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The Effect of Maintenance and Power Factor Correction Strategies on Electricity Utilization and Billing: Case Study of Bendel Feeds and Flour Mill, Edo State

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Abstract

This work examined the effect of maintenance strategy and compensators in improving the efficiency of electric energy utilization, using Bendel Feeds and Flour Mill factory in Edo State, Nigeria as case study. Data was collected using meters to measure active power, reactive power, apparent power, power factor, voltage, current, etc. before and after maintenance work were carried out on equipment and Volt Ampere Reactive (VAr) compensator facilities in the factory during load conditions. The data were collated and quantitatively analyzed to assess the behaviour of the load with and without maintenance work and VAr compensator.

The study revealed the following: maintenance work in flour mill process line improves the load power factor by 74% and reduces power losses by 65%, while the injected VAr compensator improved the load power factor from 0.75 to 0.94, that is, 25% and reduced electric power losses by 38%. Maintenance work in feed mill process line improved the load power factor by 51% and reduced electric power losses by 56%. While the VAr compensator improved the load power factor from 0.62 to 0.94, that is, 52% and reduced power loses by 56%. On the Silo process line, power losses reduced by 53% as a result of compensation, consequence upon these strategies the factory total current demand decreased by 26%, while the company saved the sum of N2,314,390.62 on electricity bill for the year 2011.

1.0 Introduction

Electrical power supply utilities usually penalize consumers with low power factor by having to pay an excessive maximum demand charge as part of their tariff. The consumer is encouraged, therefore, to control its utilized electric power so as to reduce the charge. Electrical power loss reduction through effective maintenance strategy and power factor correction is an effective way of reducing the Kilo Volt Ampere (kVA) demand. Maintenance activities such as oiling, greasing, adjustment, replacement of faulty and worn out parts, tightening of loose bolts, cable terminals, busbar connection etc, significantly contribute to reducing the current for a given output power and electrical power losses.

Maintenance is the combination of all technical and administrative actions intended to retain an item in or restore it to a state in which it can perform its required functions [1]. Maintenance is as old as man in that natural processes such as plant and animals lives are sustained by the process of maintenance which involves repair, replacement and renewal in order to ensure that living systems are in as good a working condition as possible. The main maintenance objective is to attain a condition where the system always functions as if they are new. As there exist no known methods of preventing normal wear and tear of components or system, the process of maintenance involves the maximization, containment and correction of wear and tear [1].

There are basically two broad types of maintenance schemes that sustain all forms of structures. They are planned and unplanned maintenance. Planned maintenance covers preventive, corrective and routine maintenance, while the unplanned maintenance is generally referred to as breakdown or emergency maintenance where the facility breakdown before the maintenance crew is called upon to effect repairs. The importance of having industrial and production machines in good working condition has long been recognized as a very important element contributing to the overall productivity of a company [2]. The breakdown of engineering facilities has serious social, economic and security implication, for the economy of the setup and the nation in general [3].

Many loads on Bendel Feeds and Flour Mill electrical system such as transformers, electric motors, motor driven machines, (Hammer Mill, Pellet Mill, Cooler, Crumbler, Roller Mill, Sifter, Grain Separator, Distoner, Polisher, Bagging equipment, Conveyor, Elevators, Lift and Cranes), fluorescent lighting etc are inductive in nature and hence have low

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lagging power factor [4]. Power factor is defined as the ratio of actual power (kW) consumed by an electrical load to the apparent power (kVA), irrespective of the nature of voltage and current [5]. Mathematical expression for power factors is:

$$\text{Power factor} = \frac{kW}{kVA} \qquad (1)$$

If voltage and current are both sinusoidal,

$$\text{Power factor} = \frac{kW}{kVA} = \text{Cos}\ \theta \qquad (2)$$

Where θ is the phase difference between voltage and current.

