Do Capacitor Systems Really Save Energy?

by Hany Boulos

Executive summary

Power factor is a measurement of electrical system efficiency. Many utilities have a power factor penalty built into their rate structure to penalize users with a low power factor. The most common remedy is to install a capacitor system. This paper examines both how much energy and how much cost a capacitor system could save—and why the answer is not necessarily the same.

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Summary

1.0 Abstract

This paper addresses the following questions:

1) Can a capacitor system be installed to save energy?
2) If so, how much energy cost can the installation of a capacitor in distribution system save?

Note:

This article does not consider technical aspects of the capacitor system application. It is worth pointing out that the location of the capacitor device plays an important role in the magnitude of the system energy savings. If the capacitor is located at the main switchgear bus, the low voltage system energy savings (in this case) will not be as significant.

Secondly, system energy savings are typically not the main criterion when selecting capacitor placement location. Other issues, such as voltage profile support requirement, system resonance potential, switching transient avoidance, equipment and installation costs are of greater concern.

Finally, the utility rate schedule plays an important role in NPV calculation. Each utility has its own rate structure, which can be complicated. A detailed analysis is needed to calculate the financial benefit of the capacitor system.

2.0 Introduction

Power factor is a measurement of electrical system efficiency. Many utilities have a power factor penalty built into their rate structure to penalize users with a low power factor reading in their electrical system. To improve the power factor, the most common solution is to install a capacitor system.

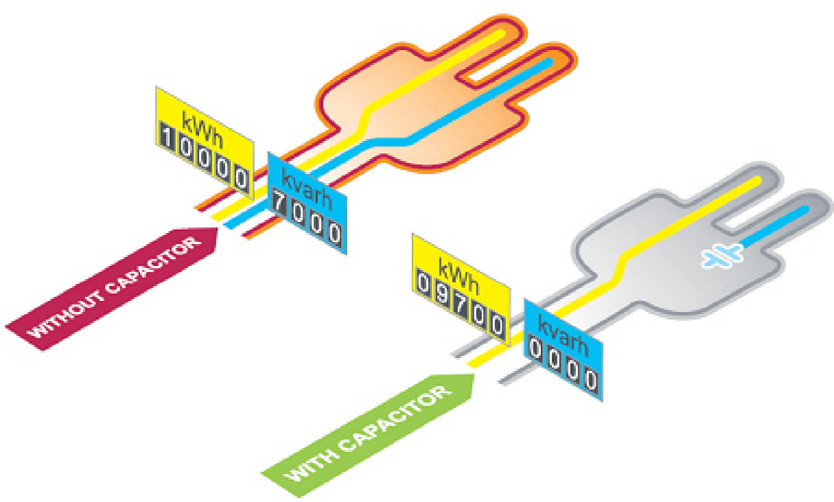
How much energy and cost can the capacitor save for the end user? There are claims that a capacitor system can save a significant percentage of the electrical energy consumption, or energy cost. The answer to the first question is different to the second one.

3.0 Calculating Energy and Cost Savings

As current flows through the conductors, the conductors heat up due to resistance in the conductor. This heating is power loss which is proportional to current ($P_{Loss}=I^2 R$). In normal electrical distribution systems, the conductor loss can account for up to six percent (6%) of the total load.

When a capacitor system is installed in a distribution system to improve system power factor, it also reduces the current magnitude flowing through the conductor and transformer. Hence, the power loss is reduced. Figure 1 illustrates the principle of how capacitors can save energy.

Figure 1



3.0 Calculating Energy and Cost Savings (con't.)

However, the reduction is normally only in the 1-2% range. This paper will try to determine the actual loss and savings with a simple example.

