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Load flow analysis of Industrial plant

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Abstract -*The Power-system analysis is mainly performed to predict or enhance the performance of an existing systems or system is being plan. Design of the industrial power system is slightly different from radial power systems. It is performed to fulfill different objectives of industrial plant namely safety, reliable service, high-power quality, and low capital and operating costs. To plan the industrial power system, different kind of power system analysis are required such as low flow analysis, short circuit analysis, relay coordination, motor starting analysis, power factor corrections, stability analysis etc. In this paper, the load flow analysis of 6.6 kV industrial plants is presented using Electrical Transient Analysis Program -7.5.5(ETAP). Load flow is conducted using NR Method. The plant is supplied from the in plant generation (2*16.5 MW Existing and 11.8 MW-newly installed). The external grid supply is used for black start of TG's.17.5 MW of existing load become 24 MW after expansion. So this study is done for check feasibility of load and generation surplus and operating philosophy selection.*

Keywords- *Load Flow Analysis, ETAP, Newton Rephson Method, Accelerated Gauss Seidel Method, Fast decoupled L.F. method.*

I. INTRODUCTION

Load flow analysis is performed to find different electrical parameters such as voltages magnitude and angle, active power, reactive power, active and reactive power in different line, line loading and all related data of power systems. Mathematical calculation is required in load flow analysis is too simple but it is became cumbersome for hand calculation. Previously, load flow analysis is performed by Ac net-work analyzers. It is performed when new systems is being plan or remarkable expansion or modification is done in existing systems [1][2].

Load flow analysis simulation is provided steady state value of different parameter such as Voltage Profile, Power Flows and current flows, Power Factor, Transformer tap changer Settings, Voltage Drops at every bus, Generator's active and reactive power demand and generation, Steady State Stability Limits, active and reactive losses, Cable / Feeder Capacity, Capacitor Size, Transformer rating including Impedance, Current Limiting Reactor Rating & Imp, MCC & Switchgear Current Ratings, Operating Mode of generators , Transmission, Distribution & Utilization kV [3].

By results it is ensured that all bus voltages and voltage drop are within acceptable limits, Voltages are within rated insulation limits of all power system apparatus, Power & Current flows must not more than maximum ratings, Circulating active and reactive power flows are determined [3].

II. ASSUMPTION AND MODELING

Following assumptions are made to performing a load flow calculation [4].

2.1 Load Models

2.1.1 Constant kVA Model (kVAc)

Under this model three assumption are made; (1) In Load Flow calculations, induction, synchronous and lump loads are considered as constant power loads. (2) The power output remains constant even though the input voltage changes (constant kVA). (3) The lump load power output behaves like a constant power load for the specified % motor load.

2.1.2 Constant I Model (I c)

Under this model four assumption are made; (1) the current remains constant even though the input voltage changes. (2) To test Battery discharge capacity, DC Constant current loads are used. (3) To test UPS systems performance, AC constant current loads may be used. (4) DC Constant Current Loads may be defined in PowerStation by defining Load Duty Cycles used for Battery Sizing & Discharge purposes

2.1.3 Constant Z Model (Zc)

Under this model four assumption are made; (1) In Load Flow calculations Static Loads, Lump Loads (% static), Capacitors and Harmonic Filters and Motor Operated Valves are considered a as Constant Impedance Loads.(2) The Input Power is changed with the square of the Input Voltage. (3) In Load Flow, Harmonic Filters is considered as capacitive loads for P.F improvement. (4) Motor operated valve is considered as constant impedance loads because of their operating characteristics.

2.2 Source Models

- **PV BUS**: Generator Bus – active power and voltage are known.
- **PQ BUS**: Load Bus – active power and reactive are known.
- **Swing Bus (SB)**: Slack Bus – Voltage and angle are known.

2.3 Different mode of Generator operations

There are four mode of operation [8]

2.3.1 Swing Mode (Grid if present, always on swing mode)

- Governor is operating in isochronous mode (This governor setting permits the generator's output to be set based on the load demand).
- Automatic Voltage Regulator

2.3.2 Voltage control

- Governor is operating in Droop Mode (This governor setting permits the generator to be base Loaded; It does mean the MW output is constants).
- Automatic Voltage Regulator

2.3.3 Reactive power control

- Governor is run in drooping mode
- Field excitation keep constant

2.3.4 Power factor control

- Governor is set in drooping mode
- Automatic voltage regulator set based power factor

When many generators are connected to grid, the grid is always kept on swing mode and generator in voltage control mode. When grid is absent, the big generator is always kept on swing mode and other generator in MVAR or PF control mode. Additionally, it is considered that frequency remains constant and network in balance conditions.

