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Loss Reduction in Port Harcourt 33/11kv Distribution Networks By Power Factor Correction

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Abstract

Poor power factor often results in high losses of active power in the network. It measures the percentage of apparent power that can be used to do actual work by the loads. However, this result in a reduction of systems reliability and creates safety problems and a much-increased energy cost. These inductive loads include induction motors, transformers, and reactors and they have a negative effect on the actual power used up by the loads. In this paper, Power factor correction (PFC) has been done by the addition of the needed capacitance to counteract the inductive load which is present in the electrical network of the Port Harcourt distribution system. The load values, MVAr values and the existing power factor of Port Harcourt electricity network where used to derive the needed shunt capacitance to a most appropriate value of 0.95. This enabled current savings of 23.15 percent in all the 11kV buses as well as reducing the required MVA needed to feed the loads to 101.48MVA as against 132.07MVA when the power factor was 0.73. These reductions were achieved by adding a capacitance of 34.48MVAr and the current reductions reduce losses along the lines since the square of current is proportional to losses. Also, the added system capacity will mean that more loads can be fed by the system when the added capacitance brings the system to a power factor of 0.95.

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1. Introduction

Low power factor causes the system to operate less economically. Ackerman (1999), the useful/real amount of power being used in a circuit is often not equal to the apparent power due to the presence of loads that are reactive in nature and such loads (inductors and capacitors) consume power that is referred to as reactive power. With the present

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call for technological revolution and industrialization in Nigeria, it has become more obvious that power holds a very pivotal role in actualizing economic growth. It is noteworthy that developing countries like Nigeria battle with the issue of acquiring more power stations (generation, transmission, and distribution) to the present national grid in order to meet the growing needs of the power sector. More so, in an attempt to grow the power capacity, other issues that have to do with managing available power that the National grid possesses arise. Businesses must be run with the mindset of making a profit and having to pay exorbitant energy bills clearly work against profitability. This similar issue in other parts of the world leads companies, institutions, and industries to find out ways to minimize sources of power loss in order to get better value for money as little energy savings can produce even greater financial savings.

Basu, S., & Bollen, M. H. (2005), the sources and causes of these losses vary and one of them is as a result of reactive power input which occurs from loads that are not linear in nature. Industrialized loads, as well as other heavy machinery, usually have reactive consequences and as the inductive loads increase, it affects the power factor of the entire system which in turn hampers power systems efficiency. Gross, C. A. (1986), most electrical loads do not consume only active power but also reactive power and the higher the reactive power distributed by the distribution network to cover the load requirements, the lower will be the Power Factor (PF). Also, most modern electronic equipment does not represent a completely passive load to the supply even though in the past loads were characterized by their resistive nature (light bulbs) or by input currents that are sinusoidal but phase-shifted (AC motors). When this power factor is low, it has negative impacts on the electric distribution network and it is represented in voltage and power losses, as well as high penalties on large consumers. Grainger, J. J. (1994), power factor correction is very relevant and useful in reducing losses prevalent in electrical networks, ensures more system capacity utilization and improve voltage regulation as these are all factors that enable energy utility companies to provide services that are cheaper and more compatible with the quality desired in today's energy industry (Inan, H., Khosravi, K., & Socher, R., 2016).

Presently in Nigeria, there are many recently built power generating, transmission and distribution stations, yet the country still experiences a high shortage of power to service various load centers. However, power losses account for a reasonable part of this problem. This paper aim at reducing losses in the distribution network using power factor correction technique. A section of Port Harcourt electricity network (PHEN) system is used as a case study for the investigation.

Literature Review

Power loss refers to wastages or differences in the utilized power by the consumer(s) when compared to actual input or generated power in an electrical system.

Mathematically,

$P_{.Loss} = P_{.Generated} - P_{.billed}$ …………………………………………………………………..1

Jiang, Y., Lee, F. C., Hua, G., & Tang, W. (1993, March), distribution losses refer to losses which occur during the process of delivering electrical energy from distribution stations (33/11 kV feeder) to specific locations like residential or commercial areas. Kersting, W. H. (2004, October), Meegahapola, L. G., Vittal, E., Keane, A., & Flynn, D. (2012, October), various types and sources of power loss exist in an electrical power system are enumerated according to their categories.