3.1 Definitions of Nomenclature

P_l: Power losses in conductor
R: Conductor resistance
$Cos(\varphi_1)$ or PF_1: Power factor before correction
$Cos(\varphi_2)$ or PF_2: Power factor after correction
C: Capacitor system in kVAR
LRC: Loss reduction coefficient
P_{lr}: Power loss reduced after power factor (PF) correction
LF: Load factor
P_1: Peak Demand before PF correction
P_2: Peak Demand after PF correction
kWH_1: kWh used before PF correction
kWH_2: kWh used after PF correction

3.2 Formulas

The formulas listed below will be used in this paper:

$$P_1 = [\text{Demand kVA}/(\text{voltage} \times 1.732)]^2 \times (R \times 3) \quad (1)$$

To calculate capacitor kVAR required for PF improvement, we have: (2)

$$C = kW \times [\tan[\alpha \cos(\varphi_1)] - \tan[\alpha \cos(\varphi_2)]]$$

To calculate reduction in system loss:

$$\text{Loss reduction coefficient (LRC)} = 1 - (PF_1/PF_2)^2 \quad (3)$$

$$P_{lr} = \text{Power losses} \times \text{Loss reduction coefficient} \quad (4)$$

We can calculate the load factor (LF) used in the energy saving calculation:

$$LF = \frac{kWHusedpermonth}{peakdemand \times averagehourpermonth} \quad (5)$$

3.0 Calculating Energy and Cost Savings (con't.)

After capacitor system installation, the actual peak demand should be lower,

$$P_2 = P_1 - P_{1x} P_{lr} + \text{capacitorloss} \quad (6)$$

$$kWH_2 = P_2 \times 720 \times LF \quad (7)$$

The net present value of the investment is calculated with:

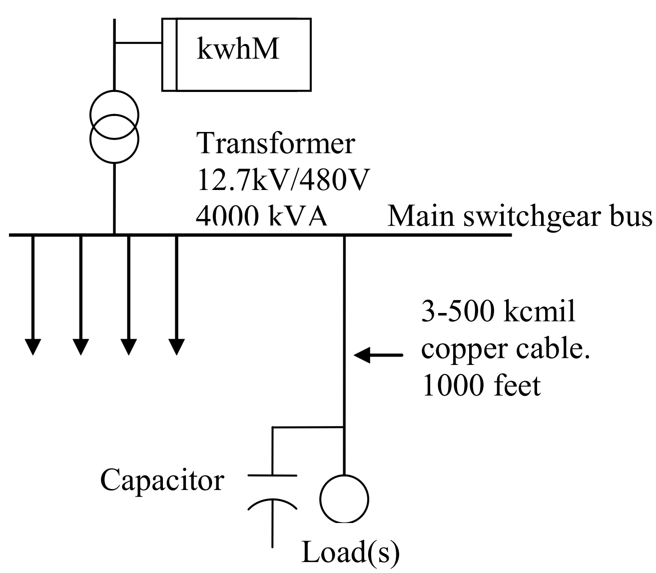
$$NPV = \sum_{t=1}^{n} \frac{M_t}{(1+i)^t} \quad (8)$$

M_t Net cash flow at each year
i Discount rate

To compare the energy and cost savings, we will use a simple radial distribution system as an example.

A MV / LV transformer primary connects utility and its secondary feeds the main switchgear. We assume that a single load (or group of loads) is connected via cable, circuit disconnect to the main bus in main distribution switchgear as shown in Figure 2. The capacitor is placed near the load.

Figure 2



3.0 Calculating Energy and Cost Savings (con't.)

In order to calculate the actual energy savings, the following data is collected.

Transformer rating: 4000 kVA with 5.75% impedance

Primary 12.7 kV delta, Secondary 480 V solid grounded wye

We will pick one feeder to analyze the actual energy savings.

One of the feeders to load(s):

One 3-conductor cable, 500 MCM, copper routed in steel conduit in air

Circuit length, 1000 feet

Resistance, 0.0290 ohms per phase per 1000 feet (NEC Chapter 9, Table 9)

The average monthly energy readings at this feeder (kWH2) are:

Energy charge: 160000 kWH

Peak demand: 300 kW

Operating PF: 0.80

This paper will use two simplified utility rate structures to calculate energy and cost savings when the necessary capacitor system to improve the power factor (PF) is installed. Financial benefits of the same capacitor system will then be evaluated in net present value (NPV) form. Taxes and other possible credits will not be included in either study.