III. LOAD FLOW CALCULATION METHOD

There are three methods normally are used for load flow solution

1. Accelerated Gauss-Seidel method
2. Newton Rephson method
3. Fast decoupled L.F. method

Most important question in power system study is which methods are best suited for specific application? The different property and performance of different load flow method can be greatly affected by type and size of problem to be solved, Computing facilities available, and the specific details of solutions. final choice is always a compromise between the different situation of goodness at which load flow methods are to be compare with each other and every such selections criteria is connected with cost, actual calculation itself in the engineering application, or in the computer accessory and different software requirement. Some of the required properties of the load flow solution method are high speed, low storage, reliability, simplicity, versatility etc. Newton Rephson method is almost universal choice for all problems.

3.1 Accelerated Gauss Seidel Method

Initially, bus voltages are assumed in the Gauss-Seidel method. Thereafter, recalculate the all bus voltage with considering power import at different buses as well as considering most updated value of respective buses. These latest voltages are utilized to find the voltages at all other buses excluding slack bus. Furthermore, this process is continuously going on up to the all bus voltage are updated. If voltage corrections are lesser than specific limit, iterations are over. To speed up the convergence of the solution a modified version of this method is used namely the Accelerated Gauss-Seidel method [1][7].

The gauss seidel method is used to solve non-linear algebraic equations. Initially, solution vector is considered based on practice experience. Thereafter, revised values of the specific variable are obtained by replacing the current value of the remaining variables. The solution is updated base on these variable values. The process runs continue till the solution is converged within mentioned accuracy. The convergence is quite sensitive to the initial assumptions [1][7]. Gauss-seidel(Y-matrix iterative method) has a slower convergence speed so that to speed up the conversance acceleration factorα is in between 1 and 2. Typically set to 1.45. [1][7].

The Y-matrix iterative methods are used for solutions of linear equation such as I=YE. Initially, it is assumed that the bus current values are known. The current mismatch value at each bus is;

$$\Delta Ii = Ii-\sum YikEk$$

$$Ei = (Ii-\sum YikEk)/Yii.$$

Therefore, the change in Ei is

$$\Delta Ei = \Delta Ii/ Yii.$$

Some of the advantage of Gauss-Seidel method are ;(1) Simplicity, comparatively good performance, no need to store previous value, less time per iteration. (2) Best suited for industrial (distribution) application where fast decoupled method diverges due to high X/R Ratio and radial or tree structure of industrial system. (3) Lower requirements of the bus initial voltage value and work well with rectangular coordinates. Some the disadvantage are ;(1) Linear convergence characteristic & convergence rate is slow. For 500 buses problem GS method requires 500 iterations where's N.R method require 4 iterations. (2) No's of iteration increases directly as the No's of bus.

3.2 Newton Raphson Method

N.R.Method is used to solve different simultaneous non linear equations with different numbers of unknown's f(x) =0. At the provided iteration point, by their tangent hyper plane, each unknown fi(x) is estimated. This linear problem is formulated as Jacobian-matrix [1][7].

$$F(X) = -J.\Delta X$$

This equation is solved for different value of ΔX. The square Jacobian matrix J is given by Jik=dfi/dxk. it is given the tangent hyper plane's slope. Matrix J is highly sparse and solved directly by triangulation and back substitution [1][7][8].

$$F(X) = [\Delta P, \Delta Q], \Delta X= [\Delta\delta, \Delta V]$$

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

The Newton (raphson) method have quadratic convergence characteristic in place of linear convergence characteristic. It is really practical method to solve large and complex load flow problems. It is fast and more robust solution methods compare to any other load flow approach and it is conversed very rapidly when the destination is near. Its performance is depends on the properties of the functions F(x). Conversions speed depends upon the linearity of the problems [1][7][8].

Some of the advantage of this method is it can conversed in 3 to 5 iteration irrespective of complexity of problems so that is a practical method which is preferred in field applications. Additionally it is work faster and sure to converse. Some of the disadvantage of this method is; (1) large computer memory is required and difficult to make programming logic.
(2) Careful selection of but initial voltage is required.

Note: for speed up convergence and to establish a set of sound initial value, few iteration make by GS Method before running L.F using this method. I used this method for L.F.

