Load Flow and Fault Analysis of 11 Bus System

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OBJECTIVES

TASK 1 - Model 11 (Eleven) bus system given in the book (Power System Dynamics and Stability, by Prabha Kundur). Explain its power flow and discuss properly.

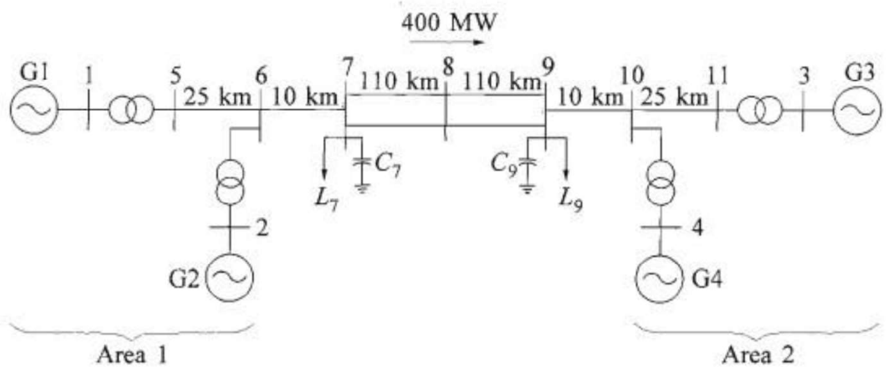


Figure E12.8 A simple two-area system

TASK 2: Create overload problem at any portion of the 11 bus system and solve it by at least two appropriate methods.

TASK 3: Create three phase fault at any point in the 11 bus system, observe note the phase currents and Sequence currents.

TASK 4: Repeat the point 3 for line to ground fault.

TASK 5: Create problem of "low power factor" and solve it by at least two methods.

INTRODUCTION

In power system engineering, the power flow study (also known as load-flow study) is an important tool involving numerical analysis applied to a power system. Unlike traditional circuit analysis, a power flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various forms of AC power (i.e. reactive, real, and apparent) rather than voltage and current. It analyzes the power systems in normal steady-state operation.

In this CEP we have attempted to model an existing 11 bus system taking care of all the parameters required for the simulation and analysis using ETAP software.

The great importance of power flow or load-flow studies is in the planning the future expansion of power systems as well as in determining the best operation of existing systems. Also the system can be analyzed and simulation results can be studied before any new change in the existing system without affecting the original system.

POWER FLOW PROLEM FORMULATION

The goal of a power flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions. Once this information is known, real and reactive power flow on each branch as well as generator reactive power output can be analytically determined. Due to the nonlinear nature of this problem, numerical methods are employed to obtain a solution that is within an acceptable tolerance.

The solution to the power flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus. A bus without any generators connected to it is called a Load Bus. With one exception, a bus with at least one generator connected to it is called a Generator Bus. The exception is one arbitrarily-selected bus that has a generator. This bus is referred to as the Slack Bus.

In the power flow problem, it is assumed that the real power and reactive power QD at each Load Bus are known. For this reason, Load Buses are also known as PQ Buses. For Generator Buses, it is assumed that the real power generated PG and the voltage magnitude |V| is known. For the Slack Bus, it is assumed that the voltage magnitude |V| and voltage phase θ are known. Therefore, for each Load Bus, the voltage magnitude and angle are unknown and must be solved for; for each Generator Bus, the voltage angle must be solved for; there are no variables that must be solved for the Slack Bus.

LOAD FLOW REQUIRED DATA

Bus Data

Required data for load flow calculations for buses includes:

1. Nominal kV
2. %V and Angle (when Initial Condition is set to use Use Bus Voltages)
3. Load Diversity Factor (when the Loading option is set to use Diversity Factor)

Branch Data

Branch data is entered into the Branch Editors, i.e., Transformer, Transmission Line, Cable, Reactor, and Impedance editors. Required data for load flow calculations for branches includes:

1. Branch Z, R, X, or X/R values and units, tolerance, and temperature, if applicable
2. Cable and transmission line, length, and unit
3. Transformer rated kV and kVA/MVA, tap, and LTC settings
4. Impedance base kV and base kVA/MVA

Synchronous Generator Data

Required data for load flow calculations for synchronous generators includes:

1. Operating mode (Swing, Voltage Control, or Mvar Control)
2. Rated kV
3. %V and Angle for swing mode of operation
4. %V, MW loading, and Mvar limits (Qmax and Qmin) for Voltage Control mode
5. MW and Mvar loading, and Mvar limits Mvar Control mode
6. MW loading and PF, and Mvar limits for PF Control mode

Static Load Data

1. Required data for load flow calculations for static loads includes:
2. Static Load ID
3. Rated kVA/MVA and kV
4. Power factor
5. % loading for desired Loading Category
6. Equipment cable data

Other Data

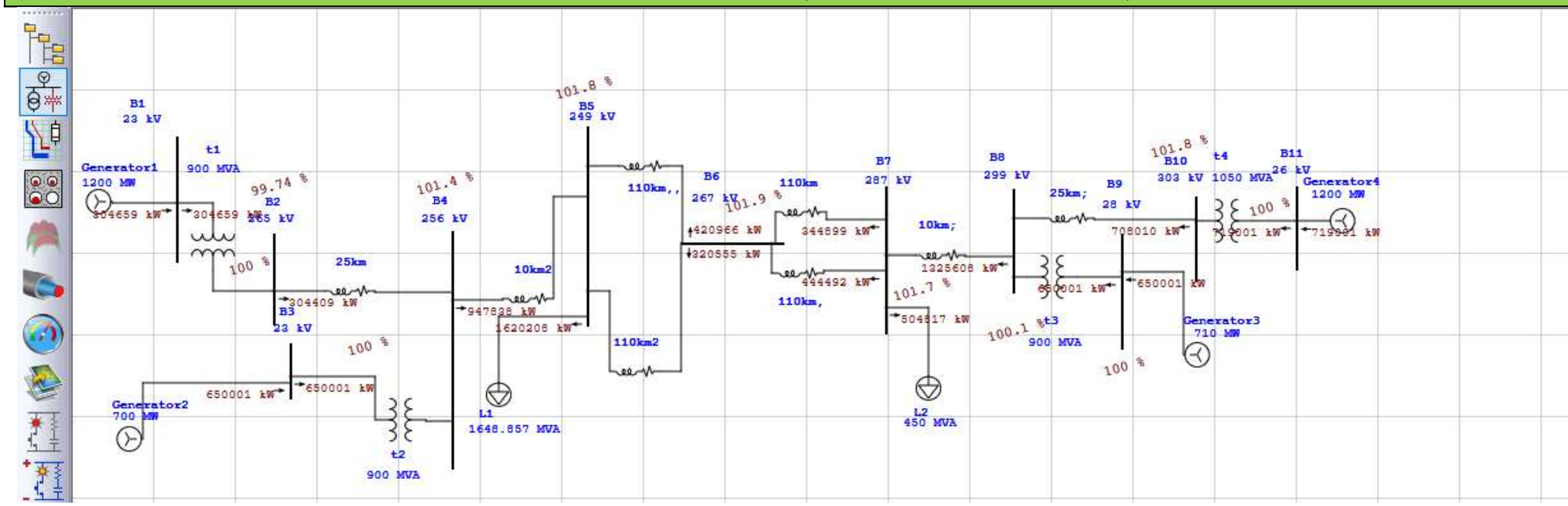
There are some study case related data, which must also be provided. This includes:

1. Method (Newton-Raphson, Fast-Decoupled, or Accelerated Gauss-Seidel)
2. Max Iteration
3. Precision
4. Acceleration Factor (when Accelerated Gauss-Seidel method is selected)
5. Loading Category
6. Initial Voltage Condition
7. Update (for bus voltages and transformer LTCs using load flow result)

TASK 1: MODELLING OF 11 BUS SYSTEM IN ETAP

After running load flow calculation we got the calculations with ***NO ERRORS*** in dialog box. Below is its diagram.

ONE LINE DIAGRAM (LOAD FLOW ANALYSIS)



DATA COLLECTION FOR MODELING

All the required data for modeling are collected from ETAP. Data required for load flow studies have been collected and they were sorted according to the easiness of the study.

The following data was collected:

1. Single line diagram of 11 bus system.
2. Reactance and MW rating of all generators connected to the network.
3. Impedances of all transmission and distribution lines and transformers.
4. Length and type of transmission lines from one substation to another.
5. Load details (MVAr and MW) of the existing network.

EXPLANATION OF POWER FLOW

Load flow analysis is performed on 11 bus system electrical network. There is a single swing bus, 3 voltage control buses, and 7 load buses. An iterative method of Newton Raphson is used for solving the System which is set on 60Hz frequency.

Electrical Transient Analyzer Program

Load Flow Analysis

Loading Category (1): Design
Generation Category (1): Design
Load Diversity Factor: None

	Swing	V-Control	Load	Total
Number of Buses:	1	3	7	11

	XFMR2	XFMR3	Reactor	Line/Cable	Impedance	Tie PD	Total
Number of Branches:	4	0	0	8	0	0	12

Method of Solution:	Adaptive Newton-Raphson Method
Maximum No. of Iteration:	99
Precision of Solution:	0.0001000

FOR BUS INPUT DATA

The total amount of Power linked to this 11 bus system is 1676 MW. Cables are used for transmission purpose and their lengths are specified as stated in the reference book. 4 Three-phase transformers are used to step-up/down the voltages. Their MVA ratings are adjusted in order to reduce the alerts occurring in the system. No phase shift has been given to transformers. The tapping of T2 is adjusted to 5% to reduce the errors and to make them work properly

4 buses are added with 4 Generators in which one of the bus is swing due to swing type generator used in the system. The MVAR limits are specifications defined in order to rectify the errors which occurred during the analysis

Bus Input Data

Bus			Initial Voltage		Load							
					Constant kVA		Constant Z		Constant I		Generic	
ID	kV	Sub-sys	% Mag.	Ang.	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar
B1	23.000	1	100.0	0.0								
B2	265.000	1	100.0	0.0								
B3	23.000	1	100.0	0.0								
B4	256.000	1	100.0	0.0								
B5	249.000	1	100.0	0.0	1316.657	80.001	292.822	17.792				
B6	267.000	1	100.0	0.0								
B7	287.000	1	100.0	0.0	360.000	0.000	140.136	0.000				
B8	299.000	1	100.0	0.0								
B9	28.000	1	100.0	0.0								
B10	303.000	1	100.0	0.0								
B11	26.000	1	100.0	0.0								
Total Number of Buses: 11					1676.657	80.001	432.958	17.792	0.000	0.000	0.000	0.000

Generation Bus				Voltage		Generation			Mvar Limits	
ID	kV	Type	Sub-sys	% Mag.	Angle	MW	Mvar	% PF	Max	Min
B1	23.000	Swing	1	100.0	0.0					
B3	23.000	Voltage Control	1	100.0	0.0	650.001			555.548	0.000
B9	28.000	Voltage Control	1	100.0	0.0	650.001			568.823	0.000
B11	26.000	Voltage Control	1	100.0	0.0	719.001			1002.411	0.000
						2019.003	0.000			

A self generated brief summary of Generation, load and demand is attached below.

SUMMARY OF TOTAL GENERATION , LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	304.660	20.903	305.376	99.77 Lagging
Source (Non-Swing Buses):	2019.003	369.789	2052.588	98.36 Lagging
Total Demand:	2323.663	390.692	2356.279	98.62 Lagging
Total Motor Load:	1676.657	80.001	1678.565	99.89 Lagging
Total Static Load:	448.368	18.444	448.747	99.92 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	198.638	292.247		
System Mismatch:	0.000	0.000		

Number of Iterations: 5

LOAD FLOW RESULT ANALYZER

This report is generated automatically by ETAP and it shows the components used in this 11bus system.

Study ID	Untitled
Study Case ID	LF
Data Revision	Base
Configuration	Normal
Loading Cat	Design
Generation Cat	Design
Diversity Factor	Normal Loading
Buses	11
Branches	12
Generators	4
Power Grids	0
Loads	2
Load-MW	2323.663
Load-Mvar	390.692
Generation-MW	2323.663
Generation-Mvar	390.692
Loss-MW	198.638
Loss-Mvar	292.247
Mismatch-MW	0
Mismatch-Mvar	0

TRANSFORMER RATINGS

This screenshot show the rating of the transformer.