3.3 Case 1 - Utility Does Not Charge a Power Factor Penalty

Here is utility rate schedule for large end users,

Distribution Charge =

$2.499 per kilowatt for all kilowatts of the billing kW

Transmission Charge =

$1.963 per kilowatt for all kilowatts of the billing kW

0.294 cents per kWH

3.0 Calculating Energy and Cost Savings (con't.)

Generation Charge =:

$4.288 per kilowatt for all kilowatts of the billing kW
5.595 cents per kWH for the first 200 kWH per kilowatt of the Billing kW
4.241 cents per kWH for the next 200 kWH per kilowatt of the Billing kW
3.302 cents per kWH for all additional kWH

Based on the above rate schedule, we have:

Distribution demand charge =	2.499 x 300 = $749.70
Transmission charge =	1.963 x 300 = $588.90
	0.00294 x 160000 = $470
Generation charge =	4.288 x 300 = $1286.40
	0.05595 x 200 x 300 = $3357
	0.04241 x 200 x 300 = $2544.60
	0.03302 x (160000 -120000) = $1320.80
Total charges =	$10,317.80

To calculate the system loss, we use:

$LCR = 1 – (PF_1/PF_2)^2 =$ $1-(0.8/0.97)^2 = 0.32$

$P_{lr} = 17.7 \times 0.32 = 5.66$ kW

Assuming the loss incurred by capacitor (detuned) is estimated at: 150 x 5 = 750 w

$P_2 = 300 + .75 – 5.66 = 295.09$ kW

To determine actual energy savings, we will need to do a few more calculations.

We can calculate the load factor (LF) used in the energy saving calculation: LF = 160000/(300x720) = 0.741

kWH consumed after capacitor installed: $kWH_2 = 295.09 \times 720 \times 0.741 = 157379$

Energy saving (%) = 1 - 157379/160000 = 1.6%

3.0 Calculating Energy and Cost Savings (con't.)

The actual monetary savings per month can be calculated by applying the above figures to utility rate schedule:

Distribution charge =	2.499 x 295.09 = $737.42
Transmission charge =	1.963 x 295.09 = $579.25 0.00294 x 1573790 = $462.69
Generation charge =	4.288 x 295.24 = $1265.33 0.05595 x 200 x 295.09= $3302.01 0.04241 x 200 x 295.09= $2502.92 0.03302 x (1573790-400X295.09) = $1299.16
Total billing =	$10,148.78
Savings =	$10,317.80 – $10,148.78 = $169.02
Monetary savings in % =	169.02 /10317.8 = 1.64%

Assuming the cost of the capacitor system is: $45 x 150 = $6750

Calculating the net present value of the investment: $NPV = \sum_{t=1}^{n} \frac{M_t}{(1+i)^t}$

M_t Net cash flow at each year
i Discount rate

We assume the discount rate of 20% in 3 years (n=3). To simplify calculations, also assume the monthly utility usage is flat. Then we have: NPV = -1352 < 0

In this case, the expenditure produces negative return.

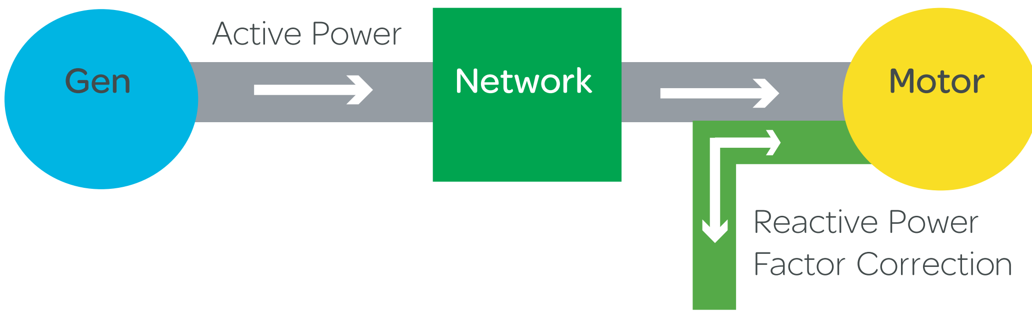
Most companies would like to see:

1) Positive NPV before making any investment
2) The investment return period less than 3 years

3.0 Calculating Energy and Cost Savings (con't.)

So how can capacitor system save energy cost? It happens when there is power factor penalty in utility rate structure. Utilities use various formulas to calculate PF penalty to end users. Case 2 demonstrates the impact of PF penalty in one of typical rate structures.