2.4.3 Fast Decoupled method

Fast decoupled method is the replacement of NR method with some approximations. In practical industrial power system there are weak interdependence between P-V and Q- δ. To sort out memory issues of NR method, the Jacobean elements related to weak coupling are neglected. Additionally, decoupling mean P-δ and Q-V problems are solved separately [1][7][8]. The decoupled equation are;

$$[\Delta P] = [H]\ [\Delta\delta]\ldots\ldots\ldots\ldots\ldots (1)$$

$$[\Delta Q] = [L]\ [\Delta V/V]\ldots\ldots\ldots\quad (2)$$

$$[\Delta P/V] = [B'] [\Delta\delta] \ldots\ldots\ldots\ldots (5)$$

$$[\Delta Q/V] = [B''] [\Delta V] \ldots\ldots\ldots (6)$$

Some of the advantages of this methods are; (1) iIts required less storage compare to NR Method and better for long and redial lines whereas disadvantages are it is less accurate and sometimes diverse in industrial power system due to high X/R ratio.

IV. VOLTAGE AND MVAR CONTROL

2.4.1 Voltage control

Methods of Improving Voltage Conditions [7][8];

1. **Transformer Replacement;** For improving voltage condition replace the transformer of appropriate rating. Relieved from under voltage transformer capacity should be increased and avoid over/full loading. For overvoltage, reverse is true but it is too expensive and time consuming method.

2. **Capacitor Addition;** Relieved from under voltage shunt capacitor will be connected at load side for supplying local reactive power requirement of load. For compensating overvoltage nothing will be do except, disconnect capacitor. It is expensive because variable value capacitor require for proper compensation.

3. **Transformer Tap Adjustment;** Transformer equipped with ON-load or OFF-load transformer for quick, easy and inexpensive voltage regulation.

2.4.2 MVAR Control

Methods of MVAR CONTOL [7][8];

1. **Change Generator from Voltage Control to Mvar Control;** For load flow study there four mode of operation of generator. Swing mode, voltage control, PF control, MVAR control. MVAR adjustment change generator from voltage control to MVAR or PF Control.

2. **Add Capacitor;** Add capacitor for supplying local reactive power requirement of load.

3. **Replace transformer with higher MVA;** Higher MVA transformer supplying large share of MVAR without disconnect MW load.

