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Improved Electric Power Distribution Network in Nigeria Using Voltage Drop/Voltage Regulation Method

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***ABSTRACT**: The distribution of power system (33/11KV) is the engine that delivers the electricity to the consumer at the receiving end for daily utilization. The analysis of distribution system is becoming too complex to solve mathematically because of the ever increasing energy demand that is the Nigeria electricity distribution is regularly being confronted with the supply of little available power to match the much needed energy (power) demand. The study adopted the application of voltage drop/voltage regulation technique for analysis and investigation, using Haroldwilson drive Borikiri axis of Port Harcourt as case study. The analysis of this work investigated the level of voltage drop on each section of the feeder (buses), on the view to determine where the voltage profile is critical. The identified critical voltage buses on the feeders and the recommended with the integration of capacitor/capacitor bank with the view to enhance improved performance in order to comply with the statutory limit of ±10%. Because the deviation of voltage level beyond acceptable limit will seriously collapse or overstressed the existing operating condition. The capacity of the Borikiri injection station: (2×7.5MVA), where (1×7.5MVA) is to supply power to the Haroldwilson drive axis while (1×7.5MVA) are to supply power to the New road axis of Borikiri, Port Harcourt. E-tap software are used in the analysis and simulation of load flow, voltage-drop, mismatches in active and reactive power are determined in order to investigate, identify the buses or feeder line that are critically overstressed or overloaded. The voltage drop/voltage regulation equations were formulated to measure the degree of overload. The application of the software Electrical Transient Analyzer program (E-tap version 12.6) requested the argumentation of capacitor (size) to the distribution network that will help improve the power system quality performance and investigate the activity of the system for future expansion planning.*

***KEYWORDS**-voltage drop/voltage regulation, load current equation, reactive power, power triangle, Power factor correction,*

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I. INTRODUCTION

Electricity supply is one of the major needs to the world economy today. This means that power industry plays a key role in determining the quality of energy produced especially at the receiving ends (consumption level). Electrical energy demand is grossily in the increase on daily bases, and this continuous trend has led to the increasing number of generating units, transmission lines and distribution networks. The function of distribution system is to receive power from the bulk power source and distribute it to the consumers at the particular voltage level and with degree of continuity acceptable to the various kinds of consumers, according to the International Electric/Electronic Engineering (IEEE) [1] compliance and practice, following the rapid shift for urbanization particularly Borikiri Port Harcourt in Rivers State as a need for economic development. It is interesting to note how the size (cross-section) of distributors' feeders is affected by an increase of supply voltage [2].Therefore, considering the declining state in the distribution network, particularly Port Harcourt in Rivers State, as a case study required the need for an effective, efficient and reliable assessment of electrical energy for an optimal energy management.

II. BACKGROUND OF STUDY

Electrical power generation, transmission and distribution are the three stages of delivering electricity to consumers at residential, industry, commercial, and administrative areas. The socio-economic development of any nation depends on the supply of adequate and stable electricity to consumers. While inadequate and unstable supply of electricity to consumers in any nation would definitely lead that nation backward in terms of its socio-economic growth. Like any other economic sector in Nigeria, the power sector has its peculiar problems. This paper aims at discussing the major factors affecting electricity generation, transmission and distribution in Nigeria, with a view to providing a platform on how to improve the electric power distribution network in the case study using the voltage drop technique. For convenience, the factors are grouped into two major categories, namely factors affecting electricity generation and factor affecting transmission and distribution. The objective of this paper is to sensitize the Government, the governed and the organized private sector in order to solve the major problems affecting electricity delivery to Nigerian consumers [3].Some efforts have been devoted to performing comprehensive reliability evaluation considering impacts of all parts of the power system [4]

III. METHODOLOGY

Considering the current state of power distribution network, particularly in the study area, there is need for the power network to be upgraded to avoid regular outage due to regular over loading of the already overstressed network. The distribution system considered the supply of electrical energy (power) that can provide a systematic development of the system to meet power requirement in order to obtain optimal benefits, this is because the voltage drop in secondary (33/11KV) is the main bases for the selection of conductor sizes for distributors, in order to enhance efficient nominal operations.

Therefore, the analysis demonstrating the calculations of load current, number of conductor per phase, voltage drop/ voltage regulation and reactive power of the load is strongly considered for this analysis.