Power Factor can be defined as the ratio of the real power (kW) to the apparent power (kVA) consumed by a component of an a.c. electrical equipment or an entire electrical installation. It also defines the degree to which electrical power is efficiently converted into useful work output.

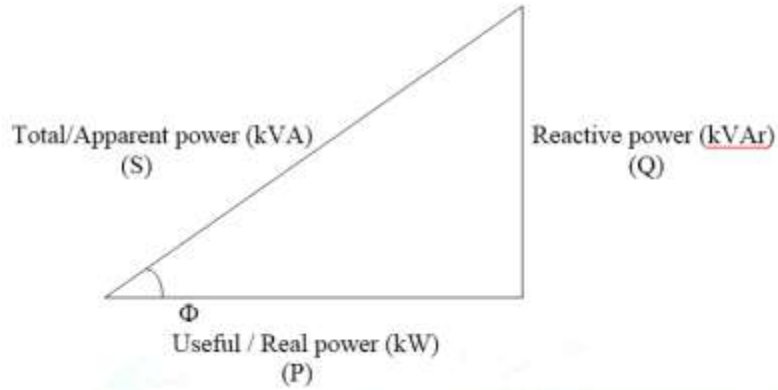

Figure 1. Phase diagram of kVA, kW and kVAr. (Power triangle)

From the power triangle above, it can be deduced that;
Apparent power (S) = Real power (P) + j Reactive power (Q) 2
Hence, $S = P^2 + Q^2$ 3
Cos Φ = P.F = Real Power ÷ Apparent Power 4
Where;
S = Current (I) × Voltage (V) 5
P = I V cos Φ 6
Q = I V sin Φ 7
The output of a capacitor bank is:
$Q_c = V^2 \omega c$ 8
Where Q_c = output in MVar, V = the system voltage in kV, C = in farads
Outstanding features of shunt capacitors are their low overall costs and their high application flexibility. Power Factor correction by shunt capacitors is by far the most satisfactory and economical method.

2. Research Methods

To correct power factor and show a reduction of losses in distribution networks, Power World Simulator (PWS) which is an analytic power system software is used to simulate a section of Port Harcourt Electricity Distribution (PHEDC) network. Transformers data, bus data, and distribution lines parameters were obtained from PHEDC. Power flow studies were then carried out in PWS environment and the desired power factors are analyzed both mathematically and with the aid of PWS using shunt capacitors to show loss reductions and the corresponding financial savings that can be achieved.

Description of Port Harcourt 33/11kv Distribution Network

Saadat, H. (1999), the network considered in this work is a section of Port Harcourt electricity distribution network and it has three (3) 33kV feeders from Ahoada, Rumuosi, and PH mains injection substations. It also consists of two (2) generators, eighteen (18) 33/11kV transformers, three (3) 33/0.415kV transformers, nine (9) switched shunts capacitors, forty-one (41) buses, and thirty-eight (38) loads attached to the network. Thunberg, E., & Soder, L. (2000), other components of the network are isolators, circuit breakers, ring mains units, and conductors.

