**Otto-von-Guericke-University Magdeburg**

**Faculty of Electrical Engineering and Information Technology**

**Non-Technical Project**

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**Comparison of power system simulation software PSS®NETOMAC with open source calculation tool Matpower**

**Submitted on:** 11/01/2016

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**Declaration by the candidate**

I hereby declare that this thesis is my own work and eﬀort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they are being marked.

Magdeburg, 2016

**ABSTRACT**

Load flow states the sinusoidal steady state of a system. In a Network, the power flow is studied using load flow analysis. It calculates the voltage, voltage angle, active power reactive power and losses in the System.

In this research paper the static load analysis of 12 bus network is analyzed in PSS®NETOMAC (Power System Simulator and Network Torsion Machine Control) and Matpower (Modelling and Simulation of both network is carried out). And the results are being compared based on Nodal voltage, Nodal Voltage angle, Losses occurred during load flow and iteration time. This paper explains how the Matpower which is open source software ,can used for Load flow simulation which gives same result as PSS®NETOMAC which is Siemens’s software.

Static analysis offers several advantages. It can provide insight into state, proximity to and mechanism of instability. Furthermore, modelling assumption helps the calculation time reduced compared to dynamic approach. However, it does not give information if the operating point can be reached and unable to applied in short term voltage stability. In practice, static analysis is used for bulk of planning and operating studies where many contingencies must be analyzed. Besides, the approach is applied in real time operation of power system where fast calculation time is necessary [1].

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# INTRODUCTION

The load flow is the most important network computation in power system. The load flow studies calculate magnitude and angle of voltage at each node other quantities such as current, real and reactive power produced and absorbed at each node, power losses can be calculated[1–3].

A load flow study calculates the steady state behavior of a power system. This is necessary that system must operate under system limits. These limits in Power, current and losses occurring can be fixed by load flow calculation. These calculations are needed for many control and planning application. For example, whenever any power system equipment in a network has to be taken out for maintenance, it is important to know whether the power system can still work within the system limits or any additional measures is required. The power system has to be secure. To analyze n-1 security Concept, the load flow of a system required to be studied. This means that if any component fails, whether the system will function within limits can be computed by load flow analysis[1–3].

The power demand in world is keep on rising. So Power system becomes more and more interconnected. A small set of simultaneous failure can propagate through entire system, causing a massive blackout. Therefore providing security against overloading is important.

The renewable energy sources (RES) generally produces power which depends on weather conditions and is unpredictable. So it is needed to integrate with Conventional energy sources. The integration of RES with conventional grid network also require intensive study of load flow [1–3].

## OBJECTIVES AND CONTRIBUTION OF THE PROJECT

The topic of this project is “Comparison of power system simulation software with focus on load flow calculation”. This research design models of medium voltage network and simulate Static load flow with generator reactive Power limits in LV networks, and compare the Results of both PSS®NETOMAC and Matpower**.**

The main purpose of this research is to design the network model in Matpower and PSS®NETOMAC.

Specific objectives are:

* Overview on Flow problem.
* Formulation of real and reactive power.
* Load flow solution methods.
* Modeling of medium voltage network in PSS®NETOMAC and Matpower.
* Simulation of static load flow with generator reactive Power limits in medium voltage networks
* Comparison of results PSS®NETOMAC and Matpower**.**

## PROJECT OUTLINE

Chapter 1 gives Introduction, Chapter 2 gives load flow concepts, limits and problems, Chapter 3 Medium voltage electrical network model, and Chapter4 shows conclusion for this project.

# LOAD FLOW CONCEPTS, LIMITS AND PROBLEMS

## BASIC FORMULATION

Figure 1 shows real and reactive power injected in the Bus.

At node i

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

At node l

|  |  |  |
| --- | --- | --- |
|  |  | (2) |

where is voltage, is current at node i, is impedance and is admittance.



Figure 1 Real and reactive power injected in the Bus

This can be written as matrix form

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

Where is Bus admittance matrix.

In which and is Self- admittance, is the magnitude and is the phase angle

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

and is mutual admittance

|  |  |  |
| --- | --- | --- |
|  |  | (5) |

Complex voltage can be written as equation (6) and (7) where is the magnitude and is the phase angle

|  |  |  |
| --- | --- | --- |
|  |  | (6) |
|  |  | (7) |

The complex power can be expressed as

|  |  |  |
| --- | --- | --- |
|  |  | (8) |

Where is complex conjugate of current, power and reactive power at node *i* is

|  |  |  |
| --- | --- | --- |
|  |  | (9) |
|  |  | (10) |

Where i=1,2…n(n number of nodes), is difference of phase angle at i and l node.

A power system consists of multiple buses which are interconnected by means of transmission lines. Power is injected into the bus from generator while power is consumed by loads [2].

Figure 2 Shows that at ith bus the net complex power injected into the Bus is given by

|  |  |  |
| --- | --- | --- |
|  |  | (11) |

Where is the active power, and is the reactive power at bus

Complex power supplied by generator is

|  |  |  |
| --- | --- | --- |
|  |  | (12) |

Where complex power consumed by load is

|  |  |  |
| --- | --- | --- |
|  |  | (13) |



Figure 2. Power flow from Ith node to Lth node[2].

Equation (14) and (15) shows that the transmitted active and reactive power *Pcal* and *Qcal* are function of nodal voltages of network and network impedances. These are calculated using power flow equations in modern power system, the calculated value are calculated using successive correcting and updating calculated nodal voltage and angle, such the mismatch in active and reactive power comes close to zero [2].The mismatch Power equations are

|  |  |  |
| --- | --- | --- |
|  |  | (14) |
|  |  | (15) |

The terms and are mismatch active and reactive power at Bus .Respectively.

|  |  |  |
| --- | --- | --- |
|  |  | (16) |
|  |  | (17) |

## CLASSIFICATION OF BUSES.

In order to calculate complex voltage and the angle at each node, the different buses of power system are being classified as [1-3]

PQ BUS

In these buses, load is connected and which draws real power  and reactive power in which the negative sign accommodates for the power flowing out of the bus. Here no generator are connected hence the generated real powerand reactive power are taken as zero. The objective of the load flow is to find the bus voltage magnitude and its angle [1-3].

PV BUS

These are the buses where generators are connected. Therefore the power generation in such buses is controlled through a prime mover while the terminal voltage is controlled through the generator excitation keeping the input power constant through turbine-governor control and keeping the bus voltage constant using automatic voltage regulator, we can specify constantand for these buses. This is why such buses are also referred to as P-V buses. It is to be noted that the reactive power supplied by the generator depends on the system configuration and cannot be specified in advance. Furthermore we have to find the unknown angle  of the bus voltage [1-3].