2.4.3 Output alert of Load flow

Table 2.1 Outputs Alerts of Load flow

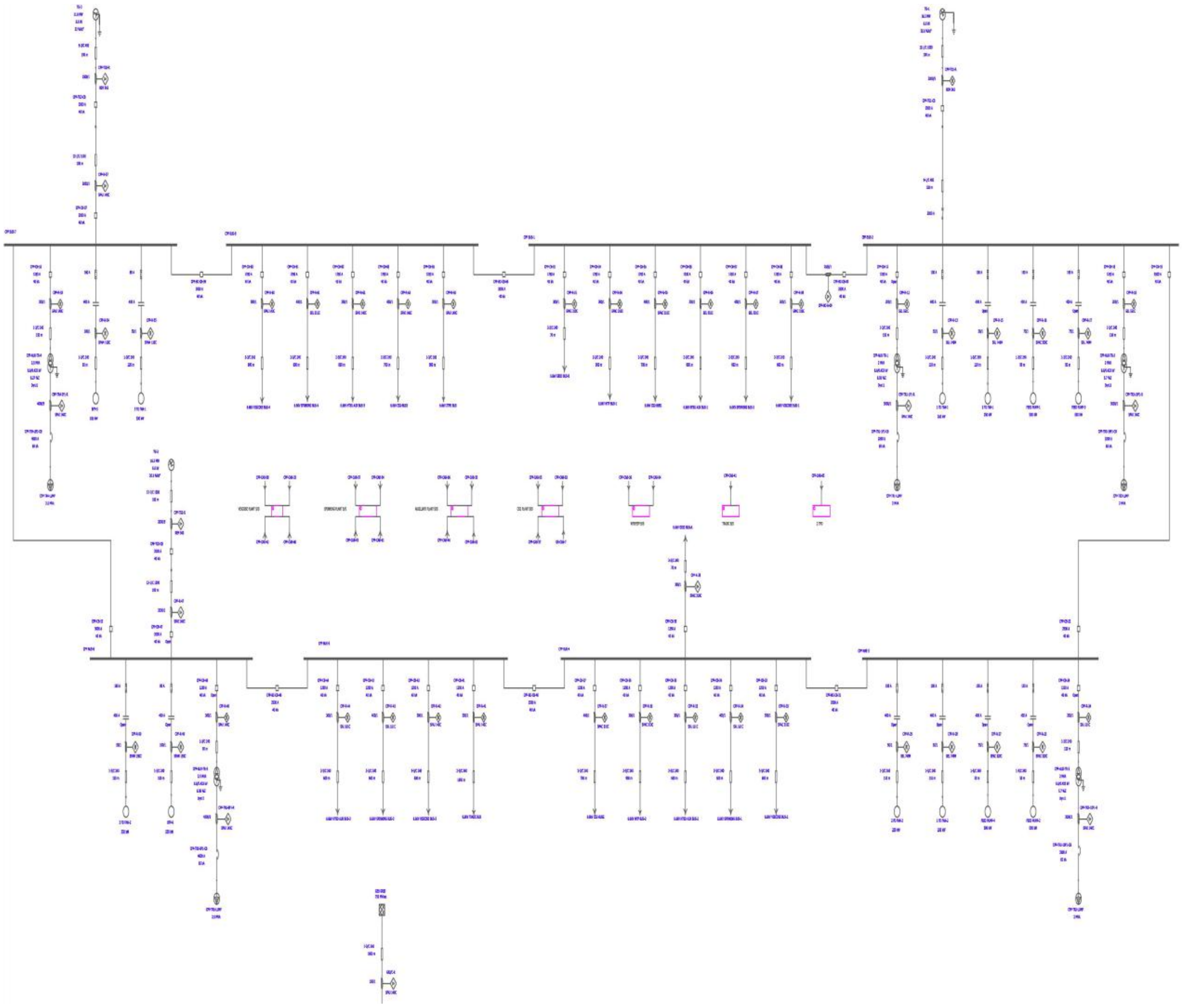
Sr No's	Power Devices	Parameters to be observed (%)	Reported Results
1	Transformer	Continuous rated I/V	O/V,U/V, Over Load
2	Bus	Continuous rated I/V	O/V,U/V, Over Load
3	Cable	Continuous rated I	Overload
4	H.V.C.B	Continuous rated I	Overload
5	L.V.C.B	Continuous rated I	Overload
6	Fuse	Rated I	Overload
7	Contactors	Continuous rated I	Overload
8	Switch	Continuous rated I	Overload
OVERALL BRANCE LOSS & VOLTAGE DROP			

V. RESULT ANALYSIS

2.5.1 Data

Following data are required to perform simulations [8];

1. Single-line diagram of industrial plant.
2. All data of transformer.
3. All data related to motor load.
4. All data of power factor improvement devices.
5. All data related to generators.
6. All data related to Bus bar, Panel, Cable.
7. All data related to interconnected resource.



