Influence of Poor Power Factor on the Cost of Electrical Energy Consumption and its Correction

Kawira M. K. and Ali W.

Abstract—The cost of power in a utility is increased by low power factor which reduces the efficiency of a system. The line losses cause low efficiency of the system. The cosine of cos angle θ which is between the voltage and the current gives power factor. Low power factor points to an inefficient load source that draws or non-working power which does not produce work.
The power and energy logger, Power Energy Logger model (PEL) 103 was used to measure voltage, current, phase angles, harmonic distortions and power factor for various facilities. A fluke temperature gun was used for monitoring the power factor. The trend in power factor for buildings under construction was lower and non-steady compared to buildings already under a predictable power load. Monitoring of the power factor and its parameters was done for a period of six months.
Analysis of cost of power consumed when power factor was low, showed that the efficiency of usage of electrical energy decreased. During a twenty-four period and a twelve-hour period a load factor of 0.4 and 0.31 respectively were obtained. The electrical power average cost was economical at 49.19 Ksh /k Wh compared to the market price of power consumed at a cost of 22.4 Ksh/k Wh. The high cost of power was due to the surcharges on low power factor.
The passive power factor correction involving linear inductors and capacitors were used to improve the power factor from an average of 0.6 to 0.954.
The improvement in efficiency of a system and devices when power factor was corrected led to energy saving, increase in available energy and savings on power bills.

Keywords: Efficiency, Energy consumption, Load factor, Passive power and Power factor.

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INTRODUCTION

Power factor measures power quality of a utility and it ranges between 0 and 1. It refers to the cosine of the phase angle θ between the voltage and current. It is an indicator of quality of the power of a system and devices (Alberto and Sonia, 2012) The difference between apparent power which is obtained from the product of the V_{rms} and the I_{rms} and actual power is that the actual power is obtained from $V_{rms} I_{rms} \cos\theta$. The component of input current which is in phase with the voltage across the load of resistance $V_{rms} I_{rms} \cos\theta$is the one that contributes to the load. The power factor becomes unity when the voltage and current sinusoidal waveforms are in phase.

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High power factor of almost unity can be obtained despite high current distortion since a power factor equal to one acts to make the circuit purely resistive [1] more efforts on energy efficiency are directed towards fixing appliances that are prone to wastage of energy such as air compressors, inefficient lighting and idle equipment among others. Low power factor raises a premises power bills in form of surcharge bills which constitutes charges of reactive power fee. A low power factor points to an inefficient load source that draws reactive or non-working power which gets wasted [6]. Most non-maintained electrical appliances produce reactive power which does not produce work. As the reactive power usage increases, the electrical power losses increase and hence the surcharge fee. Some inexpensive methods used for correcting low power factor includes checking the equipment that operate above the rated voltage and replacing them, cutting back on how often a facility runs motors with a light load, avoid running idling motors for extended periods of time. Low power factor that arises from linear loads can be corrected using passive network of capacitors. An automatic power factor correction unit that consists of a number of capacitors which are switched on by means of contactors can be used. The power factor controller switches the necessary blocks of capacitors in steps to ensure that the power factor stays above a selected power factor value. Electronic devices such as static volt – ampere reactive compensators are used for correcting low power factor arising from high voltage power systems and fluctuating industrial loads [5]. Lowering a facility's power factor reduces power losses in transformers, heating in cables, switchgears, alternators and other electrical appliances and hence lowering the cost of electrical power consumed in the utility. Therefore the cost power in bills reduce when the power factor is corrected. The buck topology produces a dc output voltage lower than its input voltage [7]. This can present a problem when the instantaneous line voltage is below the output voltage. There will be no line current and lead to significant line-current distortion [3]. High voltage swing on capacitor is observed with some single stage power factor correction [9]. Some single phase power factor solutions can be classified according to line current waveforms [10]. To mitigate minimum capacitor voltage variations the power converter's output is operated in the discontinuous mode [11].

METHODOLOGY

The following tools and instruments were used for data collection. They included: Power & Energy Logger (PEL 103) which was used to measure and log data such as voltages, currents, phase angles, harmonic distortions, and power factor. Fluke True RMS Digital Clamp Meter which was used to measures voltages, currents and resistances. Fluke Temperature Gun which was used to measure surface temperatures.