Case 1: Determination of load current (I_L) at the Distribution station to Sub- injection Station while relying on the following data:

(i) Power factor of load (pf) = 0.80
(ii) Transformer rating in (KVA) = 500
(iii) Distribution voltage (v) = 11,000 (11KV)
(iv) Active power (KW): to be determined?

From our load current (I_L) equation, we have:

$$I_L = \frac{KW}{\sqrt{3} \times v \times pf} \tag{1}$$

Similarly,

$$KVA \times pf = KW \tag{2}$$

Where:

KVA = apparent power (KVA)
KW = Active power (KW)
I_L = Load current (Amps)
V_d = Distribution voltage (V)
pf = power factor of load
$\sqrt{3}$ = square-root of 3.

$\therefore$ Active power = 400KW

Hence, the load currents at this point (Distribution station to injection sub-station) = 26.244Amps

Case 2: Determination of required number of conductor per phase becomes;

No of conductor (d) = $$\frac{Load \ \ current}{current \ carrying \ \ capacity \ \ of \ \ conductor} \tag{3}$$

Case 3: Determination of voltage drop at the point (Distribution station to injection sub-station) becomes

Voltage drop (V_{d1}) = $$\frac{\sqrt{3} \times (R\cos\phi \times \sin\phi) \times I_L}{No. \ of \ \ conductor \ / \ phase \times 100} \times Length \ \ of \ \ line \ \ section$$

Where:

$\sqrt{3}$ = 1.732
R = 0.272Ω (constant)
x =0.112Ω

$\cos\phi = 0.8$
$\sin\phi = 0.6$
I_L =26.244Amps
Number of voltage drop (Vd_1) = Vd × length of line section
∴ Voltage drop at Distribution station to injection sub-station = 31.076238V (4)
Case 4: Determination of the receiving end voltage at the point is given as:
V_{R_1} = sending end voltage (Vs) – voltage drop (Vd_1)
Therefore; voltage at the receiving end = 10968.9236V
Case 5: Determination of percentage voltage regulation at the point (Distribution station to injection sub-station) is given as:

$$\% \text{ Voltage regulation} = \frac{\text{sending end-voltage} - \text{receiving end-voltage}}{\text{Receiving end-voltage}}$$

That is,

$$\% \text{ Voltage regulation} = \frac{V_S - V_R}{V_R} \times 100$$

= 0.283% (5)
Case 6: Determination of reactive power of the load.
Considering the power triangle figure 1
Applying Pythagoras theorem

$$(KVA)^2 = (KW)^2 + (KVAR)^2$$
$$(KVAR)^2 = (KVA)^2 - (KW)^2$$

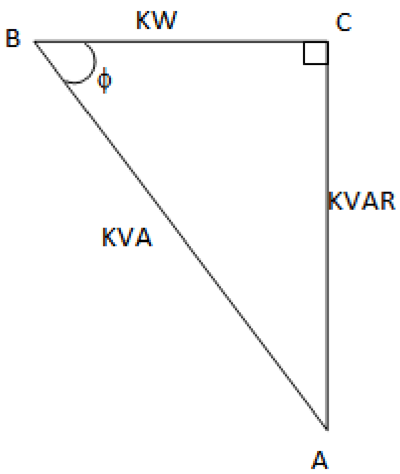

Fig 1: The power triangle

$$KVAR = \sqrt{(KVA)^2 - (KW)^2}$$

Wherefore,

$$(KVAR) = 300 \qquad (6)$$

This is applied to any other cases in the feeder of the distribution network.

The application of capacitor or banks of capacitors on the view to improve power factor enhancement will strongly make the electric power system to be more effective and seriously improve a better voltage profile. The activities and the extent of power losses on the distribution system cannot be totally ignored owing to the degree of energy demand at the receiving end on daily basis. Therefore, it is imperative to determine the accurate sizing of the capacitor bank.

