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A

Project Report

On

**"LOAD FLOW ANALYSIS IN POWER SYSTEM USING ETAP SOFTWARE"**

Project Report Submitted in partial fulfillment of the requirements

Of the degree of

**Bachelor of Engineering in Electrical Engineering**

Submitted by

Nikita Devkar (17DEE46)

Anis Nayakwadi (17DEE57)

Sachin Pandey(17DEE58)

Siddharth Patil (17DEE59)

UNDER THE GUIDANCE OF

Prof. Tahoora Qureshi

**DEPARTMENT OF ELECTRICAL ENGINEERING**

ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS

NEW PANVEL-410206

**UNIVERSITY OF MUMBAI**

Academic year 2019-2020



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Submitted by:

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- Siddharth Patil (17DEE59)

Date :-

(Prof. TAHOORA QURESHI )
Project Guide

Approved by:-

(Prof. SYED KALEEM)
Head of Department

(Dr. ABDUL RAZZAK HONNUTAGI)
Director



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# CERTIFICATE

This is to certify that the below mention students has satisfactorily completed his project work titled "**LOAD FLOW ANALYSIS IN POWER SYSTEM USING ETAP SOFTWARE".** Along with his batch mates in partial fulfillment for the **Bachelor of Engineering in Electrical Engineering** under the **UNIVERSITY OF MUMBAI** during the academic year 2019-2020.

- Nikita Devkar (17DEE46)
- Anis Nayakwadi (17DEE57)
- Sachin Pandey(17DEE58)
- Siddharth Patil (17DEE59)

In a manner satisfactory to warrant is acceptance as a pre-requisite to their Degree in Bachelor of Electrical Engineering.

Date:- ----------------

Internal Examiner External Examiner

(Prof. TAHOORA QURESHI)



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# DECLARATION

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

**DATE ……………………..**

NIKITA DEVKAR ………………….

ANIS NAYAKWADI ……………….

SACHIN PANDEY ………………….

SIDDHARTH PATIL ………………..



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# ACKNOWLEDGEMENTS

It is a matter of great pleasure and proud privilege to be able to present this project "LOAD FLOW ANALYSIS IN POWER SYSTEM USING ETAP SOFTWARE".

We would like to express our deep regards and gratitude to the Head of the department **Mr. SAYYED KALEEM.**

The completion of this project work is a milestone in student life and its execution is inevitable in the hands of a guide. We are highly indebted to our project guide **Prof. TAHOORA QURESHI**, for his invaluable guidance and appreciation for giving form and substance to this report. It is due to his enduring efforts, patience, and enthusiasm which has given this project a sense of direction and purposefulness to this project and ultimately made it in success.

We would also like to tender our sincere thanks to the staff members for their co-operation.

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# ABSTRACT

ETAP **(Electrical Transient Analysis Program)** 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, and optimization and energy management systems. It is invented and started in California, USA from1986. It is widely used for more than 30 years for power system studies across the world.

ETAP has been designed and developed by engineers for engineers to handle the diverse discipline of power systems for a broad spectrum of industries in one integrated package with multiple interface views such as AC and DC networks, cable raceways, ground grid, GIS, panels, arc flash, WTG, protective device coordination/selectivity, and AC and DC control system diagrams.

The project is based on load flow analysis of power system using etap software. Load flow analysis helps to determine the active power flow, reactive power flow, power factor, losses, bus voltage profiles etc. in the system. The study also target to analyse the load flow result outcomes, its improvement and mitigation.

Here, initially we have considered a simple SLD and modelled it in the etap software. Additionally, the simulated results from the etap software for simple SLD are compared and validated with the manual calculation also.

Further, the main SLD is constructed in etap with the detailed modelling of electrical equipment's such as grid, transformers, loads etc. The project is performed with consideration of two configurations 'Normal Configuration' and 'One_TR_Out Configuration'.

The load flow study results are simulated for various operating conditions (maximum, minimum and normal) of generator and load. From the study results it is observed that during Minimum load flow case overvoltage's are observed at 0.415 kV LV buses Bus3 & Bus5 as 107.7 %. However, with +2.5% tap setting of transformers T2 & T4 the voltages at Bus3 & Bus5 reduces within the voltage violation limit of ± 5%.

During maximum load flow case it is observed that transformer T1 is supplying power to all downstream system of 6.6 kV and 0.415 kV (as the other two transformer's T3 & T4 are out of service) causes overloading of transformer T1. To overcome this situation, the transformer T1 & T3 ratings are increased to 31.25 MVA using ONAF cooling; and OLTC tap limit to increased to ±15%. With this solution, it is observed that there is no overloading of any equipment an also the bus voltage profiles are well within the acceptable limit of ±5%.



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# LIST OF ABBREVIATION

**ETAP**- Electrical Transient Analysis Program

**SLD**- Single Line Diagram

**UGS**- Underground Raceway System

**LF**- Load Flow

**SC**- Short Circuit

**M.S**- Motor Start

**H.A**- Harmonic Analysis

**T.S**- Transient Stability

**R.C**- Relay Co-Ordination

**DCLF**- DC Load Flow

**DCSC**- DC Short Circuit

**GUI**- Graphical User Interface



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# Contents





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# CHAPTER-1
# INTRODUCTION

## INTRODUCTION OF ETAP SOFTWARE

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 and energy management systems. ETAP is invented and started in California, USA from 1986. It is globally in market for more than 30 years. It can run with Microsoft Windows 2012, 2016, 7, 8, 8.1 and 10 operating systems.

ETAP has been designed and developed by engineers for engineers to handle the diverse discipline of power systems for a broad spectrum of industries in one integrated package with multiple interface views such as AC and DC networks, cable raceways, ground grid, GIS, panels, arc flash, WTG, protective device coordination/selectivity, and AC and DC control system diagrams.

The ETAP software is available in following Multi-languages:

- English
- Chinese
- Japanese
- Korean
- Russian
- French
- Spanish
- Portuguese

In ETAP, the following data exchange options are available for importing or exporting the data

- Import IEEE format
- Import RAW format
- Import SKM projects
- Export Autocad file
- Export Metafile
- Export to PSCAD

- Import & Export from Excel

The ETAP software has capability to perform studies used for different frequencies

- 50 Hz – IEC
- 60 Hz – IEEE/ ANSI (in USA)

Various Models available in ETAP:

- One line diagram
- Underground raceway system
- Control system schematics
- Cable sizing
- Rail Traction system
- Renewable system
- Integrate with real time system

**<u>One line diagram</u>**

- ETAP provides an easy to use, fully Graphical User Interface (GUI) for constructing one-line diagrams.
- Here we can graphically add, delete, relocate, connect elements, zoom in or out, display grid off or on, change element size, change element orientation, change symbols, change equipment/device color, create personalized viewing themes, hide or show protective devices, enter properties, set operating status, etc.

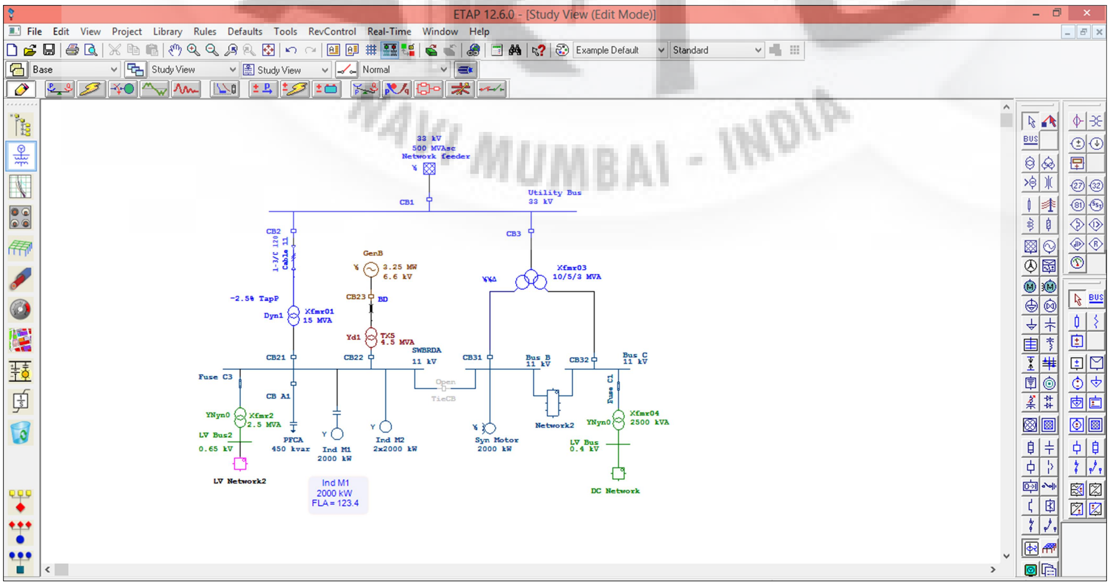


Figure 1 One Line Diagram created in ETAP



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**Underground raceway system**

- When we are designing a new system, this determines the proper size of cables to carry the specified loads.
- When performing an analysis of an existing system, it examines cable temperatures and determines their ampacities.
- The steady-state temperature calculation is based on the IEC 60287 or the NEC accepted Neher-McGrath method.

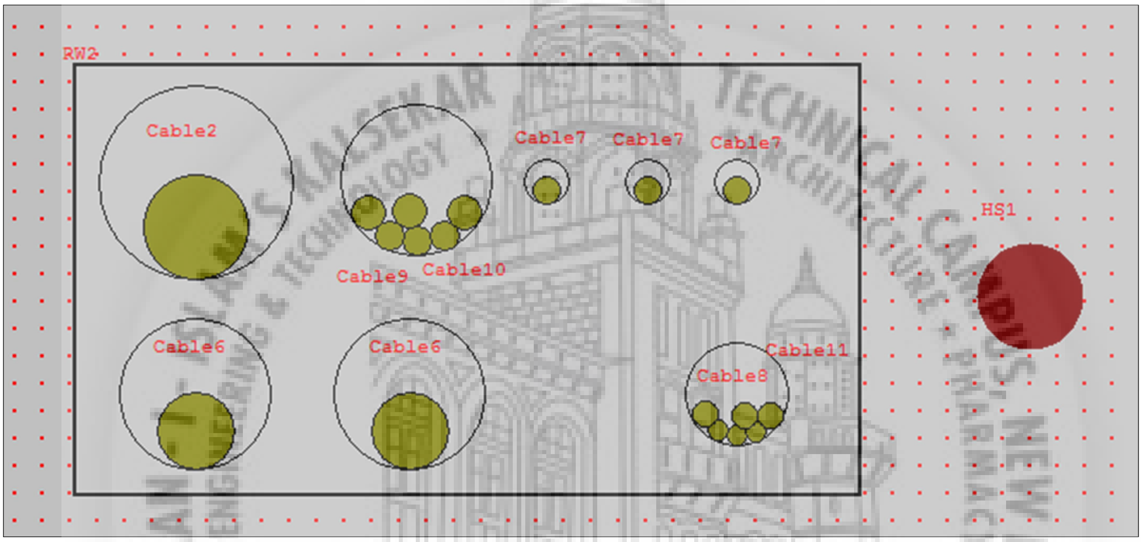


Figure 2 View of UGS system

**Control system schematics**

- The ETAP User-Defined Dynamic Models (UDM) program is a graphic logic editor (GLE) interpreter tool which allows the creation of user-defined governor, exciter, and Power System Stabilizer (PSS) models for synchronous machines, generic load and wind turbine generator models.

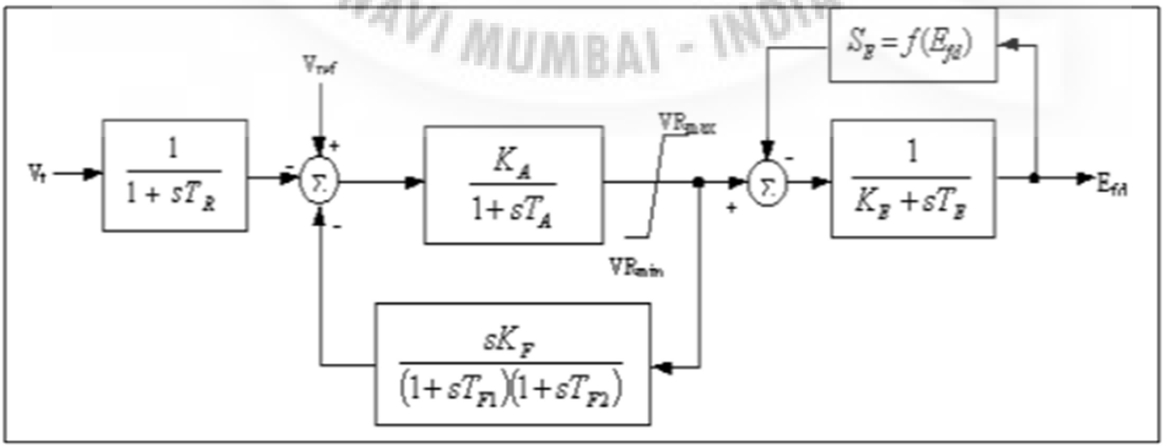

Figure 3 IEEE- Type 2 Exciter block diagram

**IEEE- Type 2 Exciter block diagram modelled in ETAP UDM**

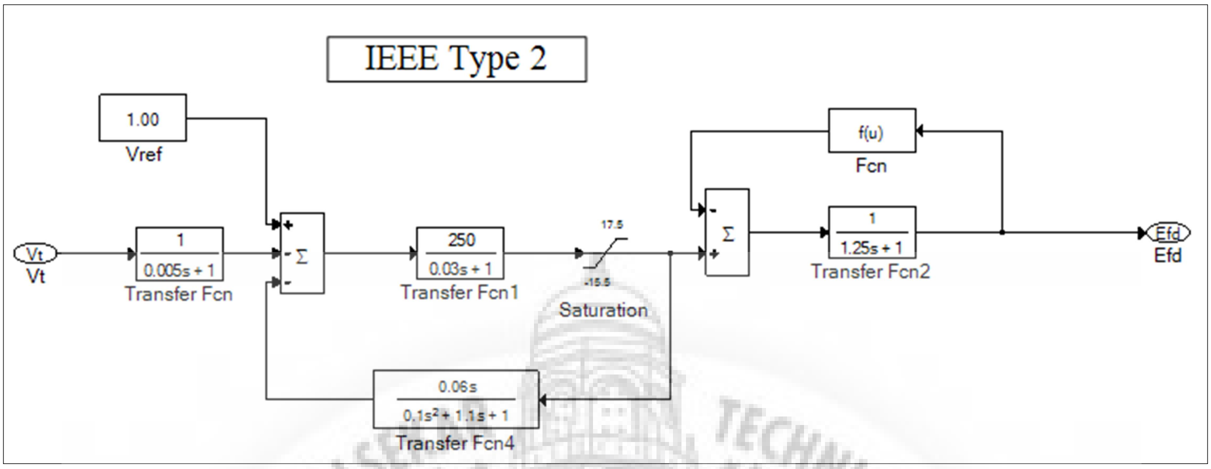


Figure 4 IEEE- Type 2 Exciter modelled in ETAP using UDM feature

**Cable sizing**

It can perform the cable sizing study as per below standards:

- BS 7671
- IEC 60364-5-52 (LV cable sizing)
- IEC 60502 (HV cable sizing)
- IEEE 399
- NEC

**Rail Traction system (e-trax)**

- eTraX includes the most accurate, user-friendly and flexible software tools for analysing and managing low and medium voltage rail power systems.
- Using advanced geospatial asset information, eTraX allows for the modelling, simulation, prediction and optimization of rail infrastructure.


Figure 5 e-Trax system

**Integrate with real time system**

ETAP Real-Time integrates with existing metering devices, programmable logic controllers, data acquisition, and archiving systems to provide the following exclusive features and capabilities:

- Advanced monitoring, simulation, and control
- Predict system response to operator actions
- Fast, optimal, and intelligent load shedding, and restoration
- System optimization, and automation
- Demand-Side Management
- Intelligent one-line diagrams
- Multi-dimensional database
- Time domain event playback with simulation capability
- Integrated alarm, warning, and acknowledgement
- Client-server configuration
- Built-in redundancy, and automatic fail over

**DC System**

The DC power system is an integral part of the entire electric power system, providing power to control circuits and backup power during emergency conditions.

It includes DC power sources, their distribution systems, and vital supporting systems that supply power to critical equipment.

A variety of DC components and AC-DC power conversion components are available to model the DC power system, including:

- DC battery
- DC bus and node
- DC cable
- DC machine, static load, lumped load, and Composite CSD (CCSD) load
- DC protective devices, such as circuit breaker, fuse, switch, and contact
- DC composite network and DC composite motor
- DC-DC converter
- AC-DC power conversion components, such as charger/rectifier, inverter, and UPS

ETAP can perform following studies for DC system:

- DC Load Flow Analysis
- DC Short Circuit Analysis
- DC Arc Flash Analysis
- Battery Sizing & discharge Analysis

**AC system studies**

Following Offline AC system analysis can be done using ETAP:

- Load Flow Analysis
- Short Circuit Analysis
- Transient Stability Studies
- Harmonic Analysis
- Protection & Relay Co-ordination Studies
- Cable Sizing
- Transformer Sizing

Since Etap has incorporated all the necessary features for Electrical Studies, it is preferred compared to other software's.

