltage	132.000	kV	128.321	97.2	3-Phase
SebI TR2 45	Bus	Under Voltage	45.000	kV	43.278	96.2	3-Phase
Weregenu 132kV	Bus	Under Voltage	132.000	kV	126.206	95.6	3-Phase
Yesu 132kV	Bus	Under Voltage	132.000	kV	127.733	96.8	3-Phase

The study is conducted on Addis Ababa region only

Alert Summary Report

	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
A.Nor <> Minilk 132kV L1	Line	Overload	510.000	Amp	537.619	105.4	3-Phase
ACE TR1	Transformer	Overload	31.500	MVA	36.208	114.9	3-Phase
Ace TR1 15	Bus	Under Voltage	15.000	kV	13.871	92.5	3-Phase
ACE TR2	Transformer	Overload	31.500	MVA	36.208	114.9	3-Phase
Ace TR2 15	Bus	Under Voltage	15.000	kV	13.871	92.5	3-Phase
Addis Center 132kV	Bus	Under Voltage	132.000	kV	121.724	92.2	3-Phase
Addis East II 132kV	Bus	Under Voltage	132.000	kV	123.935	93.9	3-Phase
Addis South II 132	Bus	Under Voltage	132.000	kV	116.166	88.0	3-Phase
AEA TR1	Transformer	Overload	25.000	MVA	32.624	130.5	3-Phase
AEA TR2	Transformer	Overload	25.000	MVA	32.624	130.5	3-Phase
ANO TR1	Transformer	Overload	25.000	MVA	32.337	129.3	3-Phase
ANO TR2	Transformer	Overload	25.000	MVA	32.337	129.3	3-Phase
ASO TR1	Transformer	Overload	25.000	MVA	31.505	126.0	3-Phase
Aso TR1 15	Bus	Under Voltage	15.000	kV	13.237	88.2	3-Phase
ASO TR2	Transformer	Overload	25.000	MVA	28.770	115.1	3-Phase
Aso TR2 15	Bus	Under Voltage	15.000	kV	13.361	89.1	3-Phase
Ayat 132kV	Bus	Under Voltage	132.000	kV	124.170	94.1	3-Phase
Cable28	Cable	Overload	231.928	Amp	382.545	164.9	3-Phase
Cable45	Cable	Overload	267.609	Amp	292.801	109.4	3-Phase
COT TR1	Transformer	Overload	16.000	MVA	18.168	113.6	3-Phase
Cot TR1 15	Bus	Under Voltage	15.000	kV	13.799	92.0	3-Phase
Cot TR1 45	Bus	Under Voltage	45.000	kV	40.613	90.3	3-Phase
COT TR2	Transformer	Overload	31.500	MVA	37.789	120.0	3-Phase
Cot TR2 15	Bus	Under Voltage	15.000	kV	14.180	94.5	3-Phase
Cotobie 132kV	Bus	Under Voltage	132.000	kV	124.422	94.3	3-Phase
GEF TR1	Transformer	Overload	25.000	MVA	62.929	251.7	3-Phase
GEF TR2	Transformer	Overload	12.000	MVA	15.952	132.9	3-Phase
GEF TR3	Transformer	Overload	25.000	MVA	35.481	141.9	3-Phase
GEL ATR1	Transformer	Overload	250.000	MVA	435.861	174.3	3-Phase
GEL ATR2	Transformer	Overload	250.000	MVA	435.861	174.3	3-Phase
GEL ATR3	Transformer	Overload	125.000	MVA	130.648	104.5	3-Phase
GEL ATR4	Transformer	Overload	125.000	MVA	130.648	104.5	3-Phase
GEL ATR5	Transformer	Overload	125.000	MVA	130.648	104.5	3-Phase
GEL TR1	Transformer	Overload	63.000	MVA	63.036	100.1	3-Phase
Gelan <>Kaliti I 132kV L1	Line	Overload	490.000	Amp	614.951	125.5	3-Phase
Gelan <>Kaliti I 132kV L2	Line	Overload	490.000	Amp	614.983	125.5	3-Phase

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The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
KAI ATR1	Transformer	Overload	125.000	MVA	130.494	104.4	3-Phase
KAI ATR2	Transformer	Overload	125.000	MVA	130.494	104.4	3-Phase
KAI ATR3	Transformer	Overload	125.000	MVA	130.494	104.4	3-Phase
KAI TR2	Transformer	Overload	22.000	MVA	22.801	103.6	3-Phase
KalI TR1 15	Bus	Under Voltage	15.000	kV	13.963	93.1	3-Phase
KalI TR1 45	Bus	Under Voltage	45.000	kV	41.662	92.6	3-Phase
KalI TR2 15	Bus	Under Voltage	15.000	kV	13.933	92.9	3-Phase
KalI TR2 45	Bus	Under Voltage	45.000	kV	41.636	92.5	3-Phase
Kaliti GIS 132kV	Bus	Under Voltage	132.000	kV	124.960	94.7	3-Phase
Kaliti I <> Mek 132kV L1	Line	Overload	490.000	Amp	600.504	122.6	3-Phase
Kaliti II 132kV	Bus	Under Voltage	132.000	kV	123.737	93.7	3-Phase
Kaliti North 132kV	Bus	Under Voltage	132.000	kV	125.389	95.0	3-Phase
KII TR1	Transformer	Overload	25.000	MVA	37.516	150.1	3-Phase
KII TR1 15	Bus	Under Voltage	15.000	kV	12.183	81.2	3-Phase
KII TR1 45	Bus	Under Voltage	45.000	kV	39.999	88.9	3-Phase
KII TR2 15	Bus	Under Voltage	15.000	kV	12.133	80.9	3-Phase
KII TR3	Transformer	Overload	20.000	MVA	34.717	173.6	3-Phase
KII TR3 15	Bus	Under Voltage	15.000	kV	14.144	94.3	3-Phase
KNO TR1	Transformer	Overload	16.000	MVA	23.978	149.9	3-Phase
KNO TR2	Transformer	Overload	16.000	MVA	23.978	149.9	3-Phase
LEG TR1	Transformer	Overload	20.000	MVA	39.939	199.7	3-Phase
Leg TR1 15	Bus	Under Voltage	15.000	kV	13.540	90.3	3-Phase
LEG TR2	Transformer	Overload	20.000	MVA	40.128	200.6	3-Phase
Leg TR2 15	Bus	Under Voltage	15.000	kV	13.529	90.2	3-Phase
Legetafo 132kV	Bus	Under Voltage	132.000	kV	124.224	94.1	3-Phase
MEK TR1	Transformer	Overload	25.000	MVA	30.681	122.7	3-Phase
Mek TR1 15	Bus	Under Voltage	15.000	kV	13.458	89.7	3-Phase
MEK TR2	Transformer	Overload	25.000	MVA	30.681	122.7	3-Phase
Mek TR2 15	Bus	Under Voltage	15.000	kV	13.458	89.7	3-Phase
Mekanisa 132kV	Bus	Under Voltage	132.000	kV	117.493	89.0	3-Phase
Minilik<>Gef 132kV L1	Line	Overload	490.000	Amp	635.119	129.6	3-Phase
Nefasilk 132kV	Bus	Under Voltage	132.000	kV	122.903	93.1	3-Phase
Seb I<>T.hail 230kV L1	Line	Overload	920.000	Amp	1116.846	121.4	3-Phase
SEBI TR2	Transformer	Overload	12.000	MVA	34.846	290.4	3-Phase
SebI TR1 45	Bus	Over Voltage	33.000	kV	44.675	135.4	3-Phase
SEBI TR3	Transformer	Overload	22.000	MVA	68.738	312.4	3-Phase

The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
SUL TR1	Transformer	Overload	25.000	MVA	30.677	122.7	3-Phase
T.Hail<>Gefr 230kV L1	Line	Overload	920.000	Amp	1091.307	118.6	3-Phase
WER TR1	Transformer	Overload	20.000	MVA	43.376	216.9	3-Phase
Wer TR1 15	Bus	Under Voltage	15.000	kV	13.372	89.1	3-Phase
WER TR2	Transformer	Overload	20.000	MVA	43.376	216.9	3-Phase
Wer TR2 15	Bus	Under Voltage	15.000	kV	13.372	89.1	3-Phase
Weregenu 132kV	Bus	Under Voltage	132.000	kV	124.446	94.3	3-Phase

Marginal Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Addis North 132kV	Bus	Under Voltage	132.000	kV	125.799	95.3	3-Phase
Aea TR1 15	Bus	Under Voltage	15.000	kV	14.259	95.1	3-Phase
Aea TR2 15	Bus	Under Voltage	15.000	kV	14.259	95.1	3-Phase
Ano TR1 15	Bus	Under Voltage	15.000	kV	14.526	96.8	3-Phase
Ano TR2 15	Bus	Under Voltage	15.000	kV	14.526	96.8	3-Phase
Cot TR3 33	Bus	Under Voltage	33.000	kV	32.012	97.0	3-Phase
Gef TR1 15	Bus	Under Voltage	15.000	kV	14.373	95.8	3-Phase
Gef TR1 45	Bus	Under Voltage	45.000	kV	43.515	96.7	3-Phase
Gef TR2 15	Bus	Under Voltage	15.000	kV	14.632	97.5	3-Phase
Gelan 132kV	Bus	Under Voltage	132.000	kV	126.646	95.9	3-Phase
Gelan 230kV	Bus	Under Voltage	230.000	kV	220.417	95.8	3-Phase
KAI TR1	Transformer	Overload	22.000	MVA	21.809	99.1	3-Phase
Kaliti I 132kV	Bus	Under Voltage	132.000	kV	126.098	95.5	3-Phase
Kaliti I 230kV	Bus	Under Voltage	230.000	kV	220.133	95.7	3-Phase
Kaliti I<>Seb I 132kV L1	Line	Overload	490.000	Amp	470.664	96.1	3-Phase
Kno TR1 15	Bus	Under Voltage	15.000	kV	14.256	95.0	3-Phase
Kno TR2 15	Bus	Under Voltage	15.000	kV	14.256	95.0	3-Phase
Minilk 132kV	Bus	Under Voltage	132.000	kV	127.601	96.7	3-Phase
Nef TR1 15	Bus	Under Voltage	15.000	kV	14.622	97.5	3-Phase
Nef TR2 15	Bus	Under Voltage	15.000	kV	14.622	97.5	3-Phase
SebI TR2 45	Bus	Under Voltage	45.000	kV	43.119	95.8	3-Phase
Sul TR1 15	Bus	Under Voltage	15.000	kV	14.618	97.5	3-Phase
YES TR1	Transformer	Overload	10.000	MVA	9.991	99.9	3-Phase
YES TR2	Transformer	Overload	10.000	MVA	9.991	99.9	3-Phase
Yesu 132kV	Bus	Under Voltage	132.000	kV	126.018	95.5	3-Phase

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The study is conducted on Addis Ababa region only

Alert Summary Report

	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

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The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
A.Nor <> Minilk 132kV L1	Line	Overload	510.000	Amp	582.745	114.3	3-Phase
ACE TR1	Transformer	Overload	31.500	MVA	36.904	117.2	3-Phase
Ace TR1 15	Bus	Under Voltage	15.000	kV	13.793	92.0	3-Phase
ACE TR2	Transformer	Overload	31.500	MVA	36.904	117.2	3-Phase
Ace TR2 15	Bus	Under Voltage	15.000	kV	13.793	92.0	3-Phase
Addis Center 132kV	Bus	Under Voltage	132.000	kV	121.376	92.0	3-Phase
Addis East II 132kV	Bus	Under Voltage	132.000	kV	123.930	93.9	3-Phase
Addis South II 132	Bus	Under Voltage	132.000	kV	115.679	87.6	3-Phase
AEA TR1	Transformer	Overload	25.000	MVA	33.494	134.0	3-Phase
Aea TR1 15	Bus	Under Voltage	15.000	kV	14.222	94.8	3-Phase
AEA TR2	Transformer	Overload	25.000	MVA	33.494	134.0	3-Phase
Aea TR2 15	Bus	Under Voltage	15.000	kV	14.222	94.8	3-Phase
ANO TR1	Transformer	Overload	25.000	MVA	33.518	134.1	3-Phase
ANO TR2	Transformer	Overload	25.000	MVA	33.518	134.1	3-Phase
ASO TR1	Transformer	Overload	25.000	MVA	32.180	128.7	3-Phase
Aso TR1 15	Bus	Under Voltage	15.000	kV	13.139	87.6	3-Phase
ASO TR2	Transformer	Overload	25.000	MVA	29.194	116.8	3-Phase
Aso TR2 15	Bus	Under Voltage	15.000	kV	13.275	88.5	3-Phase
Ayat 132kV	Bus	Under Voltage	132.000	kV	124.018	94.0	3-Phase
Cable28	Cable	Overload	231.928	Amp	393.588	169.7	3-Phase
Cable45	Cable	Overload	267.609	Amp	302.603	113.1	3-Phase
COT TR1	Transformer	Overload	16.000	MVA	18.688	116.8	3-Phase
Cot TR1 15	Bus	Under Voltage	15.000	kV	13.768	91.8	3-Phase
Cot TR1 45	Bus	Under Voltage	45.000	kV	40.497	90.0	3-Phase
COT TR2	Transformer	Overload	31.500	MVA	38.809	123.2	3-Phase
Cot TR2 15	Bus	Under Voltage	15.000	kV	14.112	94.1	3-Phase
Cotobie 132kV	Bus	Under Voltage	132.000	kV	124.240	94.1	3-Phase
GEF TR1	Transformer	Overload	25.000	MVA	65.245	261.0	3-Phase
GEF TR2	Transformer	Overload	12.000	MVA	16.694	139.1	3-Phase
GEF TR3	Transformer	Overload	25.000	MVA	36.455	145.8	3-Phase
GEL ATR1	Transformer	Overload	250.000	MVA	435.696	174.3	3-Phase
GEL ATR2	Transformer	Overload	250.000	MVA	435.696	174.3	3-Phase
GEL ATR3	Transformer	Overload	125.000	MVA	131.751	105.4	3-Phase
GEL ATR4	Transformer	Overload	125.000	MVA	131.751	105.4	3-Phase
GEL ATR5	Transformer	Overload	125.000	MVA	131.751	105.4	3-Phase
GEL TR1	Transformer	Overload	63.000	MVA	64.856	102.9	3-Phase

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Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Gelan <>Kaliti I 132kV L1	Line	Overload	490.000	Amp	617.215	126.0	3-Phase
Gelan <>Kaliti I 132kV L2	Line	Overload	490.000	Amp	617.247	126.0	3-Phase
KAI ATR1	Transformer	Overload	125.000	MVA	131.629	105.3	3-Phase
KAI ATR2	Transformer	Overload	125.000	MVA	131.629	105.3	3-Phase
KAI ATR3	Transformer	Overload	125.000	MVA	131.629	105.3	3-Phase
KAI TR1	Transformer	Overload	22.000	MVA	22.389	101.8	3-Phase
KAI TR2	Transformer	Overload	22.000	MVA	23.436	106.5	3-Phase
KalI TR1 15	Bus	Under Voltage	15.000	kV	13.924	92.8	3-Phase
KalI TR1 45	Bus	Under Voltage	45.000	kV	41.539	92.3	3-Phase
KalI TR2 15	Bus	Under Voltage	15.000	kV	13.893	92.6	3-Phase
KalI TR2 45	Bus	Under Voltage	45.000	kV	41.511	92.2	3-Phase
Kaliti GIS 132kV	Bus	Under Voltage	132.000	kV	124.673	94.4	3-Phase
Kaliti I <> Mek 132kV L1	Line	Overload	490.000	Amp	614.541	125.4	3-Phase
Kaliti II 132kV	Bus	Under Voltage	132.000	kV	123.416	93.5	3-Phase
Kaliti North 132kV	Bus	Under Voltage	132.000	kV	125.150	94.8	3-Phase
KII TR1	Transformer	Overload	25.000	MVA	38.619	154.5	3-Phase
KII TR1 15	Bus	Under Voltage	15.000	kV	12.134	80.9	3-Phase
KII TR1 45	Bus	Under Voltage	45.000	kV	39.821	88.5	3-Phase
KII TR2 15	Bus	Under Voltage	15.000	kV	12.083	80.6	3-Phase
KII TR3	Transformer	Overload	20.000	MVA	35.579	177.9	3-Phase
KII TR3 15	Bus	Under Voltage	15.000	kV	14.063	93.8	3-Phase
KNO TR1	Transformer	Overload	16.000	MVA	24.602	153.8	3-Phase
Kno TR1 15	Bus	Under Voltage	15.000	kV	14.181	94.5	3-Phase
KNO TR2	Transformer	Overload	16.000	MVA	24.602	153.8	3-Phase
Kno TR2 15	Bus	Under Voltage	15.000	kV	14.181	94.5	3-Phase
LEG TR1	Transformer	Overload	20.000	MVA	41.006	205.0	3-Phase
Leg TR1 15	Bus	Under Voltage	15.000	kV	13.463	89.8	3-Phase
LEG TR2	Transformer	Overload	20.000	MVA	41.150	205.7	3-Phase
Leg TR2 15	Bus	Under Voltage	15.000	kV	13.455	89.7	3-Phase
Legetafo 132kV	Bus	Under Voltage	132.000	kV	124.122	94.0	3-Phase
MEK TR1	Transformer	Overload	25.000	MVA	31.301	125.2	3-Phase
Mek TR1 15	Bus	Under Voltage	15.000	kV	13.367	89.1	3-Phase
MEK TR2	Transformer	Overload	25.000	MVA	31.301	125.2	3-Phase
Mek TR2 15	Bus	Under Voltage	15.000	kV	13.367	89.1	3-Phase
Mekanisa 132kV	Bus	Under Voltage	132.000	kV	117.037	88.7	3-Phase
Minilik<>Gef 132kV L1	Line	Overload	490.000	Amp	687.041	140.2	3-Phase

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The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Nefasilk 132kV	Bus	Under Voltage	132.000	kV	122.557	92.8	3-Phase
Seb I<>T.hail 230kV L1	Line	Overload	920.000	Amp	1081.593	117.6	3-Phase
SEBI TR2	Transformer	Overload	12.000	MVA	35.822	298.5	3-Phase
SebI TR1 45	Bus	Over Voltage	33.000	kV	44.728	135.5	3-Phase
SEBI TR3	Transformer	Overload	22.000	MVA	70.482	320.4	3-Phase
SUL TR1	Transformer	Overload	25.000	MVA	31.408	125.6	3-Phase
T.Hail<>Gefr 230kV L1	Line	Overload	920.000	Amp	1052.757	114.4	3-Phase
WER TR1	Transformer	Overload	20.000	MVA	44.330	221.6	3-Phase
Wer TR1 15	Bus	Under Voltage	15.000	kV	13.281	88.5	3-Phase
WER TR2	Transformer	Overload	20.000	MVA	44.330	221.6	3-Phase
Wer TR2 15	Bus	Under Voltage	15.000	kV	13.281	88.5	3-Phase
Weregenu 132kV	Bus	Under Voltage	132.000	kV	124.211	94.1	3-Phase
YES TR1	Transformer	Overload	10.000	MVA	10.121	101.2	3-Phase
YES TR2	Transformer	Overload	10.000	MVA	10.121	101.2	3-Phase