SLACK BUS

Usually this bus is numbered 1 for the load flow studies. This bus sets the angular reference for all the other buses. Since it is the angle difference between two voltage sources that dictates the real and reactive power flow between them, the particular angle of the slack bus is not important. However it sets the reference against which angles of all the other bus voltages are measured. For this reason the angle of this bus is usually chosen as. Furthermore it is assumed that the magnitude of the voltage of this bus is known [1].

As far as concern, buses and parameters classified as.

Table 1 Classification of buses in electrical network

|  |  |  |
| --- | --- | --- |
| Bus | Known Parameter | Unknown Parameter |
| Slack or Swing Bus | |V| and | *P* and *Q* |
| Generator or PV Bus | P and |V| | *Q* and |
| Load or PQ Bus | P and Q | |V| and |

## LOAD FLOW SOLUTION METHODS

The equations (14) and (15) of load flow are known as static load flow equations. By shifting all variables on one side, these equations can be written in vector form [2]

|  |  |  |
| --- | --- | --- |
|  |  | (18) |

Where

=vector function of dimension 2n.

=dependent on state vector of dimension 2n.(2n unspecified variables)

=vectors of independent variables of dimension 2n(2n independent variables which are mentioned prior)Vector consists of fixed variables and control variables.

The state variables consists of control and fixed variables must satisfy following limits

1. Voltage magnitude must satisfy the inequality

|  |  |  |
| --- | --- | --- |
|  |  | (19) |

1. Voltage angle must also follow some constraints

|  |  |  |
| --- | --- | --- |
|  |  | (20) |

This constraint limits the maximum permissible power angle of transmission line connecting buses i and l and is imposed by considerations of system stability.

1. Real and reactive power generated is also limited.

|  |  |  |
| --- | --- | --- |
|  |  | (21) |
|  |  | (22) |

## NON LINEAR (NEWTON-RAPHSON ) LOAD FLOW [2]

This method requires the construction of admittance (n x n) matrix, where n is number of bus system. The diagonal elements of the admittance matrix represent the self-admittance of the bus and the off diagonal represent the mutual admittance between buses.

|  |  |  |
| --- | --- | --- |
|  |  | (23) |

The real and reactive power calculated at specific bus using initial guess and specified voltage magnitude and angle. The iteration methods were used to solve this nonlinear equations like (Gauss Sidle and Newton Raphson). Newton Raphson was more efficient and robust and basically it calculated powers as follows[4]:

|  |  |  |
| --- | --- | --- |
|  |  | (24) |
|  |  | (25) |

Finalized the iteration will depend on tolerance of the power mismatch which calculated by the formulae:

|  |  |  |
| --- | --- | --- |
|  |  | (26) |
|  |  | (27) |

The Jacobian matrix of this method can be represented by:

|  |  |  |
| --- | --- | --- |
|  |  | (28) |

The elements of the Jacobian matrix are partial derivative values of either P or Q with respect to either |V| or δ.

|  |  |  |
| --- | --- | --- |
|  |  | (29) |

Typically the Jacobian matrix is inversed and added to the left side of the equation, the final form looks like the following:

|  |  |  |
| --- | --- | --- |
|  |  | (30) |

All unknown voltage magnitudes and angles would initially require a guess would be 1 and 0 respectively.

If iteration continue then the new voltage magnitude and angle can be updated with the following equations:

Voltage angle mismatch

|  |  |  |
| --- | --- | --- |
|  |  | (31) |

Voltage magnitude mismatch

|  |  |  |
| --- | --- | --- |
|  |  | (32) |

The exact derivative of these equations has been explained at APPENDIX A.

## SIMLIFIED POWER LOSSES METHOD [2,12,13].

Transmission Losses are distributed across all buses, according to their level of generation or consumption only. The slack bus is just a phase reference bus and like other generators bus is not responsible for compensating the total loss of system but also divide the losses between generators and loads. So power system analysis will be performed to calculate exact total losses [2,12,13].

The method to calculate real power losses presents as linear equations. At any line, losses across the series impedance of a transmission line are [2,12]:

|  |  |  |
| --- | --- | --- |
|  |  | (33) |
|  |  | (34) |

Where

R is resistance

X is Reactance

|  |  |  |
| --- | --- | --- |
|  |  | (35) |
|  |  | (36) |
|  |  | (37) |
|  |  | (38) |
|  |  | (39) |

Transmission loss is due to two components. The first is due to active power loss and second is reactive power loss.

# MEDIUM VOLTAGE NETWORK



Figure 3. Single line diagram of 11 bus medium voltage network system [5].

## DESCRIPTION OF MEDIUM VOLTAGE NETWORK.

The main task of this project is to run static load flow analysis and determine the nodal voltage, Nodal angle and the line losses in the above network and compares the result in both PSS®NETOMAC and Matpower.

In Figure 3, there are 11 Bus and 12 branches network. Main lines which are connected by Cable: Ln1:500 m NA2XS2Y 3x1x150 mm², Ln2:1200 m Cable:NA2XS2Y 3x1x120 mm² ,Ln3:400 m Cable:NA2XS2Y 3x1x95 mm², Ln4: 1000 m Cable:NA2XS2Y 3x1x95 mm²,Ln5:200 m Cable:NA2XS2Y 3x1x70 mm²,Ln6:600 m cable:NA2XS2Y 3x1x70 mm²,Ln7:100 m Cable:NA2XS2Y 3x1x95 mm²,Ln8:2000 m Overhead line:3x1x70 mm²,Ln9:900 m Cable:NA2XS2Y 3x1x120 mm²,Ln10:700 m Overhead line:3x1x95 mm² cables,Line11:The node K1 is connected to the Slack generator G5 which is connected to node K3 via 12.5 MVA (20/110 KV) star-delta transformer to K2. Line 12: The node K0 is connected to the generator G1 which is connected to node K3 via transformer T1 (2 MVA) (0.4 KV/ 20 KV) (star–delta). The phase angle shift of 30° degrees between star and delta connected transformer is assumed. Refer Figure 9. Medium voltage network drawn in NetDraw. Figure 9 for details of LV network. This network has 5 generators with 2 transformers .There are total of 8 loads connected to the house nodes and photovoltaic power plants are connected to the respective nodes as per the network. The maximum load for house connection is 1 KW. Loads are being modelled as negative generators. More detailed network parameters are described below Table 2 shows the types of nodes and its values. Table 3 Shows series impedance and half line charging suseptance of transmission lines, Table 4 shows parameter lists of the elements connected to grid, Table 5 shows Parameters of transformers in Electrical Network

Table 2.Parameters of buses in electrical network.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bus /Node | Type | V (p.u) | Phase (deg.) | P (MW) | Q (MVAr) |
| I1 | Slack | 1 | 0 | x | x |
| I2 | PV | 1 | x | 0 | x |
| I3 | PV | 1 | x | 0 | x |
| I4 | PQ | x | x | -0.63 | -0.2 |
| I5 | PQ | x | x | -0.8 | -0.6 |
| I6 | PQ | x | x | -1 | -0.2 |
| I7 | PQ | x | x | -1.03 | -0.2 |
| I8 | PV | 1 | x | 1 | x |
| I9 | PQ | x | x | 0 | 0 |
| I10 | PV | 1 | x | 1.9 | x |
| K0 | PV | 1 | x | 2 | x |

Table 3 Parameters of transformers in electrical network

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| T1 | 110 KV | 20 KV | Dy | 12.5 % | 8 % |  |
| T2 | 20 KV | 0.4 KV | Yd | 12.5 % | 8 % |  |

.