2-Winding Transformer Input Data

Transformer		Rating					Z Variation			% Tap Setting		Adjusted	Phase Shift	
ID	Phase	MVA	Prim. kV	Sec. kV	% Z1	X1/R1	+ 5%	- 5%	% Tol.	Prim.	Sec.	% Z	Type	Angle
t1	3-Phase	900.000	21.000	242.000	14.50	50.00	0	0	0	0	0	14.5000	YNd	0.000
t2	3-Phase	900.000	21.000	242.000	14.50	50.00	0	0	0	5.000	5.000	14.5000	YNd	0.000
t3	3-Phase	900.000	22.000	230.000	10.00	2.47	0	0	0	0	5.000	10.0000	YNd	0.000
t4	3-Phase	1050.000	20.000	230.000	10.00	2.47	0	0	0	0	5.000	10.0000	YNd	0.000

GENERATOR RATINGS:

	ID	Rating/Limit	Rated kV	MW	Mvar
	Generator1	1200 MW	23	304.659	20.903
	Generator2	700 MW	23	650.001	155.418
	Generator3	710 MW	28	650.001	161.728
	Generator4	1200 MW	26	719.001	52.642

LOAD FLOW REPORT (GENERATED BY ETAP)

A detailed analysis of all the buses of the Electrical Network is here. The kilovolt voltages of each bus, the Generated Actual power(P) In MW and the Generated reactive power(Q) in MVAR, the P and Q in case of load and all the description is carried out through Electrical Transient Analyzer Program. Current in Amperes , power factor of each bus and %tapping of bus (if used) are presented in separate columns

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
*B1	23.000	100.000	0.0	304.660	20.903	0	0	B2	304.660	20.903	7665.6	99.8	
B2	265.000	99.739	-2.3	0	0	0	0	B4	304.409	8.381	665.2	100.0	
								B1	-304.409	-8.381	665.2	100.0	
*B3	23.000	100.000	2.6	650.001	155.418	0	0	B4	650.001	155.418	16776.4	97.3	5.000
B4	256.000	101.439	-3.0	0	0	0	0	B5	947.838	93.873	2117.6	99.5	
								B2	-299.159	-4.581	665.2	100.0	
								B3	-648.679	-89.292	1455.8	99.1	5.000
B5	249.000	101.815	-3.9	0	0	1620.207	98.445	B4	-926.557	-78.469	2117.6	99.6	
								B6	-397.440	-66.652	917.7	98.6	
								B6	-296.211	46.676	682.9	-98.8	
B6	267.000	101.919	-0.1	0	0	0	0	B7	-320.555	29.055	682.9	-99.6	
								B7	-420.966	-99.480	917.7	97.3	
								B5	420.966	99.480	917.7	97.3	
								B5	320.555	-29.055	682.9	-99.6	
B7	287.000	101.657	3.2	0	0	504.817	0.000	B8	-1294.209	-120.874	2572.2	99.6	
								B6	344.899	-11.434	682.9	-99.9	
								B6	444.492	132.307	917.7	95.8	
B8	299.000	100.093	4.0	0	0	0	0	B7	1325.608	143.601	2572.2	99.4	
								B10	-687.157	-10.400	1325.8	100.0	
								B9	-638.452	-133.202	1258.2	97.9	5.000
*B9	28.000	100.000	6.2	650.001	161.728	0	0	B8	650.001	161.728	13811.4	97.0	
B10	303.000	101.824	5.2	0	0	0	0	B8	708.010	25.494	1325.8	99.9	
								B11	-708.010	-25.494	1325.8	99.9	5.000
*B11	26.000	100.000	7.4	719.001	52.642	0	0	B10	719.001	52.642	16008.7	99.7	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

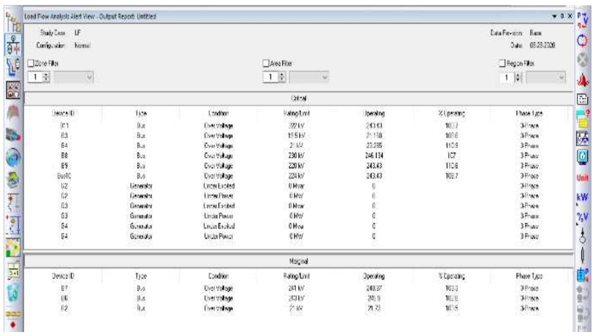
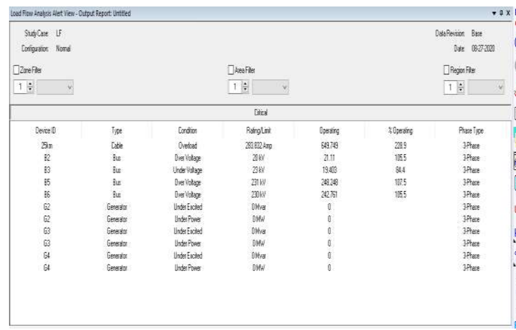
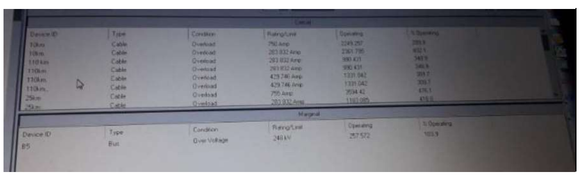
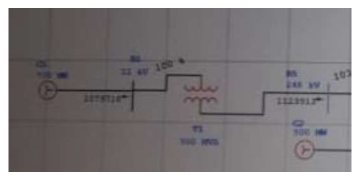
\# Indicates a bus with a load mismatch of more than 0.1 MVA

ERRORS ENCOUNTERED WHILST MODELLING SLD

Whilst modelling the 11bus system many errors encountered, below they are mentioned.

- Overloading of Cable
- Overvoltage of Bus
- Underpower of Generator
- Underexcited of Generator
- Overload of Transformer
- Overload of Generator

Below are their screenshots.

TECHNIQUES USED WHILST RECTIFYING THE ERROR

We used various techniques to rectify this error

- Rectification of Error in Transformer –We increased the MVA rating until it get resolved

- Rectification of Error in Cable – Increase the current carrying capacity of cable(we known about the current carrying capacity when we do the load flow analysis of it) the overloading of cable was rectified by this method.

- Rectification of Error in Bus – There are various techniques whilst solving this error, we can increase the terminal voltage slowly of the generator which is near the bus, or by increasing the tapping of the transformer either primary or secondary.

- Rectification of Error in Generator – When the generator is underpower we can increase the MVA rating of the lumped load so this issue also got resolved. When it is underexcited we will increase the kV rating of the generator.