Marginal Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Addis North 132kV	Bus	Under Voltage	132.000	kV	126.164	95.6	3-Phase
Ano TR1 15	Bus	Under Voltage	15.000	kV	14.528	96.9	3-Phase
Ano TR2 15	Bus	Under Voltage	15.000	kV	14.528	96.9	3-Phase
Cable20	Cable	Overload	308.469	Amp	294.548	95.5	3-Phase
Cot TR3 33	Bus	Under Voltage	33.000	kV	31.922	96.7	3-Phase
Gef TR1 15	Bus	Under Voltage	15.000	kV	14.461	96.4	3-Phase
Gef TR1 45	Bus	Under Voltage	45.000	kV	43.787	97.3	3-Phase
Gel Tr1 15	Bus	Under Voltage	15.000	kV	14.666	97.8	3-Phase
Gelan 132kV	Bus	Under Voltage	132.000	kV	126.401	95.8	3-Phase
Gelan 230kV	Bus	Under Voltage	230.000	kV	220.196	95.7	3-Phase
Kaliti I 132kV	Bus	Under Voltage	132.000	kV	125.851	95.3	3-Phase
Kaliti I 230kV	Bus	Under Voltage	230.000	kV	219.914	95.6	3-Phase
Kaliti I<>Seb I 132kV L1	Line	Overload	490.000	Amp	478.146	97.6	3-Phase
Minilk 132kV	Bus	Under Voltage	132.000	kV	128.150	97.1	3-Phase
Nef TR1 15	Bus	Under Voltage	15.000	kV	14.556	97.0	3-Phase
Nef TR2 15	Bus	Under Voltage	15.000	kV	14.556	97.0	3-Phase
SebI TR2 45	Bus	Under Voltage	45.000	kV	43.120	95.8	3-Phase
Sul TR1 15	Bus	Under Voltage	15.000	kV	14.615	97.4	3-Phase
Yesu 132kV	Bus	Under Voltage	132.000	kV	125.770	95.3	3-Phase

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Filename:	LoadForecast		Config.:	Normal

The study is conducted on Addis Ababa region only

Alert Summary Report

% Alert Settings

	Critical	Marginal
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
A.Nor <> Minilk 132kV L1	Line	Overload	510.000	Amp	632.355	124.0	3-Phase
ACE TR1	Transformer	Overload	31.500	MVA	37.693	119.7	3-Phase
Ace TR1 15	Bus	Under Voltage	15.000	kV	13.576	90.5	3-Phase
ACE TR2	Transformer	Overload	31.500	MVA	37.693	119.7	3-Phase
Ace TR2 15	Bus	Under Voltage	15.000	kV	13.576	90.5	3-Phase
Addis Center 132kV	Bus	Under Voltage	132.000	kV	120.066	91.0	3-Phase
Addis East II 132kV	Bus	Under Voltage	132.000	kV	122.881	93.1	3-Phase
Addis South II 132	Bus	Under Voltage	132.000	kV	114.179	86.5	3-Phase
AEA TR1	Transformer	Overload	25.000	MVA	34.461	137.8	3-Phase
Aea TR1 15	Bus	Under Voltage	15.000	kV	14.036	93.6	3-Phase
AEA TR2	Transformer	Overload	25.000	MVA	34.461	137.8	3-Phase
Aea TR2 15	Bus	Under Voltage	15.000	kV	14.036	93.6	3-Phase
ANO TR1	Transformer	Overload	25.000	MVA	34.855	139.4	3-Phase
ANO TR2	Transformer	Overload	25.000	MVA	34.855	139.4	3-Phase
ASO TR1	Transformer	Overload	25.000	MVA	32.932	131.7	3-Phase
Aso TR1 15	Bus	Under Voltage	15.000	kV	12.894	86.0	3-Phase
ASO TR2	Transformer	Overload	25.000	MVA	29.451	117.8	3-Phase
Aso TR2 15	Bus	Under Voltage	15.000	kV	13.056	87.0	3-Phase
Ayat 132kV	Bus	Under Voltage	132.000	kV	122.718	93.0	3-Phase
Cable20	Cable	Overload	308.469	Amp	311.802	101.1	3-Phase
Cable28	Cable	Overload	231.928	Amp	410.228	176.9	3-Phase
Cable45	Cable	Overload	267.609	Amp	318.655	119.1	3-Phase
COT TR1	Transformer	Overload	16.000	MVA	19.586	122.4	3-Phase
Cot TR1 15	Bus	Under Voltage	15.000	kV	13.605	90.7	3-Phase
Cot TR1 45	Bus	Under Voltage	45.000	kV	39.994	88.9	3-Phase
COT TR2	Transformer	Overload	31.500	MVA	39.978	126.9	3-Phase
Cot TR2 15	Bus	Under Voltage	15.000	kV	13.895	92.6	3-Phase
Cotobie 132kV	Bus	Under Voltage	132.000	kV	123.036	93.2	3-Phase
GEF TR1	Transformer	Overload	25.000	MVA	67.234	268.9	3-Phase
GEF TR2	Transformer	Overload	12.000	MVA	17.574	146.4	3-Phase
GEF TR3	Transformer	Overload	25.000	MVA	38.924	155.7	3-Phase
GEL ATR1	Transformer	Overload	250.000	MVA	441.447	176.6	3-Phase
GEL ATR2	Transformer	Overload	250.000	MVA	441.447	176.6	3-Phase
GEL ATR3	Transformer	Overload	125.000	MVA	134.346	107.5	3-Phase
GEL ATR4	Transformer	Overload	125.000	MVA	134.346	107.5	3-Phase
GEL ATR5	Transformer	Overload	125.000	MVA	134.346	107.5	3-Phase

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Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
GEL TR1	Transformer	Overload	63.000	MVA	67.159	106.6	3-Phase
Gelan <>Kaliti I 132kV L1	Line	Overload	490.000	Amp	631.245	128.8	3-Phase
Gelan <>Kaliti I 132kV L2	Line	Overload	490.000	Amp	631.278	128.8	3-Phase
Gelan 132kV	Bus	Under Voltage	132.000	kV	125.257	94.9	3-Phase
KAI ATR1	Transformer	Overload	125.000	MVA	134.274	107.4	3-Phase
KAI ATR2	Transformer	Overload	125.000	MVA	134.274	107.4	3-Phase
KAI ATR3	Transformer	Overload	125.000	MVA	134.274	107.4	3-Phase
KAI TR1	Transformer	Overload	22.000	MVA	23.111	105.1	3-Phase
KAI TR2	Transformer	Overload	22.000	MVA	24.242	110.2	3-Phase
KalI TR1 15	Bus	Under Voltage	15.000	kV	13.777	91.8	3-Phase
KalI TR1 45	Bus	Under Voltage	45.000	kV	41.086	91.3	3-Phase
KalI TR2 15	Bus	Under Voltage	15.000	kV	13.743	91.6	3-Phase
KalI TR2 45	Bus	Under Voltage	45.000	kV	41.055	91.2	3-Phase
Kaliti GIS 132kV	Bus	Under Voltage	132.000	kV	123.453	93.5	3-Phase
Kaliti I <> Mek 132kV L1	Line	Overload	490.000	Amp	634.531	129.5	3-Phase
Kaliti I 132kV	Bus	Under Voltage	132.000	kV	124.694	94.5	3-Phase
Kaliti I<>Seb I 132kV L1	Line	Overload	490.000	Amp	501.476	102.3	3-Phase
Kaliti II 132kV	Bus	Under Voltage	132.000	kV	122.144	92.5	3-Phase
Kaliti North 132kV	Bus	Under Voltage	132.000	kV	123.968	93.9	3-Phase
KII TR1	Transformer	Overload	25.000	MVA	40.004	160.0	3-Phase
KII TR1 15	Bus	Under Voltage	15.000	kV	11.980	79.9	3-Phase
KII TR1 45	Bus	Under Voltage	45.000	kV	39.286	87.3	3-Phase
KII TR2 15	Bus	Under Voltage	15.000	kV	11.928	79.5	3-Phase
KII TR3	Transformer	Overload	20.000	MVA	36.613	183.1	3-Phase
KII TR3 15	Bus	Under Voltage	15.000	kV	13.841	92.3	3-Phase
KNO TR1	Transformer	Overload	16.000	MVA	25.353	158.5	3-Phase
Kno TR1 15	Bus	Under Voltage	15.000	kV	13.965	93.1	3-Phase
KNO TR2	Transformer	Overload	16.000	MVA	25.353	158.5	3-Phase
Kno TR2 15	Bus	Under Voltage	15.000	kV	13.965	93.1	3-Phase
LEG TR1	Transformer	Overload	20.000	MVA	42.017	210.1	3-Phase
Leg TR1 15	Bus	Under Voltage	15.000	kV	13.203	88.0	3-Phase
LEG TR2	Transformer	Overload	20.000	MVA	42.103	210.5	3-Phase
Leg TR2 15	Bus	Under Voltage	15.000	kV	13.198	88.0	3-Phase
Legetafo 132kV	Bus	Under Voltage	132.000	kV	122.761	93.0	3-Phase
MEK TR1	Transformer	Overload	25.000	MVA	31.999	128.0	3-Phase
Mek TR1 15	Bus	Under Voltage	15.000	kV	13.133	87.6	3-Phase

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The study is conducted on Addis Ababa region only

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
MEK TR2	Transformer	Overload	25.000	MVA	31.999	128.0	3-Phase
Mek TR2 15	Bus	Under Voltage	15.000	kV	13.133	87.6	3-Phase
Mekanisa 132kV	Bus	Under Voltage	132.000	kV	115.580	87.6	3-Phase
Minilik<>Gef 132kV L1	Line	Overload	490.000	Amp	746.288	152.3	3-Phase
Nefasilk 132kV	Bus	Under Voltage	132.000	kV	121.248	91.9	3-Phase
Seb I<>T.hail 230kV L1	Line	Overload	920.000	Amp	1054.442	114.6	3-Phase
SEBI TR2	Transformer	Overload	12.000	MVA	37.950	316.2	3-Phase
SebI TR1 45	Bus	Over Voltage	33.000	kV	44.690	135.4	3-Phase
SEBI TR3	Transformer	Overload	22.000	MVA	74.339	337.9	3-Phase
SUL TR1	Transformer	Overload	25.000	MVA	32.726	130.9	3-Phase
T.Hail<>Gefr 230kV L1	Line	Overload	920.000	Amp	1023.043	111.2	3-Phase
WER TR1	Transformer	Overload	20.000	MVA	45.366	226.8	3-Phase
Wer TR1 15	Bus	Under Voltage	15.000	kV	13.037	86.9	3-Phase
WER TR2	Transformer	Overload	20.000	MVA	45.366	226.8	3-Phase
Wer TR2 15	Bus	Under Voltage	15.000	kV	13.037	86.9	3-Phase
Weregenu 132kV	Bus	Under Voltage	132.000	kV	123.001	93.2	3-Phase
YES TR1	Transformer	Overload	10.000	MVA	10.071	100.7	3-Phase
YES TR2	Transformer	Overload	10.000	MVA	10.071	100.7	3-Phase
Yesu 132kV	Bus	Under Voltage	132.000	kV	124.613	94.4	3-Phase

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Marginal Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Addis North 132kV	Bus	Under Voltage	132.000	kV	125.477	95.1	3-Phase
Ano TR1 15	Bus	Under Voltage	15.000	kV	14.378	95.9	3-Phase
Ano TR2 15	Bus	Under Voltage	15.000	kV	14.378	95.9	3-Phase
Cable16	Cable	Overload	267.609	Amp	264.357	98.8	3-Phase
Cot TR3 33	Bus	Under Voltage	33.000	kV	31.539	95.6	3-Phase
Gef TR1 15	Bus	Under Voltage	15.000	kV	14.436	96.2	3-Phase
Gef TR1 45	Bus	Under Voltage	45.000	kV	43.712	97.1	3-Phase
Gef TR2 15	Bus	Under Voltage	15.000	kV	14.698	98.0	3-Phase
Gefersa 230kV	Bus	Under Voltage	230.000	kV	225.060	97.9	3-Phase
Gel Tr1 15	Bus	Under Voltage	15.000	kV	14.465	96.4	3-Phase
Gelan 230kV	Bus	Under Voltage	230.000	kV	219.052	95.2	3-Phase
Kaliti I <> KGIS 132kV L1	Line	Overload	490.000	Amp	473.723	96.7	3-Phase
Kaliti I 230kV	Bus	Under Voltage	230.000	kV	218.766	95.1	3-Phase
Legetafo 230kV	Bus	Under Voltage	230.000	kV	225.176	97.9	3-Phase
Minilk 132kV	Bus	Under Voltage	132.000	kV	127.660	96.7	3-Phase
Nef TR1 15	Bus	Under Voltage	15.000	kV	14.357	95.7	3-Phase
Nef TR2 15	Bus	Under Voltage	15.000	kV	14.357	95.7	3-Phase
SebI TR2 45	Bus	Under Voltage	45.000	kV	42.979	95.5	3-Phase
Sul TR1 15	Bus	Under Voltage	15.000	kV	14.667	97.8	3-Phase
T.Hailoch 230kV	Bus	Under Voltage	230.000	kV	225.394	98.0	3-Phase

Appendix B - TL, TR and capacitor addition techniques and results

	Overloaded TLs				
	2018	2019	2020	2021	2022
	Gelan <>Kaliti I 132kV L1	Gelan <>Kaliti I 132kV L1	A.Nor <> Minilk 132kV L1	A.Nor <> Minilk 132kV L1	A.Nor <> Minilk 132kV L1
	Gelan <>Kaliti I 132kV L2	Gelan <>Kaliti I 132kV L2	Gelan <>Kaliti I 132kV L1	Gelan <>Kaliti I 132kV L1	Gelan <>Kaliti I 132kV L1
	Kaliti I <> Mek 132kV L1	Kaliti I <> Mek 132kV L1	Gelan <>Kaliti I 132kV L2	Gelan <>Kaliti I 132kV L2	Gelan <>Kaliti I 132kV L2
	Minilik<>Gef 132kV L1	Minilik<>Gef 132kV L1	Kaliti I <> Mek 132kV L1	Kaliti I <> Mek 132kV L1	Kaliti I <> KGIS 132kV L1
	Seb I<>T.hail 230kV L1	Seb I<>T.hail 230kV L1	Kaliti I<>Seb I 132kV L1	Kaliti I<>Seb I 132kV L1	Kaliti I <> Mek 132kV L1
	T.Hail<>Gefr 230kV L1	T.Hail<>Gefr 230kV L1	Minilik<>Gef 132kV L1	Minilik<>Gef 132kV L1	Kaliti I<>Seb I 132kV L1
			Seb I<>T.hail 230kV L1	Seb I<>T.hail 230kV L1	Minilik<>Gef 132kV L1
			T.Hail<>Gefr 230kV L1	T.Hail<>Gefr 230kV L1	Seb I<>T.hail 230kV L1
					T.Hail<>Gefr 230kV L1
Total	6	6	8	8	9

No. of trans. Lines needed considering 80% loading in each overloaded trans. Lines

	Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	2018				
	Gelan <>Kaliti I 132kV L1	Line	Overload	490	Amp	581.0223	118.576	1				
	Gelan <>Kaliti I 132kV L2	Line	Overload	490	Amp	581.0524	118.5821	1				
2018	Kaliti I <> Mek 132kV L1	Line	Overload	490	Amp	535.7721	109.3412	1				
	Minilik<>Gef 132kV L1	Line	Overload	490	Amp	471.7155	96.26846	1				
	Seb I<>T.hail 230kV L1	Line	Overload	920	Amp	1229.534	133.6451	2				
	T.Hail<>Gefr 230kV L1	Line	Overload	920	Amp	1213.752	131.9295	2				

	Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	2019	2018			
	Gelan <>Kaliti I 132kV L1	Line	Overload	490	Amp	592.7432	120.968	2	1			
	Gelan <>Kaliti I 132kV L2	Line	Overload	490	Amp	592.7739	120.9743	2	1			
2019	Kaliti I <> Mek 132kV L1	Line	Overload	490	Amp	563.4532	114.9905	1	1			
	Minilik<>Gef 132kV L1	Line	Overload	490	Amp	546.4587	111.5222	1	1			
	Seb I<>T.hail 230kV L1	Line	Overload	920	Amp	1170.863	127.2677	2	2			
	T.Hail<>Gefr 230kV L1	Line	Overload	920	Amp	1151.084	125.1178	2	2			

	Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	2020	2019	2018		
	A.Nor <> Minilk 132kV L1	Line	Overload	510	Amp	567.2645	111.2283	1				
	Gelan <>Kaliti I 132kV L1	Line	Overload	490	Amp	609.7403	124.4368	2	2	1		
	Gelan <>Kaliti I 132kV L2	Line	Overload	490	Amp	609.7719	124.4432	2	2	1		
2020	Kaliti I <> Mek 132kV L1	Line	Overload	490	Amp	602.2601	122.9102	2	1	1		
	Minilik<>Gef 132kV L1	Line	Overload	490	Amp	663.806	135.4706	2	1	1		
	Seb I<>T.hail 230kV L1	Line	Overload	920	Amp	1100.899	119.6629	1	2	2		
	T.Hail<>Gefr 230kV L1	Line	Overload	920	Amp	1074.623	116.8068	1	2	2		
	Kaliti I<>Seb I 132kV L1	Line	Overload	490	Amp	469.2478	95.76485	1				

	Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	2021	2020	2019	2018	
	A.Nor <> Minilk 132kV L1	Line	Overload	510	Amp	582.0261	114.1228	1	1			
	Gelan <>Kaliti I 132kV L1	Line	Overload	490	Amp	620.1507	126.5614	2	2	2	1	
	Gelan <>Kaliti I 132kV L2	Line	Overload	490	Amp	620.1829	126.5679	2	2	2	1	
2021	Kaliti I <> Mek 132kV L1	Line	Overload	490	Amp	613.9575	125.2974	2	2	1	1	
	Kaliti I<>Seb I 132kV L1	Line	Overload	490	Amp	489.8118	99.96159	1	2	1	1	
	Minilik<>Gef 132kV L1	Line	Overload	490	Amp	686.1547	140.0316	2	1	2	2	
	Seb I<>T.hail 230kV L1	Line	Overload	920	Amp	1083.984	117.8243	1	1	2	2	
	T.Hail<>Gefr 230kV L1	Line	Overload	920	Amp	1056.054	114.7885	1	1			

	Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	2022	2021	2020	2019	2018
	A.Nor <> Minilk 132kV L1	Line	Overload	510	Amp	632.2045	123.9617	2	1	1		
	Gelan <>Kaliti I 132kV L1	Line	Overload	490	Amp	634.4145	129.4724	2	2	2	2	1
	Gelan <>Kaliti I 132kV L2	Line	Overload	490	Amp	634.4474	129.4791	2	2	2	2	1
2022	Kaliti I <> KGIS 132kV L1	Line	Overload	490	Amp	474.6779	96.87303	1				
	Kaliti I <> Mek 132kV L1	Line	Overload	490	Amp	633.8679	129.3608	2	2	2	1	1
	Kaliti I<>Seb I 132kV L1	Line	Overload	490	Amp	517.7225	105.6576	1	1	2	1	1
	Minilik<>Gef 132kV L1	Line	Overload	490	Amp	745.9384	152.2323	2	2	1	2	2
	Seb I<>T.hail 230kV L1	Line	Overload	920	Amp	1056.867	114.8768	1	1	1	2	2
	T.Hail<>Gefr 230kV L1	Line	Overload	920	Amp	1026.448	111.5704	1	1	1		