Analysis demonstrating the calculations of sizing the capacity of a capacitor bank.
(i) Installed transformer (Tx) capacity at (Sub-injection station) = 500 KVA
(ii) Existing power factor = 0.77
(iii) Proposed/desired power factor for correction = 0.87

(iv) Total active power load (KW)
(v) Design calculation of capacity for capacitor rating,
The governing equation for capacitor rating for compensation is given as:

$$Qc = \frac{p}{pf_1} \times \sin\phi_1 - \frac{p}{pf_2} \times \sin\phi_2 \qquad (7)$$

Where;

Qc= Reactive power factor correction (KVAR)

p = The total active power load (KW)

pf_1 = Existing power factor of the load

pf_2 = proposed/desired power factor to be used for correction

$$\phi_1 = \cos^{-1}(pf_1) \qquad (8)$$

$$\phi_2 = \cos^{-1}(pf_2) \qquad (9)$$

$$Qc = \frac{p}{pf_1}\sin\left(\cos^{-1}(pf_1) - \frac{p}{pf_2}\sin\left(\cos^{-1}(pf_2)\right)\right) \qquad (10)$$

The power components can be represented into power triangle as shown in fig. 2

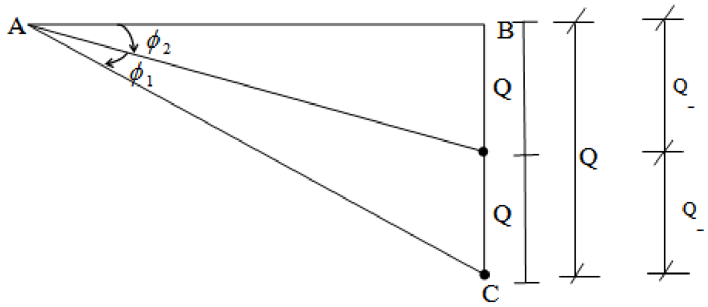

Fig 2: Components power triangle

From our power equation connecting, active power, power factor and apparent power is given as:

$$KVA \times pf = KW \qquad (11)$$

Thus,

$$Qc = \frac{p}{pf_1}\sin\left(\cos^{-1}(pf_1) - \frac{p}{pf_2}\sin\left(\cos^{-1}(pf_2)\right)\right)$$

P_{AC} = to be determined

P_{AP} = 500 x 19 = 9500 +300 = 9800KVA

P_{AP} = 9800KVA (Apparent power)

Pf_1 = 0.77

Pf_2 = 0.87

But P_{AC} = 7546KW

$$KVA \times Pf = KW$$

$$9800 \times 0.77 = KW$$

$$KW = 75460$$

$$Qc = \left(\frac{7546}{0.77}\sin\left(\cos^{-1}(0.77)\right) - \frac{7546}{0.87}\sin\left(\cos^{-1}(0.87)\right)\right)$$

$$Qc = (9800 \times \sin(39.6461) - 8673.556 \times \sin(29.54136))$$
$$Qc = 9800 \times (0.63804) - 8673.563 \times (0.4930517)$$
$$Qc = 6252.792 - 4276.515$$
$$Qc = 1976.277\,KVAR \qquad (12)$$

$Qc = 1976.277\,KVAR$ Is the required size of the capacitor that is adequate to suppress the voltage profile at sub-injection station (Buses). This is applied to any other cases in the feeder or buses of the distribution network.

IV. RESULTS AND DISCUSSION

The results of the existing case of voltage profile for substations are presented in Fig 3 to 6 from the supply grid at transmission network up to 11KV distribution feeder at Borikiri injection substation (33/11KV). The two distribution feeders are considered as the study case in this research work. The upgrading of transformer capacity and size of conductor in distribution stations are very important to avoid over stressing the distribution network. From the analysis of E-tap simulated result, the actual voltage magnitude recorded at each bus is below the required and acceptable statutory limit according to the IEEE regulation and standards which provide that voltage drop at each terminal shall not be less than (5% to 10%) normal of the sending end-voltage (between 10.5KV to 11.5KV). Evidently, this is traceable to insufficient supply of power at the generating station, thereby making the transmission and distribution network to constantly experience over voltage that normally result to black-out (outage problems) at the study case.