Calibration of the tools was carried out and the errors observed where they occurred on measured quantities as shown in Table I

Table I: Errors for measured physical quantities

Fluke Temperature Gun	
Surface Temperatures	± 0.3% of reading ± 0.25°C
FLUKE True RMS Digital Clamp Meter	
Voltage	0 to 1,000 V AC/DC / ± 1.5% + 2 V
PEL 103 Power Analyzer	
Voltage Range	10.00 to 1,000 V AC/DC / ± 0.2% + 0.5 V
Current Probe	200.0 mA to 10.00 kA AC / ± 1.2% + 70 mA
Frequency Range	DC, 50 Hz, 60 Hz & 400Hz
Calculated Power Range	10W - 10 GW/ 10 var - 10 Gvar / 10VA -10 GVA

Data logging took placeat three transformer locations in the University. The data was downloaded every two weeks over a period of six months. Equation 1.1 shows a single phase equation for determining power.

$$Power(W) = Volts \times current \times powerfactor \qquad (1.1)$$

Fig. 1 shows the relationship between real power, reactive power and the apparent power.

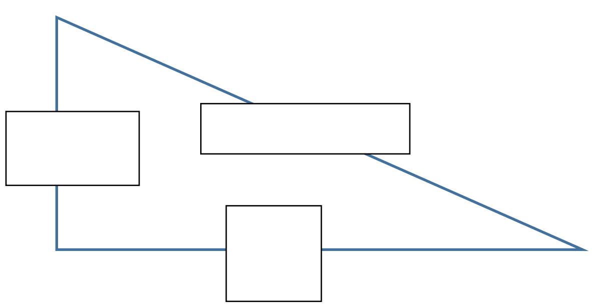


Fig.1: Power factor triangle

The capacitors were connected in parallel to the load and they could be switched on and off to maintain voltage control when the corrected feeder voltage regulation was imposed. In some cases the power factor was achieved by rectification, the average rectified load power was obtained from (1.2) [8].

$$P_d = I_s U_s \cos \phi \qquad (1.2)$$

Where I_s represents apparent rms current, U_s represents phase voltage and cos ϕ represents power factor.

Equation 1.3 was used in the measurement of magnitude of percentage reduction of energy losses in the circuits.

$$\% \, reductionlosses = 100 - 100 \times \left(\frac{originalPF}{NewPF}\right) \qquad (1.3)$$

A linear installation of capacitors was selected for the correction of the power factor. The following variables were considered during choice of capacitor installations: the load type, load size, load constancy and the load capacity. The kVAR used for sizing the capacitors depended on the reactive power that was required to be provided by the capacitors.

The resonant harmonics, h was determined using (1.4) [4].

$$h = \sqrt{\frac{kVA_{sc}}{kVAR}} \qquad (1.4)$$

Where kVA_{sc} represented short circuit capacity of the system, $kVAR$ represented amount of capacitor magnitude and h represented the harmonic number referring to a 60 Hz base. Where the h= 3,5,7, 11 etc.

The code requirements for the capacitors that were used included the kVAR tolerance of +15 – 0%, discharge resistances, capacitors with 600V and less wthin one minute must de energize to less than 50 V while those with 600 V and above should within five minutes de energize to 50 V [2]. For continuous operation the name plate was rated up to 135 % kVAR which included the effect of 110 % rated voltage, 15 % rated capacitance tolerance of harmonic voltage over the fundamental frequency. The dielectric strength was twice the rated AC and the over current protection had a fusing of between 1.65 to 2.5 times the rated current to protect the casing. The single line electrical drawing for one of the utilities was as shown in Fig. 2.