Device ID	Type	Condition	Rating/Limit	Unit	% Operating					Analysis
					2022	2021	2020	2019	2018	
A.Nor <> Minilk 132kV L1	Line	Overload	510	Amp	123.9617	114.1228	111.2283	0	0	transmission line for Gefersa Addis North could solve this problem
Gelan <>Kaliti I 132kV L1	Line	Overload	490	Amp	129.4724	126.5614	124.4368	120.968	118.576	one additional transmission line with operation optimization could solve the problem
Gelan <>Kaliti I 132kV L2	Line	Overload	490	Amp	129.4791	126.5679	124.4432	120.9743	118.5821	
Kaliti I <> KGIS 132kV L1	Line	Overload	490	Amp	96.87303	0	0	0	0	One addistional transmission line from kaliti 1 to kaliti II the problem will be solved
Kaliti I <> Mek 132kV L1	Line	Overload	490	Amp	129.3608	125.2974	122.9102	114.9905	109.3412	One transmission line could solve the problem
Kaliti I<>Seb I 132kV L1	Line	Overload	490	Amp	105.6576	99.96159	135.4706	111.5222	96.26846	one transmiison line could solve the problem
Minilik<>Gef 132kV L1	Line	Overload	490	Amp	152.2323	140.0316	119.6629	127.2677	133.6451	transmission line for Gefersa Addis North could solve this problem
Seb I<>T.hail 230kV L1	Line	Overload	920	Amp	114.8768	117.8243	116.8068	125.1178	131.9295	alterate rout for sebeta I to gefersa could solve the problem
T.Hail<>Gefr 230kV L1	Line	Overload	920	Amp	111.5704	114.7885	95.76485	0	0	

Year	overloaded Line	Action summary	Comment
2018	A.Nor <> Minilk 132kV L1	Alternate transmission line for Gefersa Addis North can solve this two transmission overloaded problem	Addis North <> Minilik becom overloaded @2020 and Minilik Gefersa will be overloaded @2018 so the action should be taken early.
	Minilik<>Gef 132kV L1		
	Gelan <>Kaliti I 132kV L1	One additional transmission line can solve the problem	Gelan<>Kaliti I transmision line is saturating because of the third auto transformer 230/132kV if this down the overload will be cleared and Auto
	Gelan <>Kaliti I 132kV L2		
	Kaliti I <> Mek 132kV L1	One additional transmission line can solve the problem	
	Kaliti I<>Seb I 132kV L1	One additional transmission line can solve the problem	
	Seb I<>T.hail 230kV L1	Alternate transmission line for Sebeta I to Gefersa can solve this two transmission overloaded problem	Seb I <> T.Hail becom overloaded @2020 and T.Hail<>Geferssa will be overloaded @2018 so the action should be taken early.
	T.Hail<>Gefr 230kV L1		
2022	Kaliti I <> KGIS 132kV L1	Alternate transmission line for Kaliti I <> Kaliti II can solve this transmission overloaded problem	

6 Transmission line addition to the network is enough to handle the future 5 years Forecasted load they are the following and the simultion result will be attached

	Additional Transmission Line	Rate	Ampacity	Year to impliment
1	Gefersa <> Addis North	132kV	510A	2018
2	Gelan <> Kaliti I	132kV	490A	
3	Kaliti I <> Mekanisa	132kV	490A	
4	Kaliti I <> Sebeta I	132kV	490A	
5	Sebeta I <> Gefersa	230kV	920A	
6	Kaliti I <> Kaliti II	132kV	490A	2022

Expecgted further works are: Transmission line design, substation equipment selection, protection and control equipment selection, and implimentation.

Remark: After all the expansion (transformer selection and addition, capacitor placement, and transmision line expanssion) the simulation result shows one overloaded line. For @2022 forecast result.that is because during the first simultaion without any expansion and remedial actions evenif the loading is good the power was not deleivered properly. the reason is under voltage. when the under voltage problem is resolved then the loading is coming in to question. Thank to the simulation software, it helps to see and resolve problems even after we thought things are all done and good to go. so accordingly on candidate line is available this time which is KalitiI<>Wer 132kV TL

7	Kaliti I<>Weregenu 132kV	132kV

Second option as a solution can be upgrading kaliti substation to 400kV and making the overloaded TLs from Kaliti I 230kV lines. Suggestion for next sudy

Overloaded TRs					
	2018	2019	2020	2021	2022
	ACE TR1	ACE TR1	ACE TR1	ACE TR1	ACE TR1
	ACE TR2	ACE TR2	ACE TR2	ACE TR2	ACE TR2
	AEA TR1	AEA TR1	AEA TR1	AEA TR1	AEA TR1
	AEA TR2	AEA TR2	AEA TR2	AEA TR2	AEA TR2
	ANO TR1	ANO TR1	ANO TR1	ANO TR1	ANO TR1
	ANO TR2	ANO TR2	ANO TR2	ANO TR2	ANO TR2
	ASO TR1	ASO TR1	ASO TR1	ASO TR1	ASO TR1
	ASO TR2	ASO TR2	ASO TR2	ASO TR2	ASO TR2
	COT TR1	COT TR1	COT TR1	COT TR1	COT TR1
	COT TR2	COT TR2	COT TR2	COT TR2	COT TR2
	GEF TR1	GEF TR1	GEF TR1	GEF TR1	GEF TR1
	GEF TR2	GEF TR2	GEF TR2	GEF TR2	GEF TR2
	GEF TR3	GEF TR3	GEF TR3	GEF TR3	GEF TR3
	GEL ATR1	GEL ATR1	GEL ATR1	GEL ATR1	GEL ATR1
	GEL ATR2	GEL ATR2	GEL ATR2	GEL ATR2	GEL ATR2
	GEL ATR3	GEL ATR3	GEL ATR3	GEL ATR3	GEL ATR3
	GEL ATR4	GEL ATR4	GEL ATR4	GEL ATR4	GEL ATR4
	GEL ATR5	GEL ATR5	GEL ATR5	GEL ATR5	GEL ATR5
	KAI ATR1	KAI ATR1	GEL TR1	GEL TR1	GEL TR1
	KAI ATR2	KAI ATR2	KAI ATR1	KAI ATR1	KAI ATR1
	KAI ATR3	KAI ATR3	KAI ATR2	KAI ATR2	KAI ATR2
	KAI TR2	KAI TR1	KAI ATR3	KAI ATR3	KAI ATR3
	KII TR1	KAI TR2	KAI TR1	KAI TR1	KAI TR1
	KII TR3	KII TR1	KAI TR2	KAI TR2	KAI TR2
	KNO TR1	KII TR3	KII TR1	KII TR1	KII TR1
	KNO TR2	KNO TR1	KII TR3	KII TR3	KII TR3
	LEG TR1	KNO TR2	KNO TR1	KNO TR1	KNO TR1
	LEG TR2	LEG TR1	KNO TR2	KNO TR2	KNO TR2
	MEK TR1	LEG TR2	LEG TR1	LEG TR1	LEG TR1
	MEK TR2	MEK TR1	LEG TR2	LEG TR2	LEG TR2
	SEBI TR2	MEK TR2	MEK TR1	MEK TR1	MEK TR1
	SEBI TR3	SEBI TR2	MEK TR2	MEK TR2	MEK TR2
	SUL TR1	SEBI TR3	SEBI TR2	SEBI TR2	SEBI TR2
	WER TR1	SUL TR1	SEBI TR3	SEBI TR3	SEBI TR3
	WER TR2	WER TR1	SUL TR1	SUL TR1	SUL TR1
		WER TR2	WER TR1	WER TR1	WER TR1
			WER TR2	WER TR2	WER TR2
			YES TR1	YES TR1	YES TR1
			YES TR2	YES TR2	YES TR2
Total	35	36	39	39	39

Device ID	Type	Condition	Rating	Unit	2022		2021		2020		2019		2018	
					Operating (MW)	% Operating	Operating	% Operating	Operating	% Operating	Operating	% Operating	Operatin g	% Operating
ACE TR1	Transformer	Overload	31.5	MVA	37.61391	119.4092	36.83403	116.9334	36.41998	115.619	34.99889	111.1076	33.90451	107.6334
ACE TR2	Transformer	Overload	31.5	MVA	37.61391	119.4092	36.83403	116.9334	36.41998	115.619	35.0012	111.1149	33.90659	107.64
AEA TR1	Transformer	Overload	25	MVA	34.33395	137.3358	33.37671	133.5068	32.93881	131.7552	31.17309	124.6924	29.90469	119.6188
AEA TR2	Transformer	Overload	25	MVA	34.33395	137.3358	33.37671	133.5068	32.93881	131.7552	31.17309	124.6924	29.90469	119.6188
ANO TR1	Transformer	Overload	25	MVA	34.73553	138.9421	33.40638	133.6255	32.79976	131.199	30.10673	120.4269	28.25919	113.0368
ANO TR2	Transformer	Overload	25	MVA	34.73553	138.9421	33.40638	133.6255	32.79976	131.199	30.10673	120.4269	28.25919	113.0368
ASO TR1	Transformer	Overload	25	MVA	32.86299	131.452	32.11924	128.477	31.68973	126.7589	30.05752	120.2301	28.79772	115.1909
ASO TR2	Transformer	Overload	25	MVA	29.38905	117.5562	29.13825	116.553	28.9384	115.7536	27.58804	110.3522	26.56797	106.2719
COT TR1	Transformer	Overload	16	MVA	19.51073	121.942	18.62056	116.3785	18.29197	114.3248	18.13305	113.3316	17.93005	112.0628
COT TR2	Transformer	Overload	31.5	MVA	39.82391	126.4251	38.66996	122.7618	38.04689	120.7838	35.59592	113.0029	33.80629	107.3216
GEF TR1	Transformer	Overload	25	MVA	67.21417	268.8567	65.21278	260.8511	64.29131	257.1653	57.8539	231.4156	53.70959	214.8384
GEF TR2	Transformer	Overload	12	MVA	17.51771	145.9809	16.64076	138.673	16.25561	135.4634	14.58322	121.5268	13.4857	112.3808
GEF TR3	Transformer	Overload	25	MVA	38.83927	155.3571	36.37382	145.4953	35.58289	142.3315	31.50411	126.0165	29.20822	116.8329
GEL ATR1	Transformer	Overload	250	MVA	441.7164	176.6866	435.9312	174.3725	432.7075	173.083	426.4005	170.5602	423.5621	169.4249
GEL ATR2	Transformer	Overload	250	MVA	441.7164	176.6866	435.9312	174.3725	432.7075	173.083	426.4005	170.5602	423.5621	169.4249
GEL ATR3	Transformer	Overload	125	MVA	134.6378	107.7102	132.017	105.6136	130.2075	104.166	125.8281	100.6625	7.962547	106.1673
GEL ATR4	Transformer	Overload	125	MVA	134.6378	107.7102	132.017	105.6136	130.2075	104.166	125.8281	100.6625	32.72064	130.8826
GEL ATR5	Transformer	Overload	125	MVA	134.6378	107.7102	132.017	105.6136	130.2075	104.166	125.8281	100.6625	31.2132	156.066
GEL TR1	Transformer	Overload	63	MVA	67.02195	106.384	64.73544	102.7547	63.3989	100.6332				
KAI ATR1	Transformer	Overload	125	MVA	134.5735	107.6588	131.9025	105.522	130.054	104.0432	125.5864	100.4691	21.45483	134.0927
KAI ATR2	Transformer	Overload	125	MVA	134.5735	107.6588	131.9025	105.522	130.054	104.0432	125.5864	100.4691	21.45483	134.0927
KAI ATR3	Transformer	Overload	125	MVA	134.5735	107.6588	131.9025	105.522	130.054	104.0432	125.5864	100.4691	36.04751	180.2376
KAI TR1	Transformer	Overload	22	MVA	23.06314	104.8324	22.34631	101.5741	22.93412	104.246	34.83144	139.3258		
KAI TR2	Transformer	Overload	22	MVA	24.19181	109.9628	23.39112	106.3233	37.73707	150.9483	32.79327	163.9663	36.62201	183.1101
KII TR1	Transformer	Overload	25	MVA	39.92012	159.6805	38.54644	154.1857	34.92016	174.6008	22.58754	141.1721	28.4351	113.7404
KII TR3	Transformer	Overload	20	MVA	36.53546	182.6773	35.51102	177.5551	24.12362	150.7726	22.58754	141.1721	28.4351	113.7404
KNO TR1	Transformer	Overload	16	MVA	25.28957	158.0598	24.54504	153.4065	24.12362	150.7726	37.7851	188.9255	29.1822	243.185
KNO TR2	Transformer	Overload	16	MVA	25.28957	158.0598	24.54504	153.4065	40.18378	200.9189	38.19999	190.9999	59.84777	272.0353
LEG TR1	Transformer	Overload	20	MVA	41.63277	208.1639	40.64655	203.2328	40.37423	201.8712	29.49479	117.9792	26.04314	104.1726
LEG TR2	Transformer	Overload	20	MVA	41.71775	208.5887	40.78917	203.9458	30.86032	123.4413	29.49479	117.9792	39.79503	198.9752
MEK TR1	Transformer	Overload	25	MVA	31.9318	127.7272	31.24118	124.9647	30.86032	123.4413	31.60911	263.4092	39.79503	198.9752
MEK TR2	Transformer	Overload	25	MVA	31.9318	127.7272	31.24118	124.9647	34.85204	290.4337	63.44201	288.3728	122.5853	98.06821
SEBI TR2	Transformer	Overload	12	MVA	38.05304	317.1087	36.13823	301.1519	69.1935	314.5159	27.78726	111.149	122.5853	98.06821
SEBI TR3	Transformer	Overload	22	MVA	73.76895	335.3134	71.10284	323.1947	30.80342	123.2137	41.45277	207.2638	122.5853	98.06821
SUL TR1	Transformer	Overload	25	MVA	32.69272	130.7709	31.37606	125.5042	43.65055	218.2527	41.45277	207.2638	122.2709	97.8167
WER TR1	Transformer	Overload	20	MVA	45.23244	226.1622	44.20842	221.0421	43.65055	218.2527	7.284658	97.12878	122.2709	97.8167
WER TR2	Transformer	Overload	20	MVA	45.23244	226.1622	44.20842	221.0421	10.04938	100.4938	21.35392	97.06326	122.2709	97.8167
YES TR1	Transformer	Overload	10	MVA	10.0499	100.499	10.10139	101.0139	10.04938	100.4938				
YES TR2	Transformer	Overload	10	MVA	10.0499	100.499	10.10139	101.0139	21.93635	99.71068				

Considering Loading category of 2022 which is maximum Transformer Sizing or load supplying arrangement performed

Device ID	Type	Condition	Rating	Unit	Total Demand @2022			Load in MW	Demand in MVA consider .8 PF	Available MVA (Existing Capability)	MVA Required to supply the forecasted Load	Additional Tra sformers to supply the needed load	@subsation	
ACE TR1	Transformer	Overload	31.5	MVA	37.49		37.49					132kV		
ACE TR2	Transformer	Overload	31.5	MVA	37.49		37.49	74.97	93.72	63.00	**30.72**	1x40MVA	**Addis Center**	
AEA TR1	Transformer	Overload	25	MVA	32.39		32.39					132kV		
AEA TR2	Transformer	Overload	25	MVA	32.39		32.39	64.77	80.97	50.00	**30.97**	1x40MVA	**Addis East II**	
ANO TR1	Transformer	Overload	25	MVA	31.32		31.32					132kV		
ANO TR2	Transformer	Overload	25	MVA	34.61		34.61	65.93	82.41	50.00	**32.41**	1x40MVA	**Addis North**	
ASO TR1	Transformer	Overload	25	MVA	36.26		36.26					132kV		
ASO TR2	Transformer	Overload	25	MVA	32.02		32.02	68.28	85.36	50.00	**35.36**	1x40MVA	**Addis South**	
COT TR1	Transformer	Overload	16	MVA	20.27		20.27					132kV		
COT TR2	Transformer	Overload	31.5	MVA	37.91		37.91	58.18	72.73	47.50	**25.23**	1x40MVA	**Cotobie**	
GEF TR1	Transformer	Overload	25	MVA	19.78	43.52	63.30					132kV		
GEF TR2	Transformer	Overload	12	MVA	16.48		16.48					2x40MVA		
GEF TR3	Transformer	Overload	25	MVA	32.14		32.14	111.93	139.91	62.00	**77.91**		**Gefersa**	
GEL ATR1	Transformer	Overload	250	MVA	441.72		441.72					400/230kV atr		
GEL ATR2	Transformer	Overload	250	MVA	441.72		441.72	883.43	981.592	500	**481.592**	2X250MVA		Auto transformer addition at
GEL ATR3	Transformer	Overload	125	MVA	134.64		134.64					230/132kV ATR		gelan can be compensated by
GEL ATR4	Transformer	Overload	125	MVA	134.64		134.64					1X125MVA		adding 400kV Transmission line
GEL ATR5	Transformer	Overload	125	MVA	134.64		134.64	403.91	448.7926667	375	**73.79266667**			from Sebeta II <> Sululta.
GEL TR1	Transformer	Overload	63	MVA	60.09		60.09	60.09	75.12	63.00	**12.12**	132kV 1x25MVA	**Gelan**	
KAI ATR1	Transformer	Overload	125	MVA	134.57		134.57					230/132kV ATR		
KAI ATR2	Transformer	Overload	125	MVA	134.57		134.57					1x125MVA		Auto transformer addition at
KAI ATR3	Transformer	Overload	125	MVA	134.57		134.57	403.72	448.6	375	73.5783			kaliti Substaion can be
KAI TR1	Transformer	Overload	22	MVA	10.22	15.49	25.71					132kV		compensated by adding 400kV
KAI TR2	Transformer	Overload	22	MVA	10.22	15.49	25.71	51.43	64.28	44.00	**20.28**	1x25MVA	Kaliti I	Trasmission line from Sebeta II
KII TR1	Transformer	Overload	25	MVA	32.96	14.10	47.07					132kV		<> Sululta.
KII TR1	Transformer	Overload	26	MVA	35.11		35.11					2x40MVA		
KII TR3	Transformer	Overload	20	MVA	25.55		25.55	107.72	134.65	71.00	**63.65**		**Kaliti II**	
KNO TR1	Transformer	Overload	16	MVA	23.73		23.73					132kV		
KNO TR2	Transformer	Overload	16	MVA	23.73		23.73	47.47	59.34	32.00	**27.34**	1x31.5MVA	**Kaliti North**	
LEG TR1	Transformer	Overload	20	MVA	42.03		42.03					132kV		
LEG TR2	Transformer	Overload	20	MVA	42.13		42.13	84.16	105.20	40.00	**65.20**	2x40MVA	**Legetafo**	
MEK TR1	Transformer	Overload	25	MVA	34.17		34.17					132kV		
MEK TR2	Transformer	Overload	25	MVA	34.17		34.17	68.34	85.43	50.00	**35.43**	1x40MVA	**Mekanisa**	
NEF TR1	Transformer	Overload	25	MVA	33.29		33.29					132kV		
NEF TR2	Transformer	Overload	25	MVA	33.29		33.29	66.59	83.24	50.00	**33.24**	1x40MVA	**Nefas Silk**	
SEB I TR1	Transformer	Overload	25	MVA	23.40	11.37	34.78					132kV		
SEB I TR3	Transformer	Overload	50	MVA	61.45		61.45	96.23	120.28	75.00	**45.28**	1x63MVA	**Sebeta I**	
SUL TR1	Transformer	Overload	25	MVA	30.82	10.35	41.18	41.18	51.47	25.00	**26.47**	132kV 1x31.5MVA	**Sululta**	
WER TR1	Transformer	Overload	40	MVA	45.87		45.87				**34.68**	132kV		
WER TR2	Transformer	Overload	40	MVA	45.87		45.87	91.74	114.68	80.00	**0**	1x40MVA	**Weregenu**	
YES TR1	Transformer	Overload	10	MVA	8.86		8.86					132kV		
YES TR2	Transformer	Overload	10	MVA	8.86		8.86	17.71	22.14	20.00	**2.14**	1x10MVA	**Yesu**	

