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ENERGY CONSERVATION IN INDUSTRY THROUGH POWER FACTOR CORRECTION

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ABSTRACT

This paper takes a look at the effect of power factor correction on the energy consumption in an industry. The use of static capacitors to achieve significant improvement in energy conservation in some industries in Kumasi has been studied.

It is estimated that on the average static capacitors can be used to save 20% on industrial electricity bills. The capital recovery period is less than two years for most of the industries studied.

Keywords: Energy, conservation, industry, power factor

INTRODUCTION

The Industrial sector of Ghana consumes about 35 per cent of the Electric Energy sold by the Electricity Corporation of Ghana. With the current rehabilitation exercise embarked upon by the corporation and the expansion of the industrial sector, it is important to distribute and use electricity more efficiently.

In any ac electric system, the value of the power factor is a measure of the electrical efficiency of that system. A system with a low power factor has low efficiency and this paper looks at the effect of using power factor correction to reduce the energy consumption in some industries in Kumasi.

Power Factor

For a single phase system supplying a load P at voltage V and current I, we have

$$P = IV \cos\theta \quad \text{.............................(1)}$$

For a balanced 3 phase load,

$$P = \sqrt{3}\, VI \cos\theta \quad \text{.........................(2)}$$

where θ is the phase angle between the line voltage V and the line current I, and $\cos\theta$ is the power factor.

For resistive loads, V and I are in phase and $\cos\theta = 1$. For circuits with windings, the current lags the voltage and $\cos\theta < 1$. Examples of such inductive circuits are motors, transformers, and furnaces. With these circuits, part of the absorbed apparent power goes to energise the magnetic circuits and does not produce useful power.

For capacitive loads the current leads the voltage. It is thus possible to alter the phase shift of inductive loads by introducing appropriate capacitive loads into circuit.

From equation (2) the conductor current is given by

$$I = \frac{P}{(\sqrt{3}V \cos\theta)} \quad \text{.......................(3)}$$

Thus a low power factor means a high current, and this has the following important effects:

1. The line losses are inversely proportional to the square of the power factor i.e. $1/\cos^2\theta$. Thus losses at 0.8 pf are 1.57 times those at unity power factor.

2. The rating of the generators and transformers are proportional to the current. Larger generators and transformers are thus required.

3. Since most industrial loads are inductive, the low power factors are usually lagging, and this causes a large voltage drop; extra regulating equipment is thus required [1].

As a consequence of the above, most industrial electricity tariffs are framed on a two-part structure, one part of which is related to the capital costs in the form of a maximum demand (MD) charge and the other to running costs in the form of a unit (KWH) charge. In Ghana, the maximum demand is based on the KVA. Now for a given kilowatt load, KVA is inversely proportional to the value of the power factor. Thus the maximum demand charge imposes an automatic power factor penalty. When the power factor of a consumer is improved the KVA maximum demand is reduced and his electricity bills are therefore lower.

The supply authorities also reap the following benefits:

1. the load output of a given plant is increased and with it the earning capacity,
2. line losses are reduced to a minimum,
3. voltage regulation is considerably improved, and
4. there is a beneficial effect upon the stability of the system.

The supply authorities are therefore able to provide more efficient distribution of electric power, with more consumers benefiting from the same generators and transformers.

POWER FACTOR CORRECTION

The magnetizing current associated with inductive loads connected to an ac circuit creates a lagging power factor. However, by connecting to the circuit devices which operate at a leading power factor, the magnetizing current is neutralized and the angle between the current and voltage is reduced or eliminated at unity power factor.

Methods of improving the power factor shall now be considered. These include the use of the following:

(a) Correct sized motors
(b) Over-excited synchronous motors
(c) Phase Advancers and
(d) Static Capacitors

These methods are considered below.

Motor Size

1. High speed induction motors are smaller in frame size and also have better power factors than low speed motors. High speed motors are thus preferred.