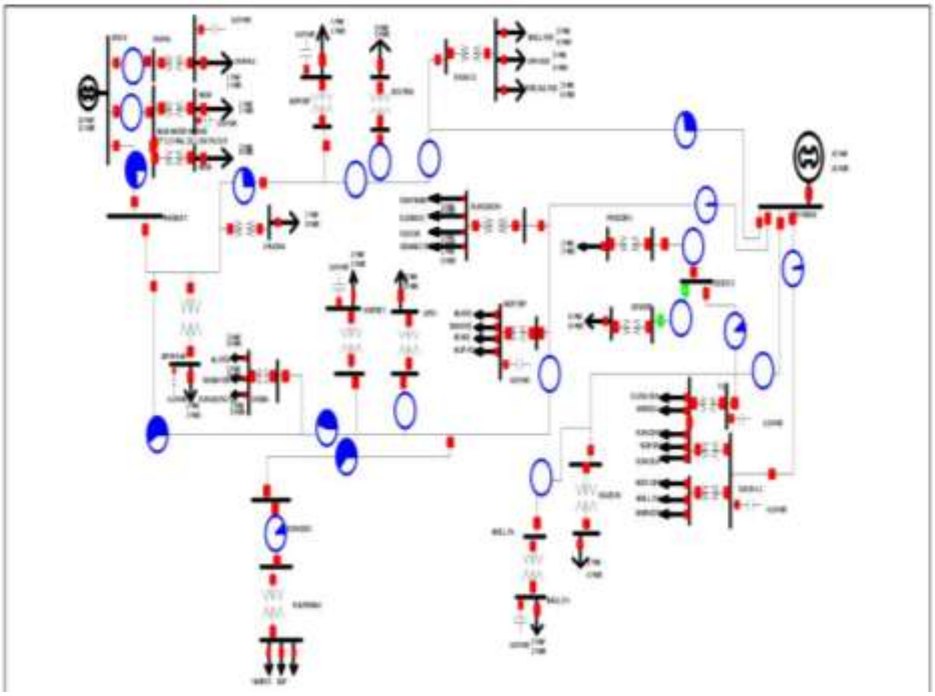

Figure 2. Section of Port Harcourt 33/11kv Electricity Distribution Network

Table 1 shows the results obtained after modeling and simulating a section of Port Harcourt electricity distribution network.

Table 1
Port Harcourt 33/11kV Electricity Load Distribution without correction of power factor

Transformer Bus 33/11kV	Transformer Rating	Load (MW)	Power (MVAr)	Power Required for Load (MVA)	Load Current (I) AMPS
Ayama	2.5	1.25	1.175	1.712328767	213.2414405
Abua Water Works I	2.5	1.43	1.3442	1.95890411	243.9482079
Abua Water Works II	2.5	1.58	0	2.164383562	269.5371808
Army Barracks	2.5	1.45	1.363	1.98630137	247.360071
Choba	15	10	0	13.69863014	1705.931524
Uniport	7.5	5	4.7	6.849315068	852.965762
Agip	15	10.2	9.588	13.97260274	1740.050154
Emuoha	2.5	1	0	1.369863014	170.5931524
Rumuodomaya	15	9.3	0	12.73972603	1586.516317
Airport	2.5	1.4	1.316	1.917808219	238.8304133
Eneka	15	8.5	0	11.64383562	1450.041795
Rukpokwu	15	8	0	10.95890411	1364.745219
Shell Industrial I	7.5	5	4.7	6.849315068	852.965762
Presidential	2.5	1.3	1.222	1.780821918	221.7710981
Stadium	2.5	1.5	0	2.054794521	255.8897286
Golden Lilly Rumuola T1	15	10	9.4	13.69863014	1705.931524
Golden Lilly Rumuola T2	15	9.5	8.93	13.01369863	1620.634948
Golden Lilly Rumuola T3	15	10	9.4	13.69863014	1705.931524
		Total	53.1382	132.0684932	16446.88582

System parameters (Ayama substation);

To obtain the required shunt capacitance at varying power factor and reactive power consumption, the most appropriate power factor as well as current reduction were obtained as shown in equations 8a-10 respectively

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P.F = cos Φ_1 = 0.73, Hence, Φ_1 = 43.11°, Tan Φ_1 = 0.94°
Transformer rating = 1.25MVA, Average load = 1.25MW, Reactive Power consumption = 1.17MVAr
Required Apparent Power = 1.71MVA, Desired Power factor = cos Φ_2 = 0.95
Φ_2 = 18.19, Tan Φ_2 = 0.33
$MVAr_1 = MW_1 * \tan \Phi_1$ 8a
$MVAr_1$ = 1.25 * 0.94 = 1.18MVAr
$MVAr_2 = MW_2 * \tan \Phi_2$ 8b
$MVAr_2$ = 1.25 * 0.33 = 0.41MVAr

- ✓ Shunt Capacitance (CMVAr) needed for Ayama substation is obtained as;

$CMVAr = MVAr_1 - MVAr_2$ 9
= 1.18 – 0.41
= 0.77MVAr

- ✓ Reductions in MVA calculations;

MVA at 0.73P.F = 1.71MVA; MVA at 0.95PF = 1.32MVA
MVA capacity = 1.71 – 1.32
= 0.39MVA