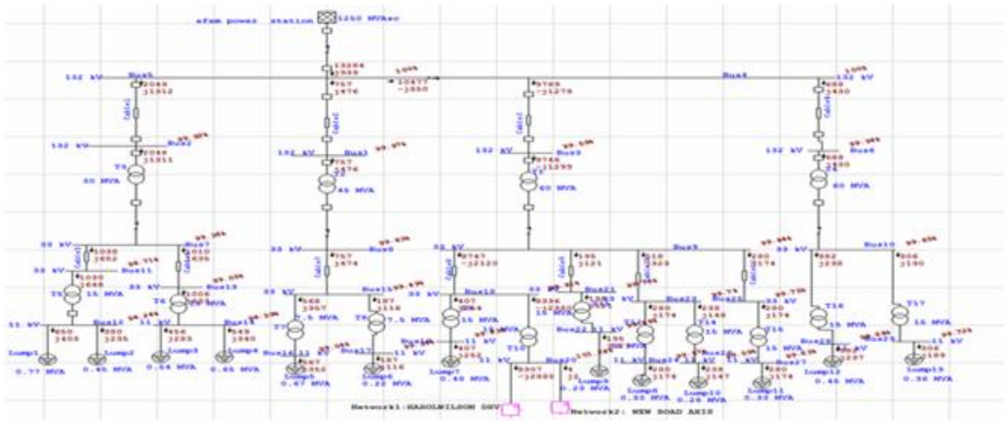

Figure 3: Single line diagram of the existing state network from Transmission to Distribution substation (simulated)

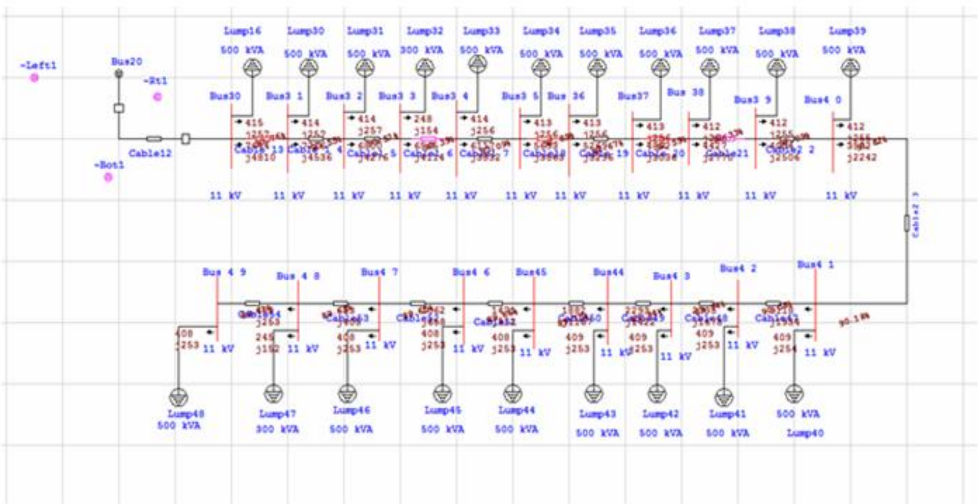

Figure 4: Single Line Diagram of Distribution Network, Haroldwilson Drive Borikiri (Simulated) Without Penetration of Capacitor Bank.

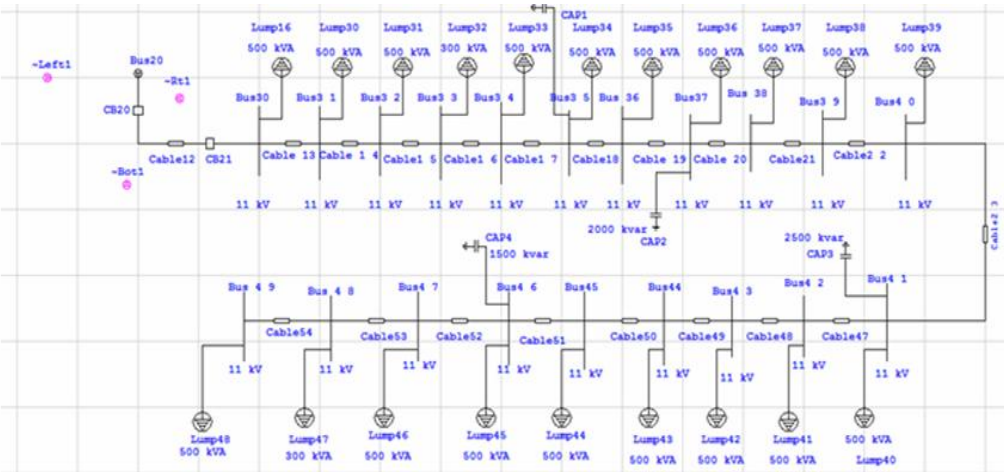

Figure 5: Single Line Diagram of the Distribution Network (11KV) Haroldwinson Drive, Borikiri, Simulated with Capacitor Bank Penetration.