2. Induction motors have maximum power factors when fully loaded and should therefore not be left on low load.

Synchronous Motors

The property of a synchronous motor operating with no load is that it takes lagging KVA when the field current is below a certain value, and leading KVA when the field current is above this value. They are mostly used on power systems where large amounts of reactive energy in a single controlled block are needed for power factor correction and voltage regulation.

Phase Advancers

Phase Advancers are a.c. commutator machines whose function is to improve the power factor of induction motors. The use of these machines becomes economical for large induction motors above 100hp.

Static Capacitors

A static capacitor takes a current which leads the voltage by an angle only a little less than 90°. It has small losses, requires no maintenance, and is very convenient in the small sizes.

METHODS OF INSTALLING STATIC CAPACITORS

We shall consider four of the methods used in installing capacitors for power factor correction in industries. [2]. These are:

1) Distributed or individual correction
2) Centralized or overall correction
3) Group-mode correction
4) Automatic power factor correction

Individual Power Factor Correction

In this method a capacitor or bank of capacitors is connected to the terminals of each load and is switched on or off with the load. This is technically the best method and offers the following advantages:

(a) Accurate inductive reactive power compensation directly at the terminals of the load requiring it.
(b) It is impossible to take energy with leading power factor since the capacitors begin to function at the same time as the loads to which they are coupled.
(c) Controls and protection on the individual capacitors are eliminated since the load's windings are sufficient to provide discharge circuits.

Its disadvantage is that it is the most expensive because

(a) it splits the required reactive power into many separate banks,
(b) it involves more total capacity than group correction.

This method is recommended for a plant with few loads of sizeable power responsible for pushing down monthly average power.

Centralized Power Factor Correction

In a case where the installed power is considerably higher than the average power absorbed by the loads and many units require improvement, power factor correction is made with a single bank of capacitors. The rating of such a bank is determined according to the average magnetising current requirement of the plant and is kept in use during its entire working period.

This is the most practical method and takes advantage of the load diversity factor of a group of induction motors and provides the most effective correction for a given amount of KVA. It also helps to reduce feeder losses and improves voltage regulation.

Group Mode Power Factor Correction

This method requires the installation of capacitors at the terminals of frequently used loads. Where both large and small-rated motors are used, it may also require individual correction of the large motors and a grouping of the smaller motors together, for collective improvement.

Automatic Power Factor Correction

In cases where the reactive power absorption varies widely over the day, a certain number of bank elements must be put in or taken out of circuit as the power varies, in order to provide a constant power factor correction. For such situations, an automatic power factor correction plant could be installed. This may employ a relay to control a number of capacitors through the medium of contactors. The number of capacitors needed at any particular time will be switched on automatically. It is also possible to operate the system manually.

MOST ECONOMIC POWER FACTOR

Wherever the idea of power factor correction is under discussion, it is often the desire of the consumer to know the new magnitude of power factor which would result in maximum savings. This value of power factor is called the Most Economic Power Factor, and it is evaluated as follows:[3,4].

Let the consumer be supplied with a load P at a power factor of cos ϕ_1. Let maximum KVA demand = S_1.

After installation of power factor improvement equipment,

let power factor = $\cos\phi_2$,

and maximum demand = S_2

Let maximum demand charge/KVA/annum = A

Then annual. savings effected by consumer through the power factor correction equipment is:

$$A(S_1 - S_2) = A\left[\frac{P}{\cos\phi_1} - \frac{P}{\cos\phi_2}\right]$$

Now KVA rating of the power factor equipment is give by (tan ϕ_1 - tan ϕ_2).

If the capacitors cost B cedis per KVA per annum, then annual expenditure on power factor correction equipment

$$= BP\ (\tan\phi_1 - \tan\phi_2)\ \text{cedis}$$

Net annual savings,

$$S = A\left[\frac{P}{\cos\phi_1} - \frac{P}{\cos\phi_2}\right] - BP\ (\tan\phi_1 - \tan\phi_2)$$

For maximum savings the differential coefficient with respect to ϕ_2 is zero. Thus Sin ϕ_2 = B/A

Hence the most economic power factor,

$$\cos\phi_2 = \cos\ (\sin^{-1} B/A)$$

Therefore the most economic power factor depends on the annual expenditure on the correction equipment and the fixed charges per KVA of maximum demand, but not on the original magnitude of power factor of the installation.