For a balanced three phase electric distribution network tied to load centre operating at different loading condition, the following mathematical relationships exists [6]. The current, I_L available in the line is;

$$I_L = \frac{P_W}{\sqrt{3}V_L \cos\theta} \qquad (3)$$

Where V_L = Line voltage and P_W is active power available in the line

$$\text{The power lost in the line } P_L = 3I_L^2 R = \frac{P_W{}^2}{V_L{}^2 Cos^2\theta} \qquad (4)$$

Equation (3) shows that the current flowing in the line is inversely proportional to the power factor. The large current at low power factor causes more copper losses (I^2R) in all the element of the supply system, such as cables, transformers, switchgear etc.

Equation (4) shows that the system losses are proportional to the inverse of the square of the power factor. For example, if the load power factor is 0.5, the associated losses will be $\left(\frac{1}{0.5}\right)^2$ or four times the loss that would arise with a unity power factor. Therefore, a low power factor will greatly contribute to system losses and associated cost [7]. High power loss in electrical systems means high production cost. Power demand from supply utility must meet the load demand as well as losses. Power loss result as heat (I^2R) on conductors, transformers, electric motors etc., and the loss determine the efficiency of machines and hence significantly influence their operating cost. To estimate the percentage power loss reduction, when electrical load power factor is improved from $Cos\theta_{initial}$ to $Cos\theta_{final}$,equation (5) applies [8].

$$\% \text{ Loss Reduction} = \left[1 - \left(\frac{Cos\theta_{initial}}{Cos\theta_{final}}\right)^2\right] \times 100 \qquad (5)$$

In theresearch by Onohaebi, et al. [9] the researchers revealed that the load current reduced by 16% when the power factor was corrected from 0.75 to 0.90 and a financial saving of N207,000.00 per annual.

In the work of Osama et al. [8], the researchers found that by improving the power factor of a factory from 0.75 to 0.95, the kVA capacity of the distribution transformer (supplying the factory) increased by 21.05%

2.0 Industrial Application

Bendel Feeds and Flour Mill Limited, established May, 1986 in then Bendel State, now Edo and Delta State is used as a case study for this work. Fig1.0 shows the factory different load centres such as Flour Mill, Feed Mill, Silo, the utility company transformer and the standby generators. The management of Bendel Feeds and Flour Mill contracted the maintenance of production machineries and equipment to specialized industrial maintenance company, Asea Brown Boveri Limited (ABB) in 2011 because of frequent breakdown, in efficiency, capacity under-utilization of production machineries and equipment leading to high cost of production and poor quality product. Bendel Feeds and Flour Mill has maintenance unit which performs routine servicing, preventive maintenance, repairs and overhaul. However, the production machineries, equipment and tools are from different manufacturers, varied and utilize different levels of technology. This calls for high technical skills and different maintenance facilities which is not available in the company's in-house maintenance department. Maintenance activities carried out by ABB include the followings: inspection, adjustments of machine, alignment tests, and change of bearings, gears, shafts, pulleys, belts, electric motor, machine realignment, testing and maintenance of programmable logic controller (PLC). Table 1 shows the factory load technical parameters such as, active power, reactive power, apparent power, power factor, frequency, voltage and current demand by flour mill, feed mill and silo process lines. The parameters were measured before and after maintenance of the production machineries and equipment, using meters.

3.0 Data Analysis

Table 1 showed that after maintenance work, the active power demand from utility transformer by flour mill process line increased from 304kW to 640kW, apparent power increased from 710kVA to 896kVA, while reactive power reduced from 638kVA to 592kVAr. The high reactive power needed to cover flour mill load requirement before maintenance work reduced the power factor to 0.43. The power factor, however, improved to 0.75 when the demand for reactive power reduced due to maintenance work. The voltage and current demand at flour mill also increased after maintenance work. Electrical power demand before and after maintenance work in feed mill and silo process lines is similar to that of flour mill as shown in Table 1.