Device ID				load to be coverd	MVA*.9	% Loading
ACE TR1	30.71799657	132kV	Addis Center	27.64619691	36	76.7949914
ACE TR2	0	1x40MVA		0		
AEA TR1	30.96695118	132kV	Addis East II	27.87025606	36	77.4173779
AEA TR2	0	1x40MVA		0		
ANO TR1	32.41194543	132kV	Addis North	29.17075089	36	81.0298636
ANO TR2	0	1x40MVA		0		
ASO TR1	35.3554929	132kV	Addis South	31.81994361	36	88.3887323
ASO TR2	0	1x40MVA		0		
COT TR1	25.22854184	132kV	Cotobie	22.70568766	36	63.0713546
COT TR2	0	1x40MVA		0		
GEF TR1	77.90701143	132kV	Gefersa	70.11631029	36	194.767529
GEF TR2	0	2x40MVA		0		
GEF TR3	0			0		
GEL ATR1	481.592	400/230kV atr	Gelan	433.4328	414	104.693913
GEL ATR2	0	2X250MVA		0		
GEL ATR3	73.79266667	230/132kV ATR		66.4134	112.5	59.0341333
GEL ATR4		1X125MVA		0		
GEL ATR5				0		
GEL TR1	12.11856078	132kV 1x25MVA		10.9067047	22.5	48.4742431
KAI ATR1	73.57833333	230/132kV ATR	Kaliti I	66.2205	112.5	58.8626667
KAI ATR2		1x125MVA		0		
KAI ATR3				0		
KAI TR1	20.28131744	132kV		18.25318569	22.5	81.1252698
KAI TR2	0	1x25MVA		0		
KII TR1	63.65031131	132kV	Kaliti II	57.28528018	72	79.5628891
KII TR1	0	2x40MVA		0		
KII TR3	0			0		
KNO TR1	27.33660071	132kV	Kaliti North	24.60294064	28.35	86.7828594
KNO TR2	0	1x31.5MVA		0		
LEG TR1	65.2029452	132kV	Legetafo	58.68265068	72	81.5036815
LEG TR2	0	2x40MVA		0		
MEK TR1	35.42993898	132kV	Mekanisa	31.88694509	36	88.5748475
MEK TR2	0	1x40MVA		0		
NEF TR1	33.23606489	132kV	Nefas Silk	29.9124584	36	83.0901622
NEF TR2	0	1x40MVA		0		
SEB I TR1	45.28288237	132kV	Sebeta I	40.75459413	56.7	71.8775911
SEB I TR3	0	1x63MVA		0		
SUL TR1	26.46897814	132kV 1x31.5MV/	Sululta	23.82208032	28.35	84.028502
WER TR1	**34.68**	132kV	Weregenu	31.20904664	36	86.6917962
WER TR2	**0**	1x40MVA		0		
YES TR1	2.142552449	132kV	Yesu	1.928297204	9	21.4255245
YES TR2	0	1x10MVA		0		

Addis Center	132kV 1x40MVA
Addis East II	132kV 1x40MVA
Addis North	132kV 1x40MVA
Addis South	132kV 1x40MVA
Cotobie	132kV 1x40MVA
Gefersa	132kV 2x40MVA
Gelan	400/230kV ATR 2X250MVA 230/132kV ATR 1X125MVA 132kV 1x25MVA
Kaliti I	230/132kV ATR 1x125MVA 132kV 1x25MVA
Kaliti II	132kV 2x40MVA
Kaliti North	132kV 1x31.5MVA
Legetafo	132kV 2x40MVA
Mekanisa	132kV 1x40MVA
Nefas Silk	132kV 1x40MVA
Sebeta I	132kV 1x63MVA
Sululta	132kV 1x31.5MVA
Weregenu	132kV 2x40MVA
Yesu	132kV 1x10MVA

Substaion		Device		Peak Load (MW)					considering 80% of the old Transformer capacity supply the demand and giving the remaining for the new TR										
									proposed MW loading for old TRs					proposed MW Loading for New TRs					
Substaion Name	Substation ID	Type	Device ID	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022	
Addis Center	ACE	2W-TR	ACE TR1	30.46	32.19	34.76	35.73	37.49	22.68	22.68	22.68	22.68	22.68	15.57	19.03	24.17	26.11	29.61	Addis Center
		2W-TR	ACE TR2	30.46	32.19	34.76	35.73	37.49	22.68	22.68	22.68	22.68	22.68						
Addis East II	AEA	2W-TR	AEA TR1	26.03	27.59	29.92	30.80	32.39	18.00	18.00	18.00	18.00	18.00	16.06	19.19	23.85	25.60	28.77	Addis East II
		2W-TR	AEA TR2	26.03	27.59	29.92	30.80	32.39	18.00	18.00	18.00	18.00	18.00						
Addis North	ANO	2W-TR	ANO TR1	24.10	25.94	28.68	29.64	31.32	18.00	18.00	18.00	18.00	18.00	[illegible]	18.60	24.38	26.40	29.93	Addis North
		2W-TR	ANO TR2	26.64	28.67	31.70	32.76	34.61	18.00	18.00	18.00	18.00	18.00						
Addis South II	ASO	2W-TR	ASO TR1	27.90	30.03	33.21	34.32	36.26	18.00	18.00	18.00	18.00	18.00	17.47	21.38	27.26	29.14	32.28	Addis South II
		2W-TR	ASO TR2	25.57	27.35	30.05	30.82	32.02	18.00	18.00	18.00	18.00	18.00						
Ayat	AYA	2W-TR	AYA TR1	5.38	6.58	8.40	8.94	9.81	18.00	18.00	18.00	18.00	18.00						Ayat
		2W-TR	AYA TR2	5.38	6.58	8.40	8.94	9.81	18.00	18.00	18.00	18.00	18.00						
Cotobie	COT	3W-TR	COT TR1-S	15.60	16.79	18.57	19.19	20.27	11.52	11.52	11.52	11.52	11.52	9.18	12.57	17.56	19.70	23.74	Cotobie
			COT TR1-T	3.02	2.46	1.54	1.61	2.05	2.88	2.88	2.88	2.88	2.88						
		2W-TR	COT TR2	29.17	31.40	34.72	35.88	37.91	22.68	22.68	22.68	22.68	22.68						
		2W-TR	COT TR3	7.10	7.64	8.45	8.74	9.23	8.64	8.64	8.64	8.64	8.64						
Gefersa	GEF	3W-TR	GEF TR1-S	15.22	16.38	18.12	18.72	19.78	11.52	11.52	11.52	11.52	11.52	28.44	35.06	45.07	48.05	52.82	Gefersa
			GEF TR1-T	35.39	37.88	41.71	42.52	43.52	10.08	10.08	10.08	10.08	10.08						
		3W-TR	GEF TR2-S	1.61	1.73	1.92	1.98	2.09	10.80	10.80	10.80	10.80	10.80						
			GEF TR2-T	12.68	13.65	15.10	15.60	16.48	10.80	10.80	10.80	10.80	10.80						
		2W-TR	GEF TR3	24.73	26.62	29.44	30.42	32.14	18.00	18.00	18.00	18.00	18.00						
Gelan	GEL	2W-TR	GEL TR1	45.23	49.04	54.76	56.72	60.09	45.36	45.36	45.36	45.36	45.36	-0.13	3.68	9.40	11.36	14.73	Gelan
Kaliti I	KAI	3W-TR	KAI TR1-S	11.92	12.83	14.19	14.67	15.49	15.84	15.84	15.84	15.84	15.84						Kaliti I
			KAI TR1-T	7.86	8.46	9.36	9.67	10.22	5.40	5.40	5.40	5.40	5.40	-5.07	-2.05	2.46	4.04	6.79	
		3W-TR	KAI TR2-S	11.92	12.83	14.19	14.67	15.49	15.84	15.84	15.84	15.84	15.84						
			KAI TR2-T	7.86	8.46	9.36	9.67	10.22	5.40	5.40	5.40	5.40	5.40						
Kaliti GIS	KGI	2W-TR	KGI TR1	5.38	6.58	8.40	8.94	9.81	18.00	18.00	18.00	18.00	18.00						Kaliti GIS
		2W-TR	KGI TR2	5.38	6.58	8.40	8.94	9.81	18.00	18.00	18.00	18.00	18.00						
Kaliti II	KII	3W-TR	KII TR1-S	25.37	27.30	30.19	31.20	32.96	18.00	18.00	18.00	18.00	18.00	20.43	27.11	37.11	40.56	46.52	Kaliti II
			KII TR1-T	9.58	10.77	12.57	13.14	14.10	7.20	7.20	7.20	7.20	7.20						
		2W-TR	KII TR2	19.66	21.16	23.40	24.18	25.55	18.00	18.00	18.00	18.00	18.00						
		2W-TR	KII TR3	27.02	29.08	32.15	33.23	35.11	18.00	18.00	18.00	18.00	18.00						
Kaliti North	KNO	2W-TR	KNO TR1	18.26	19.66	21.74	22.47	23.73	11.52	11.52	11.52	11.52	11.52	13.49	16.27	20.44	21.89	24.43	Kaliti North
		2W-TR	KNO TR2	18.26	19.66	21.74	22.47	23.73	11.52	11.52	11.52	11.52	11.52						
Legetafo	LEG	2W-TR	LEG TR1	32.34	34.81	38.50	39.78	42.03	22.68	22.68	22.68	22.68	22.68	19.92	24.70	31.84	34.37	38.80	Legetafo
		2W-TR	LEG TR2	32.93	35.25	38.71	39.95	42.13	22.68	22.68	22.68	22.68	22.68						
Mekanissa	MEK	2W-TR	MEK TR1	26.95	28.76	31.45	32.43	34.17	18.00	18.00	18.00	18.00	18.00	17.90	21.51	26.90	28.86	32.34	Mekanissa
		2W-TR	MEK TR2	26.95	28.76	31.45	32.43	34.17	18.00	18.00	18.00	18.00	18.00						
Minilik	MIN	2W-TR	MIN TR1	6.15	7.52	9.59	10.22	11.22	18.00	18.00	18.00	18.00	18.00						Minilik
		2W-TR	MIN TR2	6.15	7.52	9.59	10.22	11.22	18.00	18.00	18.00	18.00	18.00						
Nefasilk	NEF	2W-TR	NEF TR1	25.62	27.57	30.49	31.51	33.29	18.00	18.00	18.00	18.00	18.00	15.24	19.15	24.99	27.03	30.59	Nefasilk
		2W-TR	NEF TR2	25.62	27.57	30.49	31.51	33.29	18.00	18.00	18.00	18.00	18.00						
Sebeta I	SEBI	3W-TR	SEBI TR1-S	0.00	0.00	0.00	0.00	0.00	8.64	8.64	8.64	8.64	8.64						Sebeta I
			SEBI TR1-T	3.46	3.44	3.40	3.41	3.47	2.88	2.88	2.88	2.88	2.88						
		3W-TR	SEBI TR2-S	18.01	19.38	21.44	22.15	23.40	18.00	18.00	18.00	18.00	18.00	8.11	12.89	20.04	22.56	26.98	
			SEBI TR2-T	8.75	9.42	10.42	10.76	11.37	7.20	7.20	7.20	7.20	7.20						
		2W-TR	SEBI TR3	50.60	53.37	57.52	58.95	61.45	36.00	36.00	36.00	36.00	36.00						
sebeta II	SEBII	2W-TR	SEBII TR1	16.11	17.34	19.17	19.81	20.93	18.00	18.00	18.00	18.00	18.00						sebeta II
Sululta	SUL	3W-TR	SUL TR1-S	6.85	7.79	9.22	9.65	10.35	18.00	18.00	18.00	18.00	18.00						Sululta
			SUL TR1-T	24.57	26.36	29.09	29.79	30.82	18.00	18.00	18.00	18.00	18.00	6.57	8.36	11.09	11.79	12.82	
		2W-TR	SUL TR2	17.99	18.49	19.22	19.58	20.28	18.00	18.00	18.00	18.00	18.00						
Torhailoch	THA	2W-TR	THA TR1	4.61	5.64	7.20	7.66	8.41	18.00	18.00	18.00	18.00	18.00						Torhailoch
		2W-TR	THA TR2	4.61	5.64	7.20	7.66	8.41	18.00	18.00	18.00	18.00	18.00						
Weregenu	WER	2W-TR	WER TR1	36.09	38.56	42.26	43.57	45.87	28.80	28.80	28.80	28.80	28.80	14.58	19.53	26.92	29.54	34.14	Weregenu
		2W-TR	WER TR2	36.09	38.56	42.26	43.57	45.87	28.80	28.80	28.80	28.80	28.80						
Yesu	YES	2W-TR	YES TR1	7.00	7.62	8.58	8.73	8.86	7.20	7.20	7.20	7.20	7.20	-0.39	0.84	2.75	3.06	3.31	Yesu
		2W-TR	YES TR2	7.00	7.62	8.58	8.73	8.86	7.20	7.20	7.20	7.20	7.20						

60.93 = 45.36 + 15.57

	Type	Condition	Rating	Unit	2022		2021		2020		2019		2018	
					Operating	% Operating	Operating	% Operating	Operating	% Operating	Operating	% Operating	Operating	% Operating
Addis Center 132kV	Bus	Under Voltage	132	kV	119.94	90.86	121.26	91.86	122.08	92.48	123.91	93.87	125.06	94.75
Addis East II 132kV	Bus	Under Voltage	132	kV	122.65	92.92	123.71	93.72	124.53	94.34	125.73	95.25	126.50	95.84
Addis North 132kV	Bus	Under Voltage	132	kV	125.26	94.90	125.95	95.42	126.70	95.98	127.14	96.32	127.44	96.55
Addis South II 132	Bus	Under Voltage	132	kV	114.06	86.41	115.57	87.55	116.51	88.26	118.76	89.97	120.22	91.08
Ayat 132kV	Bus	Under Voltage	132	kV	122.31	92.66	123.63	93.66	124.57	94.37	126.17	95.58	127.23	96.39
Cotobie 132kV	Bus	Under Voltage	132	kV	122.80	93.03	124.02	93.95	124.85	94.58	126.39	95.75	127.38	96.50
Gefersa 230kV	Bus	Under Voltage	230	kV	224.75	97.72								
Gelan 132kV	Bus	Under Voltage	132	kV	125.13	94.79	126.28	95.67	127.01	96.22	128.58	97.41		
Gelan 230kV	Bus	Under Voltage	230	kV	218.98	95.21	220.14	95.71	220.81	96.00	222.36	96.68	223.24	97.06
Kaliti GIS 132kV	Bus	Under Voltage	132	kV	123.32	93.42	124.55	94.36	125.33	94.94	127.03	96.24	128.10	97.05
Kaliti I 132kV	Bus	Under Voltage	132	kV	124.56	94.37	125.73	95.25	126.47	95.81	128.05	97.01	129.03	97.75
Kaliti I 230kV	Bus	Under Voltage	230	kV	218.70	95.09	219.86	95.59	220.53	95.88	222.08	96.56	222.96	96.94
Kaliti II 132kV	Bus	Under Voltage	132	kV	122.01	92.44	123.30	93.41	124.10	94.01	125.90	95.38	127.04	96.24
Kaliti North 132kV	Bus	Under Voltage	132	kV	123.81	93.80	125.00	94.70	125.77	95.28	127.37	96.49	128.37	97.25
Legetafo 132kV	Bus	Under Voltage	132	kV	122.20	92.57	123.58	93.62	124.60	94.40	126.18	95.59	127.27	96.41
Legetafo 230kV	Bus	Under Voltage	230	kV	225.24	97.93								
Mekanisa 132kV	Bus	Under Voltage	132	kV	115.46	87.47	116.93	88.58	117.84	89.27	120.00	90.91	121.39	91.97
Minilk 132kV	Bus	Under Voltage	132	kV	127.45	96.55	127.94	96.92	128.63	97.44	128.67	97.48	128.72	97.52
Nefasilk 132kV	Bus	Under Voltage	132	kV	121.12	91.76	122.44	92.76	123.26	93.38	125.13	94.79	126.33	95.70
T.Hailoch 230kV	Bus	Under Voltage	230	kV	225.02	97.83								
Weregenu 132kV	Bus	Under Voltage	132	kV	122.82	93.05	124.04	93.97	124.84	94.58	126.46	95.80	127.48	96.58
Yesu 132kV	Bus	Under Voltage	132	kV	124.48	94.30	125.65	95.19	126.39	95.75	127.98	96.96	128.97	97.71

buses with under voltage condition of under 95%

	Type	Condition	Rating	Unit	under voltage occurred @year
Addis Center 132kV	Bus	Under Voltage	132	kV	2018
Addis East II 132kV	Bus	Under Voltage	132	kV	2020
Addis North 132kV	Bus	Under Voltage	132	kV	2022
Addis South II 132	Bus	Under Voltage	132	kV	2018
Ayat 132kV	Bus	Under Voltage	132	kV	2020
Cotobie 132kV	Bus	Under Voltage	132	kV	2020
Gelan 132kV	Bus	Under Voltage	132	kV	2022
Kaliti GIS 132kV	Bus	Under Voltage	132	kV	2020
Kaliti I 132kV	Bus	Under Voltage	132	kV	2022
Kaliti II 132kV	Bus	Under Voltage	132	kV	2020
Kaliti North 132kV	Bus	Under Voltage	132	kV	2021
Legetafo 132kV	Bus	Under Voltage	132	kV	2020
Mekanisa 132kV	Bus	Under Voltage	132	kV	2018
Nefasilk 132kV	Bus	Under Voltage	132	kV	2019
Weregenu 132kV	Bus	Under Voltage	132	kV	2020
Yesu 132kV	Bus	Under Voltage	132	kV	2022

	Candidate Buses	Source Bus	Source Bus connection which have effect	Further bus affecting	Maximum Under V. %	Minimum Under V. %	Maximum @year	Minimum @Year
2018	Addis Center 132kV	Kaliti I 132kV	Gelan 132kV		90.8641	94.74564	2022	2018
	Mekanisa	Kaliti I 132kV	Gelan 132kV		87.46875	91.96562	2022	2018
	Addis South II 132kV	Mekanisa 132 kV	Kaliti 132kV		86.40854	91.07747	2022	2018
2019	Nefasilk 132kV	Kaliti II 132kV	Kaliti 132kV		91.76	94.79	2022	2019
2020	Addis East II 132kV	Cotobie 132kV	Kaliti 132kV		92.92	94.34	2022	2020
	Ayat 132kV	Cotobie 132kV	Kaliti 132kV		92.66	94.37	2022	2020
	Cotobie 132kV	Kaliti I 132kV			93.03	94.58	2022	2020
	Kaliti GIS 132kV	Kaliti I 132kV			93.42	94.94	2022	2020
	Kaliti II 132kV	Kaliti I 132kV			92.44	94.01	2022	2020
	Legetafo 132kV	Ayat 132kV	Cotobie 132kV	Kaliti I 132kV	92.57	94.40	2022	2020
	Weregenu 132kV	Kaliti I 132kV			93.05	94.58	2022	2020
2021	Kaliti North 132kV	Kaliti I 132kV			93.80	94.70	2022	20221
2022	Addis North 132kV	Addis East 132kV	Cotobie 132kV	Kaliti I 132kV	94.90		2022	
	Gelan 132kV	Gelan 230kV			94.79		2022	
	Kaliti I 132kV	Gelan 132kV			94.37		2022	
	Yesu 132kV	Kaliti I 132kV			94.30		2022	

The ultimate under voltage problem with the source buses feeding the candidate buses are listed. Kaliti I substation 132kv busbar is the one which have big effect on all the candidate buses and but the bus itself face under voltage @2022 so step by step placing capacitor banks the following result is obtained.