INDUSTRIES WITH POWER FACTOR CORRECTION EQUIPMENT

There were only 4 industries in the Kumasi area which had power factor correction equipment installed at the time of preparing this report. The names of these industries as well as the year of installation of the equipment are given below:

1. Logs and Logging Limited 1986
2. Naja David Bondplex 1987
3. Timber Industry Limited 1988
4. Specialised Timber Products 1985

We shall now look at each of these industries.

Logs and Logging Limited

This is a timber sawmill and plywood industry. The major equipment used are induction motors for cranes, rollers, compressors etc. There are 3 transformers in use, each of rating 750 KVA, 11KV/440V.

Mode of Installation

There are 4 separate banks of capacitors, each of rating 92KVAr, 120A, 440V ac. They are installed on the low tension side of each of two of the transformers serving the industry. Each of these banks is protected with a 160A fusible cut-out. The entire capacitor is automatically controlled using a reversing motor switch gear, and contactors are provided for normal operation.

Cost Analysis

Cost of Equipment	=	¢6,000,000
Power Factor before installation	=	0.6
Corresponding KVA maximum demand	=	1000
Power Factor after installation	=	0.85
Corresponding maximum demand	=	700
Max demand charges	=	¢594.00/KVA/month

Monthly savings due to reduction in Max demand = 300 x ¢594.00
= ¢178,200.00

Annual Savings = ¢178,200 x 12
= ¢2,138,400.00

Capital Recovery period $= \frac{¢6{,}000{,}000.00}{¢178{,}200.00}$
= 34 months

Percentage Reduction in Energy Bill

$$= \frac{\text{Savings} \times 100\%}{\text{Total Energy Bill}}$$

$$= \frac{178{,}200 \times 100\%}{1{,}400{,}000}$$

= 12.7%

Naja David Bondplex

This industry deals with the production of veneer and plywood. It also uses induction motors of varying capacities. It has a transformer with a rating of 750 KVA, 11kV/440V ac. The installation consists of centralized units, individual units and group mode units as shown in Table 1.

Timber Industry Limited

This is basically a sawmill using three main induction motors of ratings 37KW, 45KW and 75KW, 3 phase. Power is supplied from the commercial 415V ac by the Electricity Corporation of Ghana.

TABLE 1: INDUSTRIES WITH POWER FACTOR CORRECTION EQUIPMENT

INDUSTRY	INITIAL POWER FACTOR (P.F.)	FINAL P.F.	INSTALLED CAPACITOR BANK RATING	PERCENTAGE SAVINGS	PAYBACK PERIOD (MONTHS)
1 Logs and Logging Limited	0.6	0.85	4 x 92 Kvar 120A, 440V Automatic Central Control	12.7	34
2 Naja David Bondplex	0.6	0.85	1. 300KVAr, 420A, 415V Automatic Control 2. 30KVAr, 42A, 415V Individual Control 3. 2 x 12.5KVAr, 17.5A, 415V Individual Control 4. 2 x 20KVAr, 28A, 415V Group Mode Control	10.4	17
3 Timber Industry Limited	0.55	0.85	2 x 92 KVAr, 120A, 440V Manual Central Control	11.1	21

Specialised Timber Products

This industry is a sawmill which also produces plywood. It uses induction motors of various sizes. Its correcting plant employs a 540KVAr capacitor bank, centrally corrected. At the time of the study the bank was not in use due to burnt contactors as a result of overloading.

POWER FACTOR CORRECTION ANALYSIS OF INDUSTRIES WITH LOW POWER FACTORS

All the industries in Kumasi have power factors below 0.90, most of them between 0.50 and 0.85. Thus all the industries need power factor correction plants to reduce their maximum KVA demand. The analysis includes the rating of the correction plant, the annual savings expected and the pay back period.