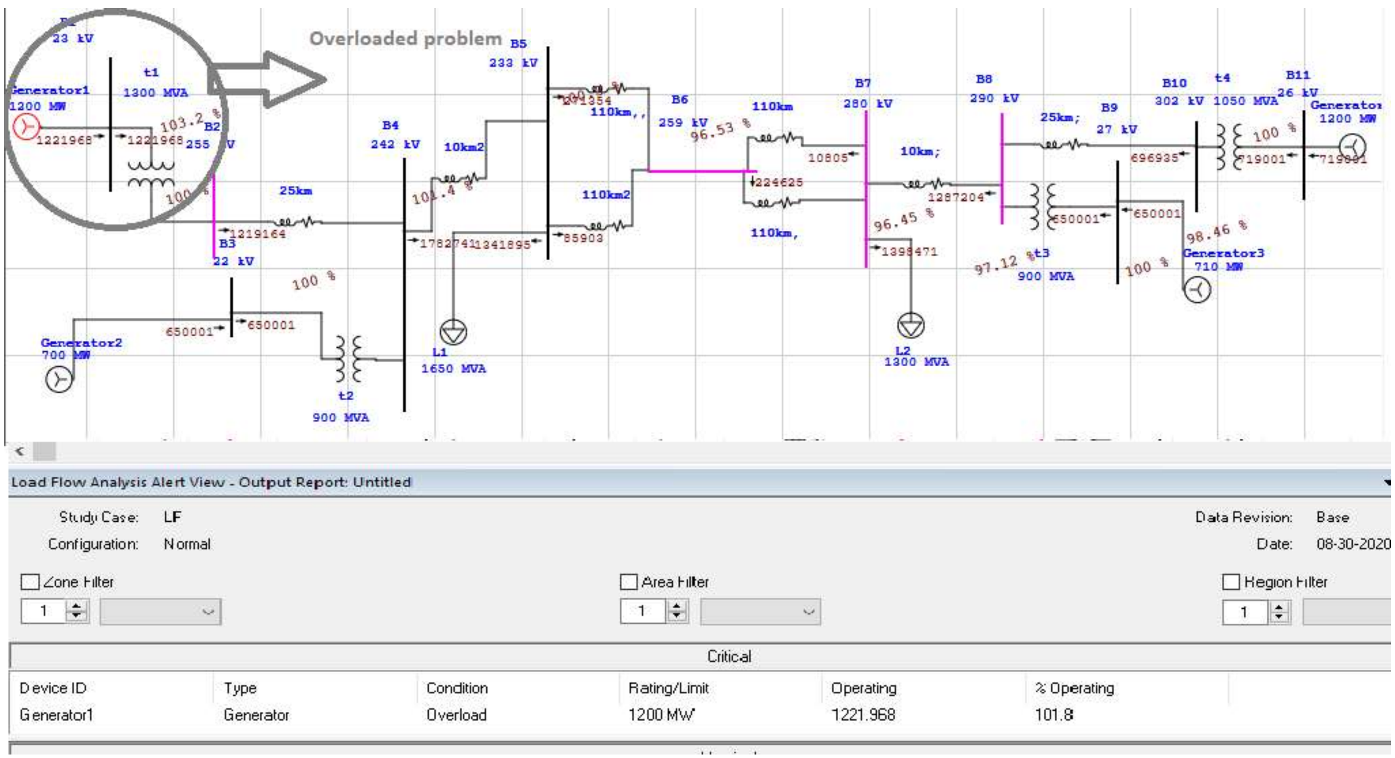
TASK 2: CREATE OVERLOAD PROBLEM AT ANY PORTION OF THE 11 BUS SYSTEM AND SOLVE IT BY TWO APPROPRIATE METHODS

We created overloaded problem at GENERATOR 1 by increasing the second load to 850MVA, thus it overloaded the generator.

Previous LOAD 2 Rating = 450MVA

New LOAD 2 Rating = 1300MVA

ONE LINE DIAGRAM (ETAP)

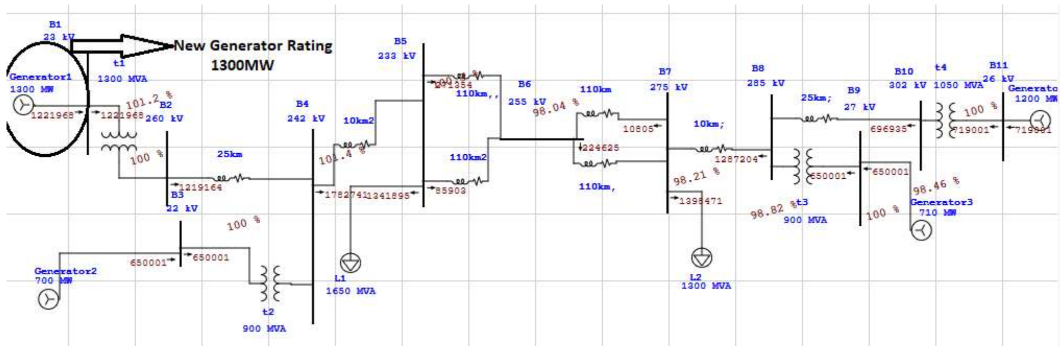


SOLVING THE PROBLEM OF OVERLOADING (*METHOD 1*)

We will increase the Generator MW to 100 it solve this method of overloading,

Previous Generator 1 Rating = 1200MW **New Generator Rating = 1300MW**

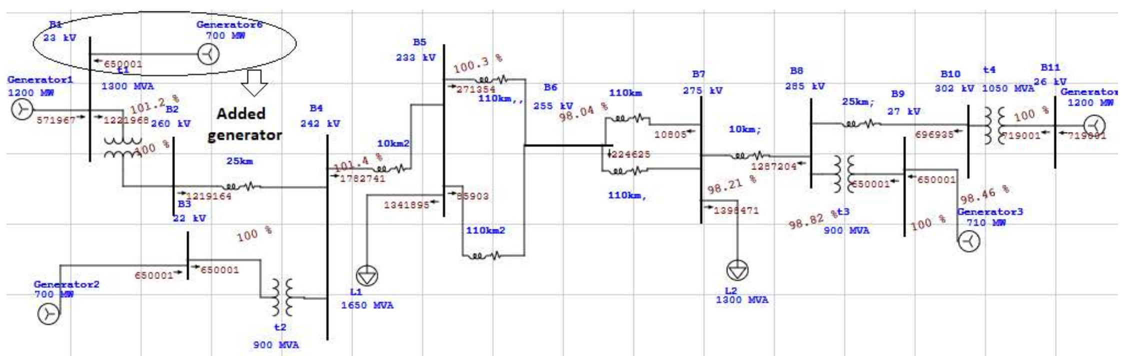
SOLVED THE PROBLEM OF OVERLOADING #1



SOLVING THE PROBLEM OF OVERLOADING (*METHOD 2*)

We will add one more generator at BUS 1 to overcome this issue of overloading the rating of new generator will be 700MW.