## THREE KEY CONCEPTS

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

**1. Virtual Reality Operation**

The program operation emulates real electrical system operation as closely as possible. For example, when we 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.

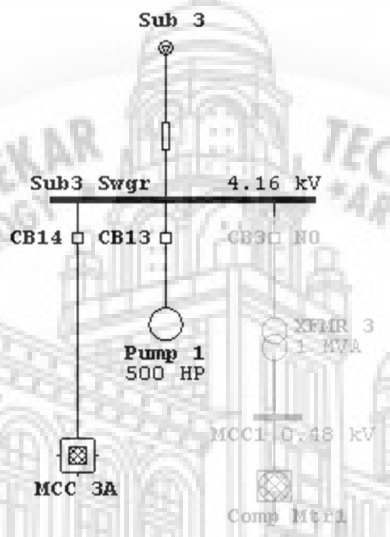


Figure 6 Component modelled in ETAP

**2. 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 de-rating 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.

**3. 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.

ETAP's one-line diagram supports a number of features to assist us in constructing networks of varying complexities.



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For example, each element can have individually varying orientations, sizes, and display symbols (IEC or ANSI). The one-line diagram also allows us to place multiple protective devices between a circuit branch and a bus.

**IEC Elements & ANSI (IEEE) Elements**

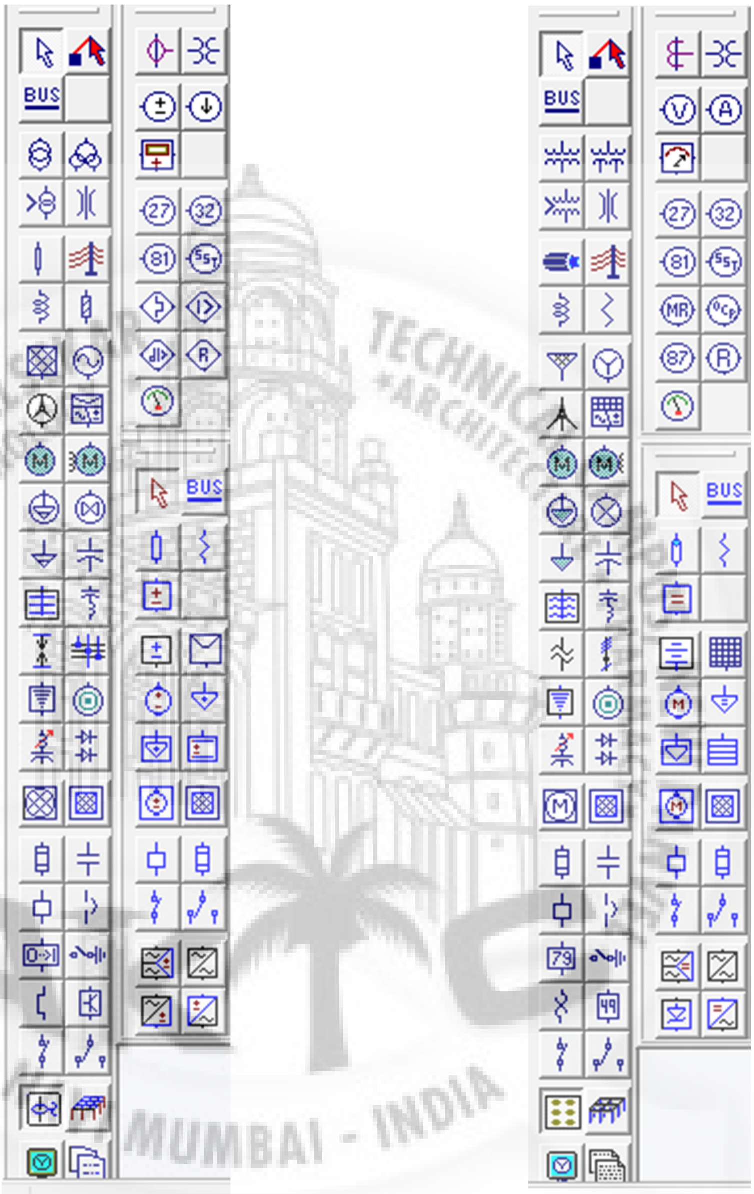

Figure 7 IEC Elements & ANSI Elements View in ETAP

## Presentation View

- ETAP provides us with a variety of options for presenting or viewing the 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).

- **Relay View**

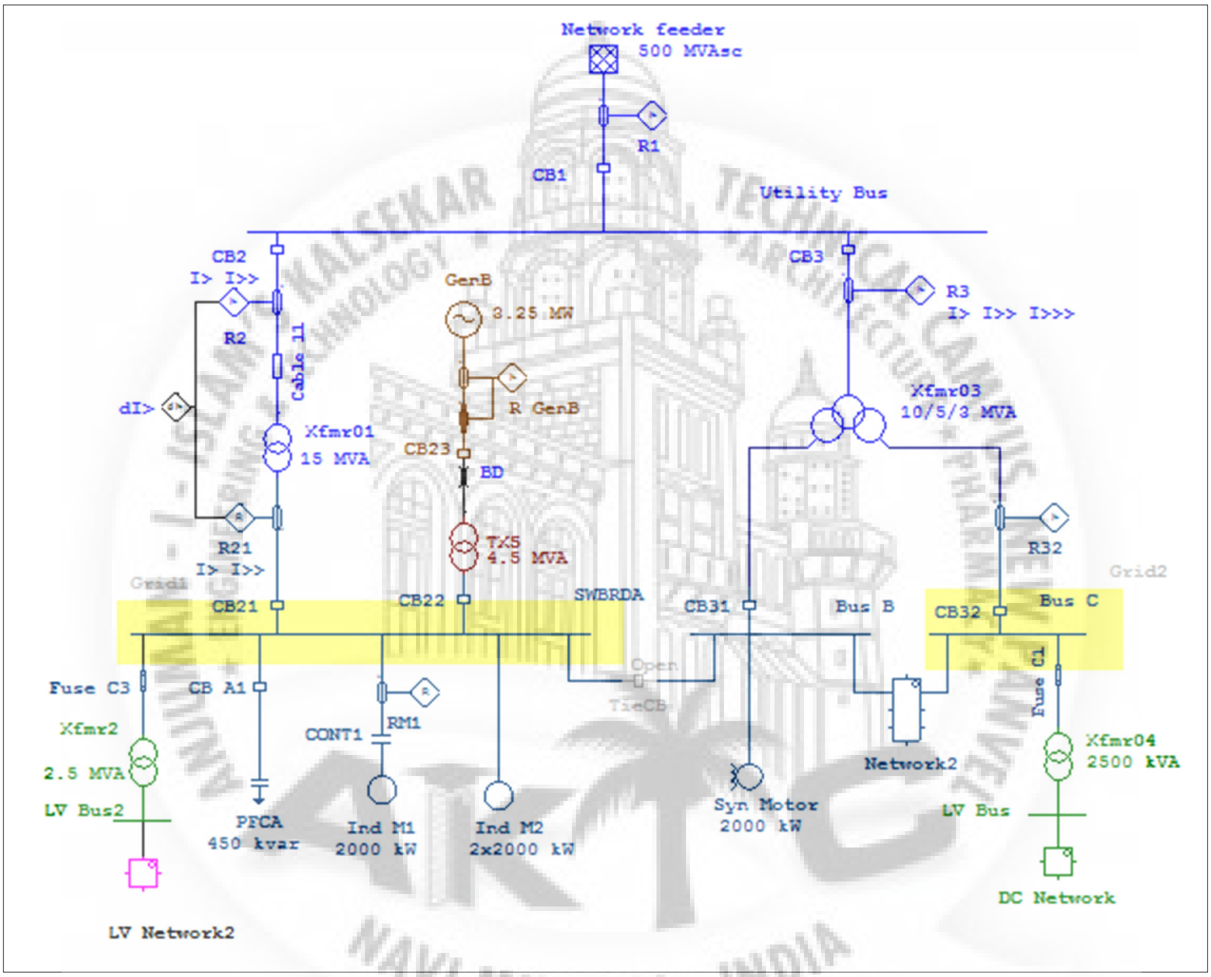


Figure 8 Relay View

## ➢ One line diagram view

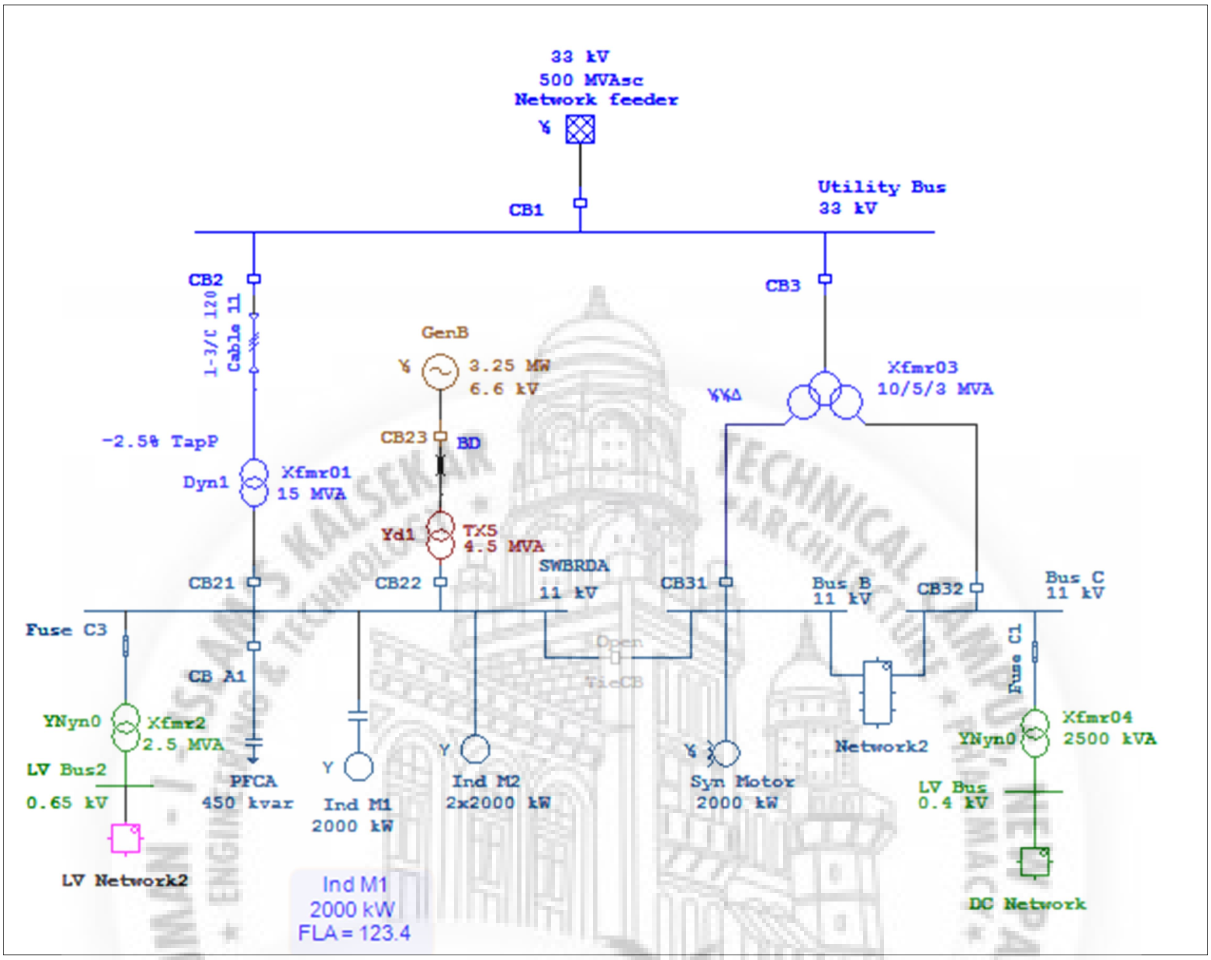

Figure 9 One line diagram view

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# CHAPTER-2

## ABOUT LOAD FLOW STUDY

The ETAP Load Flow Analysis module calculates the

- Bus Voltage Profiles and Phase Angles at each bus
- Voltage Drops
- Total Generation & Power Demand
- Branch losses
- Branch Power Factors
- Branch Currents
- Active, Reactive and Apparent power Flows throughout the electrical system
- Transformer LTC Settings

ETAP allows load flow analysis for swing, voltage regulated, and unregulated power sources with multiple power grids and generator connections. It is capable of performing analysis on both radial and loop systems. ETAP allows us to select from several different methods in order to achieve the best calculation efficiency.

ETAP provides four load flow calculation methods:

- **Newton-Raphson and Adaptive Newton-Raphson Method**

The Newton-Raphson method formulates and solves iteratively the following load flow equation:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} = \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix}$$

where :-

- ΔP and ΔQ are bus real power and reactive power mismatch vectors between specified value and calculated value, respectively;
- ΔV and Dδ represents bus voltage angle and magnitude vectors in an incremental form; and
- J1 through J4 are called Jacobian matrices.

- **Fast-Decoupled Method**

The Fast-decoupled method is derived from the Newton-Raphson method.



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It takes the fact that a small change in the magnitude of bus voltage does not vary the real power at the bus appreciably, and likewise, for a small change in the phase angle of the bus voltage, the reactive power does not change appreciably.

Thus the load flow equation from the Newton-Raphson method can be simplified into two separate decoupled sets of load flow equations, which can be solved iteratively:

$$[\Delta P] = [J_1][\Delta \delta]$$
$$[\Delta Q] = [J_4][\Delta V]$$

- **Accelerated Gauss-Seidel Method**

From the system nodal voltage equation

$$[I] = [Y_{BUS}][V]$$

the Accelerated Gauss-Seidel method derives the following load flow equation and solves it iteratively:

$$[P + jQ] = [V^T][Y^*_{BUS}][V^*]$$

These methods possess different convergent characteristics, and sometimes one is more favourable in terms of achieving the best performance. We can select any one of them depending on our system configuration, generation, loading condition, and the initial bus voltages.

In this project the **Adaptive Newton-Raphson method** is used for load flow calculations.



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# CHAPTER-3

## VALIDATION OF ETAP RESULTS WITH MANUAL CALCULATION

The simple SLD as shown below, is modelled in the ETAP. The load flow analysis is performed on the considered SLD. The output results of ETAP are validated with the hand calculation. Following is the list of inputs considered in the study:

**Inputs Required:**

| Sr. No | Grid Data | | | |
|---|---|---|---|---|
| 1. | Rating | 33 | kV | |
| **Sr. No** | **Load Data** | | | |
| 1. | Voltage | 6.9 | kV | |
| 2. | MVA Rating (S) | 14 | MVA | |
| 3. | Pf | 0.85 | PU | |
| 4. | Active Power (P) | 11.9 | MW | (S* cos phi) |
| 5. | Reactive Power (Q) | 7.375 | MVAR | (P* tan phi) |
| 6. | Current (I) | 1171.5 | A | (S/ (1.732* Voltage) |
| **Sr. No** | **Transformer Data** | | | |
| 1. | MVA rating | 25 | MVA | |
| 2. | Impedance (%) | 10 | % | |
| 3. | X/R ratio | 9999 | | |
| 4. | Reactance (%) | 10 | % | Considering pure reactive system |
| 5. | Resistance (%) | 0.001 | % | Negligible |

**Calculation for Base values:**

| Sr. No | Calculation for Base values | | | |
|---|---|---|---|---|
| 1. | MVA base | 25 | MVA | |
| 2. | kV base | 6.9 | kV | |
| 3. | Z base | 1.904 | ohm | kV^2/MVA |
| 4. | Z actual for transformer | 0.190 | ohm | Zact=Zpu*Zbase |

**Voltage drop and loss calculation in transformer:**

| Sr. No | Voltage drop and loss calculation in transformer | | | |
|---|---|---|---|---|
| 1. | Sending end voltage (Vs) | 6.9 | kV | |
| 2. | Voltage drop | 0.223 | kV | (Load current |



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| | | | | |
|---|---|---|---|---|
| | | | | I*Zact) |
| 3. | Receiving end voltage (Vr) | 6.677 | kV | Vr=Vs-Vdrop |
| 4. | Actual Load Current (Iact) | **1210.61** | A | |
| 5. | Actual 3 phase losses | **837.31** | kVAR | 3 * $Iact^2$ * Zact |
| | | **0.837** | MVAR | |

**Power Flow at the grid:**

| **Sr. No** | **Power flow at the grid** | | | |
|---|---|---|---|---|
| 1. | Active Power (P) | **11.9** | MW | =Load MW (pure reactive system, hence real power loss is zero) |
| 2. | Reactive Power (Q) | **8.212** | MVAR | =Load MVAR + losses = 7.375+0.837 =8.212 MVAR |

From above, the hand calculated load flow results can be summarized as follows:

Table 1 Hand calculated load flow results

| **Sr. No** | **Hand calculated load flow results** | | |
|---|---|---|---|
| 1. | *Actual Load Current (Iact)* | **1210.61** | A |
| 2. | *Actual 3 phase losses* | **837.31** | kVAR |
| | | **0.837** | MVAR |
| 3. | *Active Power (P)* | **11.9** | MW |
| 4. | *Reactive Power (Q)* | **8.212** | MVAR |

**Simulation results in ETAP software:**

The below figure shows the real and reactive power flows, current flow in the system.