A computer programme was written to perform the above analysis for some of the industries in Kumasi. In the analysis the capacitor cost is ¢6,500/KVAr. Power Factor is improved from the original value to the most economic value of 0.97 for all the industries. [5,6]

OBSERVATION

The power factors for the different industries were derived from the readings on their KVAH and KWH meters. The analyses made here assume fairly accurate meter readings of the fifty industries.

Table 2 shows the results of the analyses of the 50 industries in Kumasi. Figures 1, 2 and 3 are derived from this table.

Fig 1 is a plot of the original power factor against the payback period in months. This shows a payback period ranging from about 7 to 165 months for power factors from 0.37 to 0.91.

TABLE 2: ENERGY DATA ON INDUSTRIES

INDUSTRY		POWER FACTOR	OLD. MAX DEMAND/ POW. FACTOR	MAX. DEMAND IN KVA		REQUIRED CAPACITOR (KVAR)	ANNUAL SAVINGS (CEDIS)	SAVINGS (%)	PAYBACK PERIOD (MONTHS)
NAME	TYPE			OLD	NEW				
1. C.H. GHASSOUB SAWMILL	Sawmill	0.54	185	100	55.670	70.632826	315,984	29.872	13.7420
2. LOGS AND LUMBER LTD.	Timber	0.59	1271	750	456.18	494.65147	1,882,763	9.6144	18.8990
3. U.S.T.	Educational	0.80	2179	1743	1437.5	696.33041	2,177,420	4.2130	51.4953
4. KUMASI BREWERY LTD.	Brewery	0.79	1675	1323	1077.4	549.19605	1,749,961	6.0596	48.0265
5. CITY HOTEL	Hotel	0.73	247	180	135.46	90.088541	317,453	5.3176	33.2842
6. F.E.CHASSOUB	Sawmill	0.51	529	270	141.95	197.73621	912,678	28.714	12.1321
7. KOFI SARPONG SAWMILL	Sawmill	0.63	159	100	64.948	61.870224	249,647	19.384	20.2762
8. PEPRA SAWMILL	Sawmill	0.57	316	180	105.77	122.18206	529,089	25.037	15.5934
9. KUMASI STONE QUARRY	Quarry	0.63	317	200	129.89	123.74044	499,695	24.073	20.2762
10. HOTEL GEORGIA	Hotel	0.91	110	100	93.814	18.654075	44,091	2.0882	165.965
11. FRANCO WOOD PROCESSING CO.	Timber	0.61	492	300	186.65	191.85630	793,633	24.652	18.5419
12. FYNE INDUST.LTD.	Timber	0.64	234	150	98.969	91.196368	363,748	13.071	21.2223
13. NOKS HOTEL	Hotel	0.89	112	100	91.752	23.290549	58,788	5.0055	121.738
14. K'SI LOGGING & LUMBER	Logging & Lumber	0.64	703	450	296.90	273.58910	1,091,245	29.959	21.2223
15. ATWIMA TIMBERS	Timber	0.67	403	270	186.49	155.09968	595,225	10.122	24.4388
16. ASHANTI TIMBER CO.	Timber	0.37	432	160	61.030	139.60616	705,452	34.474	6.74803
17. KAC LIMITED		0.69	145	100	71.134	55.087606	205,757	11.384	26.9660
18. RIDGE TIMBER CO. LTD	Timber	0.52	192	100	53.608	72.384197	330,680	31.138	12.6449
19. EJISU FOREST PRODUCTS	Timber	0.83	410	340	290.92	118.91356	349,786	3.2345	64.8749
20. WOOD COMPLEX LTD.	Wood Processing	0.84	280	235	203.50	78.034700	224,495	5.0362	70.7070
21. POKU INDUSTRIAL COMPLEX	Timber & Offices	0.65	388	252	168.66	150.45127	592,579	16.427	22.2274
22. S.E.A. TIMBERS	Timber	0.62	274	170	108.65	106.98657	437,233	32.469	19.3843
23. TIMBER & TRANSPORT LTD	Timber	0.62	334	207	132.30	130.24653	532,395	17.259	19.3843
24. WEST AFRICA HARD WOODS	Timber	0.60	217	130	80.412	84.451357	353,461	24.482	17.7450
25. PANT TIMBERS LTD.	Timber	0.53	208	110	60.103	78.668363	355,665	24.080	13.1810
26. STATE FOOTWEAR CORP.	Footwear	0.90	174	157	145.67	33.021595	80,760	5.4281	140.692
27. BIBIANI LOG & LUMBER CO.	Logging & Lumber	0.52	846	440	235.87	318.49046	1,454,994	19.815	12.6449
28. FORESTA AFRICAN SAWMILL	Sawmill	0.88	136	120	108.86	30.530987	79,363	6.9594	108.995
29. G.W.S.C.	Offices	0.82	421	345	291.64	126.56399	380,282	3.9673	59.8204
30. NAJA DAVID BONDPLEX	Veneer & Plywood	0.79	665	525	427.57	217.93494	849,429	5.9565	48.0265
31. GANEM TIMBER LTD.	Timber	0.54	156	100	65.979	60.797578	242,499	12.876	21.2223