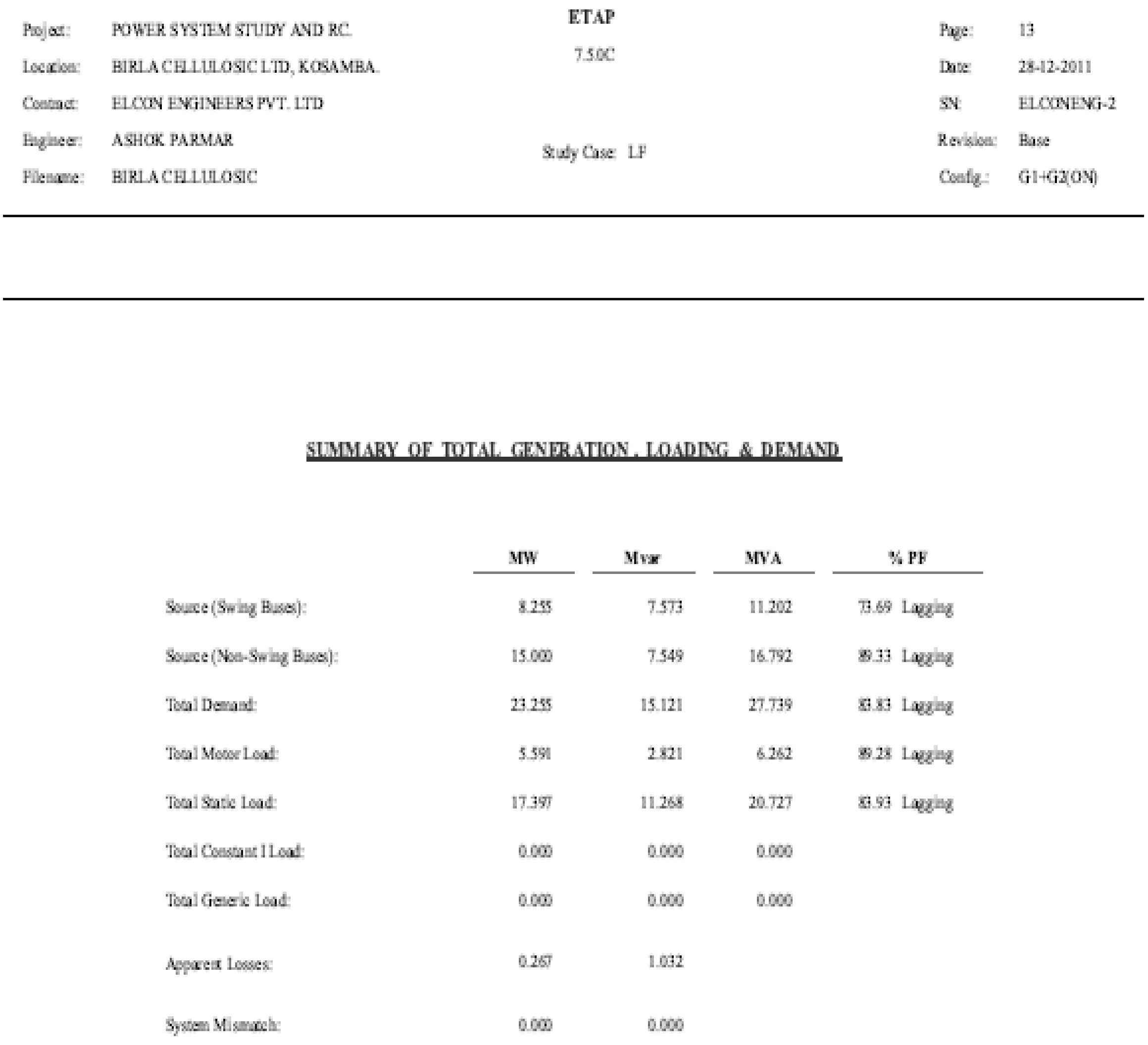
2.5.2 Results

Birla cellulosic is 175 bus system within plant steam based generation (by three generator 2*15.6MW &1*11.8 MW, G1/G2=15.6 MW, G3=11.8 MW) with 22kV Grid support for black start and emergency supply provided to CS2 (carbon disulphide). Total 175 branch of the plant formed by 37 transformer (distributions & furnace), 74 line/cable, 64 tie circuit. Load flow analysis conducted using ETAP-7.5.5 & selecting Newton Raphson method with precision of 0.0001.

Load flow study is conducted considering only in-plant generation with alternate generator combination G1+G2, G2+G3, G3+G1. All generators in parallel configuration are obviously not presented because plant load is too much low compared to available generation (load-24 MW, Generation=43 MW). When load flow study is done with all generators in parallel, one or more generator is overexcited with many bus overvoltage problems. Temperature correction applied to all line and cable resistance.

(1) G1+G2 Configuration:

- Load flow study is performed with generator G1 in swing mode (Governor- Isochronous mode & AVR) and G2 in voltage control mode (Governor-Droop Mode&AVR) with maximum power deliver 15 MW active and 13.125 Mvar reactive.
- Bus loadings of all buses (6.6Kv,433v) is too much low and not even pass to marginal limit (set 93%). maximum bus loading is 90%. PF of all directly or indirectly connected load is ranging from 0.73 to 0.92 lagging.
- Maximum transformer loading (both distribution and furnace transformer) is 94% and cable loading is below 90%.
- Maximum voltage drop 2.92% at furnace TR-4. Maximum voltage drop at end of cable (CABLE AUX-1, L-1968.5 Ft) is 0.75%. Also some LT buses show marginal over voltages.
- Total active and reactive loss in distribution network is 267 KW and 1032 KVAr.
- Swing generators operate at 11.202 MVA (8.2MW, 7.5MVAr) with 0.73 lagging PF. Non swing generator operate at 16.79 MVA (15MW,7.5 MVAr) with 0.89 lagging PF And Supply total plant demand 27.73 MVA(23.25MW,15.12MVAr) with 0.83 lag. PF



Project: POWER SYSTEM STUDY AND RC.
Location: BIRLA CELLULOSIC LTD, KOSAMBA.
Contract: ELCON ENGINEERS PVT. LTD
Engineer: ASHOK PARMAR
Filename: BIRLA CELLULOSIC