- ✓ Current Reductions

Real power (P) = IV cos Φ
At 0.73PF, I_1 = 155.67 Amps and At 0.93 PF, I_2 = 119.62 Amps
Current reduction = $I_1 - I_2$ 10
= 155.67 – 119.62
= 36.05Amps
Percentage current reduction = 23.15 %

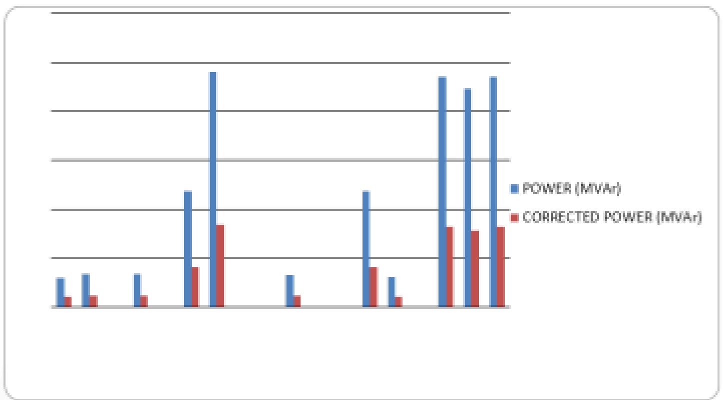

Figure 3. Chart showing the reactive power reduction when system Power factor increased to 0.95

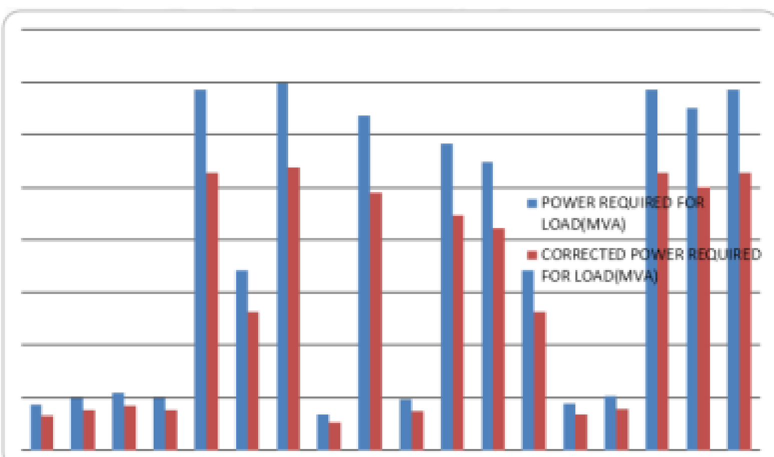

Figure 4. Chart showing the reduction in MVA when system Power factor increased to 0.95

Table 2
Showing reduced reactive power, improved system power capacity and reduced system consumption

Transformer Bus 33/11kV	Transformer Rating (kVA)	Load (MW)	Corrected Power (MVAr)	Corrected Power Required For Load (MVA)	Current (I) at 0.95PF(AMPS)
Ayama	2.5	1.25	0.4125	1.315789474	163.8592122
Abua Water Works I	2.5	1.43	0.4719	1.505263158	187.4549387
Abua Water Works II	2.5	1.58	0	1.663157895	207.1180442
Army Barracks	2.5	1.45	0.4785	1.526315789	190.0766861
Choba	15	10	0	10.52631579	1310.873697
Uniport	7.5	5	1.65	5.263157895	655.4368487
Agip	15	10.2	3.366	10.73684211	1337.091171
Emuoha	2.5	1	0	1.052631579	131.0873697
Rumuodomaya	15	9.3	0	9.789473684	1219.112539
Airport	2.5	1.4	0.462	1.473684211	183.5223176
Eneka	15	8.5	0	8.947368421	1114.242643
Rukpokwu	15	8	0	8.421052632	1048.698958
Shell industrial i	7.5	5	1.65	5.263157895	655.4368487
Presidential	2.5	1.3	0.429	1.368421053	170.4135807
Stadium	2.5	1.5	0	1.578947368	196.6310546
Golden Lilly Rumuola T1	15	10	3.3	10.52631579	1310.873697
Golden Lilly Rumuola T2	15	9.5	3.135	10	1245.330012
Golden Lilly Rumuola T3	15	10	3.3	10.52631579	1310.873697
		Total	18.6549	101.4842105	12638.13332

