Journal of Electrical and Electronic Engineering
2024, Vol. 12, No. 3, pp. 48-52
https://doi.org/10.11648/j.jeee.20241203.11

Research Article

Economic Impact of Low Power Factor on Institutions: a Case Study of Assosa University Building

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Abstract

Power factor is a measure of how efficiently electric power is consumed. It is the result of phase difference between voltage and current at different stages of power system. It's the ratio of active power or useful power to apparent power. The apparent power consists of both the active power and reactive power. If the reactive power increase in a power system, the power factor becomes low. Low power factor can affect the power system quality and the consumer to suffer in paying additional penalty charge for utility if it drops below the predetermined threshold amount. In this study, the bill data record indicates there was low power factor in each month from different energy meter. The minimum or poor power factor relative to other energy meters record was 0.124035 and its power factor charge was 12,011.58 ETB which is approximately equivalent to 214.11USD. The total power factor charge for only recorded data for four months was 71,537.33ETB (1,275.17USD). The institution is paying unwanted charge that can be improved by using power factor correction capacitor. The reactive power (kVAR) required to correct the power factor to 0.9 have been computed in this paper. The money expended for low power factor will be saved and the system's power quality increase as well.

Keywords

Apparent Power, Bill, Capacitor, Energy Meter, Reactive Power, Power Factor, Power Factor Charge

1. Introduction

Power factor is one of the vital factors that affect energy efficiency. Maintaining high energy efficiency is crucial for reducing operational cost and decrease environmental effect [1].

Power factor is the ratio of the active power or useful power to apparent power [2]. The apparent power consists of both active power and reactive power. The electric utility company delivers active power based on the tariff per kwh. The low power factor on the other hand is considered as penalty if its lower than the minimum thresh-hold value [3]. The low power factor indicates high reactive power that affects the power system quality and decrease the energy efficiency [4].

Improving power factor at the load points shall relieve the system of transmitting reactive current. Less current shall mean lower losses in the distribution system of facility since losses are proportional to the square of the current. Hence fewer kilowatt-hours need to be purchased from the utility [5].

One of the direct implications of improving the power factor of a system is that it increases the scalability of the system thus permitting more load to be added to the system

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Received: 20 February 2024; **Accepted:** 20 March 2024; **Published:** 11 September 2024

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in an economically efficient way. The probability of the transformer to become overloaded is highly reduced [6]. Power factor correction systems increase the efficiency of electricity supply, contributing in immediate cost savings [7].

Power factor can be improved by different methods. For instance, by using static capacitors, synchronous condenser and phase advancers. The power factor can be improved by using capacitor connecting in parallel with equipment in parallel with equipment operating at lagging power factor [8]. Using capacitors for power factor improvement has some advantages. These advantages are-they work under ordinary temperature or atmospheric conditions, have low losses, require little maintenance, can be easily installed since they are light and require no foundations [9]. Power capacitors provides reactive current to reduce the total amount of current the system draws from utility, so it acts as reactive current generators [10].

The other benefit of installing capacitors in to a circuit are; the effective line current reduced and decrease in voltage drop which results in improved voltage regulation and the decrease the effect of reactive line voltage drops [11].

2. Method and Discussions

Data Collection

The data includes the existing parameters recorded according to Ethiopian Electric Utility tariff from energy meter for four months. The recorded data includes power factor, active power (KW), reactive power (KVAR), demand factor, demand charge, consumption charge, power factor charge. The maximum power factor charge from the seven energy meter was 12,011.58 ETB which is equivalent to 214.11 USD. The Total Power factor charge in this month (November) is 20470.97 ETB or 364.9USD. The recorded power factor through the year indicates the existence of power factor penalty charge.

The maximum power factor charge from the seven energy meter is 12,011.58 ETB which is equivalent to 214.11 USD. The Total Power factor charge in this month (November) was 20470.97 ETB or 364.9USD.