ETAP
7.5.0C

Study Case: LF

Page: 13
Date: 28-12-2011
SN: ELCONENG-2
Revision: Base
Config.: G1+G2(ON)

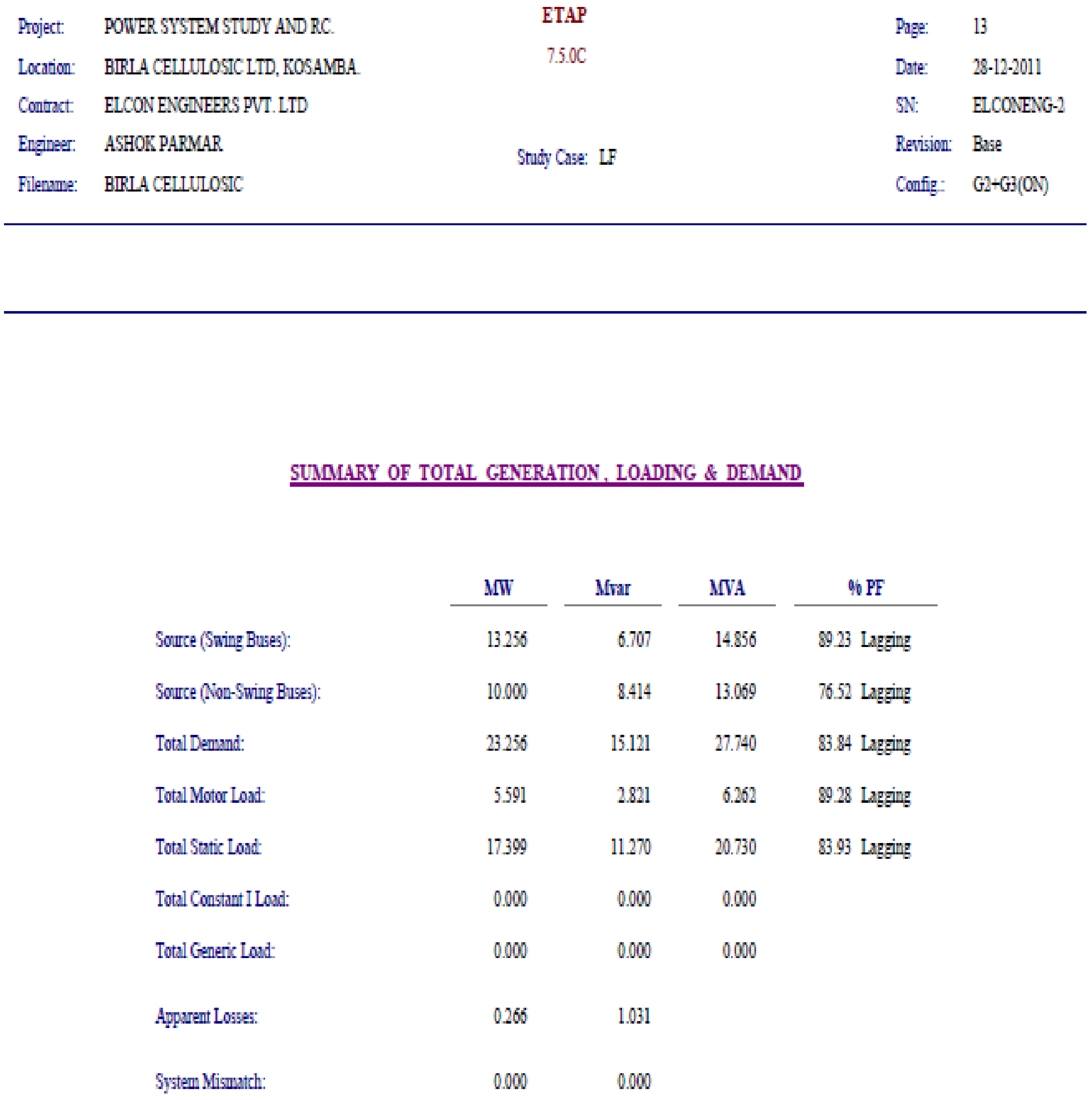
SUMMARY OF TOTAL GENERATION , LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	8.255	7.573	11.202	73.69 Lagging
Source (Non-Swing Buses):	15.000	7.549	16.792	89.33 Lagging
Total Demand:	23.255	15.121	27.739	83.83 Lagging
Total Motor Load:	5.591	2.821	6.262	89.28 Lagging
Total Static Load:	17.397	11.268	20.727	83.93 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	0.267	1.032		
System Mismatch:	0.000	0.000		