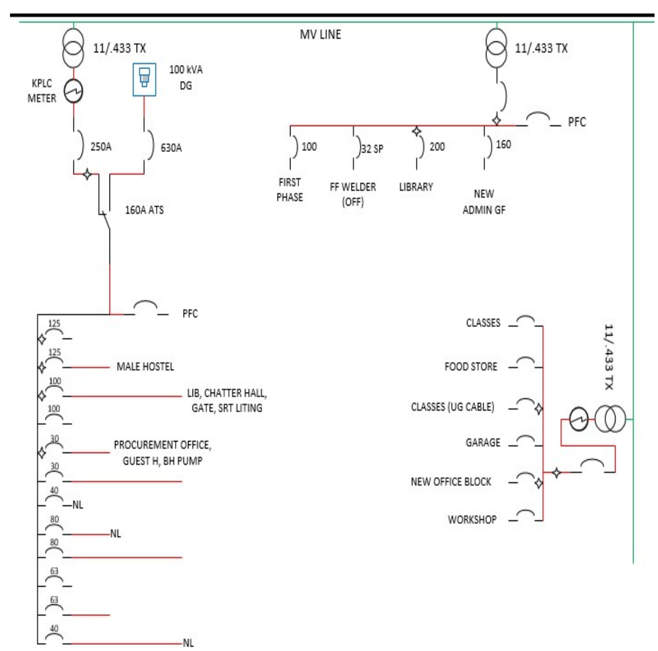


Fig.2: Single line electrical utility drawing

The percentage deviation in the phases was determined using (1.5) [12].

$$\frac{\max\,(I_m - I_r)_r\,(I_m - I_y)_r\,(I_m - I_b)}{I_m} \times 100 \qquad (1.5)$$

Where I_m is the mean of currents in the three phases.

$$\left(I_r + I_y + I_b\right)\Big/_3 \qquad (1.6)$$

Consider that I_r, I_y, I_b are the phase currents

RESULTS AND DISCUSSION

It was observed that increase in reactive power was caused by increase in circuit's reactance while the total impedance of the circuit caused an increase in apparent power. Low power factor caused more current which was higher than the rated one to be used to do the same work. This led to inefficient use of electrical power.

Phase imbalance was observed as a cause for low power factor in a building whether in construction or not. The most common causes of phase imbalance were observed to be from the buildings which had motors with imbalance in the windings, large single loads that resulted in voltage drop. In addition, switching of three phase heavy loads resulted in voltage surges and the unequal impendences in power transmission or distribution systems and consequently low power factor.

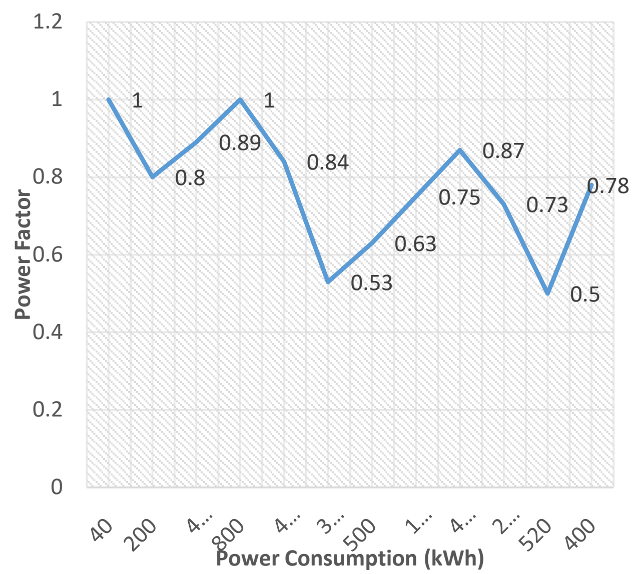
Table II shows the magnitudes of various measured quantities with respect to the power factor

Table II: Sample cost of power with respect to power factor in 2016

Month	High rate kWh	Low rate kWh	Total Usage kWh	Total Bill Ksh	Cost of power Ksh/Kwh	Power factor
January	7146	5994	13140	270913.70	20.62	0.55
February	6388	7427	13815	281728.81	20.39	0.58
March	13862	10235	24097	507209.20	21.05	0.59
April	14533	11049	25582	532491.40	20.82	0.59
May	15755	10741	26496	561491.60 21.19	21.19	0.58
June	8903	8434	17337	393663.90	22.71	0.39
July	12227	9591	21818	478449.54	21.93	0.54
August	13491	9717	23208	505961.53	21.80	0.59
September	14436	10419	24855	534345.90 0.57	21.50	0.57
October	9689	9774	19463	396196.00 0.50	20.36	0.54
November	7987	7506	15493	330134.60 0.63	21.31	0.65
December	2945	3156	6101	109406.30	17.93	0.26

The law provides for penalties for use of electrical energy with a power factor which is less than 0.8 [13]. In this study the power factor was found to have been very poor in June, October and December 2016 with the highest surcharge penalized in December 2016 which was because low power consumption that is below the sized magnitude was observed to lead to lowest power factor

The Load Factor in Fig. 2shows how inefficiently the energy was being consumed in the period of one year. Maximum power factor of 95.3 % provided the most benefit in terms of energy conservation. Reactive power that flows in the system was observed to cause power losses due to low power factor. The losses were calculated by use of (1.3).