Step 1 Initial Identified Buses

	Candidate Buses	Source Bus	Source Bus connection which have effect	Further bus affecting	Maximum Under V. %	Minimum Under V. %	Maximum @year	Minimum @Year
2018	Addis Center 132kV	Kaliti I 132kV	Gelan 132kV		90.8641	94.74564	2022	2018
	Mekanisa	Kaliti I 132kV	Gelan 132kV		87.46875	91.96562	2022	2018
	Addis South II 132kV	Mekanisa 132 kV	Kaliti 132kV		86.40854	91.07747	2022	2018
2019	Nefasilk 132kV	Kaliti II 132kV	Kaliti 132kV		91.76	94.79	2022	2019
2020	Addis East II 132kV	Cotobie 132kV	Kaliti 132kV		92.92	94.34	2022	2020
	Ayat 132kV	Cotobie 132kV	Kaliti 132kV		92.66	94.37	2022	2020
	Cotobie 132kV	Kaliti I 132kV			93.03	94.58	2022	2020
	Kaliti GIS 132kV	Kaliti I 132kV			93.42	94.94	2022	2020
	Kaliti II 132kV	Kaliti I 132kV			92.44	94.01	2022	2020
	Legetafo 132kV	Ayat 132kV	Cotobie 132kV	Kaliti I 132kV	92.57	94.40	2022	2020
	Weregenu 132kV	Kaliti I 132kV			93.05	94.58	2022	2020
2021	Kaliti North 132kV	Kaliti I 132kV			93.80	94.70	2022	20221
2022	Addis North 132kV	Addis East 132kV	Cotobie 132kV	Kaliti I 132kV	94.90		2022	
	Gelan 132kV	Gelan 230kV			94.79		2022	
	Kaliti I 132kV	Gelan 132kV			94.37		2022	
	Yesu 132kV	Kaliti I 132kV			94.30		2022	

Kaliti I 132kV bus is considerd to be the first to place Capacitor based on the Mvar available on the bus

Step 1 Load Flow simulation results

	Placed @ bus	MVAR on Bus	Selected capacitor bank	Candidate buses	bus volt(%) @2018	bus volt(%) @2019	bus volt(%) @2020	bus volt(%) @2021	bus volt(%) @2022
step 1	Kaliti I 132kV	116.2Mvar	6x20MVAR=120Mvar	Addis Center 132kV	96.74	95.66	94.34	93.67	92.65
				Mekanisa	93.9	92.64	91.06	90.32	89.18
				Addis South II 132kV	93	91.69	90.03	89.27	88.1
				Nefasilk 132kV	97.79	96.65	95.26	94.58	93.56
				Addis East II 132kV	97.53	96.48	95.55	94.96	94.15
				Ayat 132kV	98.31	97.2	96.1	95.54	94.53
				Cotobie 132kV	98.44	97.4	96.29	95.69	94.76
				Kaliti GIS 132kV	99.11	98.08	96.85	96.22	95.26
				Kaliti II 132kV	98.31	97.22	95.9	95.25	94.25
				Legetafo 132kV	98.32	97.18	96.13	95.64	94.58
				Weregenu 132kV	98.57	97.54	96.38	95.77	94.82
				Kaliti North 132kV	99.28	98.29	97.15	96.54	95.61
				Addis North 132kV	97.88	96.88	96.38	95.84	95.33
				Gelan 132kV	98.4	97.44	96.89	96.53	96.02
				Kaliti I 132kV	99.81	98.86	97.73	97.12	96.22
				Yesu 132kV	99.77	98.81	97.67	97.06	96.15

16 buses identified for under voltage problem. And 6 buses problem are solved for the whole forecast year.

Step 2 Identified buses after step 1

	Candidate Buses	Source Bus	Source Bus connection which have effect	Further bus affecting
2018	Mekanisa	Kaliti I 132kV	Gelan 132kV	
	Addis South II 132kV	Mekanisa 132 kV	Kaliti 132kV	Gelan 132kV
2020	Addis Center 132kV	Kaliti I 132kV	Gelan 132kV	
2021	Nefasilk 132kV	Kaliti II 132kV	Kaliti 132kV	Gelan 132kV
	Addis East II 132kV	Cotobie 132kV	Kaliti 132kV	Gelan 132kV
2022	Ayat 132kV	Cotobie 132kV	Kaliti 132kV	Gelan 132kV
	Cotobie 132kV	Kaliti I 132kV	Gelan 132kV	
	Kaliti II 132kV	Kaliti I 132kV	Gelan 132kV	
	Legetafo 132kV	Ayat 132kV	Cotobie 132kV	Kaliti I 132kV
	Weregenu 132kV	Kaliti I 132kV	Gelan 132kV	

Gelan 132kV bus is the next taken in to account

Step 2 Load flow simulation result

	Placed @ bus	MVAR on Bus	Selected capacitor bank	Candidate buses	bus volt(%) @2018	bus volt(%) @2019	bus volt(%) @2020	bus volt(%) @2021	bus volt(%) @2022
step 2	Gelan 132kV	-71.5Mvar	4x20MVAR=80Mvar	Mekanisa	94.04	93.35	91.82	91.4	90.63
				Addis South II 132kV	93.14	92.39	90.78	90.34	89.53
				Addis Center 132kV	96.89	96.39	95.12	94.79	94.14
				Nefasilk 132kV	97.94	97.41	96.07	95.71	95.08
				Addis East II 132kV	97.57	97.07	96.04	95.91	95.47
				Ayat 132kV	98.43	97.86	96.8	96.44	96.05
				Cotobie 132kV	98.56	98.09	97	96.73	96.25
				Kaliti II 132kV	98.46	97.98	96.71	96.38	95.78
				Legetafo 132kV	98.44	97.8	96.82	96.39	96.13
				Weregenu 132kV	98.7	98.26	97.14	96.85	96.34

10 buses identified for under voltage problem. And 7 buses problem are solved for the whole forecast year.

step 3 Identified buses after step 1 and 2

	Candidate Buses	Source Bus	Source Bus connection which have effect	Further bus affecting
2018	Mekanisa	Kaliti I 132kV	Gelan 132kV	
	Addis South II 132kV	Mekanisa 132 kV	Kaliti 132kV	Gelan 132kV
2021	Addis Center 132kV	Kaliti I 132kV	Gelan 132kV	

for this step Mekanis and Addis Center are considerd

Step 3 Load flow simulation result

	Placed @ bus	MVAR on Bus	Selected capacitor bank	Candidate buses	bus volt(%) @2018	bus volt(%) @2019	bus volt(%) @2020	bus volt(%) @2021	bus volt(%) @2022
Step 3	Mekanisa 132kV	83.4Mvar	4x20MVAR=80Mvar	Mekanisa	96.33	96.09	95.32	94.68	94.31
	Addis center 132 kV	47.8Mvar	2x20Mvar=40Mvar	Addis South II 132kV	95.4	95.1	94.24	93.58	93.17
				Addis Center 132kV	97.85	97.83	97.39	96.83	96.63

3 buses identified for under voltage problem. And 1 bus problem is solved for the whole forecast year.

Step 4

After step 3 the undervoltage is on two buses Addis South II and Mekanisa. Next place capacitor banks @ Addis South II or Increase the bank @Mekanissa

	Candidate Buses	Source Bus	Source Bus connection which have effect	Further bus affecting
2020	Addis South II 132kV	Mekanisa 132 kV	Kaliti 132kV	Gelan 132kV
2021	Mekanisa	Kaliti I 132kV	Gelan 132kV	

option 1 Place New Capacitor Bank @Addis South II needed @2020

	Placed @ bus	MVAR on Bus	Selected capacitor bank	Candidate buses	bus volt(%) @2018	bus volt(%) @2019	bus volt(%) @2020	bus volt(%) @2021	bus volt(%) @2022
Step 4 O1	Addis South II 132 kV	41.2Mvar	2x20MVAR=40Mvar	Mekanisa	97.68	97.15	96.87	96.61	95.92
				Addis South II 132kV	97.15	96.56	96.19	95.91	95.16

option 2 Place New Capacitor Bank @Mekanisa @2020

	Placed @ bus	MVAR on Bus	Selected capacitor bank	Candidate buses	bus volt(%) @2018	bus volt(%) @2019	bus volt(%) @2020	bus volt(%) @2021	bus volt(%) @2022
Step 4 O2	Mekanisa 132kV	21.2Mvar	1x20MVAR=20Mvar to be added on 80Mvar	Mekanisa	97.6	97.4	96.78	96.06	95.7
				Addis South II 132kV	96.66	96.39	95.69	94.95	94.54

The simultaion result shows option 1 is the ultimate solution for solving the problem.

Total Paced capacitors vs buses

Bus	Placed Capacitor	Placement Year
Kaliti I 132kV	6x20Mvar=120Mvar	2018
Gelan 132kV	4x20Mvar=80Mvar	2018
Mekanisa 132kV	4x20MVAR=80Mvar	2018
Addis center 132 kV	2x20Mvar=40Mvar	2018
Addis South II 132 kV	2x20MVAR=40Mvar	2020

	Under Voltage Buses				
	2018	2019	2020	2021	2022
	Addis Center 132kV	Addis Center 132kV	Addis Center 132kV	Addis Center 132kV	Addis Center 132kV
	Addis East II 132kV	Addis East II 132kV	Addis East II 132kV	Addis East II 132kV	Addis East II 132kV
	Addis North 132kV	Addis North 132kV	Addis North 132kV	Addis North 132kV	Addis North 132kV
	Addis South II 132	Addis South II 132	Addis South II 132	Addis South II 132	Addis South II 132
	Ayat 132kV	Ayat 132kV	Ayat 132kV	Ayat 132kV	Ayat 132kV
	Cotobie 132kV	Cotobie 132kV	Cotobie 132kV	Cotobie 132kV	Cotobie 132kV
	Gelan 230kV	Gelan 132kV	Gelan 132kV	Gelan 132kV	Gefersa 230kV
	Kaliti GIS 132kV	Gelan 230kV	Gelan 230kV	Gelan 230kV	Gelan 132kV
	Kaliti I 132kV	Kaliti GIS 132kV	Kaliti GIS 132kV	Kaliti GIS 132kV	Gelan 230kV
	Kaliti I 230kV	Kaliti I 132kV	Kaliti I 132kV	Kaliti I 132kV	Kaliti GIS 132kV
	Kaliti II 132kV	Kaliti I 230kV	Kaliti I 230kV	Kaliti I 230kV	Kaliti I 132kV
	Kaliti North 132kV	Kaliti II 132kV	Kaliti II 132kV	Kaliti II 132kV	Kaliti I 230kV
	Legetafo 132kV	Kaliti North 132kV	Kaliti North 132kV	Kaliti North 132kV	Kaliti II 132kV
	Mekanisa 132kV	Legetafo 132kV	Legetafo 132kV	Legetafo 132kV	Kaliti North 132kV
	Minilk 132kV	Mekanisa 132kV	Mekanisa 132kV	Mekanisa 132kV	Legetafo 132kV
	Nefasilk 132kV	Minilk 132kV	Minilk 132kV	Minilk 132kV	Legetafo 230kV
	Weregenu 132kV	Nefasilk 132kV	Nefasilk 132kV	Nefasilk 132kV	Mekanisa 132kV
	Yesu 132kV	Weregenu 132kV	Weregenu 132kV	Weregenu 132kV	Minilk 132kV
		Yesu 132kV	Yesu 132kV	Yesu 132kV	Nefasilk 132kV
					T.Hailoch 230kV
					Weregenu 132kV
					Yesu 132kV
Total	18	19	19	19	22

Additional Transformers to overcome Overloading of Transformers							
Substation		**Substation**		**Substation**		**Substation**	
Addis Center	132kV	**Cotobie**	132kV	**Kaliti I**	230/132kV ATR	**Mekanisa**	132kV
	1x40MVA		1x40MVA		1x125MVA		1x40MVA
Addis East II	132kV	**Gefersa**	132kV		132kV	**Nefas Silk**	132kV
	1x40MVA		2x40MVA		1x25MVA		1x40MVA
Addis North	132kV	**Gelan**	400/230kV ATR	**Kaliti II**	132kV	**Sebeta I**	132kV
	1x40MVA		2X250MVA		2x40MVA		1x63MVA
Addis South	132kV		230/132kV ATR	**Kaliti North**	132kV	**Sululta**	132kV 1x31.5MVA
	1x40MVA		1X125MVA		1x31.5MVA	**Weregenu**	132kV
			132kV	**Legetafo**	132kV		2x40MVA
			1x25MVA		2x40MVA	**Yesu**	132kV
							1x10MVA

All Transformers to be deployesd @2018 except Gelan TR @2020, Kaliti TR @ 202a and yesu TR @2020

Capacitors to overcome Under voltage problems		
Bus	**Placed Capacitor**	**Placement Year**
Kaliti I 132kV	6x20Mvar=120Mvar	2018
Gelan 132kV	4x20Mvar=80Mvar	2018
Mekanisa 132kV	4x20MVAR=80Mvar	2018
Addis center 132 kV	2x20Mvar=40Mvar	2018
Addis South II 132 kV	2x20MVAR=40Mvar	2020

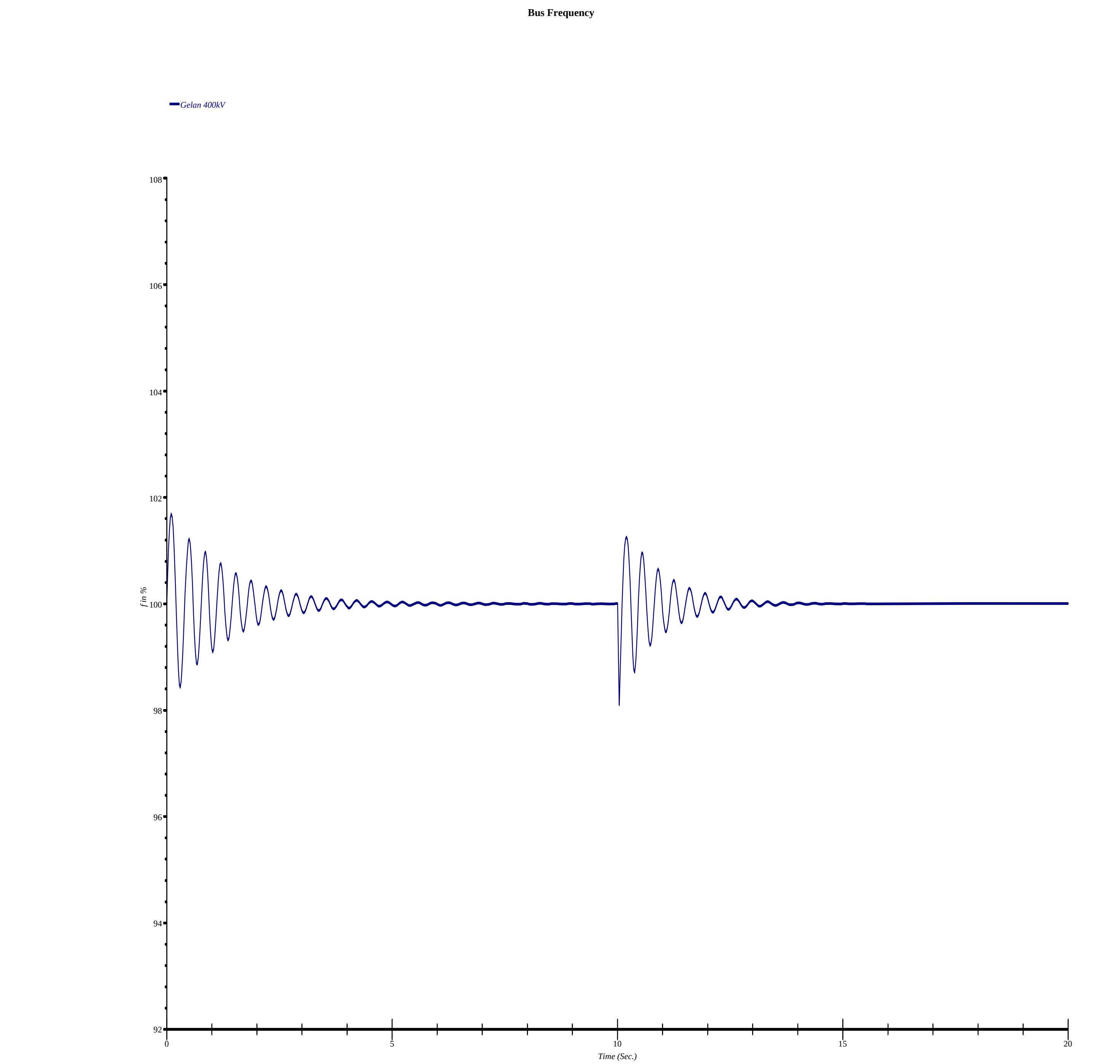
Transmission Lines to overcome Line overloading			
Additional Transmission Line	**Rate**	**Ampacity**	**Year to impliment**
Gefersa <> Addis North	132kV	510A	2018
Gelan <> Kaliti I	132kV	490A	
Kaliti I <> Mekanisa	132kV	490A	
Kaliti I <> Sebeta I	132kV	490A	
Sebeta I <> Gefersa	230kV	920A	
Kaliti I <> Kaliti II	132kV	490A	2022