Table 4 Elements connected to the network

|  |  |  |
| --- | --- | --- |
| Element | Dimension | Specification |
| Ld1 | 630 KW | H0 |
| Ld2 | 400 KW | L0 |
| Ld3 | 250 KW | G0 |
| Ld4 | 400 KW | H0 |
| Ld5 | 1000 KW | G0 |
| Ld6 | 630 KW | H0 |
| Ld7 | 400 KW | G0 |
| Ld8 | 100 KW | H0 |
| G1 | 2 MW | PV |
| G2 | 250 KW | BHKW |
| G3 | 1.5 MW | PV |
| G4 | 2 MW | Wind |
| T1 | 2000 KVA | 0.4/20 KV |
| T2 | 12.5 MVA | 110/20 KV |
| Ln1 | 500 m | Cable NA2XS2Y 3x1x150mm² |
| Ln2 | 1200 m | Cable: NA2XS2Y 3x1x120mm² |
| Ln3 | 400 m | Cable: NA2XS2Y 3x1x95mm² |
| Ln4 | 1000 m | Cable: NA2XS2Y 3x1x95mm² |
| Ln5 | 200 m | Cable: NA2XS2Y 3x1x70mm² |
| Ln6 | 600 m | Cable: NA2XS2Y 3x1x70mm² |
| Ln7 | 100 m | Cable: NA2XS2Y 3x1x95mm² |
| Ln8 | 2000 m | Overhead Line: 3x1x70mm² |
| Ln9 | 900 m | Cable: NA2XS2Y 3x1x120mm² |
| Ln10 | 700 m | Overhead Line: 3x1x95mm² |

Table 5. Series impedance and half line charging suseptance of transmission lines in electrical network



## ****MODELLING,**** SIMULATION AND RESULTS

## ****MATPOWER****

Matpower is a package of MATLAB® M-files for solving power flow and optimal power flow problems. It is intended as a simulation tool for researchers and educators that is easy to use and modify. Matpower is designed to give the best performance possible while keeping the code simple to understand and modify. It was initially developed as part of the [PowerWeb](http://www.pserc.cornell.edu/powerweb/) project[5–7].Matpower employs all of the standard steady-state models typically used for power flow analysis.

## PSS®NETOMAC

PSS®NETOMAC (Power System Simulator and Network Torsion Machine Control) is a program researched and developed by Siemens [8]. It performs calculations relating to electrical systems consisting of a network machines and open-loop and closed-loop control equipment [9–11]. The software has a uniform database and enables the following calculations:

▪ Simulation of electromagnetic and electro-mechanic transient phenomena in the time domain

▪ Calculation of instantaneous values with simulation of the network and machines by means of differential equations. Calculation of stability with simulation of the network using complex impedance and machines by means of differential equations

▪ Special calculations of load flow

▪ Frequency domain analysis

▪ Eigenvalue analyses

▪ Simulation of torsional oscillation systems

▪ Parameter identification

▪ Optimization

▪ Reduction of passive networks

With PSS® NETOMAC differential-equation systems of electrical systems are integrated step by step. In the analyses of both time and frequency domain as well as eigenvalue analyses. The load-flow program can be used to determine the working point. The possible ways of simulation are shown in [12][9–11].



Figure 4. Various models of load flow simulation in PSS® NETOMAC [9–11].

## SIMULATION RESULTS IN MATPOWER.

Table 6 shows that Newton's method power flow converges in 6 iterations and it converged in 0.34 seconds. The results of branch, nodes, generators and over all load flow are shown in the results below [13].

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table 6 Maximum P & Q mismatch with respect to number of iterations.   |  |  | | --- | --- | | Number of iterations | max P & Q mismatch (p.u.) | | 0 | 2.35E+04 | | 1 | 2.00E+04 | | 2 | 2.95E+03 | | 3 | 5.02E+02 | | 4 | 3.39E+01 | | 5 | 1.75E-01 | | 6 | 4.61E-06 | | | | | | | | | | |  | | | | | | | | | | |  | | | |  |
|  | | System Summary | | | | |  | | | | |  | | | |  | | | | | | | |
| How many? | | | |  | | | How much? | | | | | P (MW) | | | | Q (MVAr) | | | | | | |
| --------------------- | | | | | | | ------------------- | | | | | ------------- | | | | ----------------- | | | | | | |
| Buses | | | | 11 | | | Total Gen Capacity | | | | | 7.8 | | | | -1012.0 | | | to 1012.0 | | | |
| Generators | | | | 5 | | | On-line Capacity | | | | | 7.8 | | | | -1012.0 | | | to 1012.0 | | | |
| Committed Gens | | | | 5 | | | Generation (actual) | | | | | 3.82 | | | | -138.1 | | | | | | |
| Loads | | | | 4 | | | Load | | | | | 3.71 | | | |  | | | 1.2 | | | |
|  | | Fixed | | 4 | | | Fixed | | | | | 3.71 | | | |  | | | 1.2 | | | |
|  | | Dispatchable | | 0 | | | Dispatchable | | | | | -0.0 of -0.0 | | | | | | | -0.0 | | | |
| Shunts | | | 0 | | | Shunt (inj) | | | | | | | -0.0 | | | | 0.0 | | | | | | |
| Branches | | | 12 | | | Losses (I^2 \* Z) | | | | | | | 0.11 | | | | 0.13 | | | | | | |
| Transformers | | | 2 | | | Branch Charging (inj) | | | | | | | - | | | | 139.4 | | | | | | |
| Inter-ties | | | 4 | | |  | | | | | | |  | | | |  | | | | | | |
| Areas | | | 3 | | |  | | | | | | |  | | | |  | | | | | | |
|  | | | | Minimum | | | | | |  | | | Maximum | | | | | |  |  |
| Voltage Magnitude | | | | 1.000 p.u. @ bus 1 | | | | | | 1.001 p.u. @ bus 6 | | | | | | | | |  |  |
| Voltage Angle | | | | -30.05 deg | | | - | @ bus 5 | | 0.00 | | | | degee | | | @ bus 1 | | 1-3 |  |
| P Losses (I^2\*R) | | | |  | | |  | | 0.107 | | | | MW | | | @ line | |  |
| Q Losses (I^2\*X) | | | |  | | | - |  | | 0.13 | | | | MVAr | | | @ line 1-3 | | |  |