Table 2 Simulation results in ETAP software

| **Sr. No** | ***ETAP results*** | | |
|---|---|---|---|
| 1. | *Actual Load Current (Iact)* | **1209.8** | A |
| 2. | *Actual 3 phase losses* | **836.19** | kVAR |



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| | | | |
|---|---|---|---|
| | | **0.836** | MVAR |
| 3. | *Active Power (P)* | **11.9** | MW |
| 4. | *Reactive Power (Q)* | **8.211** | MVAR |

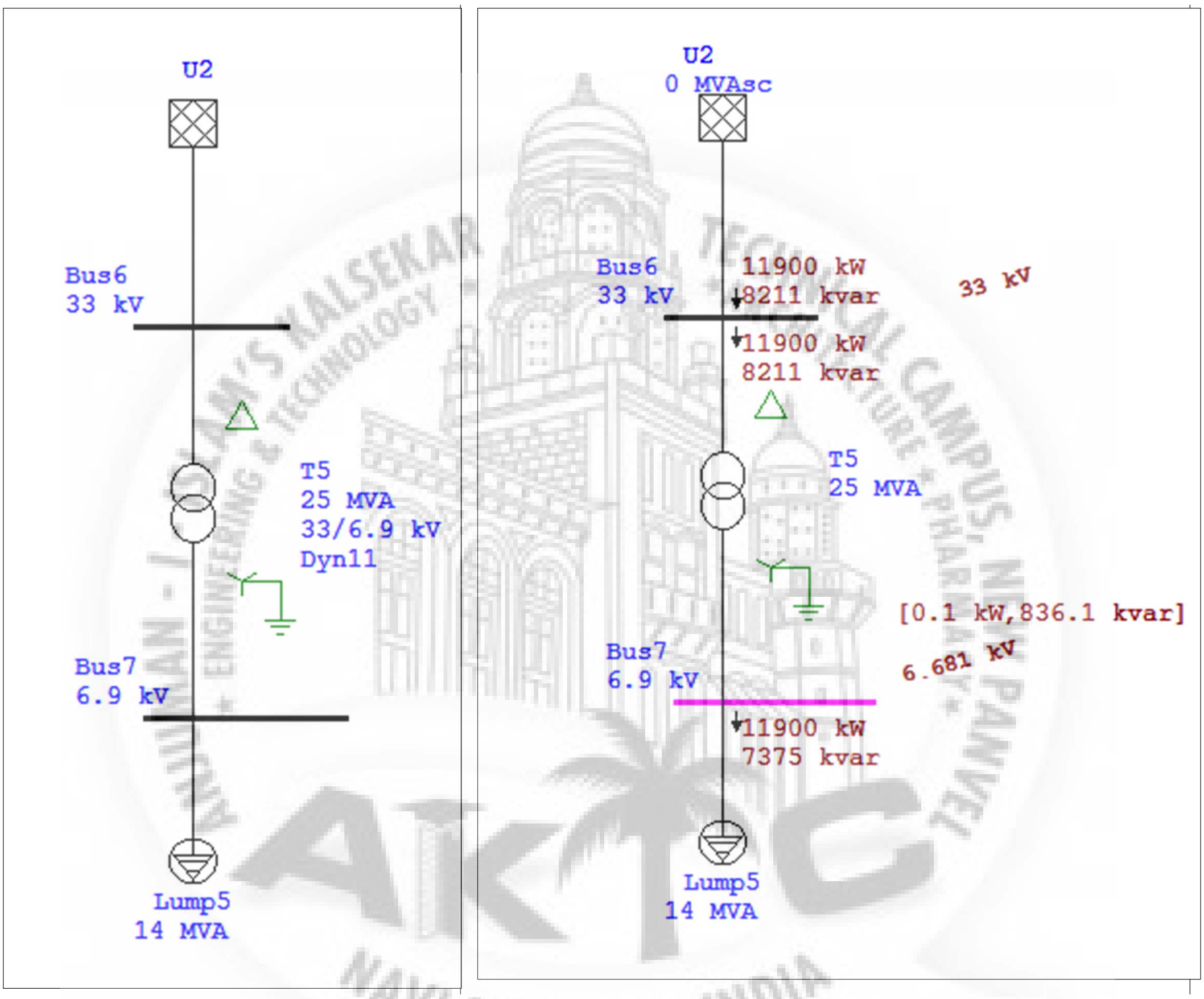


Figure 10 Active & Reactive power results in ETAP



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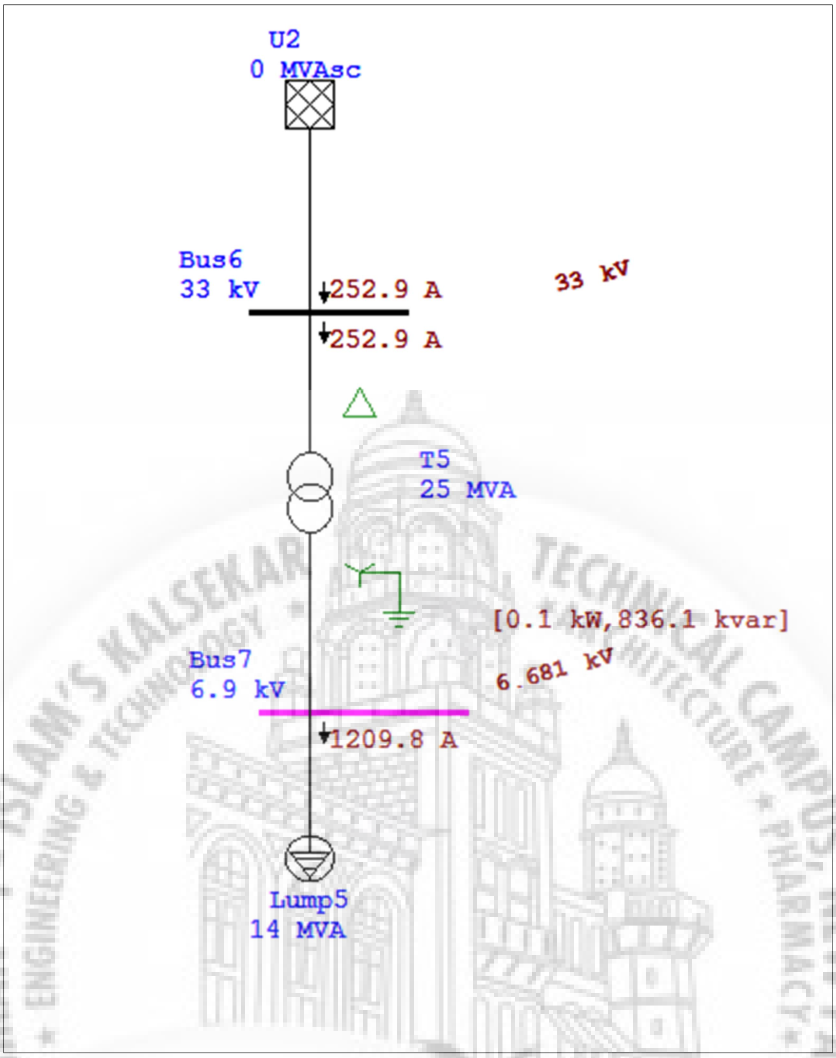


Figure 11 Load current results in ETAP

**Comparison between ETAP simulated results and Manual calculated results:**

Table 3 Comparison between ETAP simulated results and Manual calculated results

| Sr. No | Description | Manual calculated results | ETAP results | Unit |
|---|---|---|---|---|
| 1. | *Actual Load Current (Iact)* | **1210.61** | **1209.8** | **A** |
| 2. | *Actual 3 phase losses* | **837.31** | **836.19** | **kVAR** |
| | | **0.837** | **0.836** | **MVAR** |
| 3. | *Active Power (P)* | **11.9** | **11.9** | **MW** |
| 4. | *Reactive Power (Q)* | **8.212** | **8.211** | **MVAR** |

By above table it is observed that, the ETAP load flow analysis results and Manual calculated results are matches with each other. Hence validation of ETAP software results is done.

# CHAPTER-4

## SIMULATION IN ETAP

When we create a new one-line diagram presentation, we are initially in **Edit Mode** with the configuration status set to **Normal**, the default condition. The inputs considered for the study are as follows:

| COMPONENT ID | DISCRIPTION | RATING |
|---|---|---|
| U1 | GRID | 33 KV<br>SWING OPERATING MODE |
| T1 & T3 | TRANSFORMER | 25 MVA,<br>33/6.9 KV,<br>TYPICAL % Z,<br>TOLERANCE 10 %,<br>DYN11,<br>OLTC: ± 10%, 1.25 % STEPS |
| T2 & T4 | TRANSFORMER | 2.5 MVA,<br>6.6/0.433 KV,<br>TYPICAL %Z,<br>TOLERANCE 10 %,<br>DYN11 |
| LUMP1 & LUMP2 | LOAD | 14 MVA,<br>0 .85 PU POWER FACTOR,<br>6.6 KV |
| LUMP3 & LUMP4 | LOAD | 1 MVA,<br>0.85 PU POWER FACTOR,<br>0.415 KV |
| BUS1 | BUS | 33 KV |
| BUS2 & BUS4 | BUS | 6.6 KV |
| BUS3 & BUS5 | BUS | 0.415 KV |

The above mentioned inputs for each element are entered in etap and the load flow study is performed.

1. **<u>Modelling of grid</u>**
   The 100 % grid voltage is considered as 33 kV. And the grid operating mode is considered as swing source. In etap following operating modes for source are possible.

- **Swing** (%V and angle)

  For load flow studies, a swing power grid will take up the slack of the power flows in the system, i.e., the voltage magnitude and angle of the power grid terminals will remain at the specified operating values.



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There must be at least one swing machine (power grid or synchronous generator) connected to any isolated subsystem in the one-line diagram. We can have multiple swing machines connected to any bus in the system.

Any element that is connected to a swing machine is displayed as an energized element in the one-line diagram and will be included in for studies. Also, the rated voltage (kV) of a swing machine is used as the base kV of the connected bus. The base kVs of the rest of the system are then calculated using transformer turn ratios..

- **Voltage Control (**%V and MW)

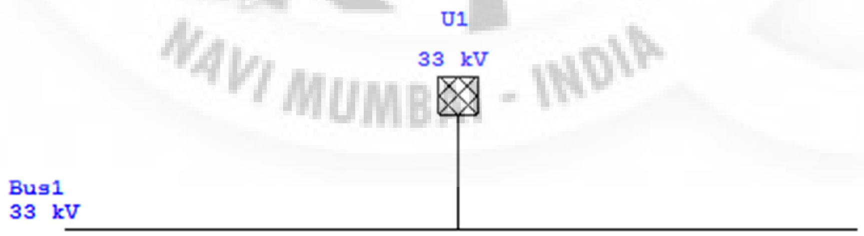
A power grid can be selected as a voltage control (regulated) system, which means that the power grid will adjust its Mvar output to control the voltage. Therefore, the terminal voltage magnitude, operating real power (MW), and minimum and maximum allowable reactive power supply (Max Q and Min Q) must be entered for voltage control power grids. A voltage control power grid means that the power grid is base loaded (fixed MW) with an Automatic Voltage Regulator (AVR) controlling the terminal voltage to a constant value. During load flow studies, if the calculated Mvar falls outside the Mvar capability limits (Max Q or Min Q limit), the value of the Mvar will be set equal to the limit and the power grid mode is changed to Mvar control.

- **Mvar Control** (MW and Mvar)

Using this option we can specify the amount of fixed MW and Mvar generation in the Rating page of the Power Grid Editor. An Mvar control power grid means that the power grid is base loaded (fixed MW) with a fixed Mvar generation (no AVR action).

- **PF Control (**MW and PF)

Setting the power grid in Power Factor (PF) Control allows us to specify the MW output as a fixed value on the Rating page. The Power Factor is also specified, ETAP calculates the out Mvar of the grid into the system.



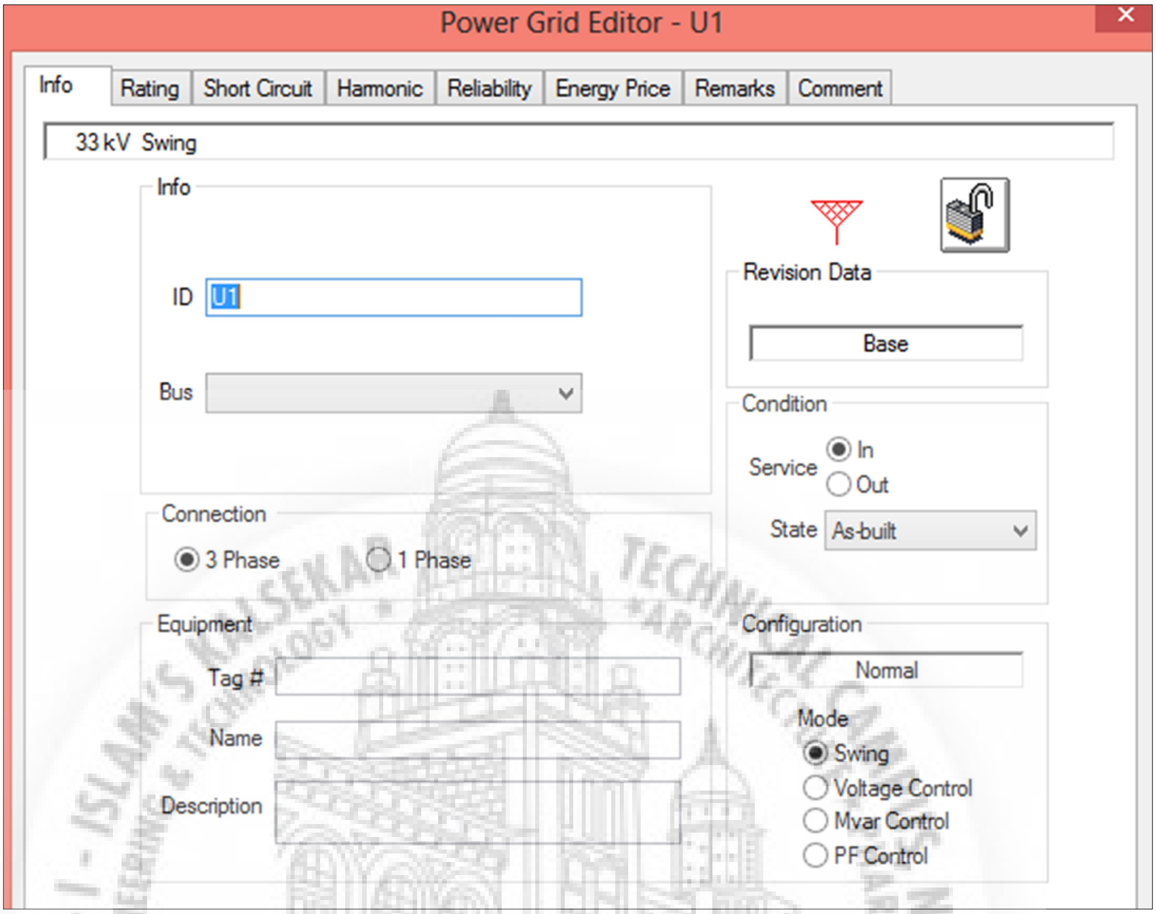



Figure 12 Modelling of swing source

2. **Modelling of transformers:**

➢ **Positive and Zero Sequence Impedances**

These are the positive and zero sequence impedances at the nominal tap setting, in percent, with the transformer MVA and kV ratings as the base values. These values are subject to manufacturer tolerance limits and tap position.