The study is conducted on Addis Ababa region only

Appendix C - Transient Stability Graphs

Project File: C:\ETAP 1260\LoadForecast_HV\LoadForecast
Output Report: Untitled

TRANSIENT STABILITY ANALYSIS



The study is conducted on Addis Ababa region only

Project File: C:\ETAP 1260\LoadForecast_HV\LoadForecast
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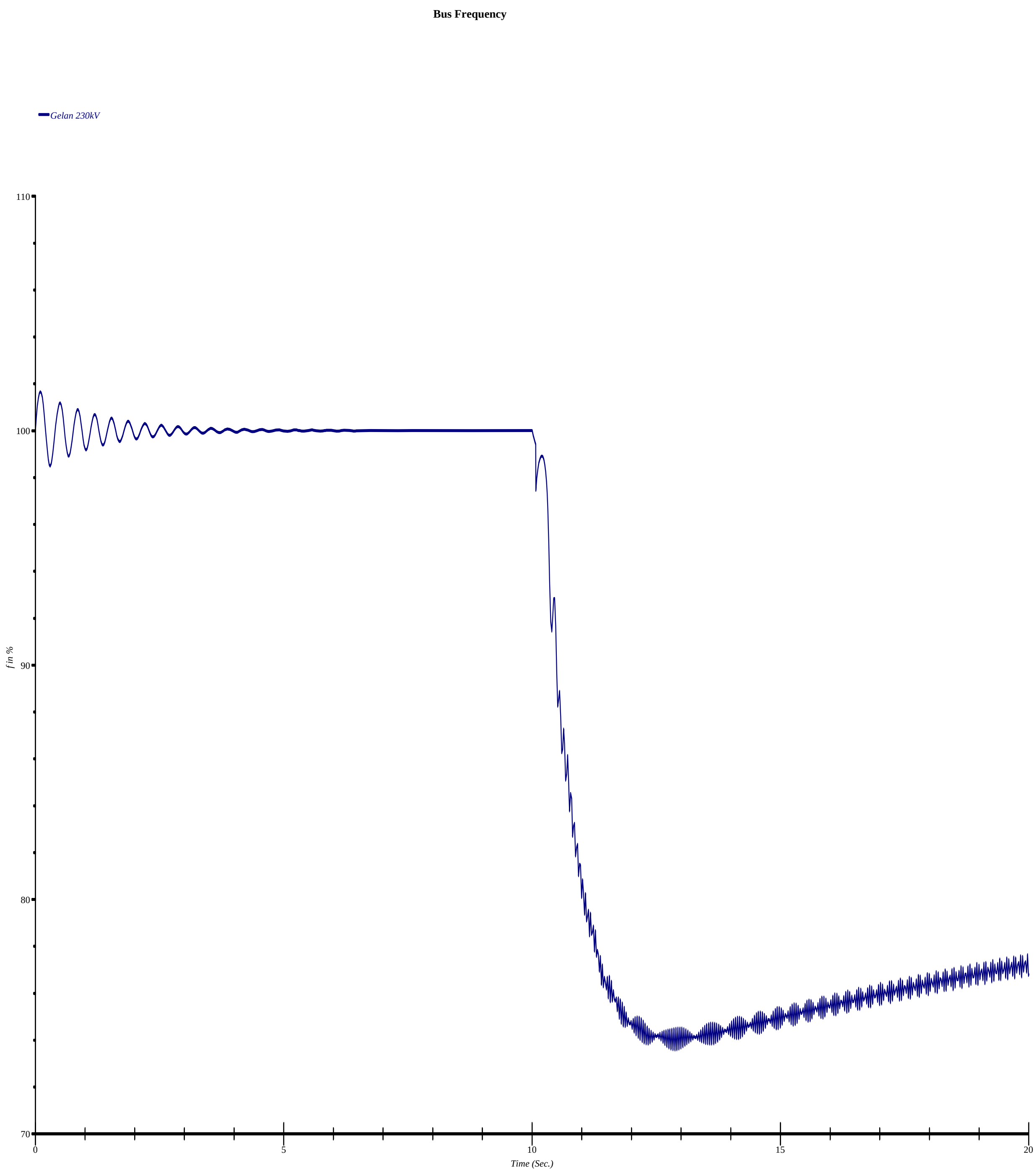
TRANSIENT STABILITY ANALYSIS



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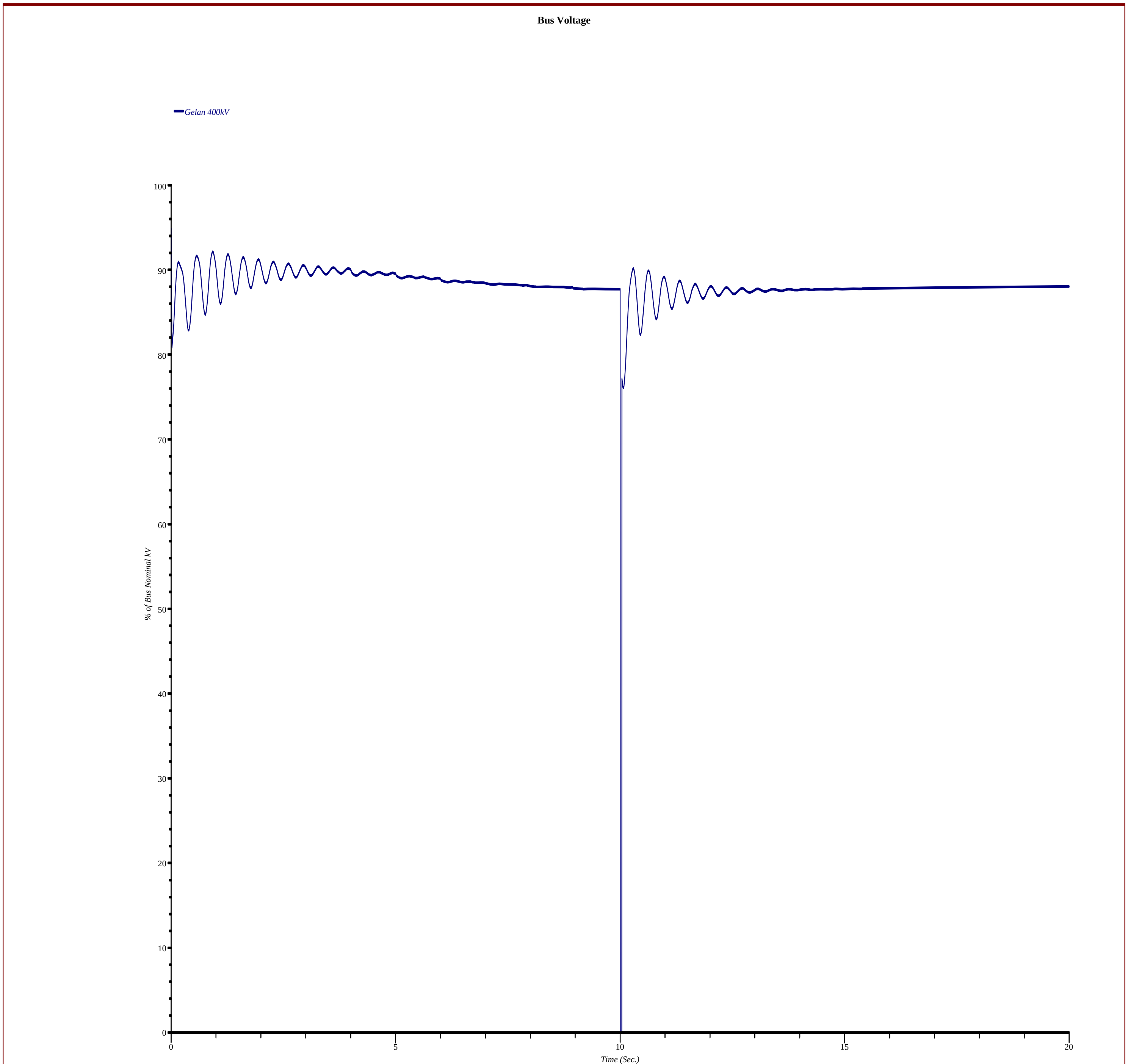
Location:	Addis Ababa		SN:	
Contract:	1		Revision:	Base
Engineer:	Abrham Workie	Study Case: TS	Config.:	Normal

The study is conducted on Addis Ababa region only

Project File: C:\ETAP 1260\LoadForecast_HV\LoadForecast
Output Report: Untitled

TRANSIENT STABILITY ANALYSIS



The study is conducted on Addis Ababa region only

Project File: C:\ETAP 1260\LoadForecast_HV\LoadForecast
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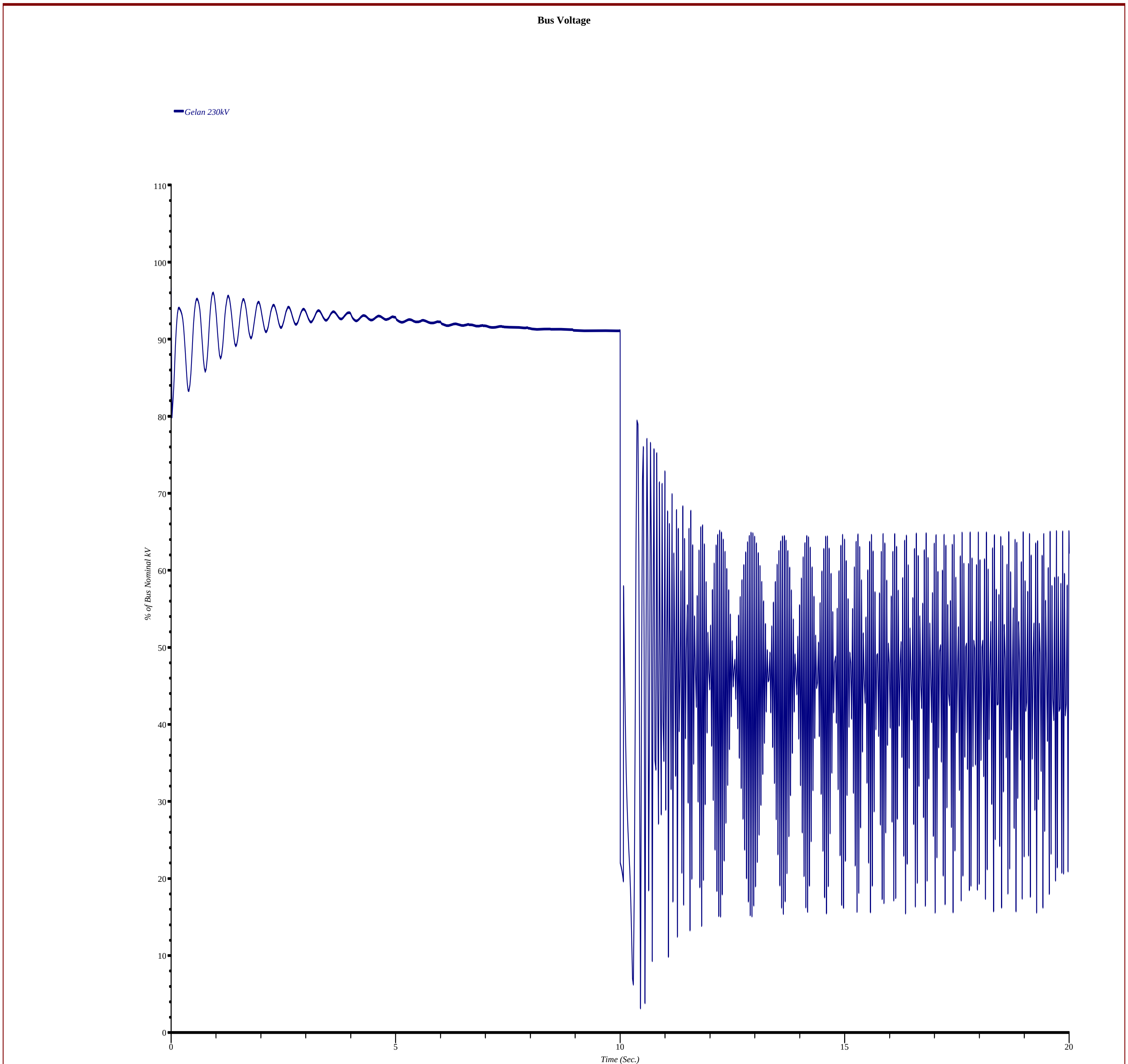
TRANSIENT STABILITY ANALYSIS



		ETAP			
Project:	Loadforecast	12.6.0H		Date:	06-13-2018
Location:	Addis Ababa			SN:	
Contract:	1			Revision:	Base
Engineer:	Abrham Workie	Study Case: TS		Config.:	Normal

The study is conducted on Addis Ababa region only

Project File: C:\ETAP 1260\LoadForecast_HV\LoadForecast
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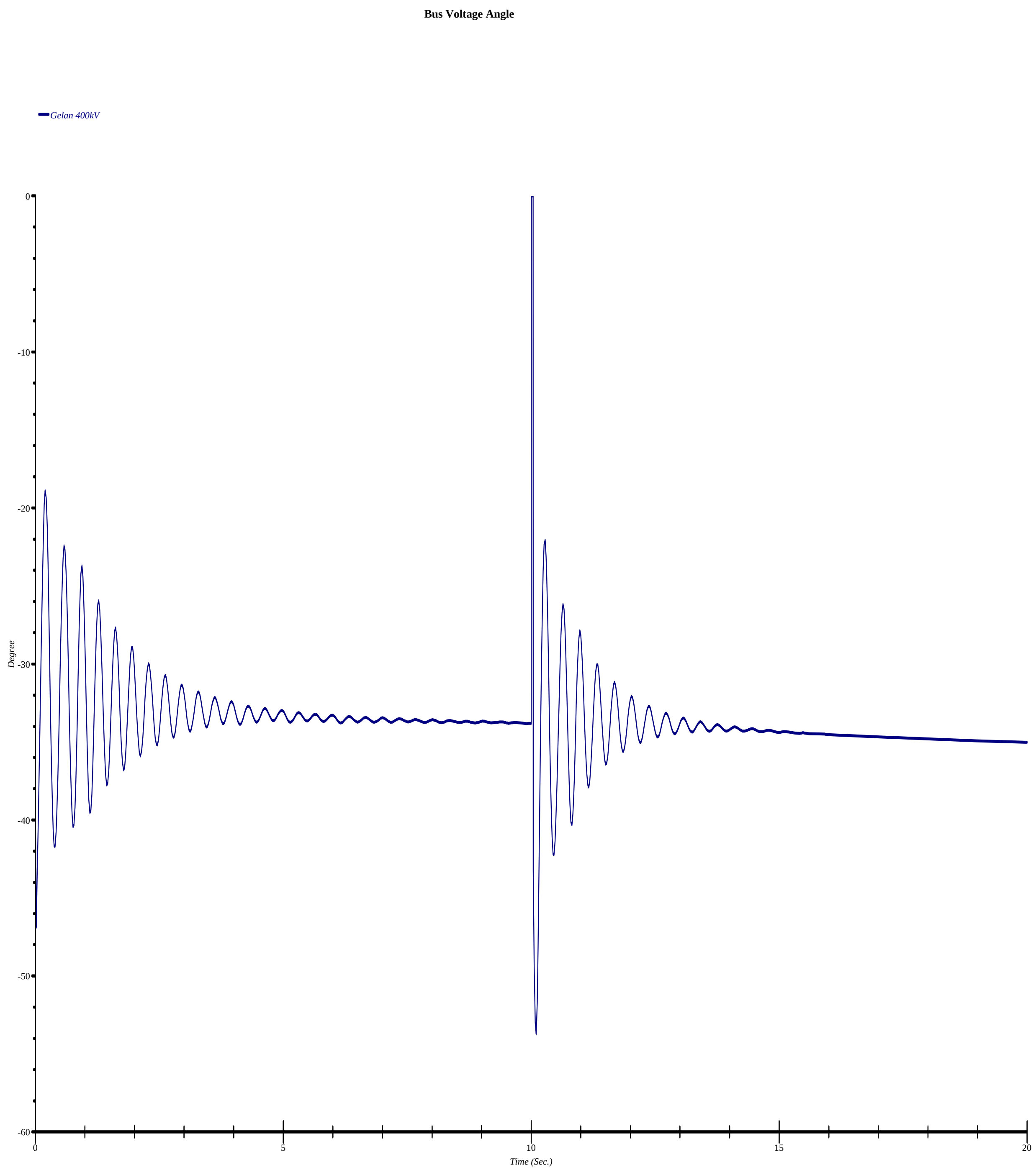
TRANSIENT STABILITY ANALYSIS



The study is conducted on Addis Ababa region only

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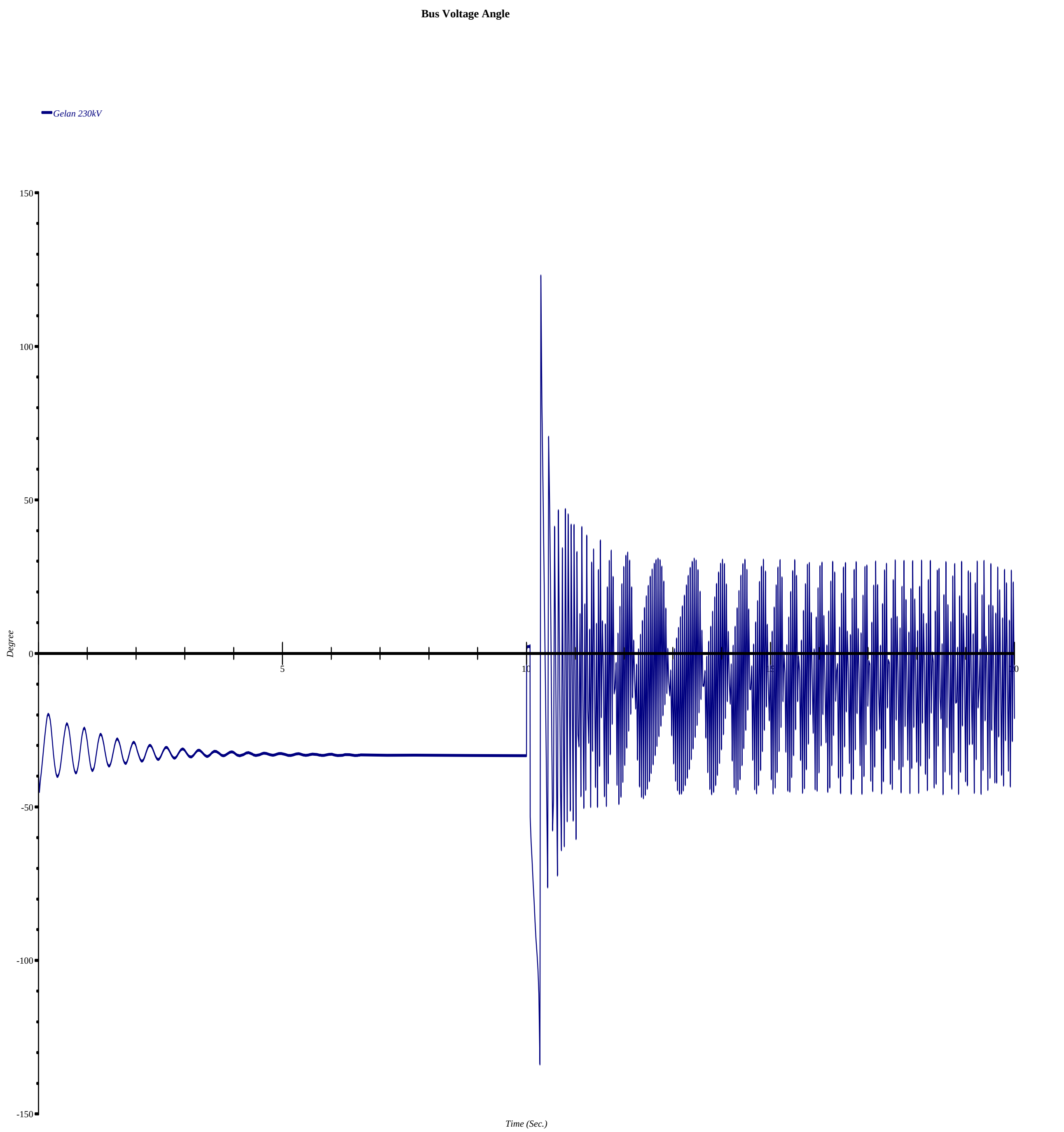
TRANSIENT STABILITY ANALYSIS