|  |  |
| --- | --- |
|  |  |
| ================================================================================  | Generator Data |  ================================================================================  Gen Bus Status Pg  Qg  # # (MW) (MVAr)  ---- ----- ------ -------- --------  1 80 1 2.00 -3.00  2 1 1 -1.93 -129.11  3 5 1 0.25 0.00  4 8 1 1.50 -3.00  5 10 1 2.00 -3.00  -------- --------  Total: 3.82 -138.44  ================================================================================  | Bus Data |  ================================================================================  Bus Voltage Generation Load  # Mag(pu) Ang(deg) P (MW) Q (MVAr) P (MW) Q (MVAr)  ----- ------- -------- -------- -------- -------- --------  80 1.001 -0.034 2.00 -3.00 - -  1 1.000 0.000\* -1.93 -129.11 - -  2 1.001 -30.046 - - - -  3 1.001 -30.045 - - - -  4 1.001 -30.047 - - 0.63 0.20  5 1.001 -30.047 0.25 0.00 1.05 0.60  6 1.001 -30.047 - - 1.00 0.20  7 1.001 -30.047 - - 1.03 0.20  8 1.001 -30.047 1.50 -3.00 - -  9 1.001 -30.046 - - - -  10 1.001 -30.046 2.00 -3.00 - -  -------- -------- -------- --------  Total: 3.82 -138.11 3.71 1.20  ================================================================================  | Branch Data |  ================================================================================  Branch From To From Bus Injection To Bus Injection Loss (I^2 \* Z)  # Bus Bus P (MW) Q (MVAr) P (MW) Q (MVAr) P (MW) Q (MVAr)  ----- ----- ----- -------- -------- -------- -------- -------- --------  1 2 3 6.16 30.10 -6.16 -45.78 0.000 0.00  2 3 4 -1.14 -52.55 1.14 17.64 0.001 0.00  3 4 5 -1.77 -17.84 1.77 7.17 0.000 0.00  4 5 6 -2.57 -7.77 2.57 -18.93 0.000 0.00  5 6 7 -3.57 18.73 3.57 -23.54 0.000 0.00  6 7 8 0.66 -6.69 -0.66 -7.74 0.000 0.00  7 8 9 2.16 4.74 -2.16 -7.41 0.000 0.00  8 9 10 -2.00 0.48 2.00 -3.00 0.000 0.00  9 9 2 4.16 6.92 -4.16 -33.10 0.000 0.00  10 3 7 5.26 -30.91 -5.26 30.03 0.001 0.00  11 1 3 -1.93 -129.11 2.04 129.24 0.107 0.13  12 80 2 2.00 -3.00 -2.00 3.00 0.001 0.00  -------- --------  Total: 0.110 0.13 | | | |  |

## SIMULATION RESULT IN PSS®NETOMAC.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | System Summary | | | |  | | | |  | |  | | | | |
| ==================================================================== | | | | | | | | | | | | | | |
| How many? | | |  | | How much? | | | | P (MW) | | Q (MVAr) | | | |
| --------------------- | | | | | ------------------- | | | | ------------- | | ----------------- | | | |
| Buses | | | 11 | | Total Gen Capacity | | | | 7.8 | | -1012.0 | to 1012.0 | | |
| Generators | | | 5 | | On-line Capacity | | | | 7.8 | | -1012.0 | to 1012.0 | | |
| Committed Gens | | | 5 | | Generation (actual) | | | | 3.95 | | 1.323 | | | |
| Loads | | | 4 | | Load | | | | 3.71 | |  | 1.237 | | |
|  | Fixed | | 4 | | Fixed | | | | 3.71 | |  | 1.237 | | |
|  | Dispatchable | | 0 | |  | | | |  | | |  | | |
| Shunts | | 0 | |  | | | | |  | |  | | | | | | |
| Branches | | 12 | | Losses (I^2 \* Z) | | | | | 0.16 | | 0.32 | | | | | | |
| Transformers | | 2 | |  | | | | |  | |  | | | | | | |
|  | |  | |  | | | | |  | |  | | | | | | |
|  | |  | |  | | | | |  | |  | | | | | | |
|  | | | | | | Minimum | | | |  | | | Maximum | | |  |
| Votage | | | | | | 0.989 p.u. @ bus 6 | | | | 1.062 p.u. @ bus 0 | | | | | |  |
| Voltage Angle | | | | | | -29,105 deg | - | @ bus 3 | | 6.162 | | | degee | @ bus 0 | |  |
| P Losses (I^2\*R) | | | | | |  |  | | 0.142 | | | MW | @ line 1-3 | |
| Q Losses (I^2\*X) | | | | | |  | - |  | | 0.17 | | | MVAr | @ line 1-3 | | |

Table 7 shows the nodes results, Table 8 shows the results of losses, Table 9 shows initial machine condition before load flow,

Table 10 shows the generator results and Table 11 shows the branch results.

Table 7 Nodes results in medium voltage network

|  |  |  |  |
| --- | --- | --- | --- |
| **Node** | **Ur [KV]** | **U/Ur [pu]** | **phi U [°]** |
| K0.R | 0.400 | 1.062 | 6.162 |
| K1.R | 110.000 | 1.000 | 0.000 |
| K10.R | 20.000 | 0.995 | -28.858 |
| K2.R | 20.000 | 0.990 | -29.078 |
| K3.R | 20.000 | 0.990 | -29.105 |
| K4.R | 20.000 | 0.989 | -29.104 |
| K5.R | 20.000 | 0.989 | -29.100 |
| K6.R | 20.000 | 0.989 | -29.091 |
| K7.R | 20.000 | 0.989 | -29.089 |
| K8.R | 20.000 | 0.991 | -29.062 |
| K9.R | 20.000 | 0.991 | -29.060 |

Table 8 Losses occur in medium voltage network.

|  |  |  |
| --- | --- | --- |
| **Net**  **Group** | **Nominal Voltage [KV]** | **Losses [MW]** |
| 20 | 20 | 0.088 |
|  |  | 0.071 |
| 1 | 0.4 | 0.000 |
| 110 | 110 | 0.001 |