In order to enhance further, the performance of production machines and equipment, reduce power losses and electricity bill, flour and feed mills power factors were improved from 0.75 and 0.62 to 0.94 respectively, and Silo power factor improved from 0.65 to 0.95 as shown in Table1, by connecting capacitor banks (VAr compensator) to the mills as shown in Fig 1.0. Table 2 presented the old and new setting as well as total capacity of the VAr compensator for flour mill, feed mill and silo process lines. Table 3 showed that the reactive power (kVAr). Apparent power (kVA) and current drawn by the factory from the utility company (PHCN) reduced by 763 kVAr (67.4%), 379.5 kVA (24.1%) and 601.9 Amperes (26.3%) for flour mill, feed mill and Silo process lines respectively, as a result of VAr compensator.

Energy Cost Reduction in Factory Power Consumption as a result of Compensator

Electricity billing by utility companies for medium and large industries is done on two-part tariff structure, i.e. one part for actual energy drawn in kW terms during the billing cycle of one month and the second part for capacity drawn in terms of kVA [10]. This means that the electric demand charge directly depends on the overall power factor in the factory. Table 5 is utility company electricity tariff. The tariff structure shows the customer demand level, fixed charge, meter maintenance charge, demand charge, and energy charge. Using Tables 3 and 5, the effect of application of VAr compensator in industrial loads and its capability in electric energy cost reduction is hereby presented;

From power holding company of Nigeria (PHCN) industrial tariff code D5 [see Table 5].

Demand charge per KVA = N484.01

KVA reduction = 379.5 (see Table 3)

Energy reduction cost/month = N484.01 x 379.5 + 5%VAT = N192,865.8848

Energy cost reduction per annual

= N192,865.8848 x 12 months

= N2,314,390.617

Table 2: Compensators, June, 2011

	Flour Mill		**Feed Mill**		**Silo**	
	Old Setting	New Setting	Old Setting	New Setting	Old Setting	New Setting
Mode	Off	Automatic	Off	Automatic	Off	Automatic
C/K (sensitivity)	0.23	0.07	0.17	0.12	0.33	0.23
Cos θ	0.8	0.95	0.91	0.95	0.84	0.95
Capacitor	8 x 50 kVAr	8 x 50 kVAr	7 x 50 kVAr	7 x 50 kVAr	6 x 32.5 kVAr	6 x 32.5 kVAr
Total capacity of Compensator	400kVAr		350kVAr		195kVAr	

Table 3: Reduction in Factory Power Consumption as a result of Compensator

	Reactive Power (kVAr)		**Apparent Power (kVA)**		**Current Drawn (A)**	
	With power factor equipment	**Without power factor equipment**	**With power factor equipment**	**Without power factor equipment**	**With power factor equipment**	**Without power factor equipment**
Flour Mill	220	592	660	896	936	1281.3
Feed Mill	114	364	412	446	576.7	669.3
Silo	34.5	175.5	121.5	231	172.5	336.5
Total	368.5	1131.5	1193.5	1573	1685.2	2287.1
Reduction	763		379.5		601.9	
% Reduction	67.4		24.1		26.3	

Table 4: Effect of Maintenance and Compensation Strategies on Power Loss Reduction

	Flour mill		**Feed Mill**		**Silo**
Data	Maintenance	Compensator	Maintenance	Compensator	Compensator
Cos $\theta_{initial}$	0.43	0.73	0.42	0.62	0.65
Cos θ_{final}	0.73	0.93	0.62	0.94	0.95
% loss reduction	65	38	56	56	53

Table 4 shows the percentage power loss reduction as a result of maintenance and compensation strategies for flour mill, feed mill and silo process lines. The effect of maintenance and compensation strategies on power lost reduction is presented in Table 4. Using equation (5) and tables 1 and 3.