Project:	Loadforecast	ETAP 12.6.0H	Date:	06-13-2018
Location:	Addis Ababa		SN:	
Contract:	1		Revision:	Base
Engineer:	Abrham Workie	Study Case: TS	Config.:	Normal

The study is conducted on Addis Ababa region only

Project File: C:\ETAP 1260\LoadForecast_HV\LoadForecast
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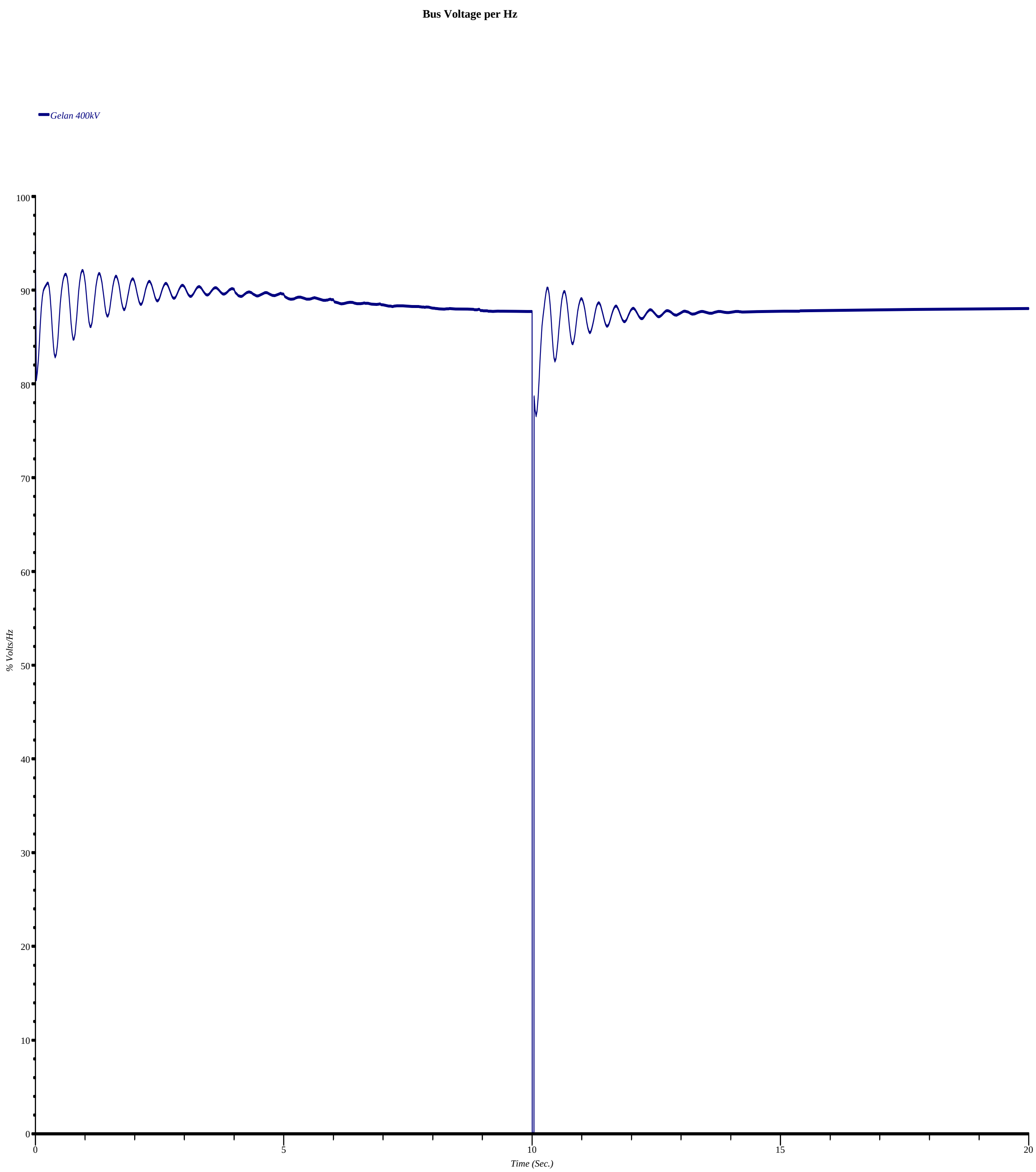
TRANSIENT STABILITY ANALYSIS



The study is conducted on Addis Ababa region only

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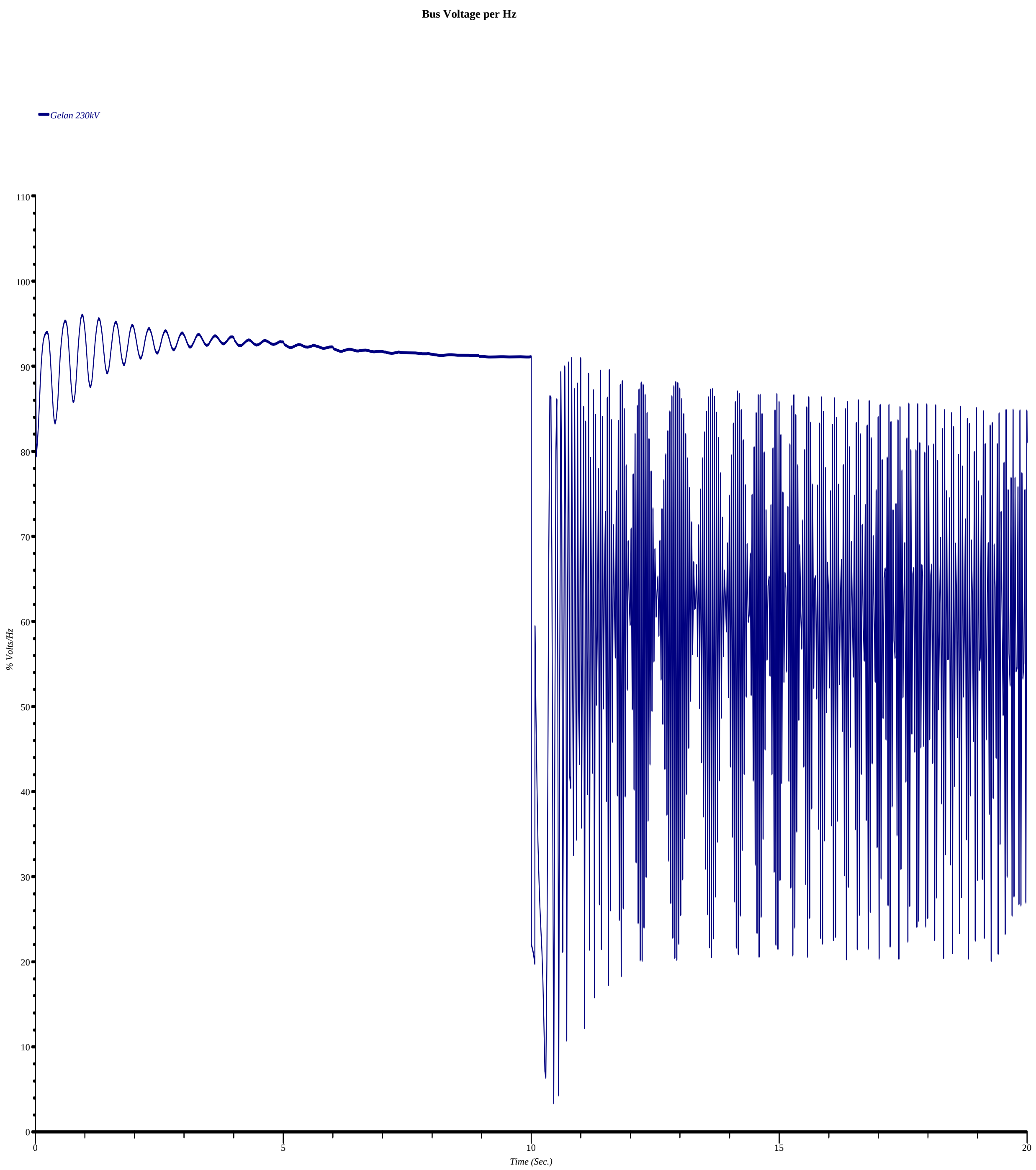
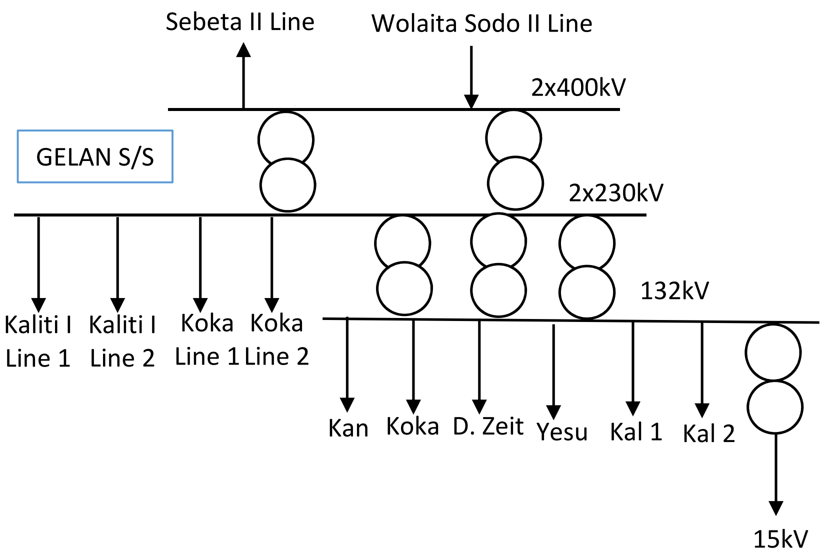
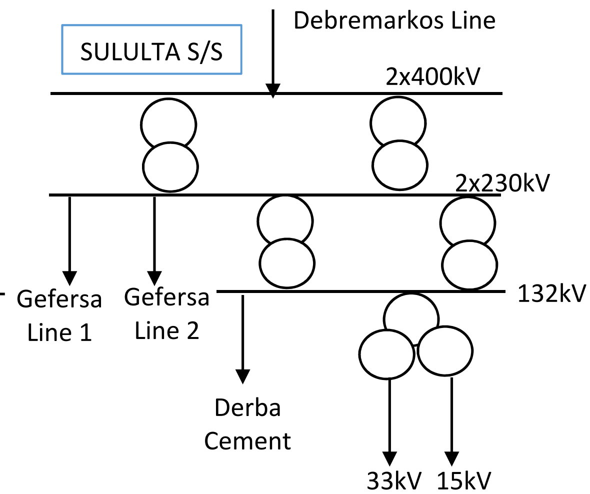
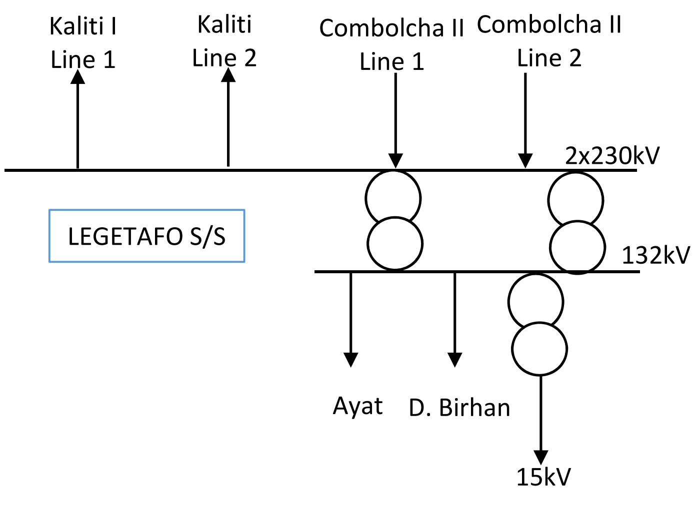
TRANSIENT STABILITY ANALYSIS

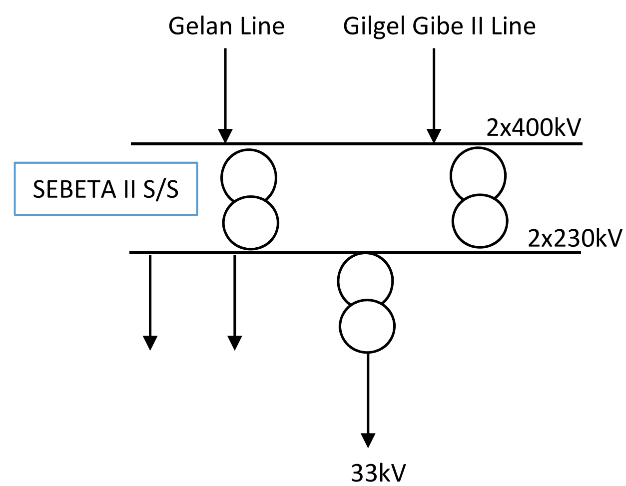


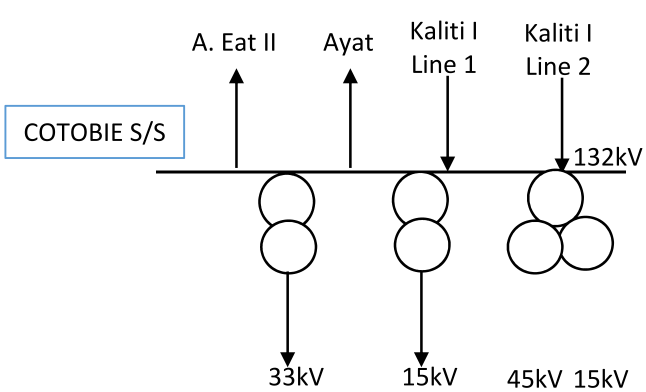
Appendix D - SLD of Substations in AATS

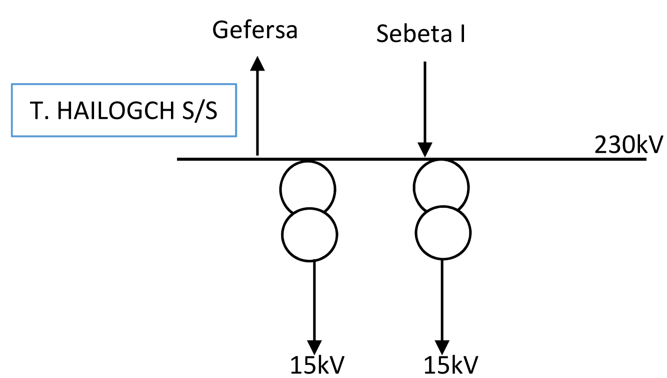


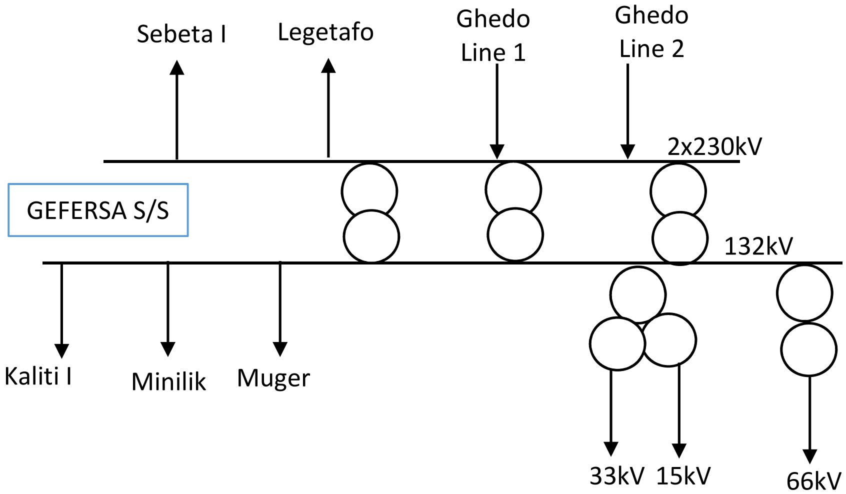


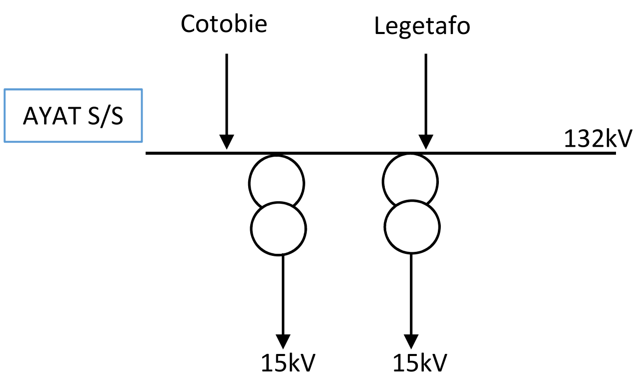


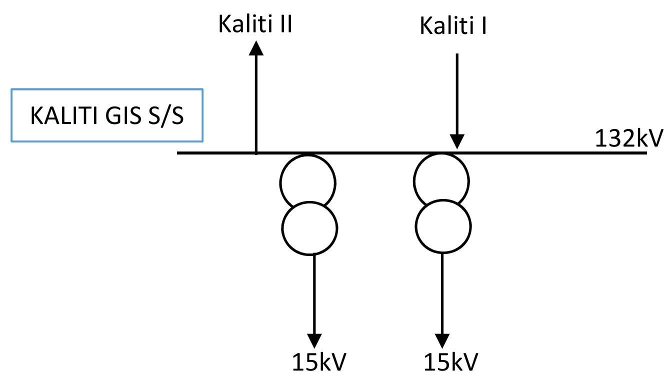


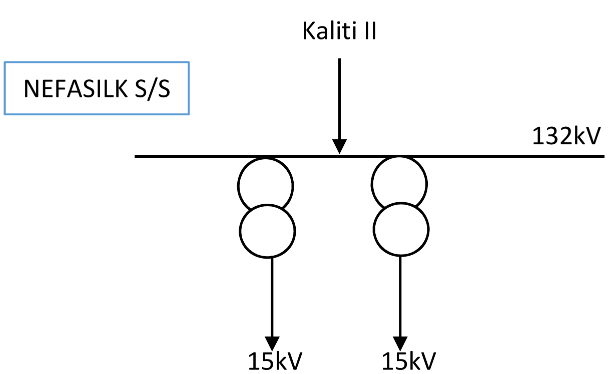


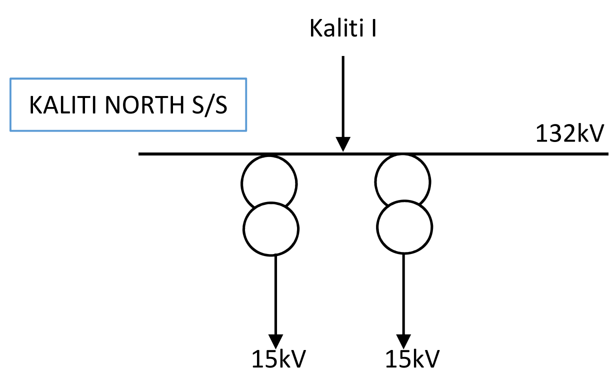


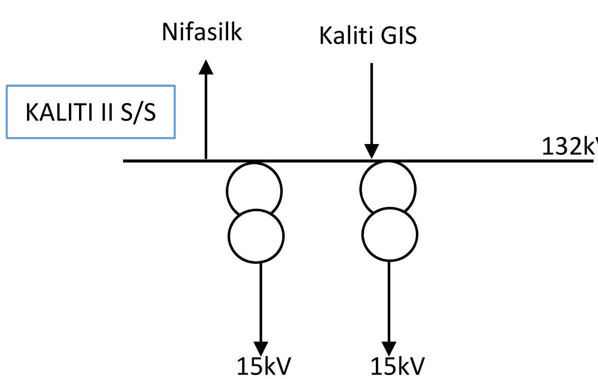

Sebeta I
Legetafo
Ghedo Line 1
Ghedo Line 2
2x230kV
GEFERSA S/S
132kV
Kaliti I
Minilik
Muger
33kV
15kV
66kV