Table 9 Initial machine conditions results in medium voltage network.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name (long)** | **Voltage [pu]** | **Main Flux [pu]** | **El. Torque [pu]** | **Exciter Volt [pu]** | **Load Angle [°]** |
| G1 | 1.062 | 1.064 | 0.853 | 1.948 | 47.002 |
| G5 | 1.000 | 0.999 | -0.748 | 2.558 | -31.272 |
| G4 | 0.995 | 0.997 | 0.853 | 1.925 | 52.358 |
| G3 | 0.991 | 0.993 | 0.639 | 1.631 | 44.507 |
| G2 | 0.989 | 0.989 | 0.106 | 1.157 | 9.377 |

Table 10 Generators results in medium voltage network.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Type** | **Name** | **U [pu]** | **Phi [°]** | **P [MW] Net** | **Q [MVAr] Net** | **S [MVA] Net** | **CosPhi Net** |
| GEN | G1 | 1.062 | 6.162 | 2.000 | 0.000 | 2.000 | 1.000 |
| GEN | G5 | 1.000 | 0.000 | -1.768 | 1.323 | 2.208 | -0.801 |
| GEN | G4 | 0.995 | -28.858 | 2.000 | 0.000 | 2.000 | 1.000 |
| GEN | G3 | 0.991 | -29.062 | 1.500 | 0.000 | 1.500 | 1.000 |
| GEN | G2 | 0.989 | -29.100 | 0.250 | 0.000 | 0.250 | 1.000 |

Table 11. Branch results in .medium voltage network

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Start Node** | **Element** | **S [MVA]** | **P [MW]** | **Q [MVAr]** | **U [KV]** | **Ur [KV]** | **U/Ur [pu]** | **phi U [°]** | **I KA]** | **Ireal KA** | **Iimag [KA]** |
| K3.R | T2 | 2.195 | -1.782 | 1.281 | 19.795 | 20.000 | 0.990 | -29.105 | 0.064 | 0.064 | 0.007 |
| K1.R | T2 | 2.218 | 1.780 | -1.323 | 110.000 | 110.000 | 1.000 | 0.000 | 0.012 | -0.009 | -0.007 |
| K2.R | T1 | 1.866 | 1.858 | -0.170 | 19.809 | 20.000 | 0.990 | -29.078 | 0.054 | -0.050 | 0.022 |
| K0.R | T1 | 2.000 | -2.000 | -0.000 | 0.425 | 0.400 | 1.062 | 6.162 | 2.719 | 2.703 | 0.292 |
| K9.R | Ln9 | 1.001 | -0.999 | 0.064 | 19.820 | 20.000 | 0.991 | -29.060 | 0.029 | 0.026 | -0.013 |
| K2.R | Ln9 | 1.000 | 0.999 | -0.039 | 19.809 | 20.000 | 0.990 | -29.078 | 0.029 | -0.026 | 0.013 |
| K10.R | Ln8 | 1.900 | -1.900 | 0.033 | 19.898 | 20.000 | 0.995 | -28.858 | 0.055 | 0.049 | -0.026 |
| K9.R | Ln8 | 1.893 | 1.892 | -0.037 | 19.820 | 20.000 | 0.991 | -29.060 | 0.055 | -0.049 | 0.026 |
| K8.R | Ln7 | 0.893 | 0.893 | 0.029 | 19.819 | 20.000 | 0.991 | -29.062 | 0.026 | -0.022 | 0.013 |
| K9.R | Ln7 | 0.893 | -0.893 | -0.027 | 19.820 | 20.000 | 0.991 | -29.060 | 0.026 | 0.022 | -0.013 |
| K8.R | Ln6 | 2.393 | -2.393 | -0.029 | 19.819 | 20.000 | 0.991 | -29.062 | 0.070 | 0.061 | -0.035 |
| K7.R | Ln6 | 2.389 | 2.389 | 0.042 | 19.787 | 20.000 | 0.989 | -29.089 | 0.070 | -0.060 | 0.035 |
| K6.R | Ln5 | 1.476 | 1.444 | 0.305 | 19.780 | 20.000 | 0.989 | -29.091 | 0.043 | -0.033 | 0.028 |
| K7.R | Ln5 | 1.476 | -1.445 | -0.301 | 19.787 | 20.000 | 0.989 | -29.089 | 0.043 | 0.033 | -0.028 |
| K5.R | Ln4 | 0.444 | 0.444 | 0.002 | 19.773 | 20.000 | 0.989 | -29.100 | 0.013 | -0.011 | 0.006 |
| K6.R | Ln4 | 0.445 | -0.444 | 0.024 | 19.780 | 20.000 | 0.989 | -29.091 | 0.013 | 0.012 | -0.006 |
| K5.R | Ln3 | 0.494 | 0.356 | 0.342 | 19.773 | 20.000 | 0.989 | -29.100 | 0.014 | -0.004 | 0.014 |
| K4.R | Ln3 | 0.486 | -0.356 | -0.331 | 19.776 | 20.000 | 0.989 | -29.104 | 0.014 | 0.004 | -0.014 |
| K4.R | Ln2 | 1.120 | 0.986 | 0.531 | 19.776 | 20.000 | 0.989 | -29.104 | 0.033 | -0.018 | 0.028 |
| K3.R | Ln2 | 1.106 | -0.987 | -0.498 | 19.795 | 20.000 | 0.990 | -29.105 | 0.032 | 0.018 | -0.027 |
| K2.R | Ln1 | 2.865 | -2.857 | 0.209 | 19.809 | 20.000 | 0.990 | -29.078 | 0.083 | 0.076 | -0.035 |
| K3.R | Ln1 | 2.861 | 2.855 | -0.195 | 19.795 | 20.000 | 0.990 | -29.105 | 0.083 | -0.076 | 0.036 |
| K10.R | Ld8 | 0.105 | -0.100 | -0.033 | 19.898 | 20.000 | 0.995 | -28.858 | 0.003 | 0.002 | -0.002 |
| K7.R | Ld7 | 0.447 | -0.400 | -0.200 | 19.787 | 20.000 | 0.989 | -29.089 | 0.013 | 0.007 | -0.011 |
| K7.R | Ld6 | 0.643 | -0.630 | -0.131 | 19.787 | 20.000 | 0.989 | -29.089 | 0.019 | 0.014 | -0.012 |
| K6.R | Ld5 | 1.053 | -1.000 | -0.329 | 19.780 | 20.000 | 0.989 | -29.091 | 0.031 | 0.021 | -0.023 |
| K5.R | Ld4 | 0.421 | -0.400 | -0.131 | 19.773 | 20.000 | 0.989 | -29.100 | 0.012 | 0.008 | -0.009 |
| K5.R | Ld3 | 0.263 | -0.250 | -0.082 | 19.773 | 20.000 | 0.989 | -29.100 | 0.008 | 0.005 | -0.006 |
| K5.R | Ld2 | 0.421 | -0.400 | -0.131 | 19.773 | 20.000 | 0.989 | -29.100 | 0.012 | 0.008 | -0.009 |
| K4.R | Ld1 | 0.661 | -0.630 | -0.200 | 19.776 | 20.000 | 0.989 | -29.104 | 0.019 | 0.013 | -0.014 |
| K7.R | L10 | 0.595 | 0.085 | 0.589 | 19.787 | 20.000 | 0.989 | -29.089 | 0.017 | 0.006 | 0.016 |
| K3.R | L10 | 0.595 | -0.086 | -0.589 | 19.795 | 20.000 | 0.990 | -29.105 | 0.017 | -0.006 | -0.016 |
| K1.R | G5 | 2.208 | -1.768 | 1.323 | 110.000 | 110.000 | 1.000 | 0.000 | 0.012 | 0.009 | 0.007 |
| K10.R | G4 | 2.000 | 2.000 | 0.000 | 19.898 | 20.000 | 0.995 | -28.858 | 0.058 | -0.051 | 0.028 |
| K8.R | G3 | 1.500 | 1.500 | 0.000 | 19.819 | 20.000 | 0.991 | -29.062 | 0.044 | -0.038 | 0.021 |
| K5.R | G2 | 0.250 | 0.250 | 0.000 | 19.773 | 20.000 | 0.989 | -29.100 | 0.007 | -0.006 | 0.004 |
| K0.R | G1 | 2.000 | 2.000 | 0.000 | 0.425 | 0.400 | 1.062 | 6.162 | 2.719 | -2.703 | -0.292 |
| K1.R | $R00002 | 0.012 | -0.012 | 0.000 | 110.000 | 110.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| K0.R | $R00001 | 0.000 | -0.000 | 0.000 | 0.425 | 0.400 | 1.062 | 6.162 | 0.000 | 0.000 | 0.000 |