ETAP models the transformers in the system using the positive and zero sequence impedances. ETAP takes the voltage of the swing bus (a bus with a connected swing machine) as the base voltage. It then calculates the system base voltages using the transformer turn ratio. If the transformer turn ratio matches the ratio of the base kVs of the buses between which it is connected, but the actual numbers are not the same (e.g., the primary bus base kV is 13.8 and the secondary bus is 4.349 kV, while the transformer kV ratings are 13.2-4.16 kV), ETAP adjusts the nameplate impedance to a new base with the following formula:

$$Z_{t,\,new} = Z_{t,\,rated} * (\text{Transformer Rated kV/Bus Base kV})^2$$

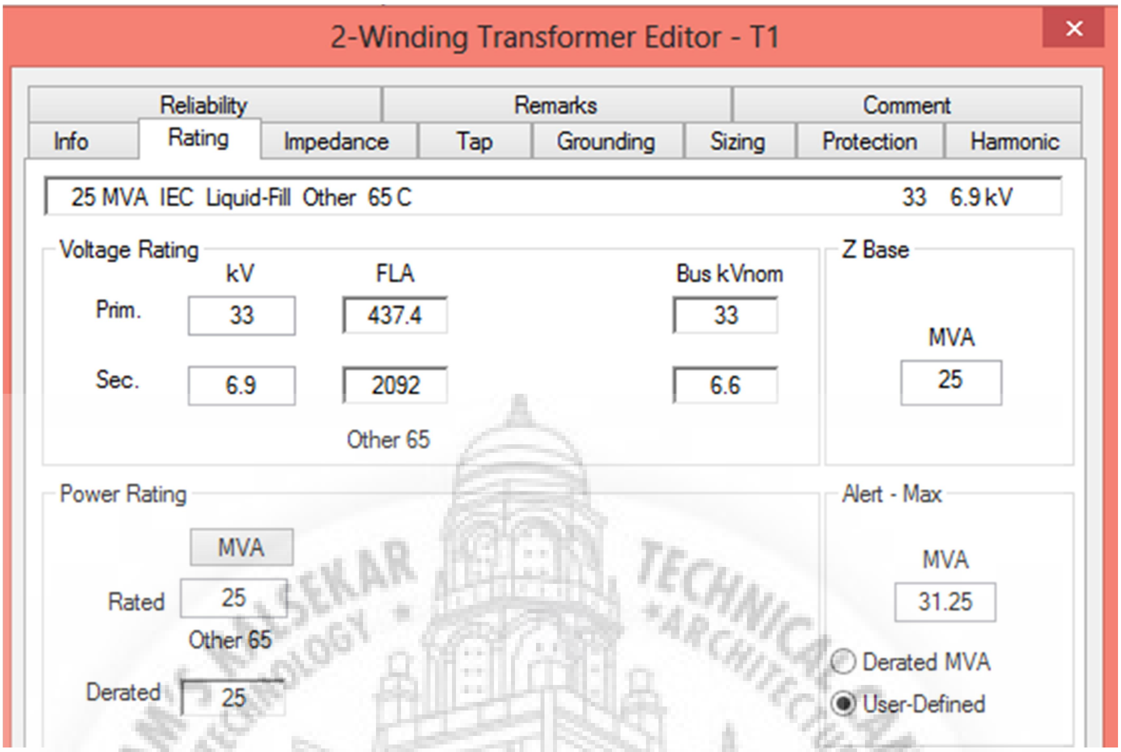



Figure 13 Modeling of two winding transformer

- **Typical Z and X/R and Typical X/R**

We can click the appropriate button to obtain the typical 2-winding transformer impedance together with X/R ratio, or X/R ratio only. The typical impedance and X/R ratio data for IEC 2-winding transformers are based on IEC 60076-5 1994 and Areva Ch.5 “Equivalent Circuits and Parameters of Power System Plant” listed in the table below:

Table 4 Typical Z and X/R and Typical X/R ratio

| Rating | %Z | X/R |
|---|---|---|
| MVA ≤ 0.63 | 4 | 1.5 |
| 0.63 < MVA ≤ 1.25 | 5 | 3.5 |
| 1.25 < MVA ≤ 3.15 | 6.25 | 6 |
| 3.15 < MVA ≤ 6.3 | 7.15 | 8.5 |
| 6.3 < MVA ≤ 12.5 | 8.35 | 13 |
| 12.5 < MVA ≤ 25 | 10 | 20 |
| 25 < MVA ≤ 200 | 12.5 | 45 |
| 200 < MVA | 12.5 | 45 |



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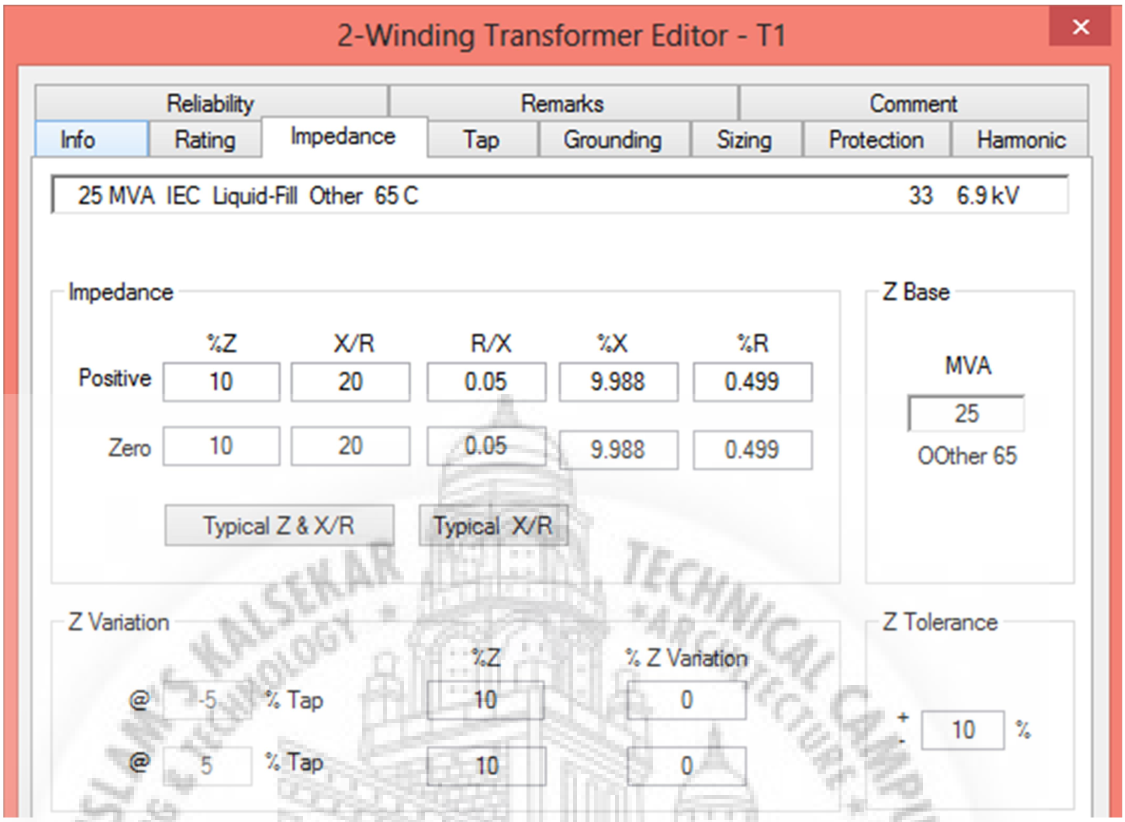



Figure 14 Modeling of two winding transformer impedance

- **Z Tolerance**

We can enter the transformer impedance tolerance as a percentage of the nominal value in this field. This value should be zero for an existing transformer with a known impedance value. For a new transformer with a designated impedance value this should be the impedance tolerance range specified by the manufacturer. The value of the tolerance must be entered as a positive value and ETAP will automatically use the positive or negative value, which will result in a conservative solution.

Table 5 Transformer Z Tolerance

| | *Tolerance* | |
|---|---|---|
| | **Negative** | **Positive** |
| Load Flow | | X |
| Short-Circuit | X | |
| Motor Starting | | X |
| Transient Stability | | X |
| Harmonics | | X |
| Optimal Power Flow | | X |

For example, if 7.5% tolerance is specified, ETAP will use +7.5% tolerance for load flow, motor starting, dynamic stability, and harmonic calculations, while using -7.5% for short-circuit calculations.

- **Tap changer**

The purpose of a tap changer is to regulate the output voltage of a transformer. It does this by altering the number of turns in one winding and thereby changing the turns ratio of the transformer. There are two types of transformer tap changers: an on-load tap changer (OLTC) and a fixed or off circuit tap changer (OCTC).

An OLTC varies the transformer ratio while the transformer is energized and carrying load.

An OCTC is a tap changer that cannot be moved while the transformer is energized. It often has 5 positions (A,B,C,D,E, or 1,2,3,4,5).

In this example the 25 MVA transformers are considered with OLTC as: ± 10% voltage variation and 1.25 % step size

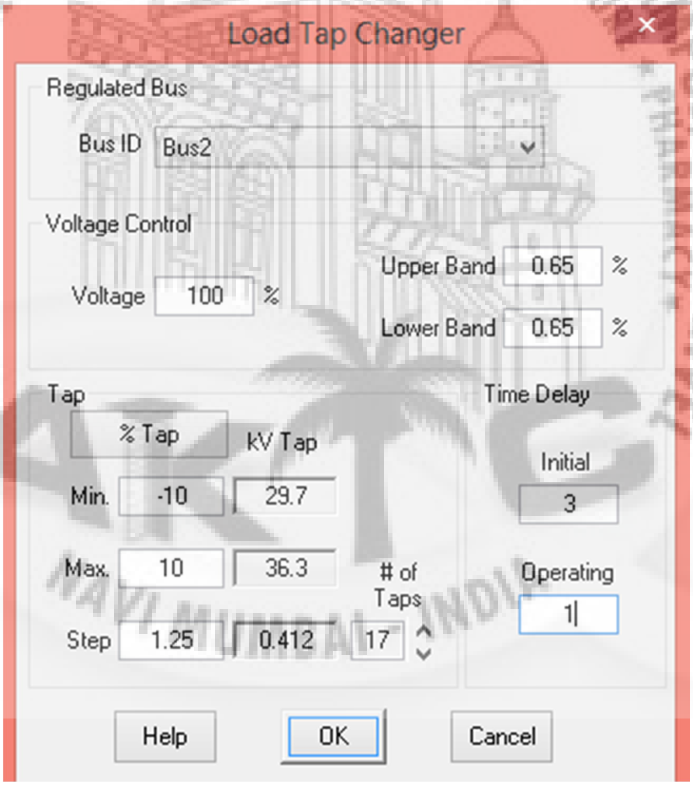
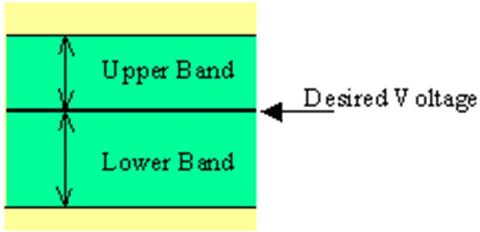



Figure 15 Modelling of On Load Tap Changer (OLTC)




The upper band and lower band together define the dead band for the LTC. As shown in the diagram, when the voltage of the regulated bus falls within the dead band (green area), the LTC will not move. If the voltage of the regulated bus is higher than the Upper Band or less than Lower Band, the LTC will make a step adjustment to control the bus voltage close to its desired value.

In order for the LTC to work properly, ETAP forces the sum of the upper and lower bands to be larger than or equal to the LTC step.

### 3. Modelling of lumped loads

ETAP allows user to model three different types of loads:

1. Motor load
2. Static load
3. Lumped load

- Constant Power Load (Motor Load)

Constant power loads include induction motors, synchronous motors, conventional and unbalanced lumped loads with % motor load, UPS's, and chargers. The power output remains constant for all changes in input voltage. Below are the respective I-V and P-V curves for a constant power load:

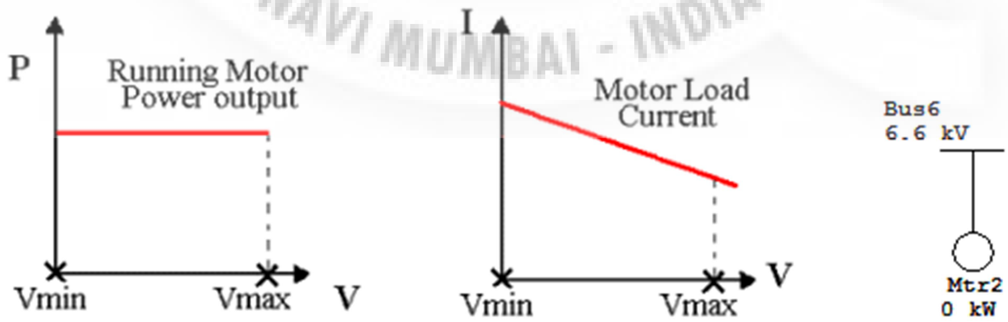



Figure 16 I-V and P-V curves for a constant power load

- Constant Impedance Load (Static Load)



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Constant impedance loads include static loads, capacitors, harmonic filters, MOV's, and conventional and unbalanced lumped loads with % static load. The input power increases proportionally to the square of the input voltage. Below are the respective I-V and P-V curves for a constant impedance load:

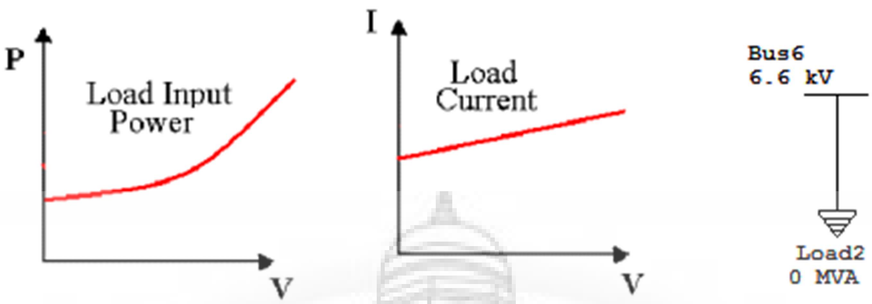
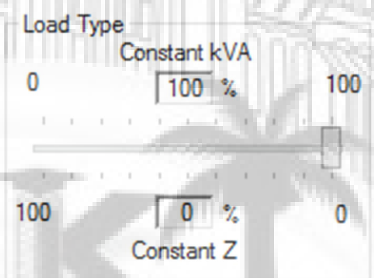



Figure 17 I-V and P-V curves for a constant impedance load

- Combination of constant power load and constant impedance load (lumped load)

We can select the percentage motor and static loading of the lumped load by shifting the slider position. When the rated motor load or static load at the respective bus is not known, ETAP allows user to model the load as combination of motor and static load. If the slider is set to 100% RHS side the load will act as a constant power load. Also, if the slider is set to 100% LHS side the load will act as a constant impedance load.



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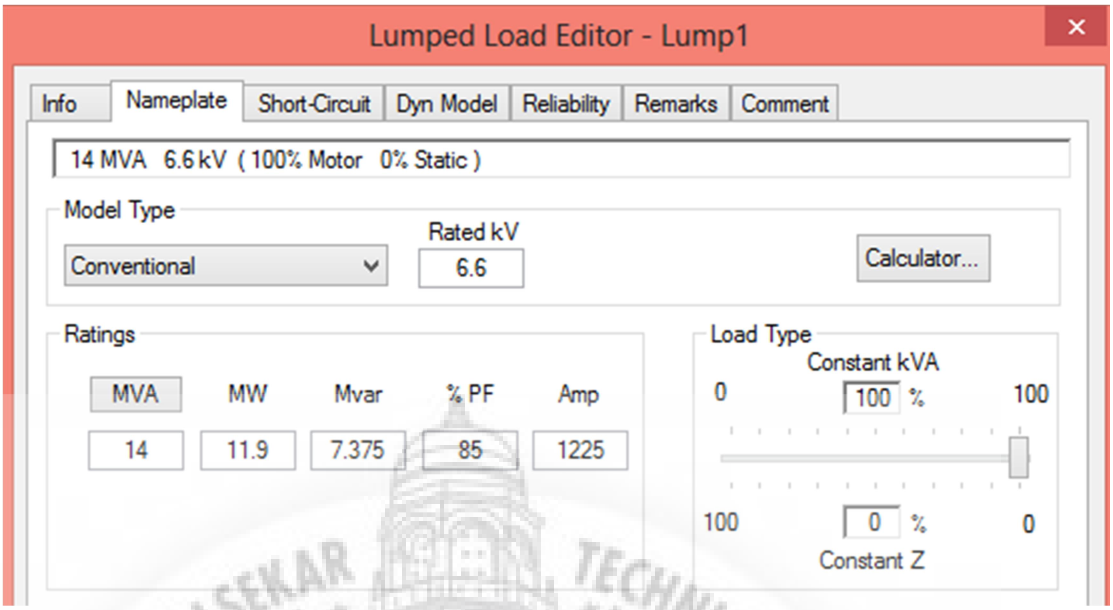


Figure 18 Modelling of Lumped Load

# CHAPTER-5

## EXAMPLE CONSIDER FOR LOAD FLOW STUDY

For the below shown SLD two configurations are studied:

1. Normal Configuration:

   In this case, all the transformers are in working condition, bus coupler is considered as open and the power is supplied to the HV & LV loads through the transformers T1-T2 & T3-T4 radially.

2. One_TR_Out Configuration:

   In this case, transformers T3 & T4 are considered as out of service condition, bus coupler is considered at HV & LV bus is closed and the power is supplied to the HV loads through transformer T1 & LV loads through the transformers T2.