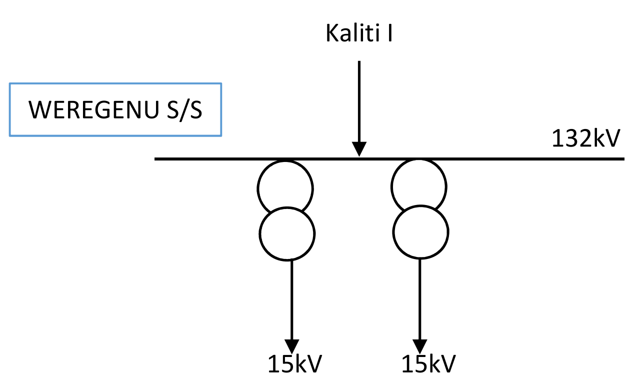

Cotobie
Legetafo
AYAT S/S
132kV
15kV
15kV

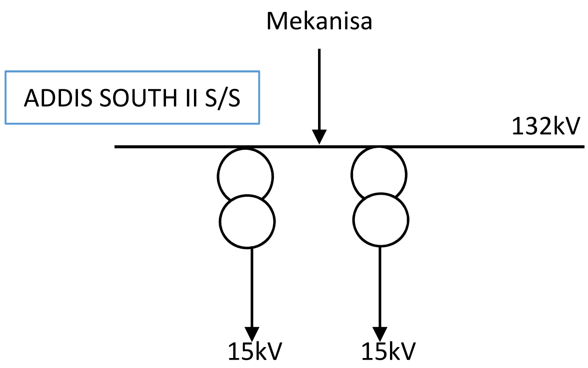

Kaliti II
Kaliti I
KALITI GIS S/S
132kV
15kV
15kV

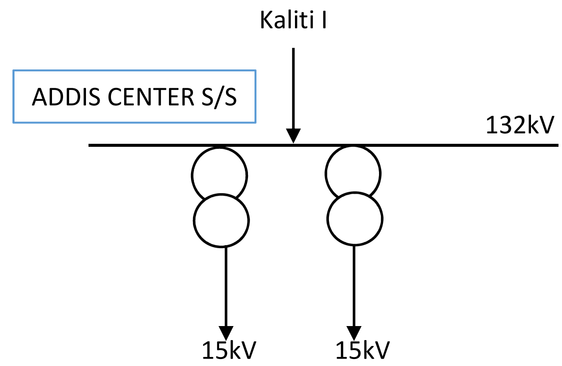

Kaliti II
NEFASILK S/S
132kV
15kV
15kV

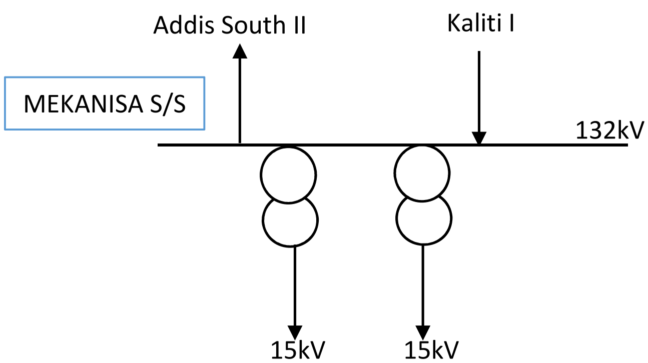

Kaliti I
KALITI NORTH S/S
132kV
15kV
15kV


Nifasilk
Kaliti GIS
KALITI II S/S
132kV
15kV
15kV


Kaliti I
WEREGENU S/S
132kV
15kV
15kV


Mekanisa
ADDIS SOUTH II S/S
132kV
15kV
15kV


Kaliti I
ADDIS CENTER S/S
132kV
15kV
15kV


Addis South II
Kaliti I
MEKANISA S/S
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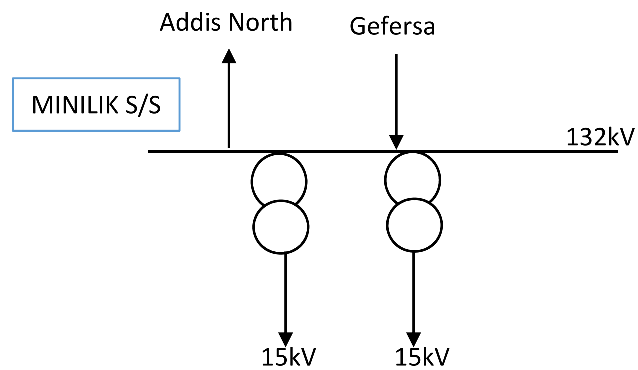
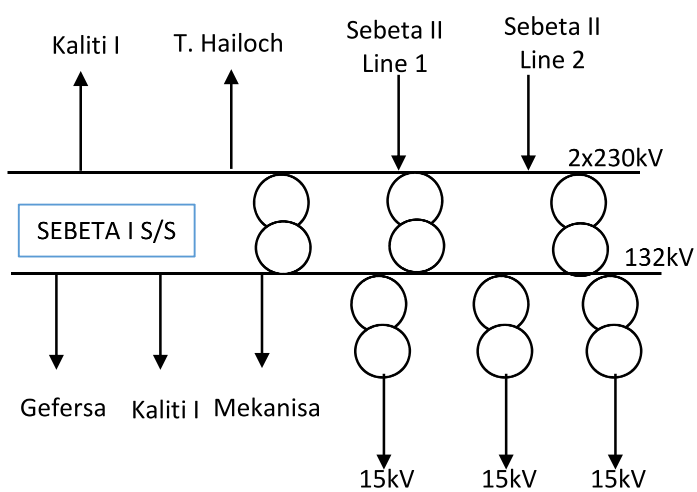
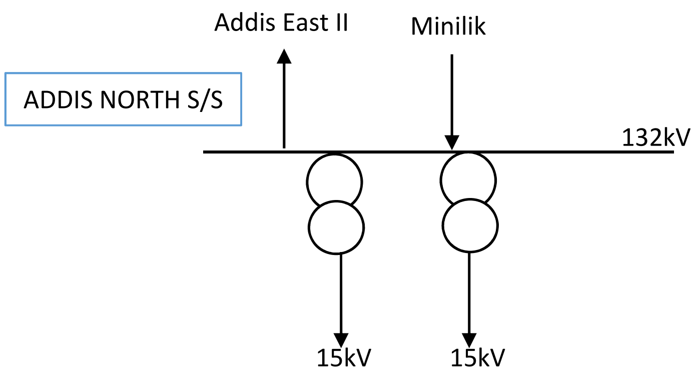
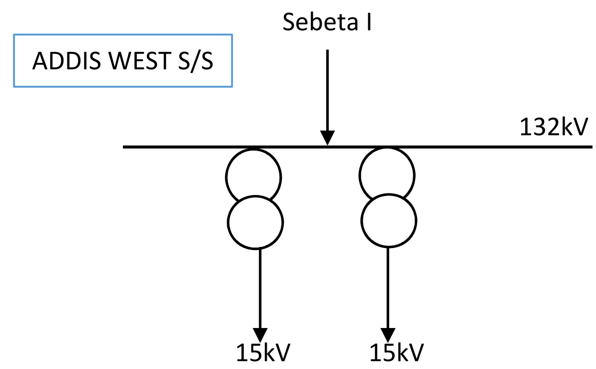
15kV
15kV


Addis North
Gefersa
MINILIK S/S
132kV
15kV
15kV


Kaliti I
T. Hailoch
Sebeta II Line 1
Sebeta II Line 2
2x230kV
SEBETA I S/S
132kV
Gefersa
Kaliti I
Mekanisa
15kV
15kV
15kV


ADDIS NORTH S/S
Addis East II
Minilik
132kV
15kV
15kV


ADDIS WEST S/S
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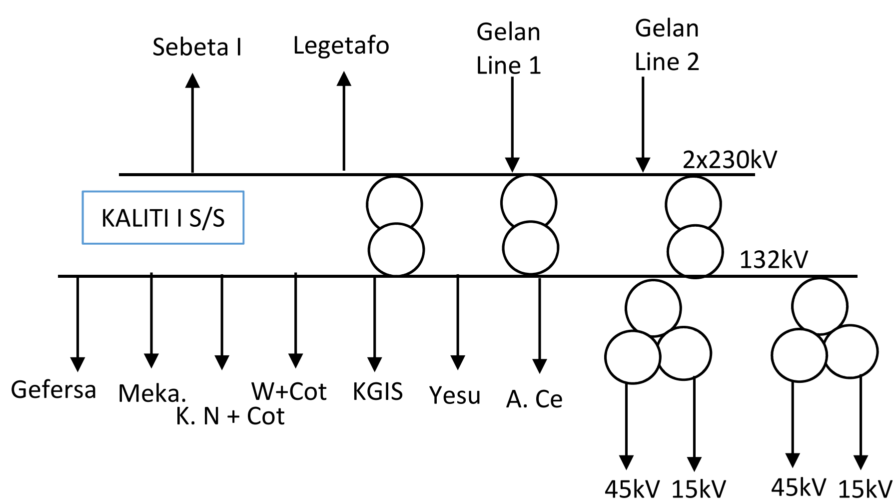
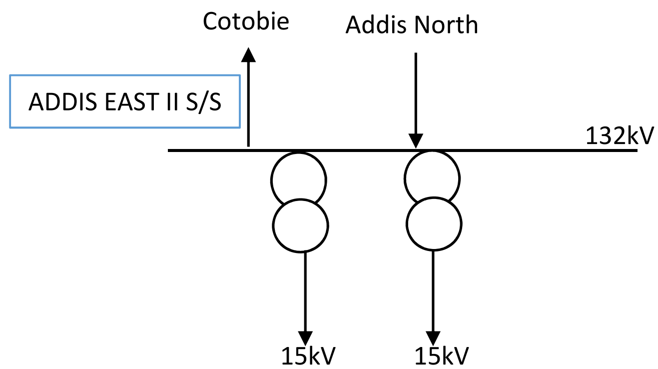
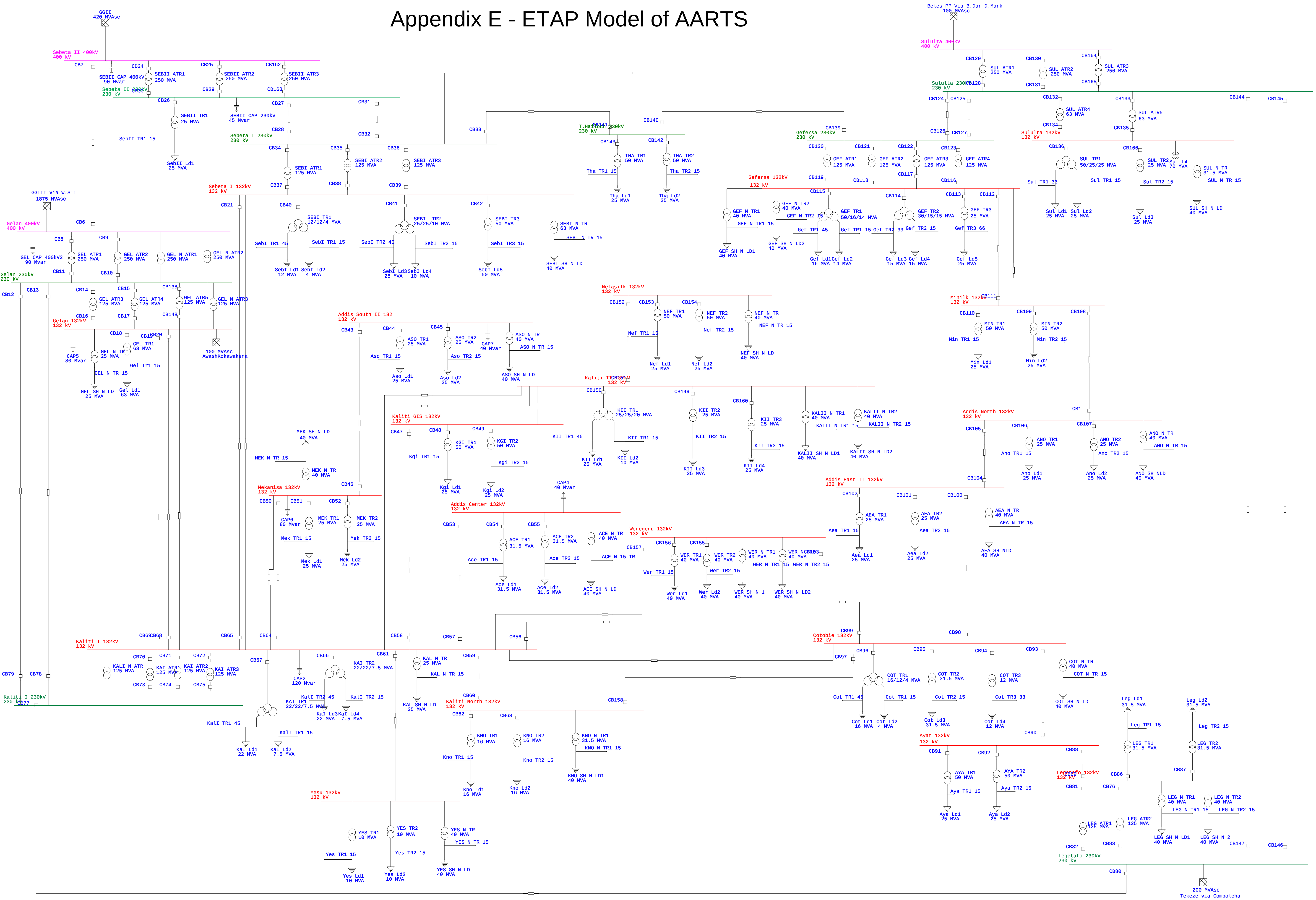
15kV

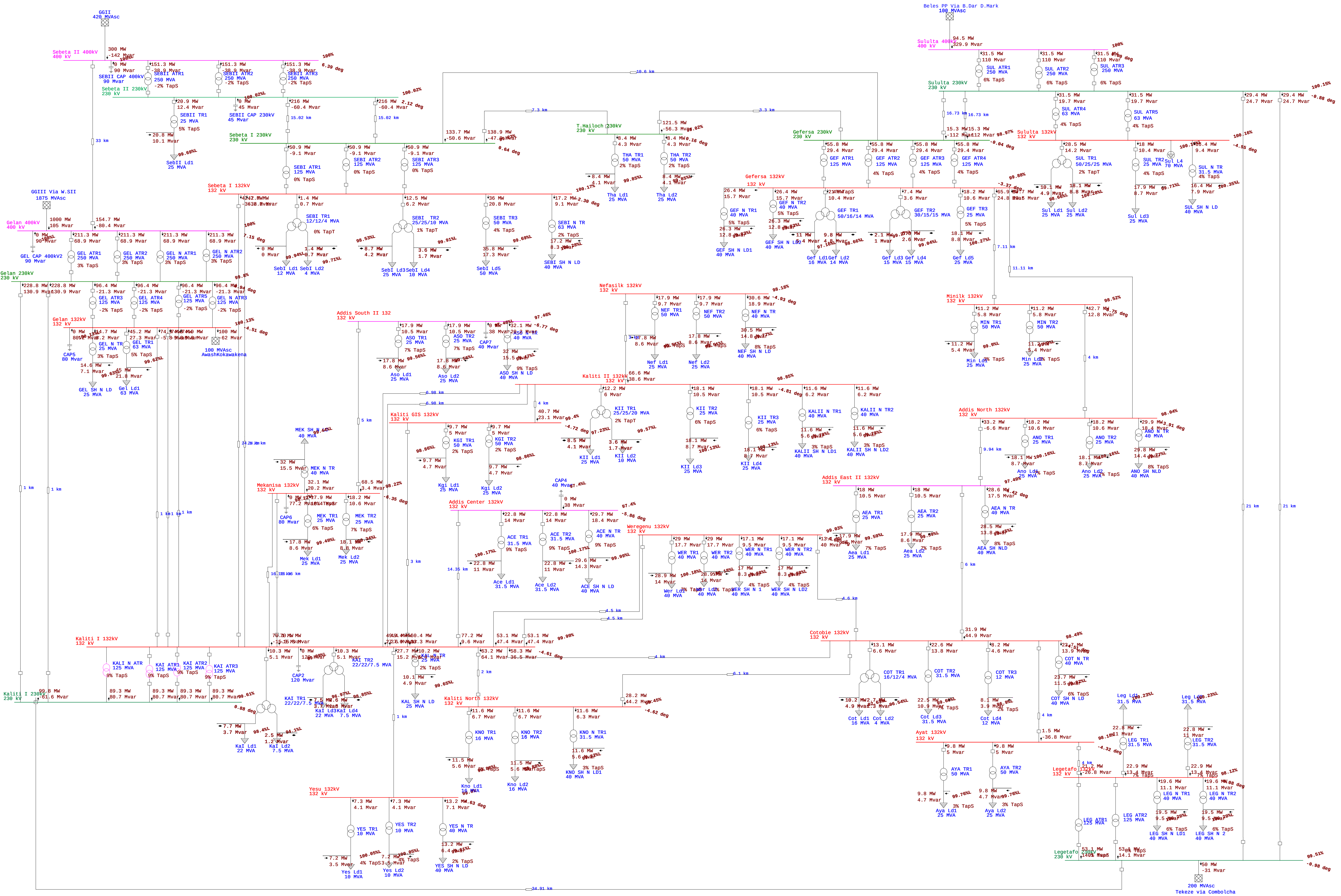

Sebeta I
Legetafo
Gelan
Line 1
Gelan
Line 2
2x230kV
KALITI I S/S
132kV
Gefersa
Meka.
K. N + Cot
W+Cot
KGIS
Yesu
A. Ce
45kV
15kV
45kV
15kV


Cotobie
Addis North
ADDIS EAST II S/S
132kV
15kV
15kV

Appendix E - ETAP Model of AARTS



One-Line Diagram - OLV1 (Load Flow Analysis)



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