## Comparison of Results between PSS®NETOMAC and MATPOWER.

Here the simulation is compared based on static load flow analysis with generator reactor power limits. All generators having reactive power limits within  MVAr to  MVAr expect slack generator which compensates all power (real and reactive power). Refer APPENDIX A, APPENDIX B for details. All results are compared based on nodal voltage (per unit), nodal Angle (degrees), real and reactive Losses, iterations and convergent time [14].

In Matpower, 11 buses are represented from Bus from 0 to 10. In PSS®NETOMAC, nodes are represented by K.0 to K.10.Table 7 and bus data in Matpower gives results of voltage and voltage angle at given node, Figure 5 and Figure 6 compares that voltage (per unit) at the nodes from K0 to K10 between PSS®NETOMAC and Matpower. At K0 Slack bus is at voltage 1 p.u and angle 0° degree .In Matpower, the slack generator has and.Total generation (actual) reactive power and branch charging (injection) is. In PSS®NETOMAC, slack generator has and . This difference between two softwares is due to approach The reactive power required for transmission[branch charging(injection)] is not taken into account in PSS®NETOMAC whereas the total losses in real and reactive power from both software indicates same value as shown in Figure 7 [14]

The maximum voltage (p.u) occurs at K0, in PSS®NETOMAC, it is 1.062 p.u and in Matpower, it is 1.001 p.u. The minimum voltage (p.u), in PSS®NETOMAC, it is 0.989 p.u @ Bus K.6 and in Matpower; it is 1.0 p.u @ Bus K.11. This difference is because in Matpower, in PV bus voltage (p.u) is fixed whereas in PSS®NETOMAC, there is a slight change as per requirement

Figure 5 Voltage (per unit) at the nodes from K0 to K10 between PSS®NETOMAC and Matpower.

Table 7 and bus data in Matpower of the network gives results of voltage and voltage angle at given node, The Figure **6** compares that voltage Angle (Degree ) at the nodes from K0 to I10 between PSS®NETOMAC and Matpower [14].



Figure 6 Voltage angle (degree) at the nodes from K0 to I10 between PSS®NETOMAC and Matpower.

At K1 Slack bus is there having Voltage 1 p.u and angle 0**°**degree.

The maximum voltage Angle (Degree), occurs at K0, in PSS®NETOMAC, it is 6.1162° degree and in Matpower**,** it is0.034° Degree**.** This difference is not so large**,** both give positive angle, this difference does not make much of difference in Power flow.

The minimum voltage Angle (Degree) , in PSS®NETOMAC ,it is @ Bus K3 and in Matpower, it is @ Bus K5.This is almost same and small difference due to iteration tolerance and iteration step.

## LOSSES OCCUR IN TRANSMISSION LINES.

Table 8, Table 10, Table 11and the branch results in Matpower computes the transmission losses. Figure 7 compares transmission losses (active and reactive ) which occurs at various transmission lines, in the network see Figure 3,there are 12 transmission lines (12 branches).Maximum Power losses occur at line 11 ( the node connecting node 1 and node 3) for both PSS®NETOMAC and Matpower .Equations (33-39) will compute the power losses [15].As power flow is a vector, so vector notation is used during real and reactive power loss calculation



Figure 7 The transmission losses (active and reactive) which occur at various transmission lines in the network.

Total active power loss (MW) in Matpower is 0.11 MW whereas in PSS®NETOMAC it is 0.162 MW. Total reactive power loss (MVAr) in Matpower is 0.13 MVAr whereas in PSS®NETOMAC it is 0.088 MVAr. The active and reactive power loss is almost similar, small difference is due to .numerical iteration limit

Maximum active power (MW) loss is 0.107 MW in Matpower and 0.142 MW in PSS®NETOMAC at Line11 (Node 1 to Node 3). Maximum reactive Power (MVAr) loss is 0.13 MVAr in Matpower and 0.17 MVAr in PSS®NETOMAC at Line11. This shows that at same line maximum power loss occurs which indicates the fact that power flows similarly in both software

## ITERATIONS AND CONVERGING TIME.

From Table 6.shows the results of Newton's method power flow converged in 6 iterations in Matpower. It converses in 0.34 seconds. Figure 8 shows the converging of max P&Q mismatch

PSS®NETOMAC converges in 5 seconds. Load flow converged after 14 iteration(s)

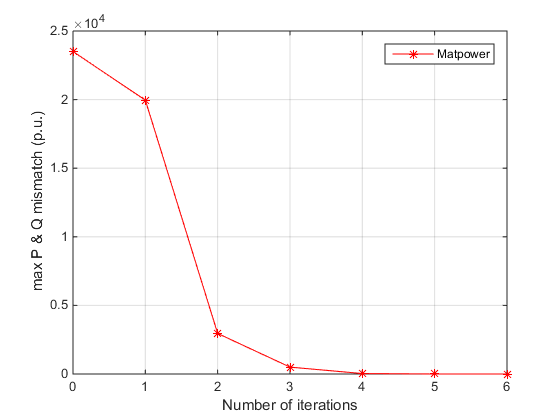


Figure 8 Maximum P & Q mismatch with respect to number of iterations in Matpower.