(2) G2+G3 Configuration :(This Configuration Recommended Due To Lower Losses)

- Load flow study performed with big generator G2 in swing mode and G3 in voltage control mode with maximum power deliver 10 MW active and 9.7 MVAr reactive.
- Bus loadings of all buses (6.6Kv,433v) is too much low and not even pass to marginal limit (set 93%). maximum bus loading is 90%.PF of all directly or indirectly connected load is ranging from 0.73 to 0.92 lagging.
- Maximum transformer loading (both distribution and furnace transformer) is 94% and cable loading below 90%.

- Maximum voltage drop 2.92% at furnace TR-4. Maximum voltage drop at end of cable (CABLE AUX-1, L-1968.5 Ft) is 0.75%. Also some LT buses show marginal over voltages.
- Total active and reactive loss in distribution network is 265 KW and 1030 KVAR.
- Swing generators operate at 14.85 MVA (13.25 MW,6.7 MVAR) with 0.89 lagging PF. Non swing generator operate at 13.06 MVA (10 MW,8.4 MVAR) with 0.76 lagging PF And Supply total plant demand 27.74 MVA(23.25MW,15.12MVAR) with 0.83 lag.PF



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Study Case: LF

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Date: 28-12-2011
SN: ELCONENG-2
Revision: Base
Config.: G2+G3(ON)

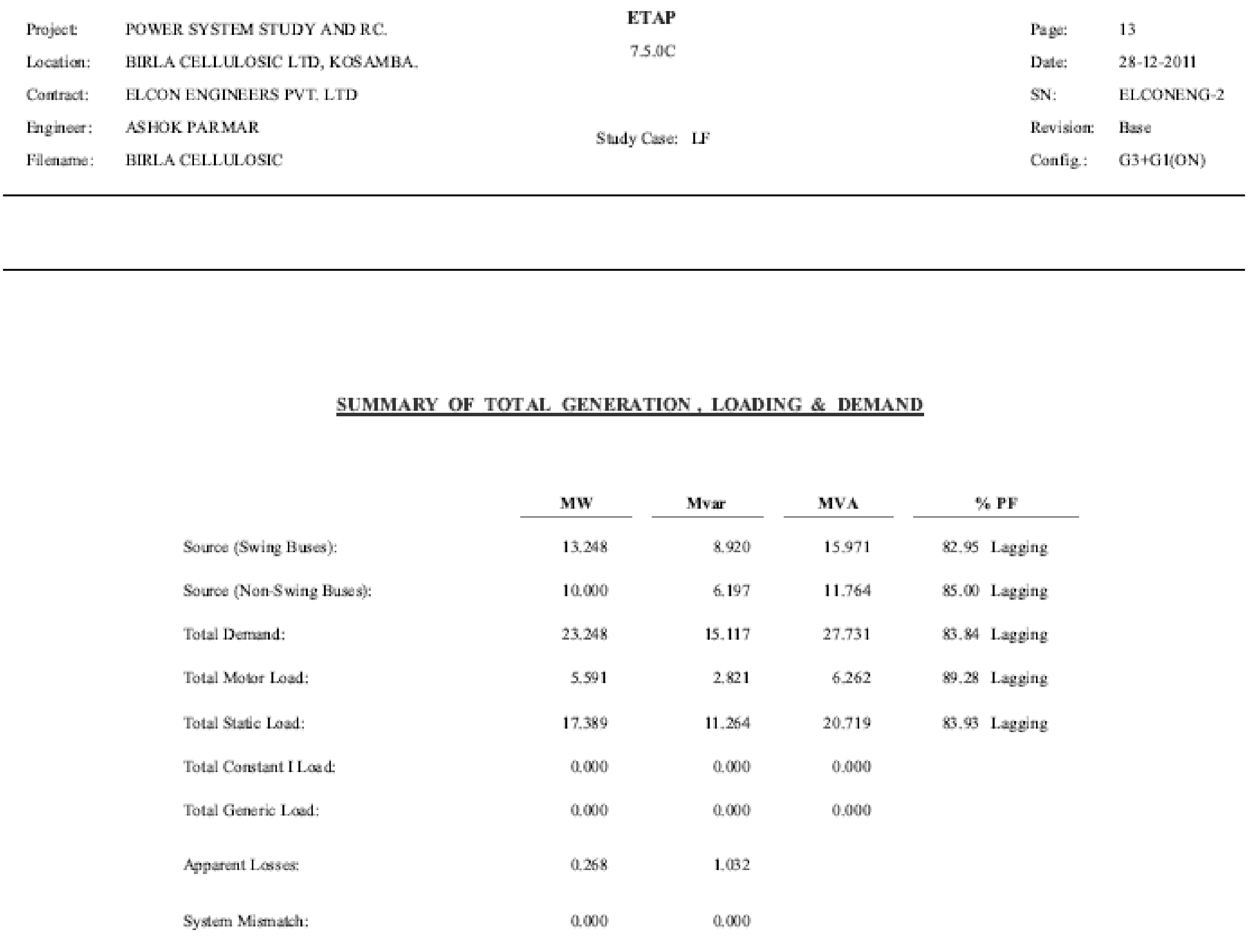
SUMMARY OF TOTAL GENERATION , LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	13.256	6.707	14.856	89.23 Lagging
Source (Non-Swing Buses):	10.000	8.414	13.069	76.52 Lagging
Total Demand:	23.256	15.121	27.740	83.84 Lagging
Total Motor Load:	5.591	2.821	6.262	89.28 Lagging
Total Static Load:	17.399	11.270	20.730	83.93 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	0.266	1.031		
System Mismatch:	0.000	0.000		