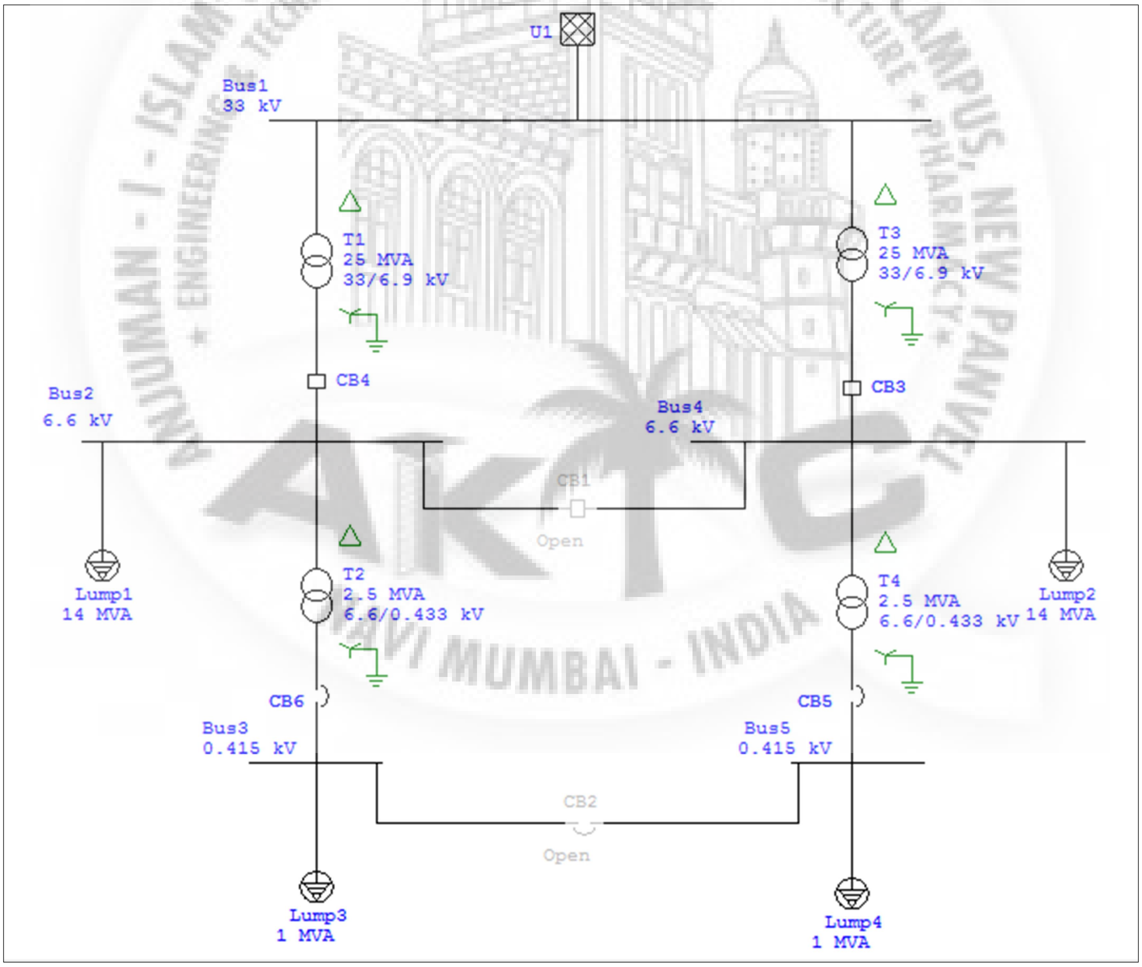


Figure 19 Normal Configuration

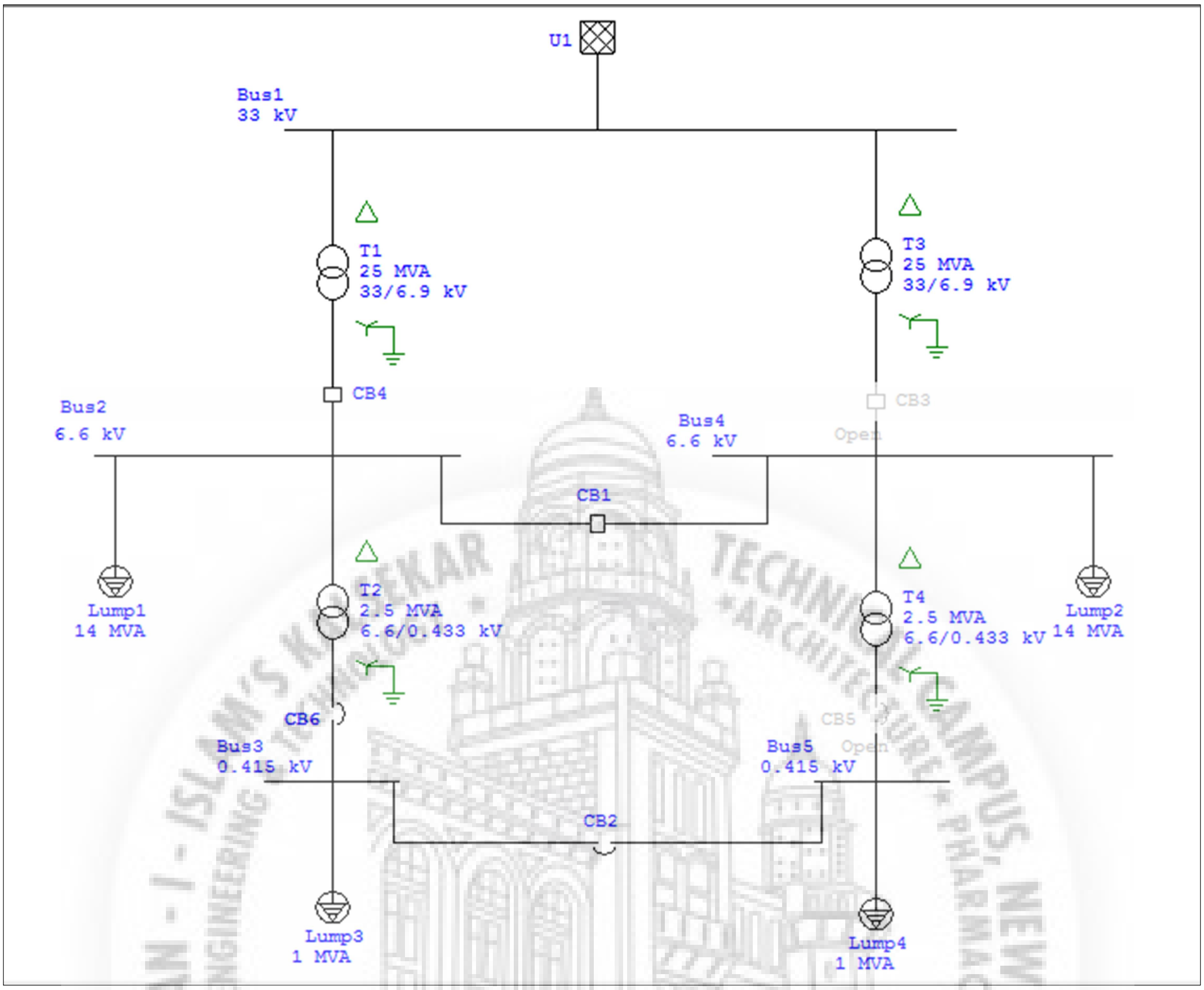


Figure 20 One_TR_Out Configuration

❖ **Loading Category:**

This group is used to assign a percentage loading to each one of the ten loading categories for the lumped load, i.e., each lumped load can be set to have a different operating loading level for each loading category. We can select any of these loading categories when conducting load flow study. The following three loading categories are considered:

| LOADING CATEGORY | LOAD FACTOR (%) |
|---|---|
| MAX LOAD | 90 |
| NORMAL LOAD | 70 |
| MIN LOAD | 40 |

❖ **Generation Category:**

This group is used to assign the different power settings to each of the ten generation categories for the power grid. Each grid can be set to have a different operating power level for each generation category. Depending on the operation mode, some of the values become editable as follows:

| GENERATION CATEGORY | SOURCE VOLTAGE (%) |
|---|---|
| MAX GEN | 110 |
| NORMAL GEN | 100 |
| MIN GEN | 90 |

❖ **Load Flow Study Cases:**

Considering Above loading and generation categories the possible load flow cases are 3X3=9. Among all these cases the following worst cases are monitored for the study.

| SR. NO. | LOAD FLOW STUDY CASES | LOADING CATEGORY | GENERATION CATEGORY |
|---|---|---|---|
| 1. | MAX_LFS | MAX LOAD | MIN GEN |
| 2. | NORMAL_LFS | NORMAL LOAD | NORMAL GEN |
| 3. | MIN_LFS | MIN LOAD | MAX GEN |

The shortlisted above study cases are then run with the configuration considered i.e. Normal & One_TR_Out configuration

| SR. NO. | LOAD FLOW STUDY CASES | CONFIGURATION |
|---|---|---|
| 1. | MAX_LFS | ONE_TR_OUT |
| 2. | NORMAL_LFS | NORMAL |
| 3. | MIN_LFS | NORMAL |

The unique report ID used for each load flow cases are:

| SR. NO. | LOAD FLOW STUDY CASES | CONFIGURATION | REPORT ID |
|---|---|---|---|
| 1. | MAX_LFS | ONE_TR_OUT | MAX_LFS_RPT |
| 2. | NORMAL_LFS | NORMAL | NORMAL_LFS_RPT |
| 3. | MIN_LFS | NORMAL | MIN_LFS_REPORT |

## LOAD FLOW STUDY CRITERIA

- **System Voltage Variation Criteria:**
  At all running loads under normal and single outage operating conditions, the voltages should be held constant within a tolerance of ±5%

- **System Power Factor Criteria**:
  The overall system power factor at the terminals of generating source (grid), shall not be less than 0.80 lagging power factor.

- **Transformer Tap Criteria**:

  All Transformer tap ranges should be adequate to ensure that voltages on their secondary side are maintained within limits even under the worst loading conditions associated with single circuit outages.

- **Equipment Loading Criteria**:

  At all running loads under normal operating conditions the loading of cables & transformers should not be more than 50%. And during single outage operating conditions the loading of cables & transformers should not be more than 100%.



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# LOAD FLOW STUDY RESULTS

## 1. Normal load flow case results:

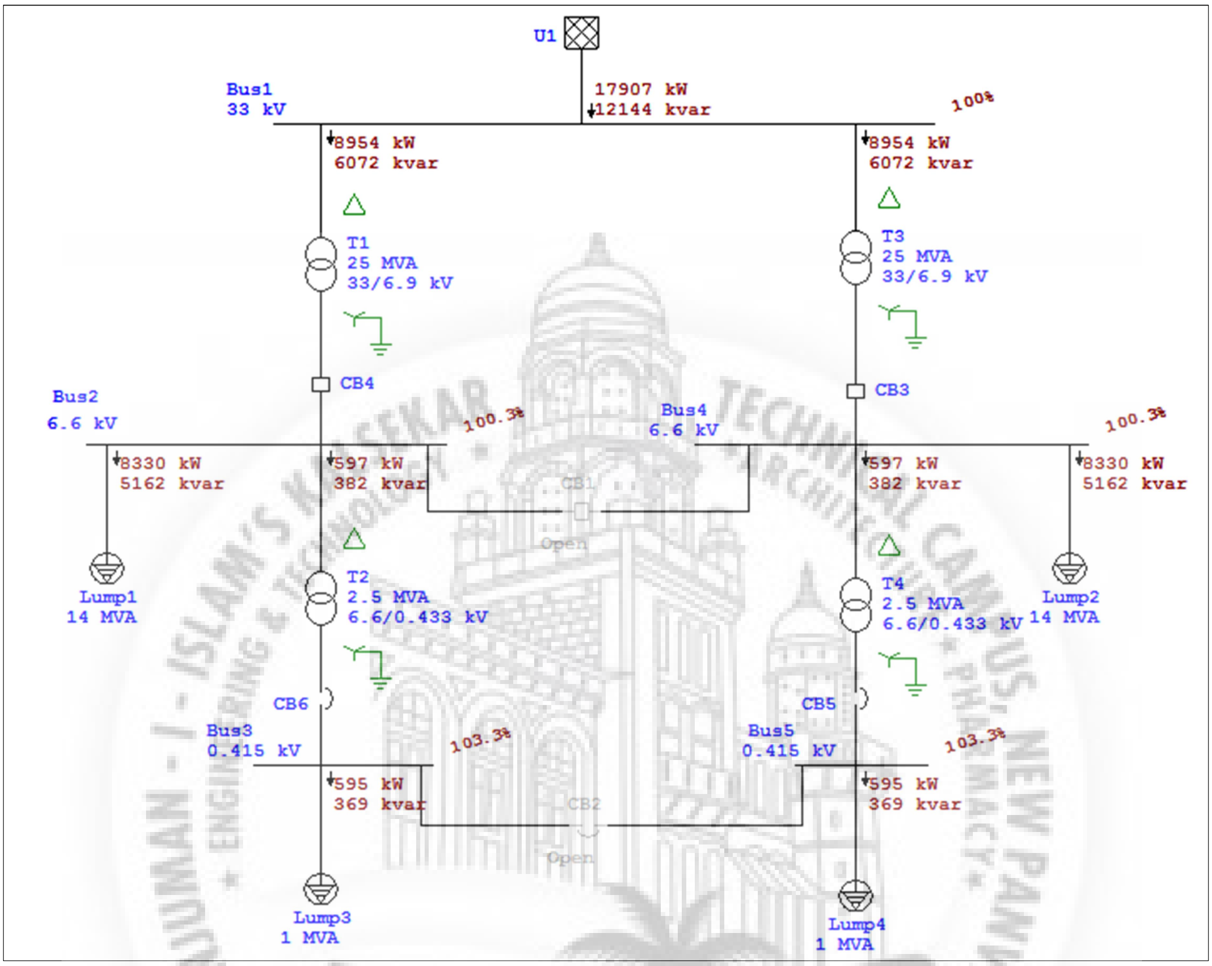


Figure 21 Normal Load Flow case results

**Alerts:**

No alerts are observed during normal load flow study.

## 2. Minimum load flow case results:



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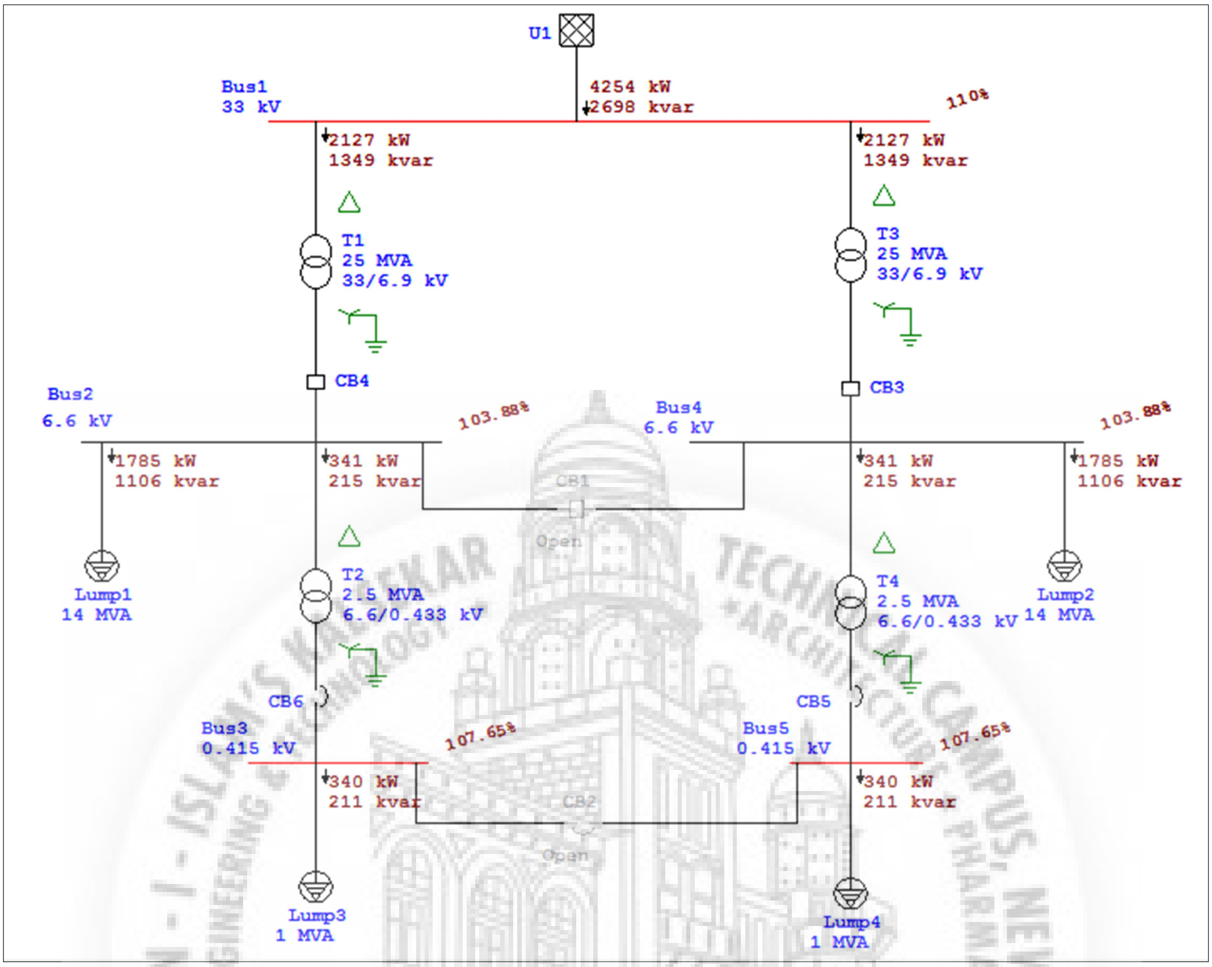


Figure 22 Minimum Load Flow case results

**Alerts:**

Following alerts are observed during minimum load flow study:

| | | | Critical | | |
|---|---|---|---|---|---|
| Device ID | Type | Condition | Rating/Limit | Operating | % Operating |
| Bus1 | Bus | Over Voltage | 33 kV | 36.3 | 110 |
| Bus3 | Bus | Over Voltage | 0.415 kV | 0.447 | 107.7 |
| Bus5 | Bus | Over Voltage | 0.415 kV | 0.447 | 107.7 |

Table 6 Minimum Load Flow case results

| SR. NO | DEVICE ID | CON DITION | OPERATING VOLTAGE [kV] | % OPERATING VOLTAGE |
|---|---|---|---|---|
| 1. | BUS 1 | OVER VOLTAGE | 36.3 | 110 |
| 2. | BUS 3 | OVER VOLTAGE | 0.447 | 107.7 |
| 3. | BUS 5 | OVER VOLTAGE | 0.447 | 107.7 |

By above results it is envisaged that, during minimum load flow case, the overvoltage's are observed at Bus1, Bus3 & Bus5 as 110%, 107.7 % & 107.7 %



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respectively. Among this the Bus1 overvoltage can be ignored as bus1 is directly connected to generating grid.