Table 1. *Recorded poor power factor and its charge.*

Month	Power factor	Power factor charge (in Birr)
January	0.26036	7075.35
February	0.21693	6045.69
March	0.182712	11,306.23
November	0.124035	12,011.58

3. Mathematical Computation for Power Factor Correction Capacitor

Power factor is the ratio of active power to apparent power [12].

$$Pf = cos\theta = \frac{kW}{KVA} \tag{1}$$

$$tan\,\theta = \frac{kVar}{kW} \tag{2}$$

$$kVar = kW(tan\,\theta 1 - tan\,\theta 2) \tag{3}$$

and,

$$\begin{aligned} \theta 1 &= cos^{-1} Pf1 \\ \theta 2 &= cos^{-1} Pf2 \end{aligned} \tag{4}$$

The angle Φ1 and Φ2 are the actual power factor and the desired power factor respectively. The equations (1-4) are used to compute the desired reactive power assuming the lowest actual power factor from four different months.

Case 1- take the minimum power factor in November (pf= 0.124035)

At recorded P=329kW and Q=786 kVAR

Substituting the Active and Reactive power value in equation 4,

$$\theta 1 = cos^{-1} P\,f1 = 82.875°$$

and,

$$\theta 2 = cos^{-1} 0.9 = 25.842°$$

Then after obtaining the phase difference, the reactive power for the power factor correction capacitor can be obtained by inserting the Φ1 and Φ2 value in equation 3.

$$kVar = 329(tan\,82.875° - tan\,25.842°) = 2472.664$$

Case 2- take the minimum pf in January(pf= 0.260362 and P=363kW)

$$\theta 1 = cos^{-1} 0.260362 = 74.91°$$

$$\theta 2 = cos^{-1} 0.9 = 25.842°$$

$$kVar = 363(tan\,74.91 - tan\,25.842) = 1170.32$$

Case 3- the minimum power factor in February.(pf=0.21693 and P=387)

$$\theta 1 = cos^{-1} 0.21693 = 77.47°$$

$$kVar = 387(tan\,77.47 - tan\,25.842 = 1554.71$$

Case 4- taking minimum pf in March.(pf=0.1827123 and P=408)

$$\theta 1 = cos^{-1} 0.1827123 = 79.47°$$

$$kVar = 408(tan\, 79.47° - tan\, 25.842°) = 1997.8251$$

3.1. Sizing the Capacitor Bank

The relationship between Reactive power, charging current and voltage is given by [13].

$$kVAR = \frac{Ic \times V}{1000} \quad (5)$$

Hence Capacitor charging current(Ic),

$$Ic = \frac{kVAR}{V} \times 10^3 \quad (6)$$

On the other hand, the required Capacitive reactance is obtained by-

$$Xc = \frac{V}{Ic} = \frac{1}{2\pi f C} \quad (7)$$

$$C = \frac{Ic}{2\pi f V} \quad (8)$$

Using the recorded value from energy meter in November (P=329, Q=786 and pf=0.124035)

Desired kVAR = 2472.664

Voltage =380V (three phase according to Ethiopian standard)

Hence,

$$Ic = \frac{2472.664}{380} = 6507A$$

$$C = \frac{6.507}{2\pi * 50HZ * 380} = 0.054534 = 54534\mu F$$

The capacitor value in January

$$C = \frac{kVAR}{2\pi f V^2} \times 10^3 = \frac{1170.32}{2 \times 3.14 \times 50 \times 380^2} \times 10^3$$

$$= 0.025811F$$

The capacitor value in February

$$C = \frac{kVAR}{2\pi f V^2} \times 10^3 == \frac{1554.71}{2 \times 3.14 \times 50 \times 380^2} \times 10^3$$

$$= 0.0342888 \text{ F}$$

The capacitor value in March

$$C = \frac{kVAR}{2\pi f V^2} \times 10^3 == \frac{1997.8251}{2 \times 3.14 \times 50 \times 380^2} \times 10^3$$

$$= 0.0440616F$$

3.2. Over-Voltage Case

It's estimated that capacitor units should be suitable for continuous operation at up to 135% of rated reactive power and 110% rated rms voltage [14].