4.0 Results

- From Table 1, maintenance work improved load power factor for flour mill process line from 0.43 to 0.75 (74.4%), and that of feed mill process line from 0.41 to 0.62 (51.2%). Injected VAr compensator improved load power factor for flour mill process line from 0.75 to 0.94 (51.6%), feed mill process line from 0.62 to 0.94 (52%) and that of Silo process line from 0.65 to 0.95 (46.2%).
- From Table 4, electrical power losses reduction are 65% and 56% for flour mill and feed mill process lines respectively, as a result of maintenance work. While the injected VAr compensator reduced electrical power losses for flour mills, feed mill and Silo process lines by 38%, 56% and 53% respectively.
- Bendel Feeds and Flour Mill Limited saved N2,314,390.62 (Two Million Three Hundred and Fourteen Thousand, Three Hundred and Ninety Naira, Sixty Two Kobo) annually on electricity Bill by improving the load power factor to 0.94. Besides KVA demand charge saving the company also derived the following benefits:
- Reduction in current as a result of reduction in KVA and reactive current demand.
- Reduction in heating and energy losses in the standby generator, transformer, and distributors (cables connecting the generator/transformer with load panel) as a result of reduction in reactive current demand.
- The high power factor (0.94) leads to low capital cost for new standby generator, switchgear and cable whenever there is need for replacement.
- Large reactive current requires higher excitation current in the standby generator alternator leading to burning of excitation coil and diodes is avoided.
- The high power factor increases life span as well as reduces the rate of depreciation of standby generator, transformer, switch gear and distributors.

5.0 Conclusion

The management decision to maintain the following production line equipment; VAr compensators, Boiler, Hammer Mill, Pellet Mill, Cooler, Crumbler, Roller Mill, Sifter, Grain Separator, Distoner, Polisher, Bagging equipment, Conveyor, Elevators, Lift, Crane, Electric Motors, Transformers, Generators, etc, as a result of frequent breakdown, inefficiency, capacity under-utilization leading to high cost of production and poor quality product resulted in a remarkable improvement in product quality, capacity utilization and significant reduction in equipment breakdown and production cost. Table 1 in effect shows that the Mills design maximum power demand value is higher than the full load demand. This shows that there is room for expansion and capacity for the company's product mix to compete favourably in existing market and make more profit.

6.0 Acknowledgement

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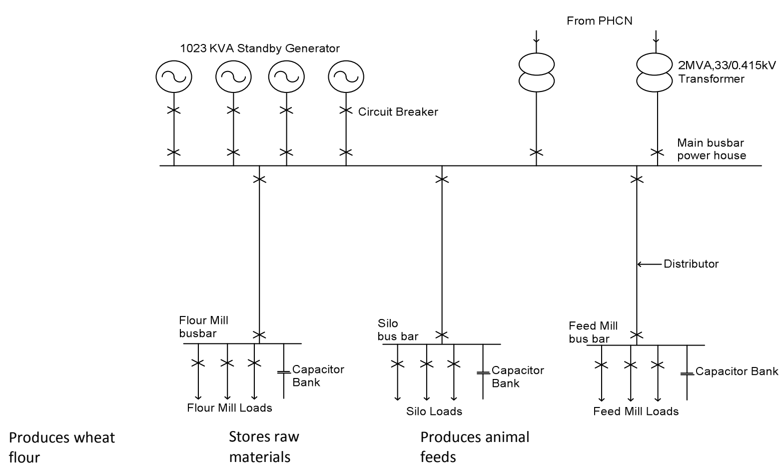

Fig. 1.0: Factory Electrical Distribution System

Table 1: Effect of maintenance and VAr compensator on Flour Mills, Feed Mill and Silo. June, 2011