SOLVED THE PROBLEM OF OVERLOADING #2

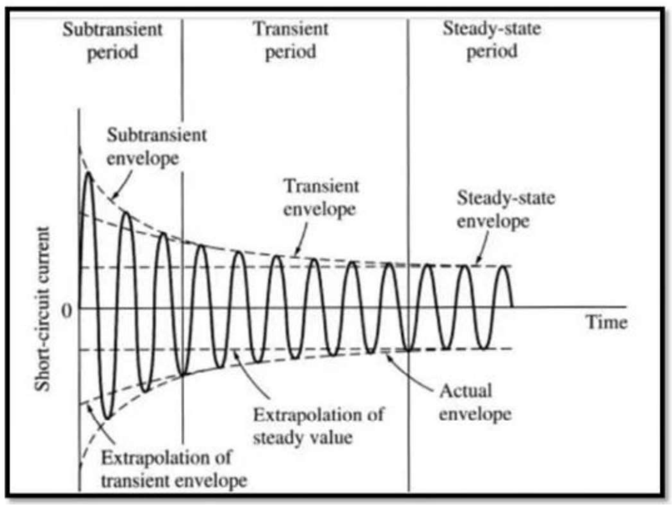


THREE PHASE FAULT

The three phase faults are balanced or symmetrical short circuit faults, whenever we are performing short circuit analysis of a system there are three stages in values.

- Sub transient
- Transient
- Steady State

FAULT CURRENT TYPES



Type	Cycles	Value
Sub transient	0.5 – 1.5	Highest
Transient	1.5 – 4	Intermediate
Steady State	Beyond 4	Lowest

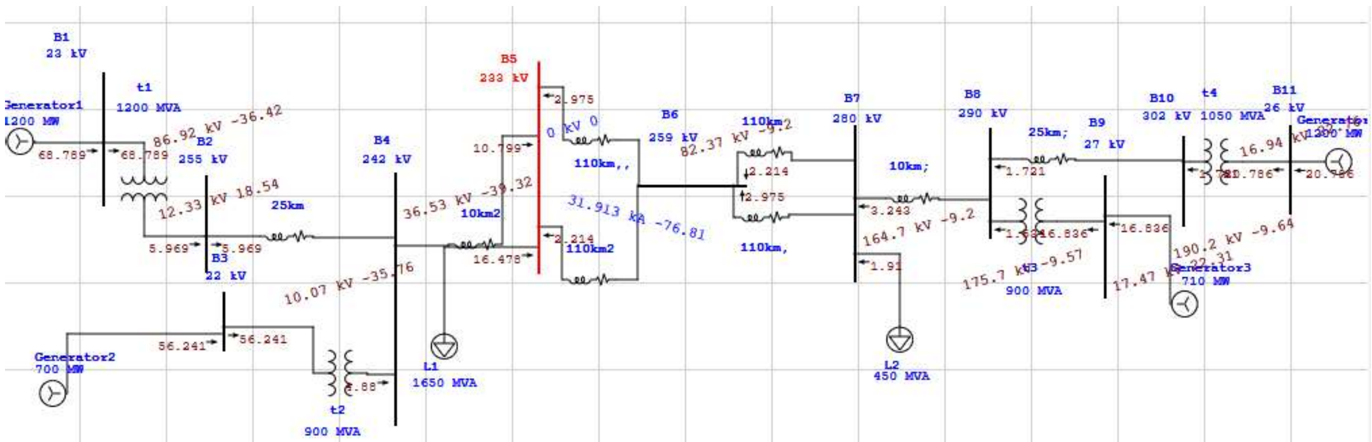
We have to make ANY BUS faulty by pressing fault button, the BUS becomes Red, then in right option of ETAP there is option of selecting three types transient, subtransient and steadystate.

We can view three faults in display option of short circuit analysis.

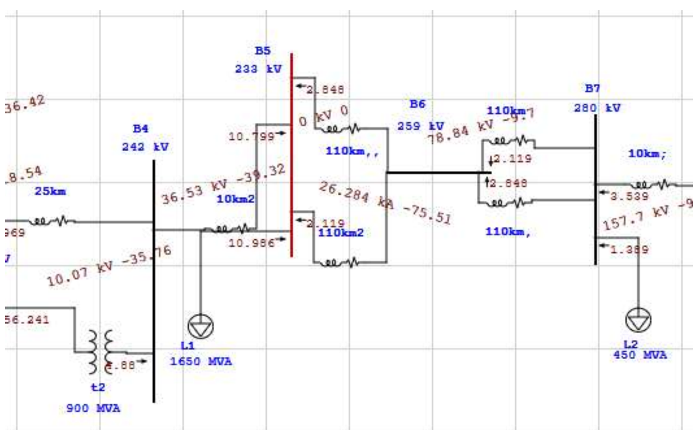
- Three Phase
- L-G
- L-L
- L-L-G

TASK 3: THREE PHASE FAULT AT BUS NO (5) IN 11 BUS SYSTEM

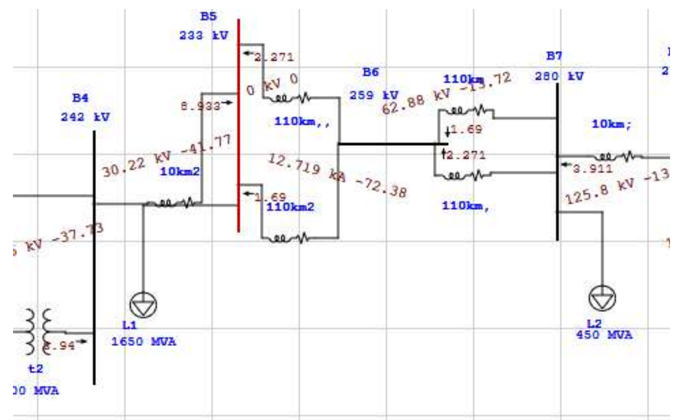
SUBTRANSIENT



TRANSIENT



STEADY STATE



RESULTS OF THREE PHASE FAULTS:

(Sub transient)
Short Circuit Current = **31.913kA ,** Phasor Angle = **76.81**

(Transient)
Short Circuit Current = **26.284kA ,** Phasor Angle = **75.51**

(Steady State)
Short Circuit Current = **12.719kA ,** Phasor Angle = **72.38**

ETAP GENERATED REPORT (SUB TRANSIENT)