# CONCLUSION.

In this project, the 11 Bus medium voltage network is analyzed. Modelling and Simulation in PSS®NETOMAC and Matpower show us operating parameters of LV Network. Results of static load flow simulation indicate if there is problem with power distribution and overloads in Network.

The Section 3.5, 3.6, 3.7, 3.8 and 3.9 shows that the Matpower results are similar to PSS®NETOMACresults.

The comparative results between slack node, power flow, nodal Voltage, Nodal angle, losses and iteration time shows that Matpower can be used for modelling and simulation of load flow.

These results in Static load flow are almost equal .Later the results in Dynamic load flow can be analyzed.

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# APPENDIX A

Parts of the Jacobian matrix can be calculated with following equations [4]:

J1 diagonal element

J1 off diagonal element

The general form of the method will be:

N bus general form of N-R method with

The matrix size is calculated by, where nbus is the total number of bus of network; ng is the total number of generator bus in network and ns is the number of slack bus.

# APPENDIX B

## MATPOWER PROGRAM

%% generator data with Reactive Power limits

function mpc = casenew

% Summary of this function goes here

% Detailed explanation goes here

%% Matpower version

mpc.version = '2';

% System MVA Base

mpc.baseMVA=2;

%% bus data

% bus\_i type Pd Qd Gs Bs area Vm Va baseKV zone Vmax Vmin

mpc.bus = [

80 2 0 0 0 0 1 1 0 0.4 1 1.01 0.99;

1 3 0 0 0 0 2 1 0 110 1 1.01 0.99;

2 2 0 0 0 0 1 1 0 20 1 1.01 0.99;

3 2 0 0 0 0 2 1 0 20 1 1.01 0.99;

4 1 0.63 0.2 0 0 3 1 0 20 1 1.01 0.99;

5 1 1.05 0.6 0 0 3 1 0 20 1 1.01 0.99;

6 1 1 0.2 0 0 3 1 0 20 1 1.01 0.99;

7 1 1.03 0.2 0 0 2 1 0 20 1 1.01 0.99;

8 2 0 0 0 0 1 1 0 20 1 1.01 0.99;

9 1 0 0 0 0 1 1 0 20 1 1.01 0.99;

10 2 0 0 0 0 1 1 0 20 1 1.01 0.99;

];

%% generator data with Reactive Power limits

% bus Pg Qg Qmax Qmin Vg mBase status Pmax Pmin

mpc.gen = [

80 2.0 0 3 -3 1 2.0 1 2.0 0;

1 0 0 1e3 -1e3 1 2.0 1 2.0 0;

5 0.25 0 3 -3 1 2.0 1 0.25 0;

8 1.50 0 3 -3 1 2.0 1 1.50 1.0;

10 2 0 3 -3 1 2.0 1 2 0;

];

% Settings

bkV04=400;

bkV20=20000;

bkV110=110000;

bMVA=2000;

freq=50;

l1=0.5;

l2=1.2;

l3=0.4;

l4=1;

l5=0.2;

l6=0.6;

l7=0.1;

l8=2;

l9=0.9;

l10=0.7;

R1=0.443;

R2=0.32;

R3=0.253;

R4=0.206;

R5=0.413;

R6=0.31;

X1=0.137;

X2=0.13;

X3=0.125;

X4=0.112;

X5=0.36;

X6=0.35;

C1=191;

C2=212;

C3=231;

C4=249;

C5=10;

C6=10;

uk=12.5;

ur=8;

ST1=12500000;

ST2=2000000;

LR1=l1\*R4\*bMVA/bkV20^2

LR2=l2\*R3\*bMVA/bkV20^2

LR3=l3\*R2\*bMVA/bkV20^2

LR4=l4\*R2\*bMVA/bkV20^2

LR5=l5\*R1\*bMVA/bkV20^2

LR6=l6\*R1\*bMVA/bkV20^2

LR7=l7\*R2\*bMVA/bkV20^2

LR8=l8\*R5\*bMVA/bkV20^2

LR9=l9\*R3\*bMVA/bkV20^2

LR10=l10\*R6\*bMVA/bkV20^2

LX1=l1\*X4\*bMVA/bkV20^2

LX2=l2\*X3\*bMVA/bkV20^2

LX3=l3\*X2\*bMVA/bkV20^2

LX4=l4\*X2\*bMVA/bkV20^2

LX5=l5\*X1\*bMVA/bkV20^2

LX6=l6\*X1\*bMVA/bkV20^2

LX7=l7\*X2\*bMVA/bkV20^2

LX8=l8\*X5\*bMVA/bkV20^2

LX9=l9\*X3\*bMVA/bkV20^2

LX10=l10\*X6\*bMVA/bkV20^2

LC1=l1\*C4\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

LC2=l2\*C3\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

LC3=l3\*C2\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

LC4=l4\*C2\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

LC5=l5\*C1\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

LC6=l6\*C1\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

LC7=l7\*C2\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

LC8=l8\*C5\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

LC9=l9\*C3\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

LC10=l10\*C6\*2\*pi\*freq\*1e-9\*(bkV20^2/bMVA)

TR1=ur/100\*(110000/bkV110)^2\*bMVA/ST1

TR2=ur/100\*(20000/bkV20)^2\*bMVA/ST2

TX1=(110000/bkV110)^2\*bMVA/ST1\*sqrt(uk^2-ur^2)/100

TX2=(20000/bkV20)^2\*bMVA/ST2\*sqrt(uk^2-ur^2)/100

TC1=0;

TC2=0;

n1=bkV110/bkV20\*bkV20/bkV110;

n2=bkV20/bkV04\*bkV04/bkV20;

ang=30;

%rate

l70=.208 \* bkV20/1000;

l95=.248 \* bkV20/1000;

l120=.283 \* bkV20/1000;

l150=.315 \* bkV20/1000;

lh70=.29 \* bkV20/1000;

lh95=.35 \* bkV20/1000;