TABLE 2: ENERGY DATA ON INDUSTRIES (CONT'D

INDUSTRY NAME	INDUSTRY TYPE	POWER FACTOR	OLD MAX DEMAND/ POW. FACTOR	MAX. DEMAND IN KVA OLD	MAX. DEMAND IN KVA NEW	REQUIRED CAPACITOR (KVAR)	ANNUAL SAVINGS (CEDIS)	SAVINGS (%) *	PAYBACK PERIOD (MONTHS)
32. WOOD INDUST. LTD.	Timber	0.70	153	107	77.216	57.641574	212,297	13.275	28.3701
33. MONTER TIMBERS	Timber	0.58	224	130	77.731	87.003120	372,567	20.709	16.2738
34. FABI TIMBERS	Timber	0.66	295	195	132.66	114.24153	444,214	12.410	23.2974
35. MAXWELL OWUSU TIMBERS	Timber	0.62	355	220	140.61	138.42733	565,831	14.892	19.3843
36. STAR TIMBERS	Timber	0.54	380	205	114.12	144.79729	647,766	32.251	13.7420
37. MARS TIMBERS CO. LTD.	Timber	0.52	221	115	61.649	83.241827	380,282	28.010	12.6449
38. APPIAH MENKA COMPLEX	Soap Production	0.65	162	105	70.360	62.688029	246,908	17.508	22.2274
39. KUMI & CO SAWMILL	Sawmill	0.59	169	100	60.824	65.953530	279,241	18.391	16.9900
40. SPECIALIST TIMBER PDT.	Timber	0.51	292	149	78.340	109.12109	503,663	16.026	12.1321
41. HOTEL AMISSAH	Hotel	0.79	127	100	61.443	41.511417	132,272	9.6152	48.0265
42. ASENEMASO SAWMILL	Sawmill	0.46	250	115	54.536	88.852685	430,987	34.406	9.86904
43. DANIEL SAWMILL	Sawmill	0.50	200	100	51.546	74.071369	345,377	34.145	11.6412
44. EHWIAA SAWMILL	Sawmill	0.57	181	103	60.525	69.915290	302,756	20.841	15.5934
45. A.G.T. TIMBERS	Timber	0.72	935	673	499.54	345.60236	1,236,377	8.8719	31.5151
46. KASSARDJAN	Contractor	0.69	268	185	131.59	101.91262	380,650	21.059	26.9680
47. GHANA SEED CO. LTD.	Seed Processing	0.44	227	100	45.360	78.772337	389,468	39.259	9.08455
48. TRIO ENCOURAGE		0.68	147	100	70.103	56.278804	213,105	12.269	25.6588
49. Y.T.EL BITAR LTD.	Timber	0.46	283	130	61.649	100.44216	487,202	35.543	9.86994
50. GHANA WOOD SAWMILL	Sawmill	0.59	169	100	60.824	65.953530	279,241	22.241	16.9900