Fiig. 3: Power factor against load factor

Fig. 3 shows the efficiency with which the power at the facility was being used. The study showed that a 24 hour operation must have a load factor of above 0.67 to be efficient while a load factor of 0.49 and above was observed to result to less losses for 12 hour operation.

Power factor correction using capacitors gets them acting as reactive current providers hence offsetting the non-working power used by inductive loads. The loads which operate under low power factor draw a higher current compared to same loads with high PF system for the same amount of useful work. The low PF causes usage of more apparent power compared to a load with high PF for the same amount of useful power transferred. A power bank of capacitors was used to correct the power factor. The resonant circuit greatly increased the harmonic distortions.

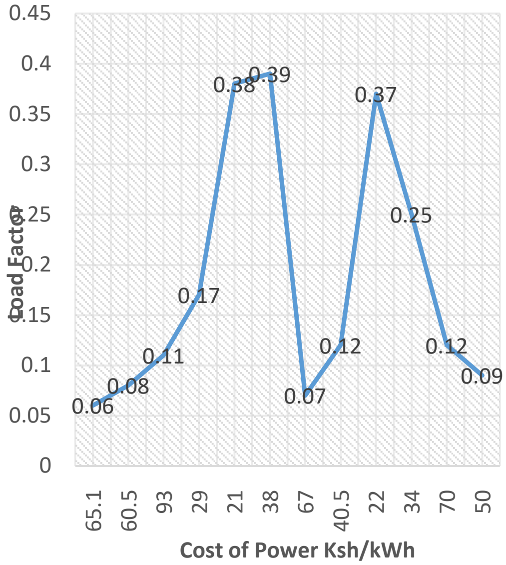


Fig. 4: Power factor against cost of power

The annual average cost of electricity was cited as 23.19 Ksh/ kWh in 2016 and hence Table III shows that the cost of power at the studied facilities was higher compared to the cited value of 23.19.Ksh/ kWh. Fig. 4 shows the lower the load factor the higher the cost of electrical power. Avoidance of peaks during power supply by creation of more demand during the off peak period increased the load factor. The load factor in this study ranged between 0.07 and 0.39 which contributed to the power surcharge of the utility. It results to overloading the system with excessive kVA and hence wastage of power.

Table III: power factor and cost of power

Power Factor	Maximum Demand (Kw)	Total Usage (kWh)	Total cost of Power	Cost of Power (KWh)
1.00	3	114	7413.99	65.04
0.8	4	233	14,300.00	61.37
0.39	56	4179	395,641.00	94.67
1.00	7	880	25,300.00	28.75
0.85	17	4589	98,390.5	21.44
0.54	13	3638	130,602.80	35.90
0.64	9	528	34,708.14	65.74
0.75	15	1313	53,399.8	40.67
0.86	18	4255	95,724.5	22.50
0.73	11	1958	66,367.9	33.90
0.50	8	682	48,195.5	70.67
0.75	6	423	20,977.20	49.59

Conclusion

The highest power factor that that led to maximum energy conservation was 95.3%.Minimizing the losses of power was achieved by use of capacitors. The cost of power reduced by 30.2 % when it was corrected using a bank of capacitors. The load factor in utilities which is in the range of 0.07 to 0.38 resulted to wastage of power in terms of payment of surcharge bills. The power usage affected the magnitude of the load factor and hence balancing of loads enhanced further reducing the cost. A load factor of more than 0.67 was required for a 24 hour operation compared to 0.49 for a 12 hour operation. Levelling of energy consumption to avoid peaks during high demand and increasing demand during low demand periods increased the load factor. A system and devices becomes inefficient when it draws higher current due to a low power factor.

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