SHORT- CIRCUIT REPORT

Fault at bus: **B5**

Prefault voltage = 233.000 kV = 100.00 % of nominal bus kV (233.000 kV)
= 87.91 % of base kV (265.048 kV)

Contribution		3-Phase Fault		Line-To-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus	To Bus	% V	kA	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
ID	ID	From Bus	Symm. rms	Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
B5	Total	0.00	31.913	0.00	110.06	133.08	21.586	21.586	1.37E-001	5.84E-001	9.53E-001	1.19E+000
B4	B5	15.09	10.799	33.40	103.42	105.45	11.397	19.530	4.52E-001	1.71E+000	9.77E-001	1.38E+000
B6	B5	31.80	2.975	37.17	92.01	105.57	1.555	0.754	2.86E+000	5.76E+000	4.36E+001	4.05E+000
B6	B5	31.80	2.214	37.17	92.01	105.57	1.542	1.661	6.11E+000	6.13E+000	1.69E+001	1.05E+001
L1	B5	88.26	16.478	88.26	88.26	88.26	7.412	0.000	1.16E-001	1.16E+000		

(TRANSIENT)

SHORT- CIRCUIT REPORT

Fault at bus: **B5**

Prefault voltage = 233.000 kV = 100.00 % of nominal bus kV (233.000 kV)
= 87.91 % of base kV (265.048 kV)

Contribution		3-Phase Fault		Line-To-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus	To Bus	% V	kA	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
ID	ID	From Bus	Symm. rms	Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
B5	Total	0.00	26.284	0.00	104.85	127.79	19.692	19.692	1.82E-001	7.05E-001	9.53E-001	1.19E+000
B4	B5	15.09	10.799	31.82	99.84	103.15	11.355	17.817	4.52E-001	1.71E+000	9.77E-001	1.38E+000
B6	B5	30.44	2.848	36.06	89.31	103.04	1.612	0.688	2.94E+000	6.05E+000	4.36E+001	4.05E+000
B6	B5	30.44	2.119	36.06	89.31	103.04	1.555	1.516	6.32E+000	6.46E+000	1.69E+001	1.05E+001
L1	B5	88.26	10.986	88.26	88.26	88.26	5.469	0.000	1.73E-001	1.73E+000		

(STEADY STATE)

SHORT- CIRCUIT REPORT

Fault at bus: **B5**

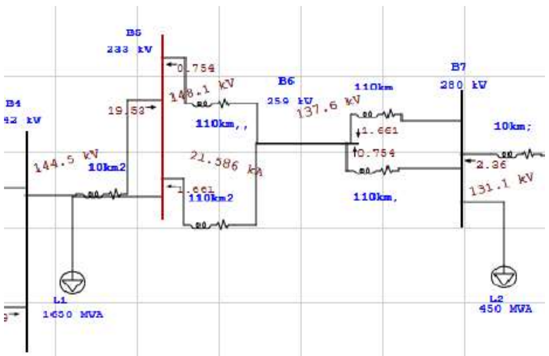
Prefault voltage = 233.000 kV = 100.00 % of nominal bus kV (233.000 kV)
= 87.91 % of base kV (265.048 kV)

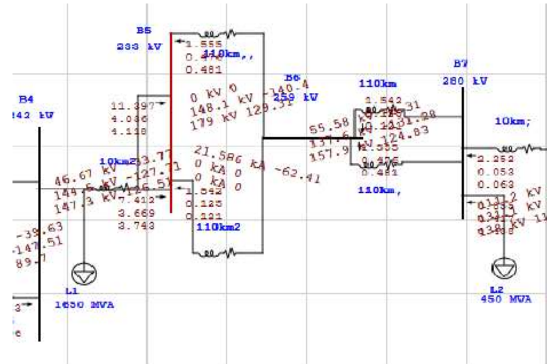
Contribution		3-Phase Fault		Line-To-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus	To Bus	% V	kA	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
ID	ID	From Bus	Symm. rms	Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
B5	Total	0.00	12.719	0.00	89.39	106.20	13.551	13.551	4.56E-001	1.43E+000	9.53E-001	1.19E+000
B4	B5	12.49	8.933	25.73	87.04	90.96	10.529	12.260	4.58E-001	2.09E+000	9.77E-001	1.38E+000
B6	B5	24.28	2.271	31.15	79.92	90.62	1.676	0.473	3.15E+000	7.82E+000	4.36E+001	4.05E+000
B6	B5	24.28	1.690	31.15	79.92	90.62	1.504	1.043	7.34E+000	8.63E+000	1.69E+001	1.05E+001

TASK 4: LINE TO GROUND FAULT AT BUS NO (5) IN 11 BUS SYSTEM

SUBTRANSIENT

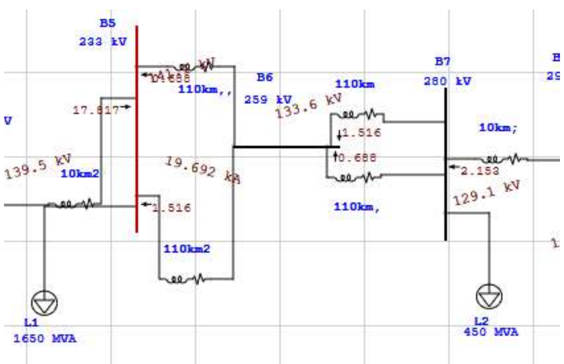
Phase voltage and zero sequence current	*Sequence current and voltage*	*Phase current and voltage*