### 3. Maximum load flow case results:

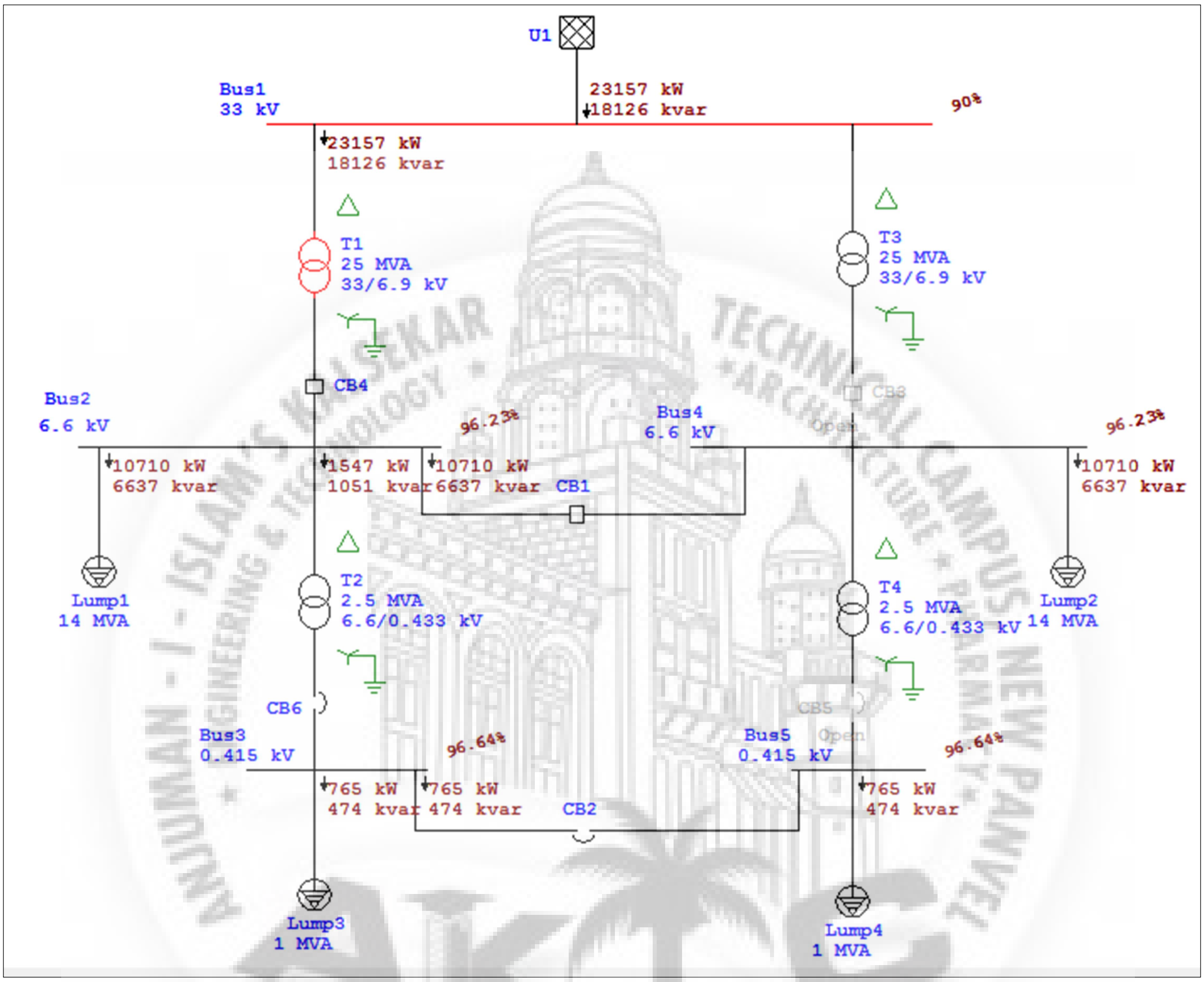


Figure 23 Maximum Load Flow case results

**Alerts:**

Following alerts are observed during maximum load flow study:

| Critical | | | | | |
|---|---|---|---|---|---|
| Device ID | Type | Condition | Rating/Limit | Operating | % Operating |
| Bus1 | Bus | Under Voltage | 33 kV | 29.7 | 90 |
| T1 | Transformer | Overload | 25 MVA | 29.408 | 117.6 |

Table 7 Maximum Load Flow case results

| SR. NO | DEVICE ID | CONDITION | OPERATING VOLTAGE / MVA | % OPERATING VOLTAGE / MVA |
|---|---|---|---|---|
| 1 | BUS 1 | UNDER VOLTAGE | 29.7 KV | 90 % |
| 2 | T1 | OVERLOAD | 29.40 MVA | 117.6 % |

By above results it is envisaged that, during maximum load flow case, the under-voltage is observed at Bus1 (90%). However, Bus1 under-voltage can be ignored as bus1 is directly connected to generating grid. Transformer T1 is overloaded with 117.6% and operating at 29.40 MVA. The MVA rating of transformer T1 is 25 MVA.

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❖ **Load Flow Study Mitigation/ Recommendation:**

From all the three worst cases performed it is noted that, the system is working properly for only Normal operating scenario. The mitigation / recommendation needs to be find out, to resolve the alerts observed during Minimum and Maximum load flow cases.

1. **Mitigation for Minimum Load Flow case**

   For Minimum Load Flow case overvoltage's are observed at 0.415 kV LV buses Bus3 & Bus5 as 107.7 %. We need to control the bus voltage magnitude in ± 5% limit as per the load flow criteria defined. One of the adoptive method to control the bus voltage magnitude in limit under all variable load condition is to introduce a tap changer for a transformer.

   Transformers T2 & T4 are supplying the voltages to Bus3 & Bus5 respectively. It is recommended to add fixed tap changer with voltage variation limit of ± 5% with 2.5% step size at transformers T2 & T4.

   The following results are observed when the fixed tap changer tap is set to +2.5% for transformers T2 & T4.

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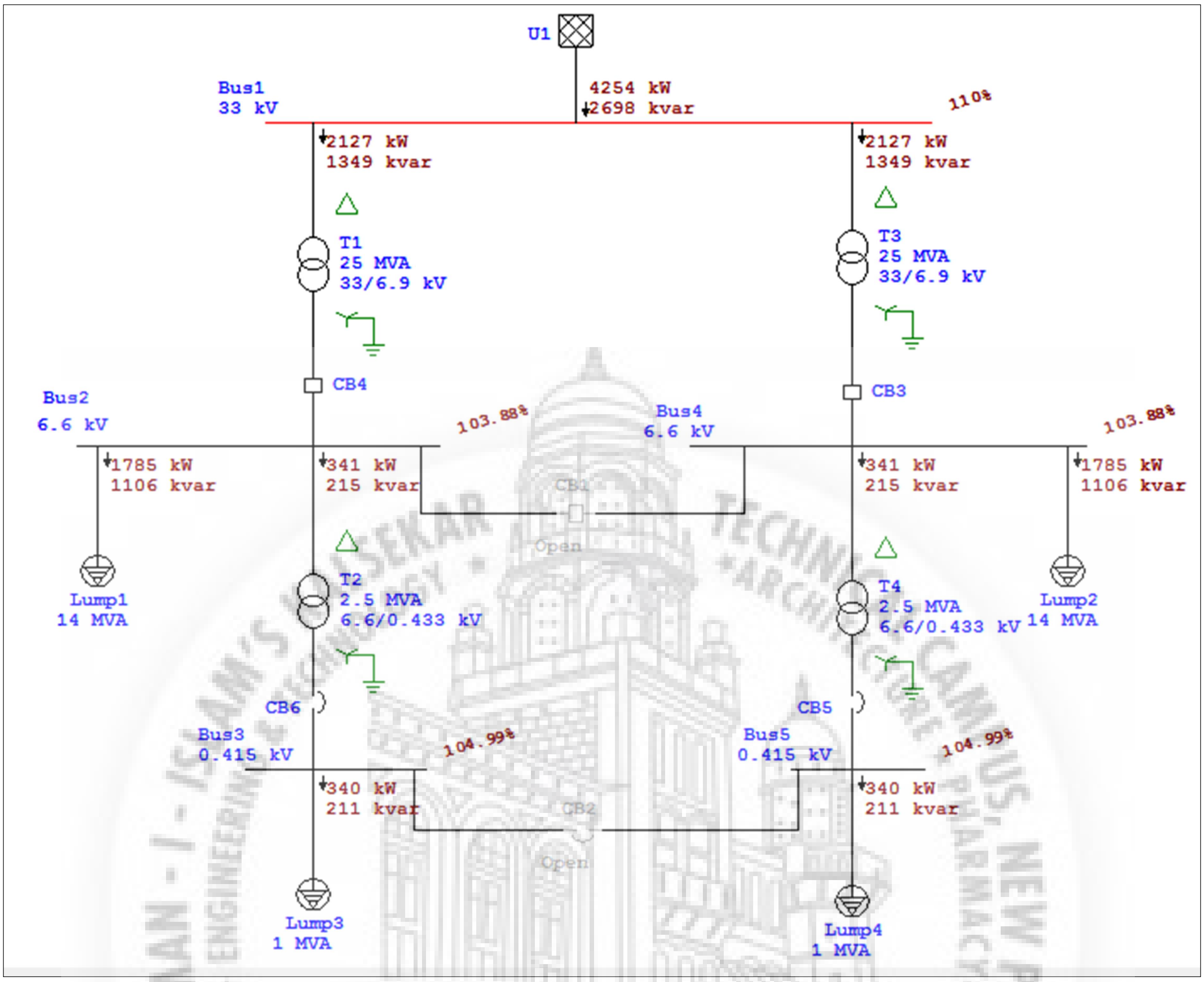


Figure 24 Minimum load flow case with fixed tap set to +2.5% for transformers T2 & T4

It is observed that, with +2.5% tap setting of transformers T2 & T4 the voltages at Bus3 & Bus5 is 104.99 % which is well within the voltage violation limit of ± 5%.

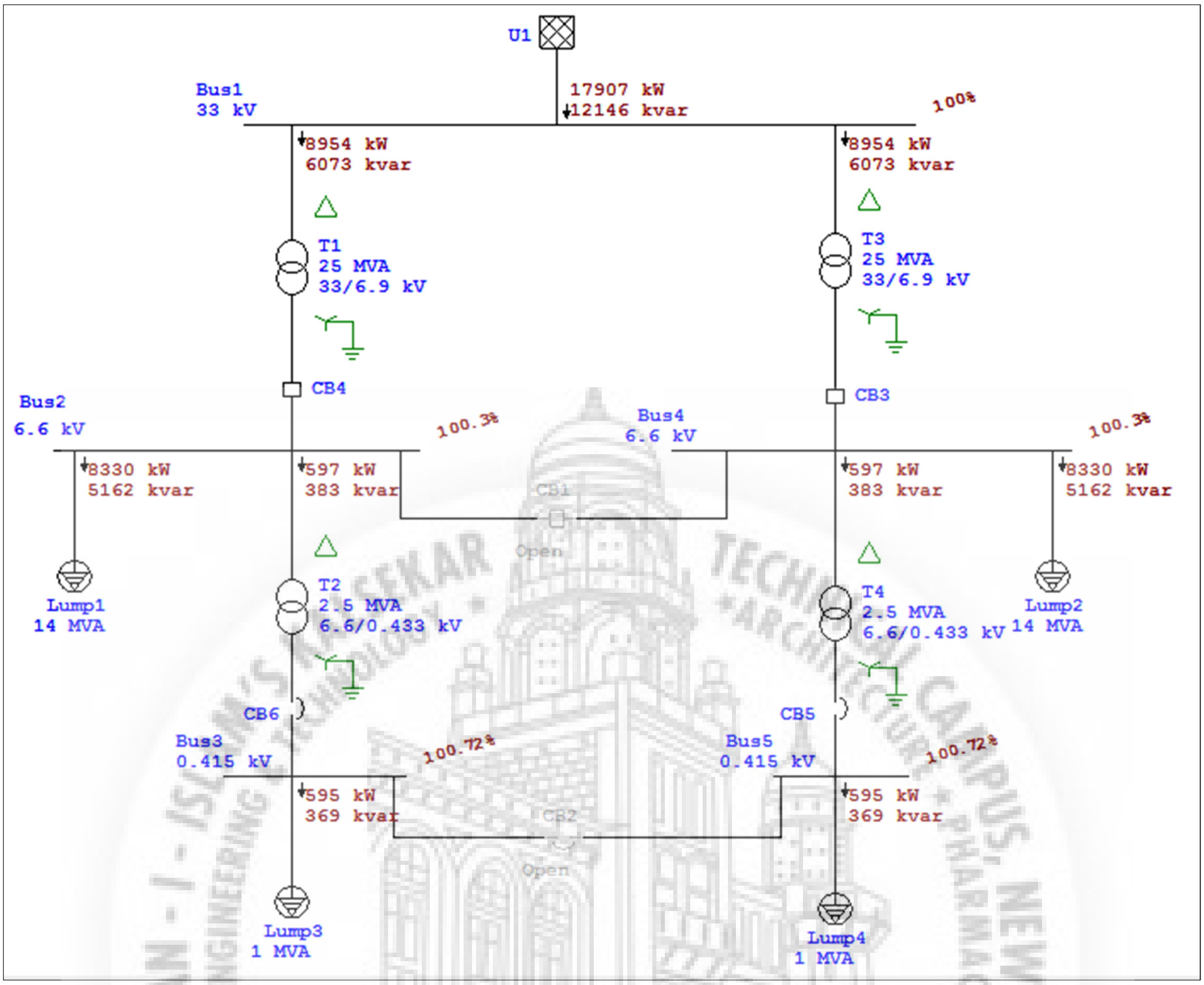


Figure 25 Normal load flow case with fixed tap set to + 2.5% for transformers T2 & T4

It is observed that, with + 2.5% tap setting of transformers T2 & T4 the voltages at Bus3 & Bus5 are 100.72 % during normal load flow case.

Hence optimum tap position for transformers T2 & T4 is +2.5 %.

2. **Mitigation for Maximum Load Flow case**

For Maximum Load Flow case it is observed that transformer T1 is supplying power to all downstream system of 6.6 kV and 0.415 kV, as the other two transformer's T3 & T4 are out of service. This causes overloading of transformer T1. It can be recommended to reduce the load demand for this case (as one parallel transformer is out of service). But reduction of load is not the practical solution. Hence it is recommended to increase the size of the transformer to avoid the overloading of it.

By adopting ONAF (Oil Natural Air Force) type cooling, the 25 MVA transformer can be used upto 31.25 MVA loading. The following scenarios are performed with consideration of transformer T1 rating as 31.25 MVA and % impedance Z increases to 12.5 %. In this scenario the transformer T2 and T4 are considered with fixed tap changer set to +2.5%.