Table 1: Study Case of Existing and Improved State of the Distribution Network.

BUS NO	Existing State without Capacitor Bank Penetration (%) Voltage Magnitude.	Improved State with Capacitor Bank Penetration (%) Voltage Magnitude.	Deviation
BUS 30	93.771	101.265	7.494
BUS 31	93.558	101.209	7.651
BUS 32	93.517	101.200	7.683
BUS 33	93.403	101.179	7.776
BUS 34	93.191	101.170	7.979
BUS 35	92.985	101.151	8.166
BUS 36	92.767	101.071	8.304
BUS 37	92.691	101.048	8.357
BUS 38	92.475	100.995	8.52
BUS 39	92.237	100.877	8.64
BUS 40	91.968	100.757	8.789
BUS 41	90.329	100.243	9.914
BUS 42	90.222	100.168	9.946
BUS 43	90.082	100.076	9.994
BUS 44	89.984	100.015	10.031
BUS 45	89.878	99.948	10.07
BUS 46	89.802	99.915	10.113
BUS 47	89.798	99.911	10.113
BUS 48	89.775	99.89	10.115
BUS 49	89.758	99.874	10.116

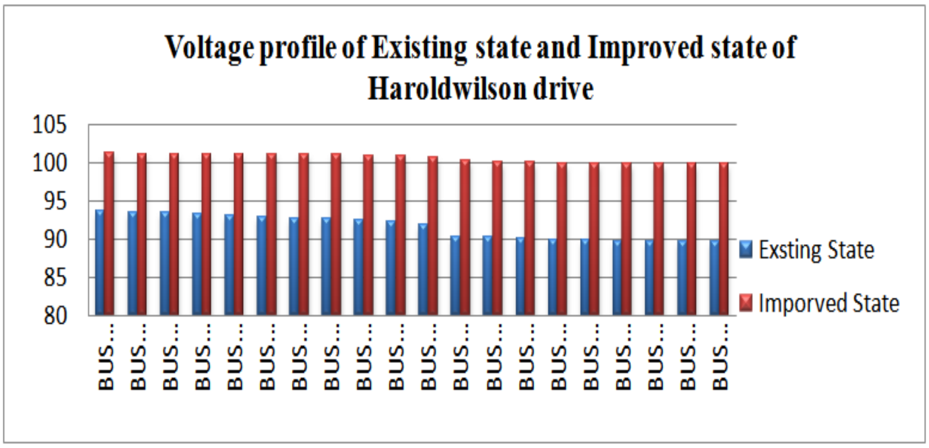

Figure 6: Voltage profile of existing and improved state of the distribution network.

Figure 6: The above chart is the voltage profile of existing and improved state of the distribution network condition. For the existing state, shows that all busses in the feeder are operating within 89.8-93.7 of the nominal voltage while the improved state network condition, the capacitor bank compensation were added to relief the overloaded area and increased the voltage profile of the buses to be within 99.8-101 of the nominal voltage.

Table 2: Result of voltage drop calculation and voltage regulation for the distribution network of Haroldwilson drive, Borikiri.

Feeder Name	Transformation ratio	Power KVA	Power KW	KVAR	Length KM	Voltage drop	% voltage	Load current	Receiving end voltage	Send voltage	% voltage regulation
Distribution station	11/0.415	500	400	300	350	31.0762375	31076.238	26.244	10968.9236	11,000	0.283

V. CONCLUSION

The distribution systems are normally designed to operate at specified power capability and voltage level within the operating condition of power system. Evidently, when the operating voltage is outside the allowable values, it will seriously affect the quality of power reaching the consumers at receiving ends. This work have strongly investigated and identified the power losses, overloading, poor maintenance and illegal connection on the distribution network as factors responsible for voltage drop and mismatches. The analysis of voltage drop and regulation accounts for inadequate and insufficient power supply. The results obtained shows that some of the feeder buses to the substations are already over stressed, that they are beyond the acceptable regulatory limits of voltage drop as declared by the IEEE regulatory limit of ±10%. While some are within the statutory (marginal limit).

Hence, it is a necessity that power system (distribution) Network should always be within the voltage range. The analysis and investigation are also conducted using Haroldwilson drive Borikiri axis of Port Harcourt for purpose of verification and validation.

The voltage drop/voltage regulation techniques are adopted for this analysis and investigation. The base case of voltage profile are simulated via excel program plot presented as composite bar chart.