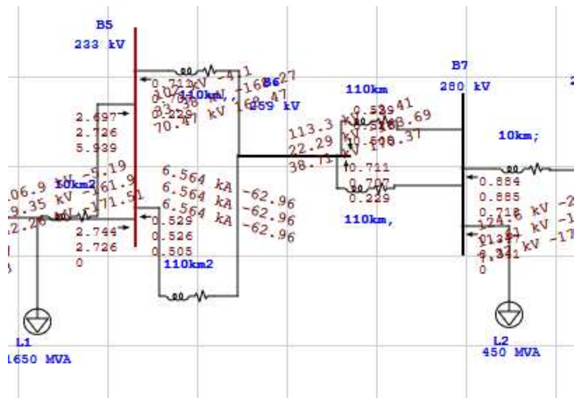


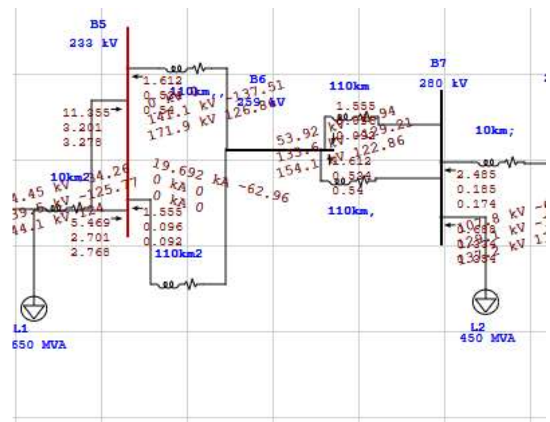


TRANSIENT

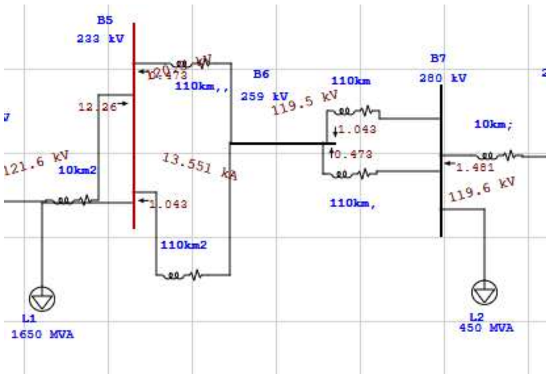
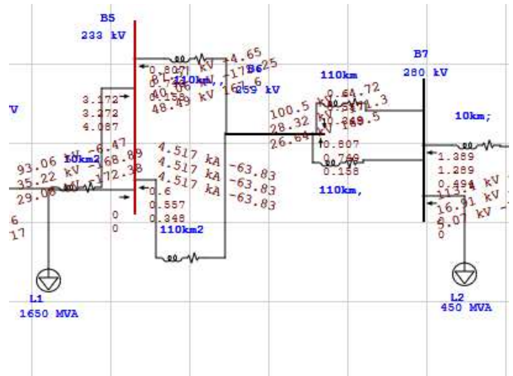
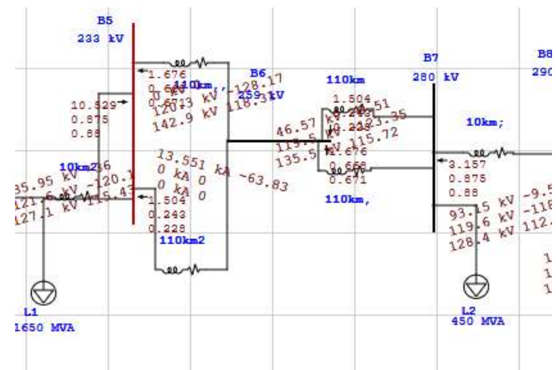
Phase voltage and zero sequence current	*Sequence current and voltage*	*Phase current and voltage*







STEADY STATE

Phase voltage and zero sequence current	***Sequence current and voltage***	***Phase current and voltage***
		

RESULTS LINE TO GROUND FAULTS:

- ***SUBTRANSIENT:***

  Phase voltage and zero sequence current = **21.586kA**

  Sequence current and voltage = **7.195kA ,** Phasor Angle = **62.41**

  Phase current and voltage = **21.586kA ,** Phasor Angle = **62.41**

- ***TRANSIENT:***

  Phase voltage and zero sequence current = **19.692kA**

  Sequence current and voltage = **6.564kA ,** Phasor Angle = **62.96**

  Phase current and voltage = **19.692kA ,** Phasor Angle = **62.96**

- ***STEADY STATE***

  Phase voltage and zero sequence current = **13.551kA**

  Sequence current and voltage = **4.517kA ,** Phasor Angle = **63.83**

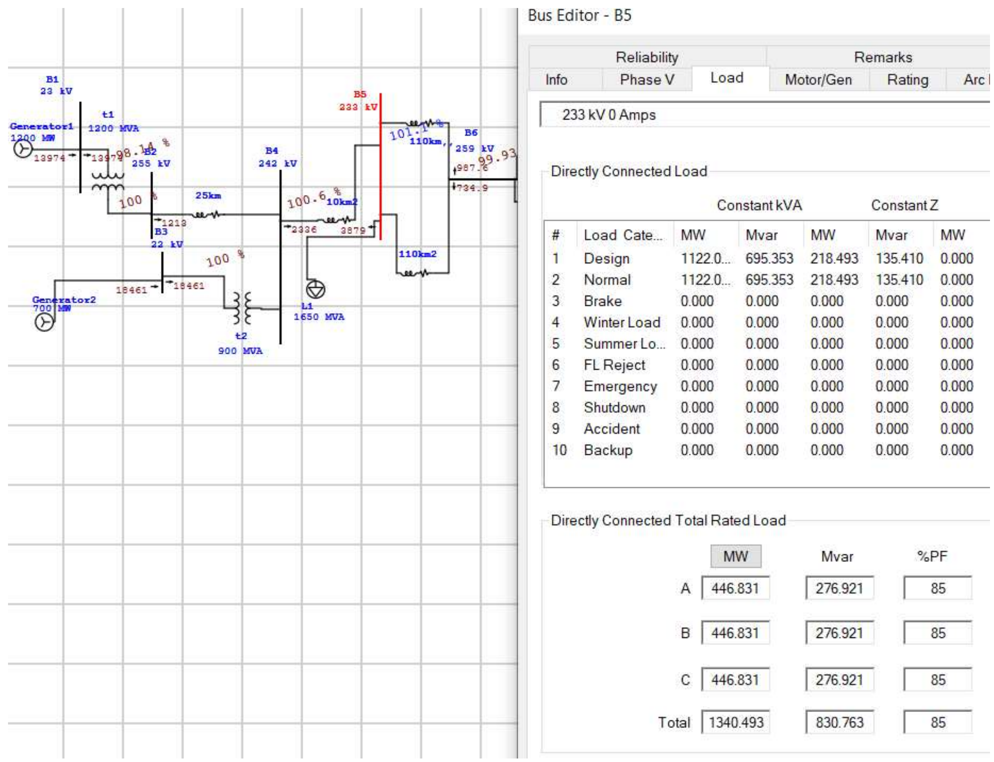
  Phase current and voltage = **13.551kA ,** Phasor Angle = **63.83**

TASK 5: CREATE PROBLEM OF "LOW POWER FACTOR" AND SOLVE IT BY AT LEAST TWO METHODS.