Figure 3



3.4 Case 2 - Utility Charges Power Factor Penalty in the Form of kVA Demand Charge When Power Factor is Below 0.95

(The kWH rate schedule in Case 1 is used here.)

Distribution demand charge =	\$2.499 per kVA
Transmission demand charge =	\$1.963 per KVA
Generation demand charge =	\$4.288 per kVA

The billing before capacitor installation can be calculated as follows:

Distribution demand charge =	2.499 x 300 x 0.95/.8 = 2.299 x 356.25 = \$890.27
Transmission charge =	1.963 x 356.25 = \$699.32 0.00294 x 160000 = \$558.6
Generation charge =	4.288 x 356.25 = \$1527.60 0.05595 x 200 x 300 = \$3357 0.04241 x 200 x 300 = \$2544.6 0.03302 x (160000 -120000) = \$1320.80
Total charges =	\$10,898.19

3.0 Calculating Energy and Cost Savings (con't.)

After we install a 150 kVAR capacitor bank, we know the billing kVA now is: 295.09 x0.95/0.97 = 288.96

The billing calculation after capacitor system installation is as follows

Distribution demand charge =	2.499 x 288.96 = $722.11
Transmission charge =	1.963 x 288.96 = $567.23 0.00294 x 157379 = $462.69
Generation charge =	4.288 x 288.96 = $1239.06 0.05595 x 200 x 295.09= $3302.01 0.04241 x 200 x 295.09= $2502.92 0.03302 x (1573790-400X295.09) = $1299.16
Total charges =	$10,095.17
Billing savings =	10,898.19 – $10,095.17= $803.01
Energy savings in % =	803.01/10898.19 = 7.37%

Calculating the net present value of the investment:

$$NPV = \sum_{t=1}^{n} \frac{M_t}{(1+i)^t}$$

M_t Net cash flow at each year
i Discount rate

We assume the discount rate of 20% in 3 years (n=3). To simplify calculations, also assume the monthly utility usage is flat. Then we have: NPV = $14,673 > 0

In this case, the expenditure generates positive number. And the magnitude indicates that this is a very attractive NPV.

4.0 Conclusion

Capacitor does reduce energy consumption. In both cases, the reduction in system kWh loss is around 1.6%, as shown in Table 1.

However, in Case 1, the monetary saving in energy reduction alone is difficult to justify the capital investment based on utility rate structure (NPV < 0).

But Case 2 is different as it demonstrates a very attractive NPV figure because of the utility power factor penalty rate structure. So, if you see a utility billing that is based on KVA used, pay attention to the billing or rate structure details. You may be able to save a lot of money.

Table 1

	Case 1		Case 2	
	Before PF Correction	After PF Correction	Before PF Correction	After PF Correction
P_1 (kW)	17.70	12.04	17.70	12.04
LRC	32%		32%	
C (kCAR)		150		150
C_{loss} (kW)		0.75		0.75
P_{lr}		5.66		5.66
P	300	295.09	300	295.09
Billing Demand (kVA)			356.25	288.96
LF	0.74	0.74	0.74	0.74
kWH Used	160,000	157,379	160,000	157,379
Energy Saving (kWH)		2,621		2,621
Energy Saving (%)		1.64%		1.64%
Total Billing	$ 10,317.80	$ 10,148.78	$ 10,898.19	$ 10,095.17
C Cost		$ 6,750.00		$ 6,750.00
NPV		$ (1,352.58)		$ 14,673.43