(3) G3+G1 Configuration:

- Load flow study performed with big generator G1 in swing mode and G3 in voltage control mode with maximum power deliver of 10 MW active and 6.19 Mvar reactive.
- Bus loadings of all buses (6.6Kv,433v) is too much low and not even pass to marginal limit (set 93%). maximum bus loading is 90%.PF of all directly or indirectly connected load is ranging from 0.73 to 0.92 lagging.
- Maximum transformer loading (both distribution and furnace transformer) is 94% and cable loading below 90%.
- Maximum voltage drop 2.92% at furnace TR-4. Maximum voltage drop at end of cable (CABLE AUX-1, L-1968.5 Ft) is 0.75%. Only one LT bus show marginal over voltage.
- Total active and reactive loss in distribution network is 268 KW and 1032 KVAr.

Swing generators operate at 15.97 MVA (13.24 MW,8.92 MVAr) with 0.83 lagging PF. Non swing generator operate at 11.76 MVA (10 MW,6.1 MVAr) with 0.85 lagging PF And Supply total plant demand 27.73 MVA(23.24MW,15.11MVAr) with 0.83lag.PF.



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Revision: Base
Config.: G3+G1(ON)

SUMMARY OF TOTAL GENERATION , LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	13.248	8.920	15.971	82.95 Lagging
Source (Non-Swing Buses):	10.000	6.197	11.764	85.00 Lagging
Total Demand:	23.248	15.117	27.731	83.84 Lagging
Total Motor Load:	5.591	2.821	6.262	89.28 Lagging
Total Static Load:	17.389	11.264	20.719	83.93 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	0.268	1.032		
System Mismatch:	0.000	0.000		

VI. CONCLUSION

Load flow is conducted using Newton Rephson method with after one iteration found that Bus loading, Branch loading (transformer & cable), total active and reactive power losses, under and overvoltage at the end of distribution system are within prescribe limit, Except Some L.T. buses are marginally overvoltage for all operating philosophy. Additionally, active and reactive power loss for G2+G3 configuration is less compare to remaining two operating philosophy (G1+G2 and G3+G1). Therefore, G2+G3 operating philosophy is recommended as outcome of load-flow analysis. Perform load flow study for different operating philosophy and found that bus loading, branch loading ,cable loading for all operating philosophy, 16.5MW+11.8 MW or 2x16.5 MW or 11.8 MW+2x16.5 MW are within limit. Additionally, Voltage at all buses is within limit for all operating philosophy, except some L.T. Bus is marginally overvoltage but it is not objectionable at all. Furthermore, power factor at all swing and non swing source maintain between 0.73 lag to 0.89 lag for all operating philosophy. Total active and reactive loss of plant is as follow.

Table 5.1 Losses for various Configurations

Sr no	Configuration	Active loss	Reactive loss
1	G1+G2	267 KW	1032KW
2	G2+G3	266KW	1031KW
3	G3+G1	268KW	1032KW

G1=16.5MW, G2=16.5MW, G3=11.8MW

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