Two methods are used to improve the power factor of the generator 1 which has low power factor.

(i) Adding the capacitor bank at the load which is of greater rating by doing calculations
(ii) Use the synchronous motor and changed its model to condenser so that it become a synchronous condenser.

ORIGINAL POWER FACTOR OF BUS (0.85)



SOLVING THE PROBLEM OF LOW POWER FACTOR (*METHOD 1*)

We will perform the calculations to calculate the MVar of capacitor bank in order to place with the load to solve this low power factor problem

$$\text{MVar of capacitor} = P \times (tan\theta_1 - tan\theta_2)$$

$$tan\theta_1 = \tan(\cos^{-1} 0.85) = 0.610$$

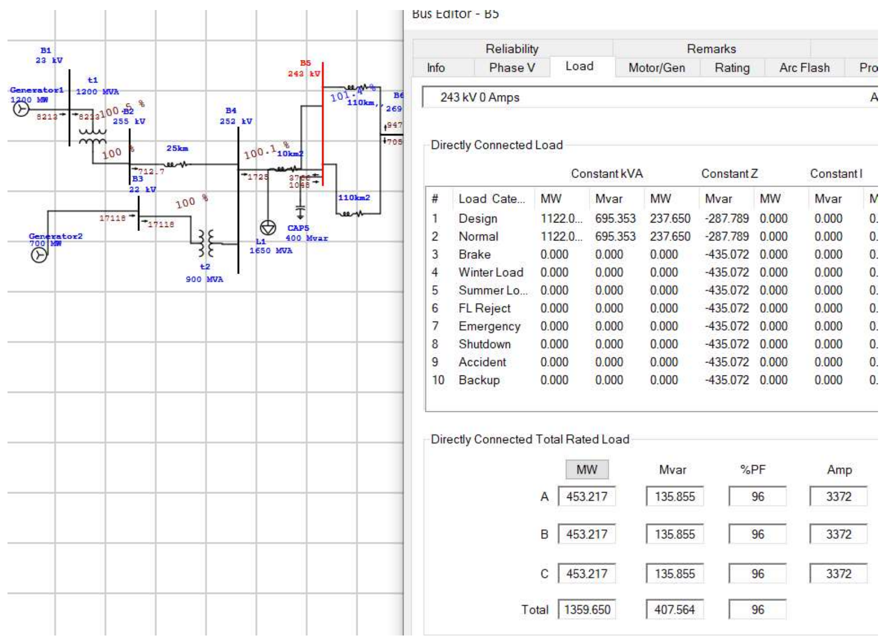
$$tan\theta_2 = \tan(\cos^{-1} 0.96) = 0.292$$

We have to put a capacitor in parallel with load with a rating of at most *400MVar*

Previous Power factor = 0.85 (85%)

New Improved Power factor = 0.96 (96%)

SOLVED THE PROBLEM OF LOW POWER FACTOR (METHOD 1)

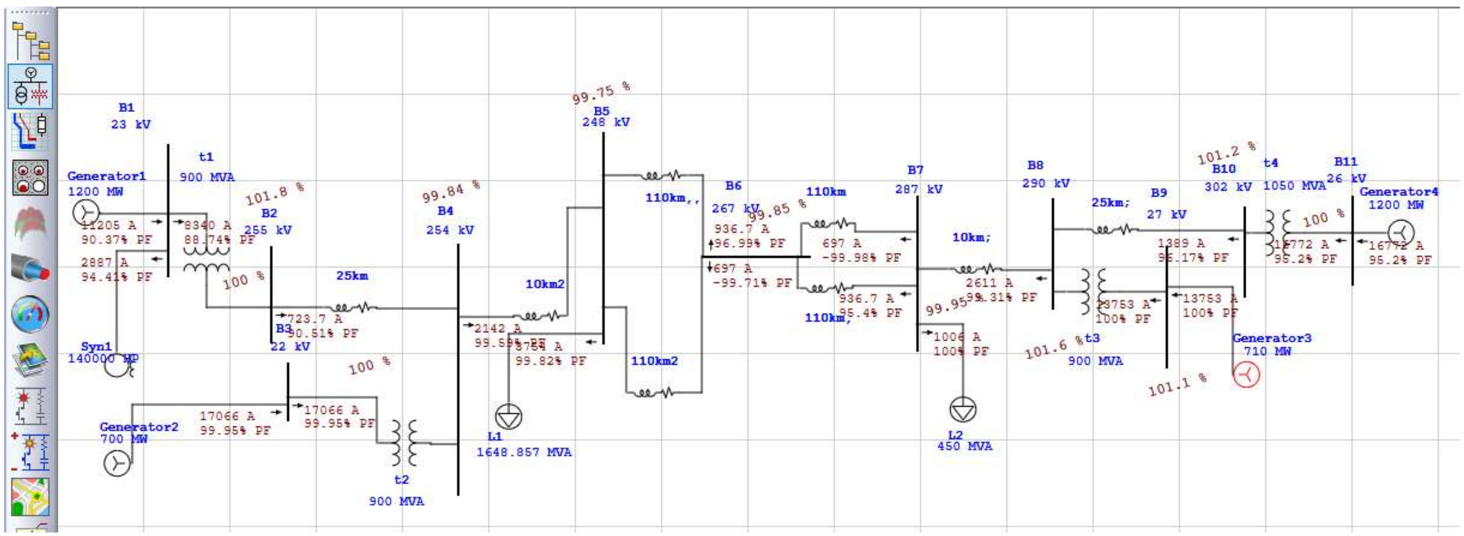


<u>SOLVING THE PROBLEM OF LOW POWER FACTOR (*METHOD 2*)</u>

We will add one more generator at BUS 1 to overcome this issue of overloading the rating of new generator will be 700MW.

SOLVED THE PROBLEM OF LOW POWER FACTOR (METHOD #2)

Here we have used the synchronous motor and changed its model to condenser so that it become a synchronous condenser which is used as a tool for power factor correction. The horsepower rating is adjusted according to required power factor. This increases the power factor



CONCLUSION

Load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power flow study is the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line. We also perform short circuit fault in which we obtained three phase fault and line to ground faults.

We used ETAP in this CEP which is most comprehensive analysis platform for the design, simulation, operation and automation of generation, distribution and industrial power systems. This software provides power system analysis in which we can understand the power system there parameters and comprehensively how power system works we can find losses at generation side, distribution and transmission losses so in this way we can manage our load and we can set conditions at which power factor system can work efficiently and also we design for the system for protection of any fault occurs in system.