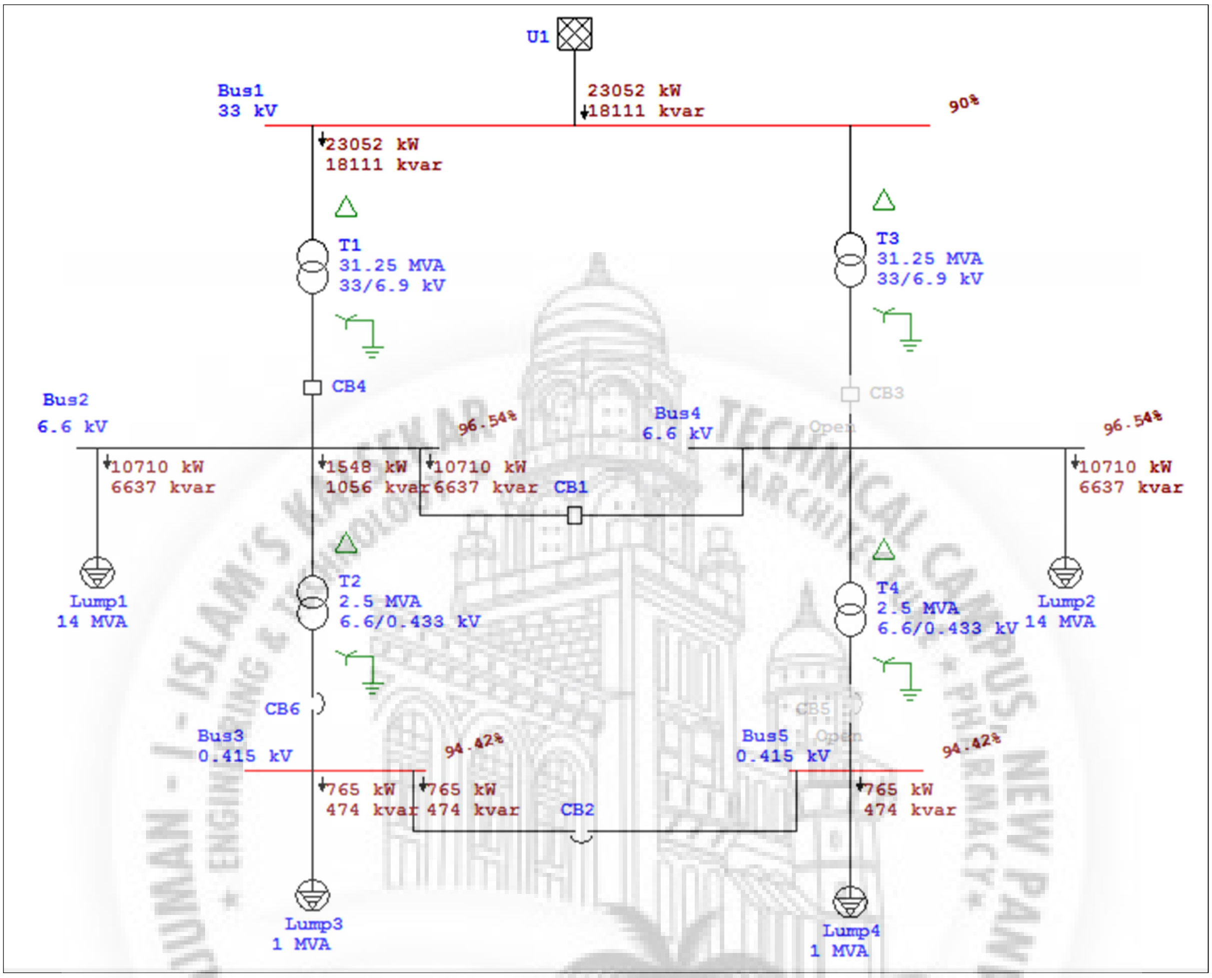


Figure 26 Maximum load flow case with T1 & T3 transformer rating increased to 31.25 MVA, %Z=12.5%, OLTC with ±10%, step size=1.25

The under-voltage is observed at LV buses Bus3 and Bus5. Hence increasing the transformer T1 and T3 OLTC limit to ±15% with step size=1.25.



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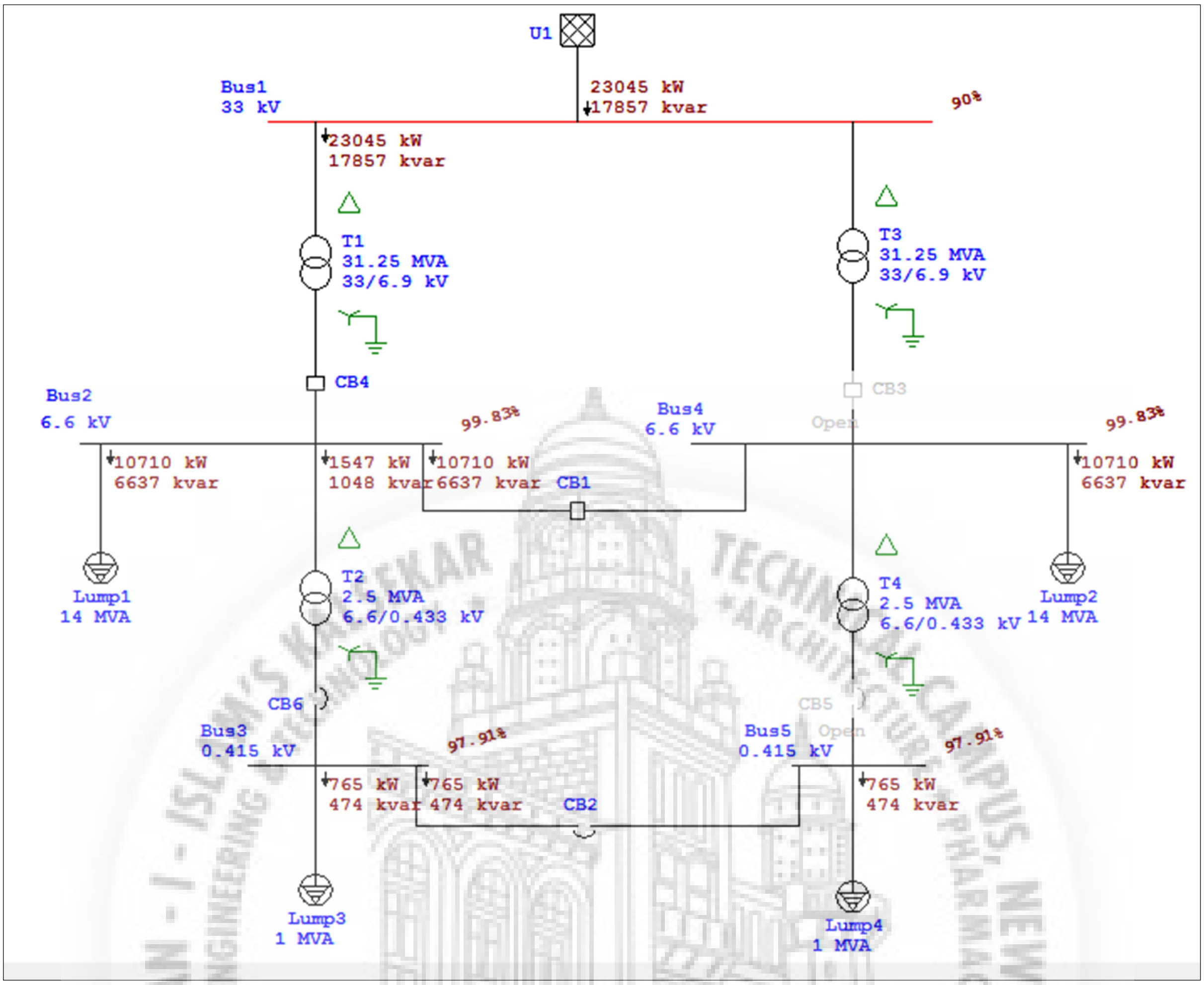


Figure 27 Maximum load flow case with T1 & T3 transformer rating increased to 31.25 MVA, %Z=12.5%, OLTC with ±15%, step size=1.25



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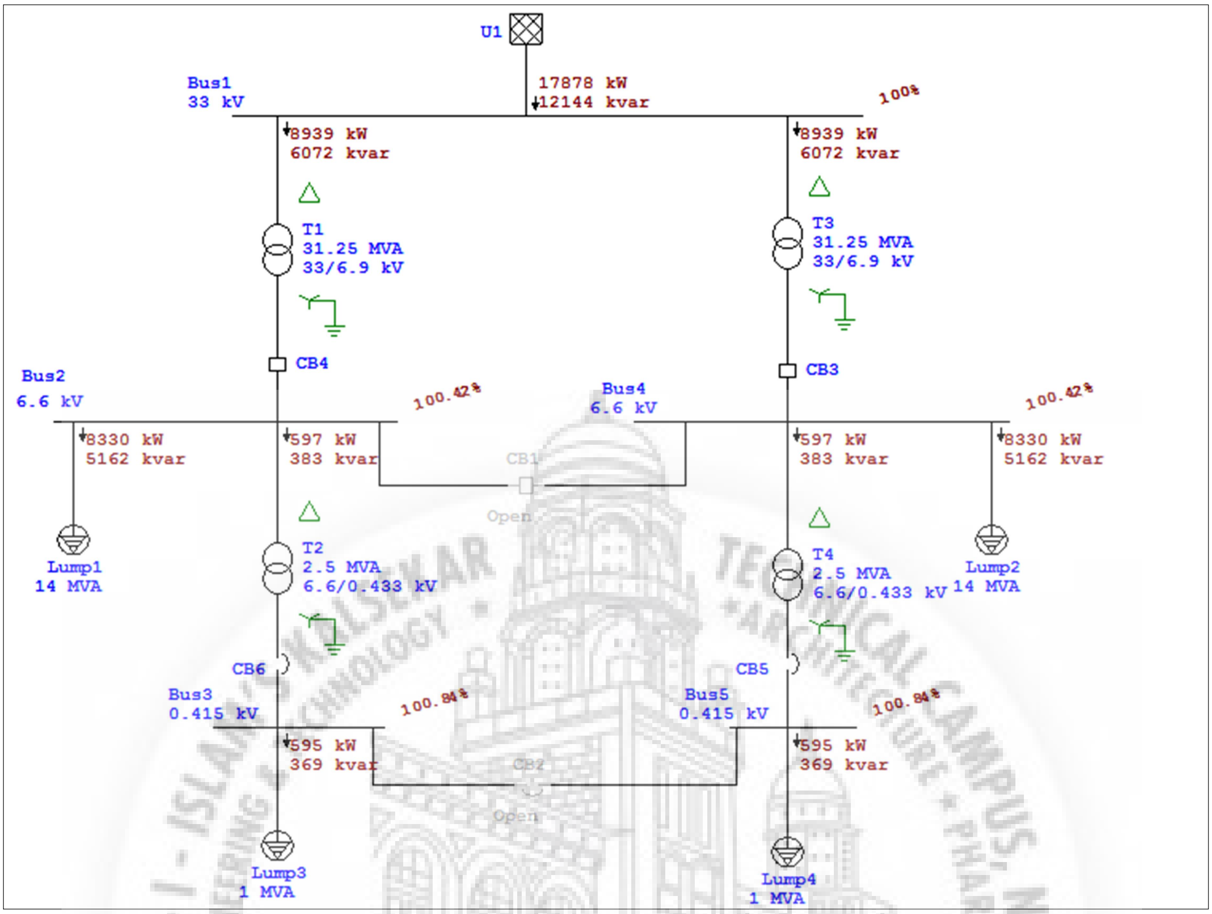


Figure 28 Normal load flow case with T1 & T3 transformer rating increased to 31.25 MVA, %Z=12.5%, OLTC with ±15%, step size=1.25



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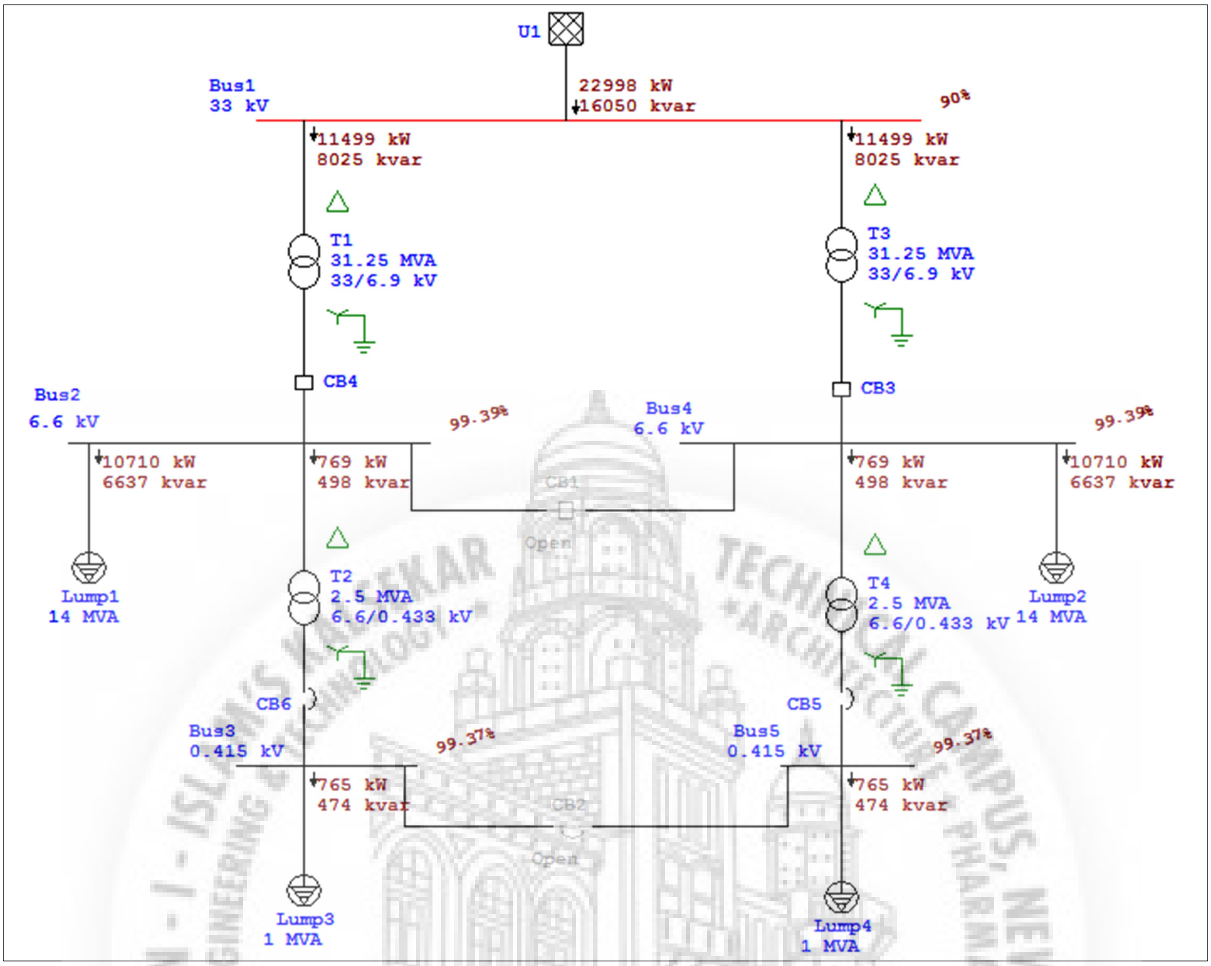


Figure 29 Minimum load flow case with T1 & T3 transformer rating increased to 31.25 MVA, %Z=12.5%, OLTC with ±15%, step size=1.25

From above it is observed that , with suggested mitigations 01 and 02 (i.e. fixed tap changer set to + 2.5 at transformers T2 and T4; transformer T1 & T3 rating increased to 31.25 MVA using ONAF cooling; increase in OLTC tap limit to ±15%, step size=1.25 for transformers T1 & T3) there is no overloading of any equipment, bus voltage profiles are well within the acceptable limit of ±5%, no over-voltages or under-voltages are observed during various load flow cases performed.



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## CAPACITOR BANK SIZING TO IMPROVE THE POWER FACTOR AT THE GRID

It is always priority to maintain the reactive power demand and indirectly the power factor at the grid during all variable load condition. One of the recommended way to improve the power factor is use of capacitor banks which contributes reactive power to the system. The preferred location for the capacitor bank is 6.6 kV; as 33 kV capacitor bank will be more costlier.