% Branch Details

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| % | fbus | | Tbus r x b | | rateA | | rateB | | rateC | | ratio | | angle | | status | | angmin | | angmax | |
| mpc.branch=[ | | | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 2 3 LR1 LX1 LC1 l150 l150 l150 0 0 1 -360 360; % Ln1 | | | | | | | | | | | | | | | |  | |  | |  | |
| 3 4 LR2 LX2 LC2 l120 l120 l120 0 0 1 -360 360; % Ln2 | | | | | | | | | | | | | | | |  | |  | |  | |
| 4 5 LR3 LX3 LC3 l95 l95 l95 0 0 1 -360 360; % Ln3 | | | | | | | | | | | | | | | |  | |  | |  | |
| 5 6 LR4 LX4 LC4 l95 l95 l95 0 0 1 -360 360; % Ln4 | | | | | | | | | | | | | | | |  | |  | |  | |
| 6 7 LR5 LX5 LC5 l70 l70 l70 0 0 1 -360 360; % Ln5 | | | | | | | | | | | | | | | |  | |  | |  | |
| 7 8 LR6 LX6 LC6 l70 l70 l70 0 0 1 -360 360; % Ln6 | | | | | | | | | | | | | | | |  | |  | |  | |
| 8 9 LR7 LX7 LC7 l95 l95 l95 0 0 1 -360 360; %Ln7  9 10 LR8 LX8 LC8 lh70 lh70 lh70 0 0 1 -360 360; % Ln8 | | | | | | | | | | | | | | | |  | |  | |  | |
| 9 2 LR9 LX9 LC9 l120 l120 l120 0 0 1 -360 360; % Ln9 | | | | | | | | | | | | | | | |  | |  | |  | |
| 3 7 LR10 LX10 LC10 lh95 lh95 lh95 0 0 1 -360 360; % Ln10 | | | | | | | | | | | | | | | |  | |  | |  | |
| 1 3 TR1 TX1 TC1 0 0 0 n1 ang 1 -360 360; % T1 | | | | | | | | | | | | | | | |  | |  | |  | |
| 80 2 TR2 TX2 TC2 0 0 0 n1 ang 1 -360 360; % T2 | | | | | | | | | | | | | | | |  | |  | |  | |
|  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| ]; | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |

## NETDRAW.

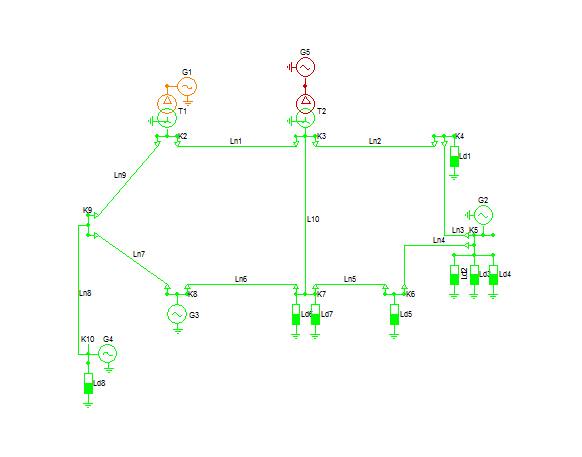


Figure 9. Medium voltage network drawn in NetDraw.

PSS®NETOMAC PROGRAM **.**

\*\*\*\*  
$ Fixed Frequency Source Data  
$1......12......23......3AA1....12....23....34....45....56....67...78...89...9ZZ  
E  
$ Machine Data  
$1......12......23......3AA1....12....23....34....45....56....67...78...89...9ZZ  
S G1  
1 RG 2.35 0.4 0.85 3000 50.  
2 0.0807 .00262 .004 8.18  
5 0.035 0.16 .956 .20 1.8  
6 .035 0.156 .184 0.336 1.75  
S G5  
1 RG 2.35 110 0.85 3000 50.  
2 0.08 .005 .004  
5 4 0.2 8 .4 1.8  
6 .2 0.4 .4 0.6 1.7  
S G4  
1 RG 2.35 20 0.85 3000 50.  
2 0.0807 .00262 .004 8.18  
5 0.035 0.16 .956 .20 1.8  
6 .035 0.156 .184 0.336 1.75  
S G3  
1 RG 2.35 20 0.85 3000 50.  
2 0.0807 .00262 .004 8.18  
5 0.035 0.16 .956 .20 1.8  
6 .035 0.156 .184 0.336 1.75  
S G2  
1 RG 2.35 20 0.85 3000 50.  
2 0.0807 .00262 .004 8.18  
5 0.035 0.16 .956 .20 1.8  
6 .035 0.156 .184 0.336 1.75  
E  
$ Network Data  
$1......12......23......3AA1....12....23....34....45....56....67...78...89...9ZZ  
$--- Fixed Frequency Sources  
$--- Machines  
VK0 G1 2  
SK1 G5 1 0  
VK10 G4 2  
VK8 G3 1.5  
VK5 G2 .25  
$--- Transformers  
TK2 T1 Yd20 20 2 8 12.5  
TK0 110.4 0.4  
RK0 $R00001 01 1.0E+6 0.4  
$  
TK1 T2 Dy110 110 12.5 0.5 10.5  
TK3 0120 20  
RK1 $R00002 01 1.0E+6 110  
$  
$--- Breakers

$--- Lines (With Fault Locations and Fault Branches)  
LK3 K2 Ln1 0.5 0.206 0.112 249 20 .315  
LK9 K2 Ln9 0.9 0.253 0.125 231 20 .283  
LK3 K4 Ln2 1.2 0.253 0.125 231 20 .283  
LK4 K5 Ln3 0.4 0.320 0.13 212 20 .248  
LK5 K6 Ln4 1 0.320 0.13 212 20 .248  
LK6 K7 Ln5 0.2 0.443 0.137 191 20 .208  
LK3 K7 L10 0.7 0.31 0.35 10 20 .35  
LK7 K8 Ln6 0.6 0.443 0.137 191 20 .208  
LK9 K8 Ln7 0.1 0.320 0.13 212 20 0.248  
LK9 K10 Ln8 2 0.413 0.36 10 20 .29  
$--- Serial Impedances  
$--- Loads  
VK4 Ld1 01-.63 -.2  
VK5 Ld3 01-.25 -.082  
VK5 Ld4 01-.4 -.131  
VK5 Ld2 01-.4 -.131  
VK10 Ld8 01-.1 -.033  
VK7 Ld6 01-.63 -.131  
VK7 Ld7 01-.4 -.2  
VK6 Ld5 01-1. -.329  
$--- Macros  
$--- Instrumentation Transformers  
E  
CONTROLLER IN LOADFLOW:  
E  
$ Controller Data  
E  
$ Load Torque of Working Machines  
$1......12......23......3AA1....12....23....34....45....56....67...78...89...9ZZ  
ENDE