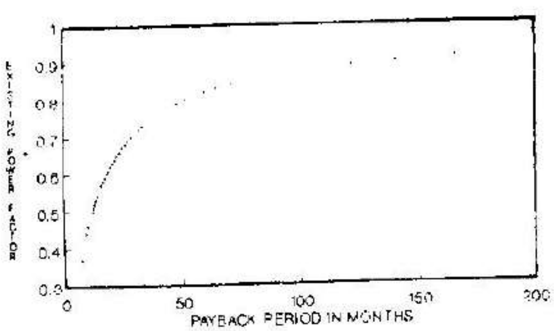


Fig. 1 Power Factor Correction Analysis

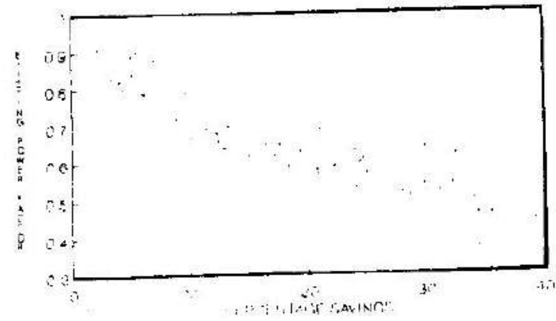
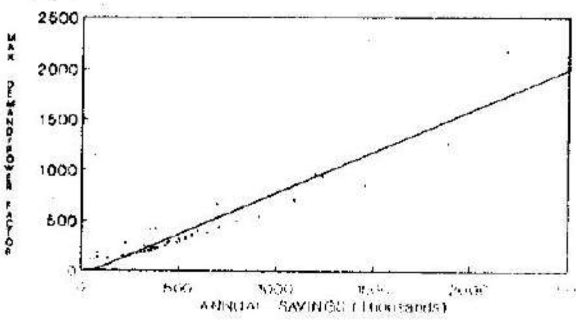


Fig.2 Power Factor Correction Analysis

POWER FACTOR CORRECTION ANALYSIS
FIG. 3



It is observed that a large number of industries have power factors less than 0.7 with payback period less than 3 years. Those with poorer power factors of less than 0.5 will even benefit more from power factor improvement since the payback period is less than 1 year.

The few industries with power factors greater than 0.9 will still benefit from further power factor improvement but the payback period is relatively high.

Fig 2 shows that the percentage savings in electricity bills increases to 39 as the original power factor decreases from 0.91 to 0.37.

Fig 3 depicts the graph of the ratio of the maximum demand to the power factor versus the annual cash savings in the electricity bill. This shows a fairly linear relationship (with a coefficient of correlation of 0.94), which can be used to deduce a company's savings, once its maximum demand and power factor are known.

Fig 3 shows that a number of industries are losing millions of cedis annually through poor power factors.

Analysis of the results indicates that whatever the initial power factor, a company will gain significantly by installing capacitors to improve upon the power factor.

RECOMMENDATION AND CONCLUSION

The accuracy of the above analysis depends on the instruments and the meter readers. It is therefore recommended that meter readers are well trained and that digital instruments are used to replace the old analogue ones. It will eventually pay off if faulty instruments are replaced or re-calibrated. This can be done only if a report is made on such instruments and their replacements budgeted for.

The country will save a lot on energy if capacitor banks are installed in industries to improve upon their power factor. The Electricity Corporation of Ghana should take steps to ensure that industries install such capacitors, as this will reduce the bills of both the industries as well as the Electricity Corporation.

Further help on the acquisition of the right size of capacitors required could be obtained from the Department of Electrical and Electronic Engineering, U.S.T., Kumasi.

In conclusion, this work has been able to show the importance and savings in both energy and costs obtained by the installation of power factor correction equipment on industrial premises. It is thus left to the industries concerned to take advantage of this analysis to save money for themselves as well as for the nation.

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