Table 3
Table showing the total capacitance added total MVA released and the total current reduction on the 11kV bus

Transformer Bus 33/11kV	Load (MW)	Capacitance Needed (CMVAr)	Reductions In Power(MVA)	Current Reduction	Percentage Current Reduction
Ayama	1.25	0.7625	0.396539293	49.38222832	23.15789474
Abua Water Works I	1.43	0.8723	0.453640952	56.4932692	23.15789474
Abua Water Works II	1.58	0	0.501225667	62.4191366	23.15789474
Army Barracks	1.45	0.8845	0.45998558	57.28338486	23.15789474
Choba	10	0	3.172314348	395.0578266	23.15789474
Uniport	5	3.05	1.586157174	197.5289133	23.15789474
Agip	10.2	6.222	3.235760634	402.9589831	23.15789474
Emuoha	1	0	0.317231435	39.50578266	23.15789474
Rumuodomaya	9.3	0	2.950252343	367.4037787	23.15789474
Airport	1.4	0.854	0.444124009	55.30809572	23.15789474
Eneka	8.5	0	2.696467195	335.7991526	23.15789474
Rukpokwu	8	0	2.537851478	316.0462613	23.15789474
Shell Industrial I	5	3.05	1.586157174	197.5289133	23.15789474
Presidential	1.3	0.793	0.412400865	51.35751746	23.15789474
Stadium	1.5	0	0.475847152	59.25867399	23.15789474
Golden Lilly Rumuola T1	10	6.1	3.172314348	395.0578266	23.15789474
Golden Lilly Rumuola T2	9.5	5.795	3.01369863	375.3049353	23.15789474

Golden Lilly Rumuola T3	10	6.1	3.172314348	395.0578266	23.15789474
	Total	34.4833	30.58428262	3808.752506	

3. Results and Analysis

Discussion

Figure 2. shows a section of Port Harcourt 33/11Kv electricity distribution network consisting of the transformers, breakers, isolators, reactors, capacitors etc. After simulating the model, reactive power (MVAr), as well as power required for load(MVA) and load current(I), were obtained as shown in table 1.0.computation of shunt capacitance, MVA capacity and current reduction for the various substations were obtained using the relevant mathematical expressions as shown in equation 8a-10 and results compared with that obtained from PWS. Figures 3.0 and 4.0 shows how power factor increment from about 0.73 which is obtainable to 0.95 using the required sizes and placement of shunt capacitors results in a reduction of reactive power and improvement of active power system capacity as well as reduced systems consumption. This culminates to overall power consumption cost reduction.

Table 2 shows the results obtained at the corrected power factor of 0.95, the total power required for the load is 101.4842105MVA and 18.6549MVAr.while the current amounted to 12638.1332A.however before the correction was made, the total power required for the load is 132.0684932MVA and 53.1382MVAr for 16446.88582A as shown in table 1.0.table 3.0 shows the total capacitance added and current reduction as well as the total MVA obtained. This implies that when appropriate power factor correction is done, the cost of power distribution and utilization will appreciably be reduced as shown both in tables 1.0 and 2.0 respectively.

4. Conclusion

From the results obtained and the analysis of the section of Port Harcourt 33/11kV considered, improvements were made in various aspects of the network. Firstly, a total capacitance of 34.48MVAr addition was made to the network which was added to the 11kV side of thirteen (13) buses of the network. Also, it was discovered that this brought the power factor of the system from 0.73 to 0.95. This correction to 0.95PF created an additional MVA capacity of 30.58MVA which could very well be redistributed to cover other loads of the network. Furthermore, the current flowing through the 11kV buses was drastically reduced by 3808.75Amps which will also reduce the I^2R losses which are directly proportional to the square of the current in the line. Hence a current reduction of 23.16 percent was obtained. There is no gainsaying that a tremendous amount of savings has been achieved by the addition of the appropriate amount of MVAr to the system.

Conflict of interest statement and funding sources
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Statement of authorship
The author(s) have a responsibility for the conception and design of the study. The author(s) have approved the final article.

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