The capacitor bank size for **minimum load flow case** is calculated as follows:

First run the Minimum case load flow:

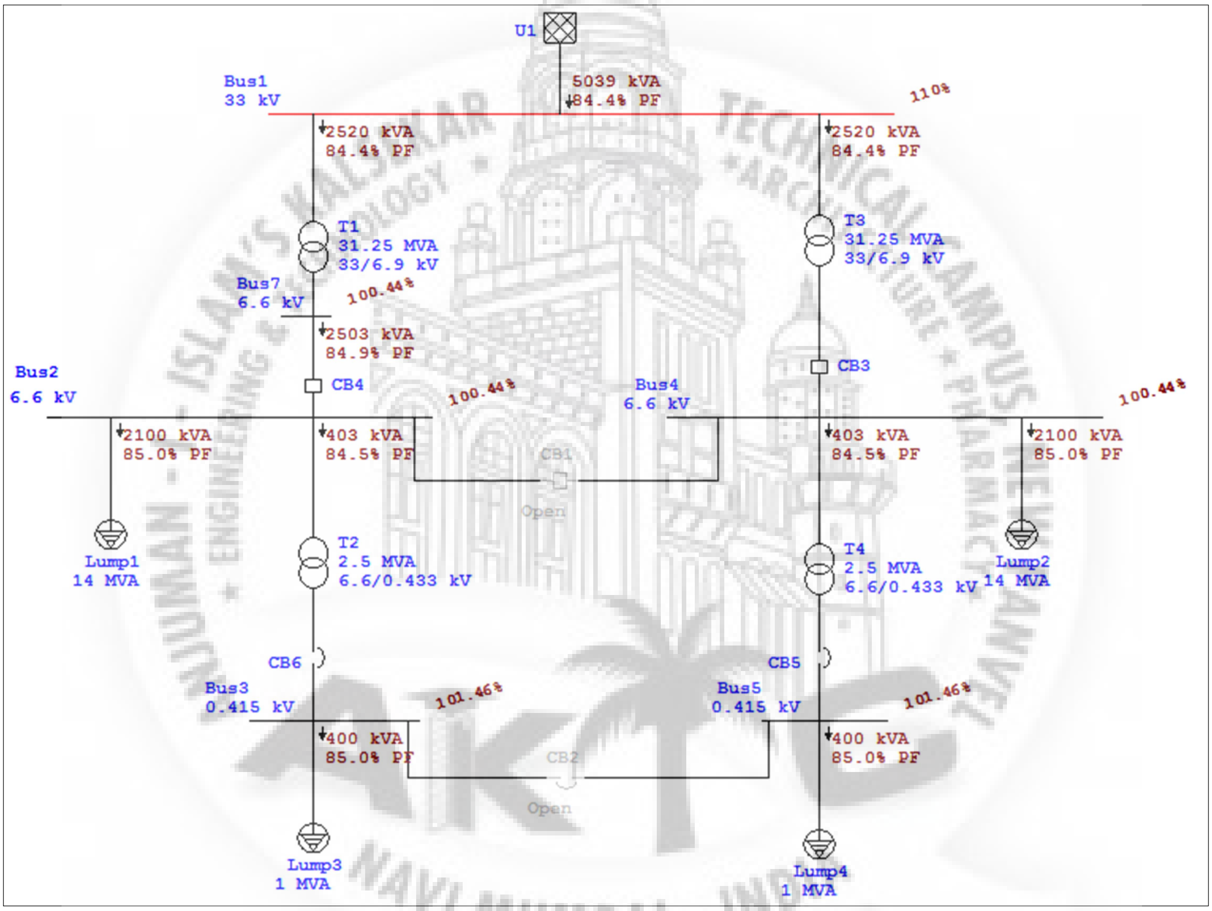


Figure 30 Minimum Load Flow case results

At 6.6 kV bus (after transformer T1), the total load connected to the bus is 2.503 MVA, power factor is 84.9%. The real power flow is 2.13 MW and reactive power flow is 1.32 MVAR. The existing power factor at the 33 kV grid is 84.4%.

The desired power factor at the 33 kV grid is 95%. Hence at the 6.6 kV level the desired power factor should be:

= 95+ (84.9-84.4)=95.5 %= 0.955 pu

Calculation required for capacitor bank size:

Table 8 Capacitor bank size

| | | | |
|---|---|---|---|
| Existing load reactive power demand | 1.32 | MVAR | |
| Load reactive power demand (for 95.5% power factor) | 0.66 | MVAR | Q = P(MW) * tan (phi)= 2.13*tan (acos 0.955) |
| Reactive power needs to be supplied from capacitor bank | =1.32-0.66 =0.6626 | MVAR | |
| Voltage of capacitor bank | 6.6 | KV | |
| Capacitive reactance (Xc) | 65.74 | OHM | $=kV^2/MVAR= 6.6^{\wedge 2} / 0.6626$ |
| Capacitance | 4.84 E-05 | FARAD | =1/(2*pi*f*Xc) |

Capacitors added in the model:

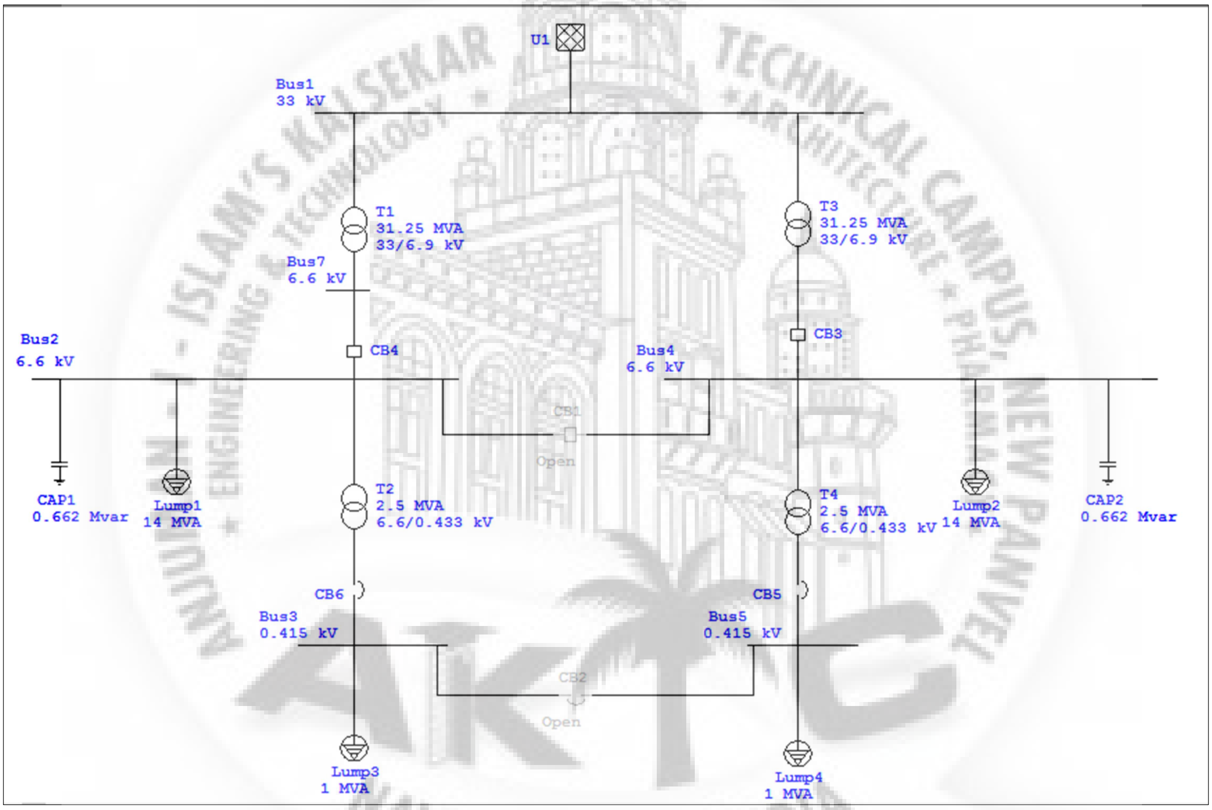


Figure 31 6.6 kV capacitor banks added in the SLD

Running the minimum load flow case with two 0.662 MVAR capacitor banks available at 6.6 kV buses:



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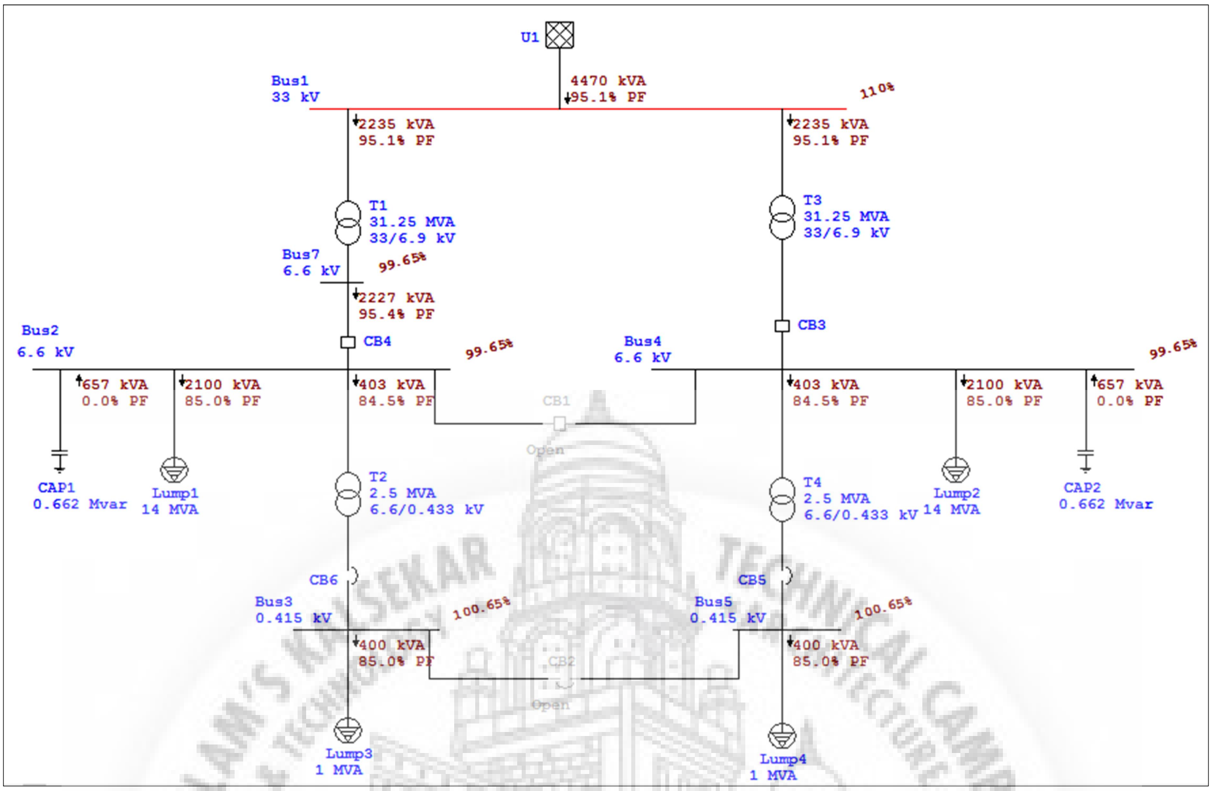


Figure 32 Minimum Load Flow case results with two 0.662 MVAR capacitor banks available at 6.6 kV buses

By above image it is seen that, with consideration of two 0.662 MVAR capacitor banks available at 6.6 kV buses the power factor at the grid is improved to 95.1% from 84.4%.

The maximum load flow case and normal load flow case are also run with the above capacitor banks and results for the same are as below:

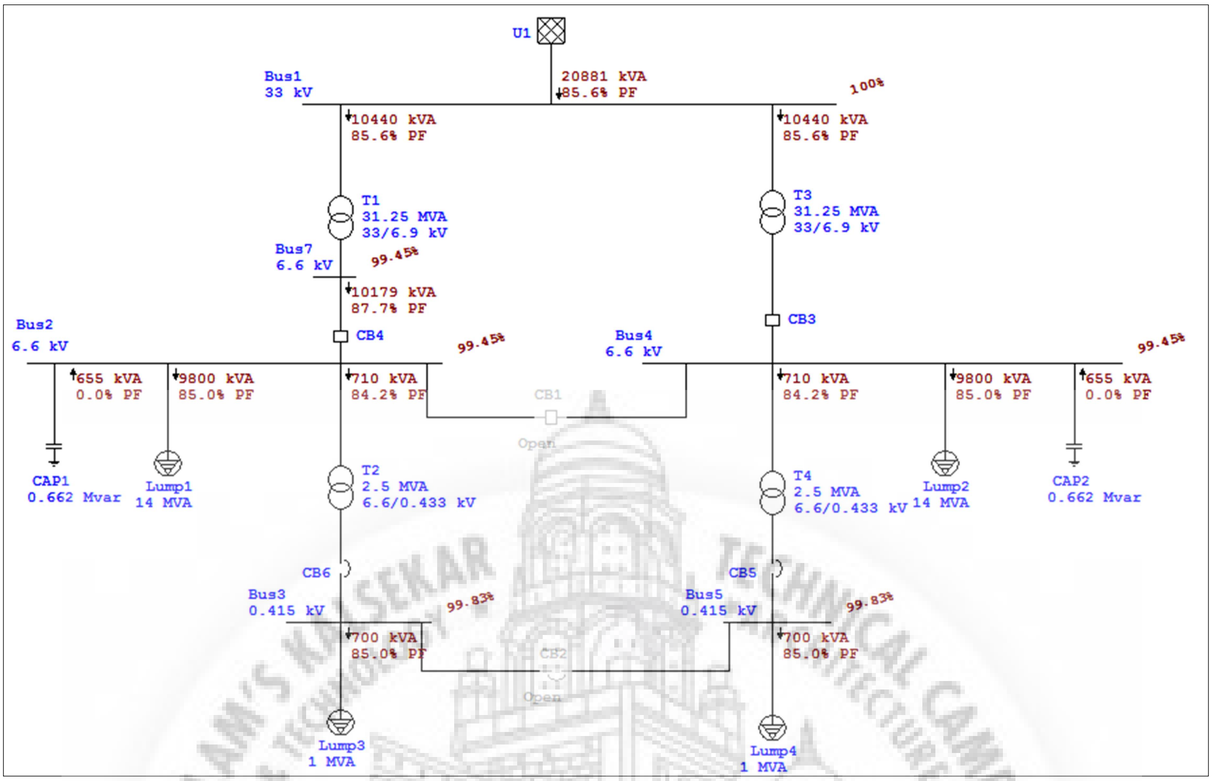


Figure 33 Normal Load Flow case results with two 0.662 MVAR capacitor banks available at 6.6 kV buses

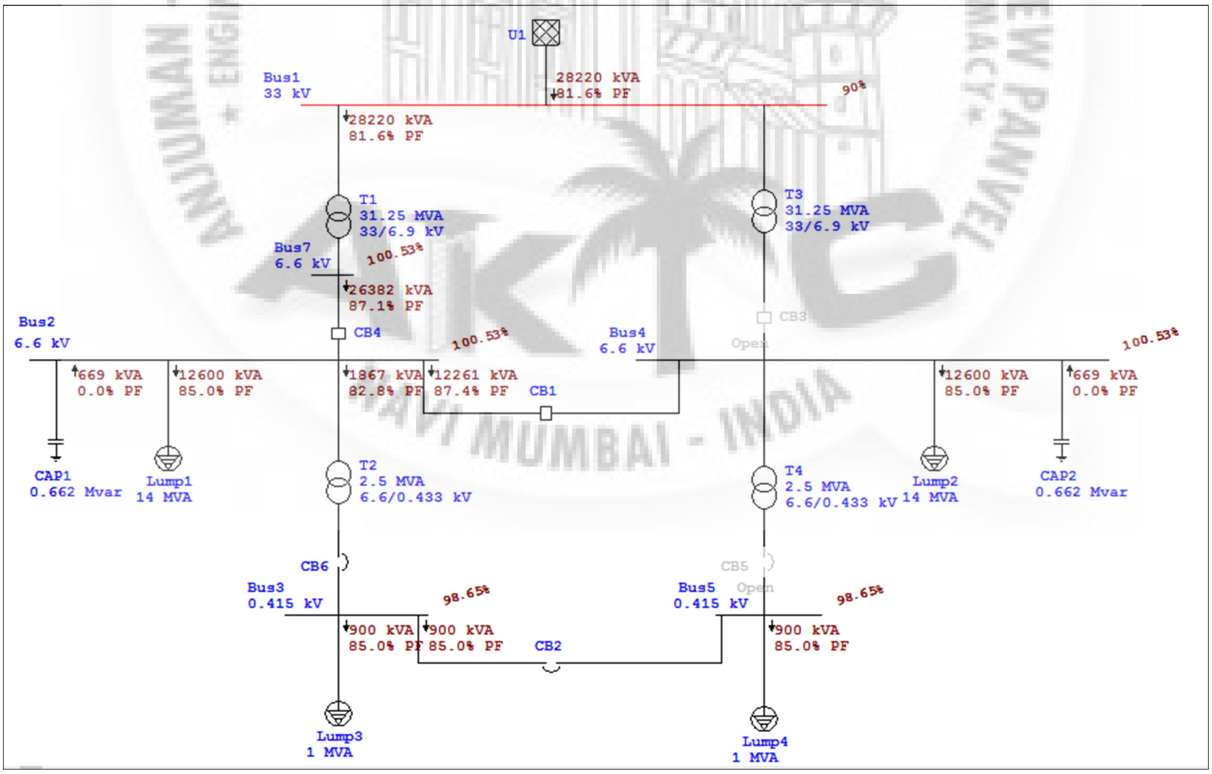


Figure 34 Maximum Load Flow case results with two 0.662 MVAR capacitor banks available at 6.6 kV buses

For the normal load flow study case the power factor at the grid is 85.6% and for Maximum load flow study case the power factor at the grid is 81.6%.

The stage II capacitors can be designed to compensate the reactive power for Normal and Maximum load condition and to improve the power factor at the grid. However, it should be take care that during minimum load flow case stage II capacitor is in off condition so that the power factor at the grid will not go to leading mode.

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# CHAPTER-6
## CONCLUSION

From the above study analysis it can be concluded that the load flow analysis of power system can be easily done with the etap software. Determination of active power flow, reactive power flow, power factor, losses, bus voltage profiles etc. in the system by using etap software is learned

Additionally, the analysis of load flow results is carried out and the various modifications are recommended in the system, in order to achieve the successful operation of the system during various and worst operating condition.



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# CHAPTER-7
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- Ms- Excel



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