RECOMMENDATION

Considering the analysis and investigation of this study, the 33/11KV distribution network should be upgraded via:

(i) Integration of capacitor bank/capacitor to the over stressed or over loaded buses or feeders where the voltage profiles are critically investigated on the view to improve power factor correction.
(ii) Load flow analysis program should be integrated and installed at distribution network to regularly monitor the status of the existing state of the systems always.

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APPENDIXS

The table below is the simulated result of the study case of 33/11KV load flow report of the distribution network (Haroldwilson drive) Borikiri axis of Port Harcourt.

Project:
Location:
Contract:
Engineer:
Filename: pg cather

ETAP
12.6.0H

Study Case: LF

Page: 2
Date: 18-03-201
SN:
Revision: Base
Config.: Normal

Bus	Voltage			Generation		Load		Load Flow			
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp
*Bus5	132.000	100.000	0.0	13.283	0.931	0	0	Bus2	2.049	1.312	10.6
								Bus1	0.757	0.476	3.9
								Bus4	10.476	-0.858	46.0
Bus6	132.000	99.945	0.0	0	0	0	0	Bus4	-0.688	-0.430	3.5
								Bus10	0.688	0.430	3.5
Bus7	33.000	99.356	-0.5	0	0	0	0	Bus11	1.038	0.652	21.6
								Bus13	1.010	0.635	21.0
								Bus2	-2.047	-1.286	42.6
Bus8	33.000	99.831	-0.1	0	0	0	0	Bus15	0.757	0.474	15.7
								Bus1	-0.757	-0.474	15.7
Bus9	33.000	99.843	-1.3	0	0	0	0	Bus18	8.746	-2.129	157.7
								Bus21	0.195	0.121	4.0
								Bus23	0.518	0.323	10.7
								Bus25	0.280	0.174	5.8
								Bus3	-9.741	1.510	172.7
Bus10	33.000	99.852	-0.1	0	0	0	0	Bus6	-0.688	-0.428	14.2
								Bus28	0.382	0.238	7.9
								Bus29	0.306	0.190	6.3
Bus11	33.000	98.714	-0.4	0	0	0	0	Bus7	-1.030	-0.648	21.6
								Bus12	1.030	0.648	21.6
Bus12	11.000	98.244	-0.8	0	0	1.030	0.638	Bus11	-1.030	-0.638	64.7
Bus13	33.000	99.047	-0.5	0	0	0	0	Bus7	-1.006	-0.633	21.0
								Bus14	1.006	0.633	21.0
Bus14	11.000	98.390	-0.9	0	0	1.006	0.623	Bus13	-1.006	-0.623	63.0
Bus15	33.000	99.487	-0.1	0	0	0	0	Bus8	-0.754	-0.473	15.7
								Bus16	0.568	0.357	11.8
								Bus17	0.187	0.116	3.9
Bus16	11.000	99.043	-0.4	0	0	0.567	0.352	Bus15	-0.567	-0.352	35.4
Bus17	11.000	99.342	-0.2	0	0	0.187	0.116	Bus15	-0.187	-0.116	11.6
Bus18	33.000	99.814	-1.4	0	0	0	0	Bus9	-8.742	2.134	157.7
								Bus19	0.407	0.234	8.4
								Bus20	8.335	-2.388	152.0
Bus19	11.000	99.628	-1.5	0	0	0.407	0.252	Bus18	-0.407	-0.252	25.3
Bus20	11.000	101.286	-4.5	0	0	0	0	Bus30	8.306	-2.893	455.8
								Bus51	0.004	0.002	0.2
								Bus18	-8.310	2.891	455.9
Bus21	33.000	99.767	-1.3	0	0	0	0	Bus9	-0.195	-0.121	4.0
								Bus22	0.195	0.121	4.0
Bus22	11.000	99.679	-1.4	0	0	0.195	0.121	Bus21	-0.195	-0.121	12.1

Project:	ETAP	Page: 1
Location:	12.6.0H	Date: 18-03-2019
Contract:		SN:
Engineer:	Study Case: LF	Revision: Base
Filename: pg cather		Config.: Normal