Hence to size the capacitor bank the over voltage considered is computed as

$$kVnew = kV + 10\%kV \quad (9)$$

Where kVnew- is considered as over voltage

3.3. Loss Reduction

Capacitor can tolerate a permanent overcurrent of 30 % and permit a maximum tolerance of 10% on nominal capacitance [15]. As a result, the cable should be sized as,

$$I_{cable} = 1.43 \times ic \quad (10)$$

The loss reduction is calculated as

$$\%\text{loss reduction} = 100 \left[\left(1 - \left(\frac{\text{present PF}}{\text{improved PF}}\right)^2\right]\right. \quad (11)$$

In case 1 the loss reduction is equal to

$$\%\text{loss reduction} = 100 \left[\left(1 - \left(\frac{0.124035}{0.9}\right)^2\right]\right. = 98.1\%$$

Hence the loss reduced by 98.1 percent in November.

The loss reduction for case2 (in January) becomes

$$\%\text{loss reduction} = 100 \left[\left(1 - \left(\frac{0.260362}{0.9}\right)^2\right]\right. = 91.63\%$$

The loss reduction for case 3 (in February)

$$\%\text{loss reduction} = 100 \left[\left(1 - \left(\frac{0.21693}{0.9}\right)^2\right]\right. = 94.19\%$$

The loss reduction for case 4 (in March)

$$\%\text{loss reduction} = 100 \left[\left(1 - \left(\frac{0.1827123}{0.9}\right)^2\right]\right. = 95.878\%$$

4. Economic Advantage

Power factor correction has economic benefit in decreasing the total consumption payment and avoiding the low power factor penalty charge [16].

From the data gained on the bill, the power factor charge for example in November was 12,011.58 ETB, which is very high amount of money relative to normal consumption.

The tariff for the desired power factor (0.9) can be computed as follows

$$pfcharge = MDrate\left[MDrecord\left(\frac{0.9}{pfactual} - 1\right)\right] \quad (12)$$

As a result, if the actual power factor is corrected to the desired power factor the power factor charge value becomes zero according to equation 13.

Hence if the actual value is equal or greater than the desired value there is no payment or penalty charge. By correcting the power factor 12,011.58 Birr might be saved in this month. As a result, if the actual power factor is corrected to the desired power factor the power factor charge value becomes zero according to equation 13.

Hence if the actual value is equal or greater than the desired value there is no payment or penalty charge. By correcting the power factor 12,011.58 Birr will be saved in this month.

The energy cost without power factor charge was 3260.04 birr or 58.11 USD only

$$Total\ savings\ in\ monthly\ energy\ cost =$$

$$energy\ cost\ before\ PFC - Energy\ cost\ after\ PFC$$

$$Total\ savings\ in\ monthly\ energy\ cost = 15{,}271.62 - 3260.04 = 12{,}011.58$$

The total money saved by only the removal of power factor penalty charge in November from the seven recorded energy meter becomes

$$991 + 192 + 814.64 + 2163.16 + 1995 + 12{,}011.58 + 303.59 = 20470.97ETB = 364.9USD$$

In January the power factor charge from five energy meter is

$$548.92 + 2408.45 + 3581.34 + 7075.35 + 287.29 = 13901.35 = 247.795USD$$

In February,

$$6045.69 + 313.68 + 1696.95 + 2444.22 + 872.94 = 11373.48ETB = 202.734USD$$

In March

$$872.94 + 2298.31 + 8960 + 1995 + 11{,}306.23 + 359.05 = 25791.53ETB = 459.742USD$$

The total expenditure in the four months becomes

$$20470.97ETB + 13901.35 + 11373.48ETB + 25791.53ETB = 71{,}537.33ETB = 1275.175USD$$

5. Conclusion

Some institutions suffer to pay high electric charge because of poor power factor. Correcting the power factor play great role in saving the institutions unexpected budget and wastage of power. The computed loss reduction in all cases is greater than ninety percent. As a result, the maximum amount of wastage occurred because of low power factor is extreme. This loss indicates the economic impact and the poor contribution in power quality of the building. On the other hand the extra expenditure can be saved by correcting the power factor using capacitor.

Abbreviations

C	Capacitor
ETB	Ethiopian Birr
F	Farad
KV	Kilo Volt
KVAR	Kilovolt Amper
Kw	Kilowatt
MD	Maximum Demand
Pf	Power Factor
PFC	Power Factor Correction

Author Contributions

Zelalem Bayesa Habte is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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