	Flour mill				Feed mill				Silo		
	Before Servicing of the production facilities, without compensation	**After Servicing of the production facilities, without compensation**	**After Commissioning of the Compensation**	**Design Maximum Value**	**Before Servicing of the production facilities, without compensation**	**After Servicing of the production facilities, without compensation**	**After Commissioning of the Compensation**	**Design Maximum Value**	**After Servicing of production facilities, without compensation**	**After Commissioning of the Compensation**	**Design Maximum Value**
Active Power (kW)	304	640	624	800	164	292	394	400	150	115.5	120
Reactive Power (kVAr)	638	592	220	250	361	364	114	150	175.5	34.5	45
Apparent Power (kVA)	710	896	660	1000	398	446	412	450	231	121.5	150
Power Factor	0.43	0.75	0.94	Min 0.8	0.41	0.62	0.94	Min 0.8	0.65	0.95	Min 0.8
Frequency (Hz)	49.74	51	50.28	52	50	50.2	50.7	52	49.95	50.5	52
Voltage Phase 1 – N (V)	229	234	235	240	236	233	238	240	227	234	240
Voltage Phase 2 – N (V)	229	234	234	240	236	233	237	240	227	234	240
Voltage Phase 3 – N (V)	228	232	233	240	235	230	236	240	226	232	240
Voltage Phase 1 – 2 (V)	393	405	406	415	407	403	412	415	392	405	415
Voltage Phase 2 – 3 (V)	394	403	404	415	407	401	410	415	391	403	415
Voltage Phase 1 – 3 (V)	394	403	403	415	407	401	410	415	390	403	415
Current Phase 1 (A)	1029	1,316	980	1,428	548	686	616	700	343.5	193.5	200
Current Phase 2 (A)	1000	1,296	916	1,428	568	678	562	700	340.5	169.5	200
Current Phase 3 (A)	1029	1,232	912	1,428	569	644	552	700	325.5	154.5	200

Appendix A: Table of Implementation of New Tariff Structure Effective All Bills Produced From the 1st July, 2011

Old Tariff Codes	**New Tariff Codes**	**Customer Demand Level**	**Fixed Charge Per Month**	**Meter Maintenance Charge Per Month**	**Demand Charge Per KVA**	**Minimum Charge Per Month**	**Energy Charge Per Month**
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1.L11	R1	< 5KVA	50.00	250.00	0.00	50.00	2.2
1.2L12	R2	< 5KVA < 15KVA	75.00	250.00	0.00	75.00	7.3
1.3L1.3	R3	< 15KVA< 45KVA	300.00	1,251.00	0.00	300.00	11.0
1.4L14	R4	< 45KVA< 500KVA	300.00	4,003	0.00	12,509.00	15.6
1.5L15	R5	< 500KVA< 20MVA	0.00	5,504.00	0.00	78,178.00	15.6
2.0 Commercial							
2.1L4	C1	< 5KVA	204.00	227.00	0.00	204.00	11.1
2.2L.5	C2	< 5KVA < 15KVA	272.00	1,134.00	0.00	272.00	14.5
2.3L.6	C3	< 15KVA< 45VA	544.00	3,629.00	391.05	11,340	14.5
2.4112.116.119	C4	< 45KVA< 500KVA	0.00	4,990.00	42.51	70,874	14.5
3.0 Industrial		< 500KVA< 20MVA	0.00				
3.11.7	D1	< 5KVA	201.00	223.00	0.00	201.00	11.7
3.21.8	D2	< 5KVA< 15KVA	268.00	1,116.00	0.00	268.00	15.2
3.3L9	D3	< 15KVA< 45KVA	536.00	3,570.00	412.31	11,157	15.2
3.4H3.117	D4	< 45KVA< 500KVA	0.00	4,909.00	448.16	69,733	15.2
3.5HA	D5	< 500KVA< 20MVA	0.00	4,909.00	484.01	3,347.191	15.2
4.0 Street Lighting							
4.1D1	S1	1ph.3ph	0.00	940.00	0.00	451.00	8.6
5.0 Special Tariff Class							
5.1	A1	< 5KVA	120.00	500.00	0.00	120.00	11.2
5.2	A2	< 5KVA< 15KVA	240.00	1,600.00	0.00	5,00.00	11.2
5.3H4	A3	< 15KVA< 45VA	0.00	2,200.00	0.00	31,250.00	11.2
5.4HG	A4	< 45KVA< 500KVA	0.00	2,200.00	0.00	31,250.00	11.2
5.5	A5	< 500KVA< 20MVA	240.00	1,600.00	230.00	5,00.00	11.2

Source: Power Holding Company of Nigeria (PHCN).

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