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Bus1	132.000	99.968	0.0	0	0	0	0	Bus5	-0.737	-0.476	3.9	84.6	
								Bus8	0.737	0.476	3.9	84.6	
Bus2	132.000	99.918	0.0	0	0	0	0	Bus5	-2.048	-1.311	10.6	84.2	
								Bus7	2.048	1.311	10.6	84.2	
Bus3	132.000	99.594	-0.1	0	0	0	0	Bus4	-9.745	1.307	43.2	-99.1	
								Bus9	9.745	-1.307	43.2	-99.1	
Bus3 1	11.000	101.209	-4.7	0	0	0.427	0.265	Bus3 2	7.438	-3.440	425.0	-90.8	
								Bus30	-7.865	3.175	439.8	-92.7	
Bus3 2	11.000	101.200	-4.7	0	0	0.427	0.265	Bus3 1	-7.436	3.442	425.0	-90.7	
								Bus3 3	7.009	-3.707	411.2	-88.4	
Bus3 3	11.000	101.179	-4.8	0	0	0.256	0.159	Bus3 2	-7.003	3.714	411.2	-88.3	
								Bus3 4	6.747	-3.872	403.6	-86.7	
Bus3 4	11.000	101.170	-4.9	0	0	0.427	0.265	Bus3 3	-6.738	3.887	403.6	-86.6	
								Bus3 5	6.311	-4.151	391.9	-83.5	
Bus3 5	11.000	101.151	-5.0	0	0	0.427	-1.782	Bus3 4	-6.301	4.164	391.9	-83.4	
								Bus 36	5.874	-2.382	328.9	-92.7	
Bus3 9	11.000	100.877	-5.4	0	0	0.426	0.264	Bus4 0	4.140	-1.425	227.8	-94.6	
								Bus 38	-4.567	1.161	245.2	-96.9	
Bus4	132.000	100.000	0.0	0	0	0	0	Bus3	9.788	-1.288	43.2	-99.1	
								Bus6	0.688	0.410	3.5	84.8	
								Bus5	-10.476	0.858	46.0	-99.7	
Bus4 0	11.000	100.757	-5.5	0	0	0.426	0.264	Bus3 9	-4.133	1.431	227.8	-94.5	
								Bus4 1	3.706	-1.696	212.3	-90.9	
Bus4 1	11.000	100.243	-6.3	0	0	0.425	-2.249	Bus4 0	-3.664	1.738	212.3	-90.4	
								Bus4 2	3.238	0.511	171.7	98.8	
Bus4 2	11.000	100.168	-6.3	0	0	0.425	0.264	Bus4 1	-3.236	-0.509	171.7	98.8	
								Bus4 3	2.811	0.246	147.8	99.6	
Bus4 3	11.000	100.076	-6.3	0	0	0.425	0.265	Bus4 2	-2.808	-0.243	147.8	99.6	
								Bus44	2.383	-0.020	125.0	100.0	
Bus4 6	11.000	99.915	-6.4	0	0	0.425	-1.254	Bus45	-1.530	0.549	83.4	-94.1	
								Bus4 7	1.105	0.685	68.3	85.0	
Bus4 7	11.000	99.911	-6.4	0	0	0.425	0.263	Bus4 6	-1.105	-0.685	68.3	85.0	
								Bus 4 8	0.680	0.421	42.0	85.0	
Bus 4 8	11.000	99.890	-6.4	0	0	0.255	0.158	Bus4 7	-0.680	-0.421	42.0	85.0	
								Bus 4 9	0.425	0.263	26.3	85.0	
Bus 4 9	11.000	99.874	-6.4	0	0	0.425	0.263	Bus 4 8	-0.425	-0.263	26.3	85.0	

Project:	ETAP	Page: 3
Location:	12.6.0H	Date: 18-03-2019
Contract:		SN:
Engineer:	Study Case: LF	Revision: Base
Filename: pg cather		Config.: Normal

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
Bus71	0.415	1	100.0	0.0								
Bus72	11.000	1	100.0	0.0								
Bus73	0.415	1	100.0	0.0								
Bus74	11.000	1	100.0	0.0								
Bus75	0.415	1	100.0	0.0								
Bus76	11.000	1	100.0	0.0								
Bus77	0.415	1	100.0	0.0								
Bus78	11.000	1	100.0	0.0								
Bus79	0.415	1	100.0	0.0								
Total Number of Buses: 77					10.448	6.475	2.612	-6.381	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
Bus5	132.000	Swing	1	100.0	0.0					
						0.000	0.000			