

## Calculating tool for power factor and compensating vectorial capacitors on inductive charges

### Herramienta para el cálculo del factor de potencia y capacitores compensadores vectoriales en cargas inductivas

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#### Abstract

In the present work, a power factor (PF) calculation tool for single-phase electric networks is shown. This tool is made in Matlab and Simulink; it contains several useful functions such as the condenser code to achieve the desired result, from the measured value to the unit. It is also possible to visualize the voltage and current phase shift when the system is in the compensation system and its decrease as the PF approaches the unit. On the other hand, it is worth noting the decrease in current by the increase of the PF or compensation. All benefits can be seen graphically for a better understanding of possible compensation solutions.

**Power factor, Vector, Element, Current**

#### Resumen

En el presente artículo se muestra una herramienta para el cálculo del factor de potencia (FP) para redes eléctricas monofásicas. Esta herramienta está elaborada en Matlab y Simulink; contiene varias prestaciones útiles como el cálculo del capacitor para lograr el FP deseado, desde el valor medido hasta la unidad. Además, se puede visualizar claramente el desfase del voltaje y la corriente cuando el sistema se encuentra sin ningún tipo de compensación y la disminución de este conforme el FP se va acercando a la unidad. Por otra parte, y una de las más importantes es la disminución de la corriente al incrementar el FP o la compensación. Todos los beneficios se pueden ver en forma gráfica para una mayor comprensión de las posibles soluciones de compensación.

**Factor de potencia, Vector, Elemento, Corriente**

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## Introduction

Demanding a greater amount of reactive power will result in a poorer power factor, due to unnecessary high currents with large losses and voltage drops. Consequently, consumers are penalized for the utility of the power factor. The installation of a capacitor bank, the power of which corresponds to the nominal load, decreases the value of the input current without causing overvoltages in the load (Joksimovic, 2015).

Nowadays it is very important and an urgent need to improve the energy quality and efficiency of the electrical system; for that there are active solutions for the PFC (Power Factor Correction) (Pinheiro, 2012).

One article mentions that the boost power factor correction (PFC) converter is a popular choice due to its known dynamics and simplicity, actively controlling the current of the AC line, to be sinusoidal and in phase with the AC (alternating current), line voltage ACV (alternating current voltage), commonly known as PFC (Clark, Musavi, & Eberle, 2014).

One of the purposes of the use of tools and techniques for PFC is to maintain the load side voltage in a sine wave form, which is essential for the safe and efficient operation of critical loads (Jian Ye, 2019).

The PFC plays an essential role in eliminating power losses. A PFC places the input current in phase with input voltage waveforms. When the power factor is 1.0, the input current is perfectly in phase with the input voltage (R. Meendevi, 2017).

Working with the application of devices for power factor correction is paramount to obtain the benefits that are specified as:

- Reduction of losses in conductors.
- Reduction of voltage drops.
- Increased power availability of transformers, lines and generators.
- Increase of the lifespan of facilities.

And, on the other hand, the economic gains showed below:

- Reduction of costs for electric billing.
- Elimination of rates due to low power factor.

- Bonus of up to 2.5% of billings when there is a power factor greater than 0.9.

In general, the power factor in a 24-hour period is below 0.9, which consumes a large amount of additional energy and, in turn, is penalized by electric power companies (Ke Wang, 2017).

In addition, taking into account that in Mexico the prices of electric power consumption are variable, according to the amount of power taken from the power grid and the average annual temperature, it is very important to have a power factor as close as possible to the unit, to avoid excessive costs of unused electricity. The rates are detailed in table 1.

Rate	1	1A	1B	1C	1D	1E	1F
Thousands of pesos	0.25	0.3	0.4	0.85	1	2	2.5

**Table 1** Consumption rates (CFE, 2019)

The data in the table clearly shows the importance of not exceeding the consumption from what is indicated; in addition, consumption lower than the one marked by the rates of the Federal Electricity Commission (CFE) is subsidized by the government in Mexico.

## Program for vector calculation

It has always been important to have a power factor close to the unit; however, it is necessary to ensure that all types of electrical systems comply with this requirement as much as possible, but taking into account that the system should not resonate for it can oscillate, causing the power grid to fail. For this purpose, a tool was developed in Matlab with the aim of allowing anyone who has this tool to calculate the necessary compensation for the desired PF; in addition to dynamically observing the behavior of the equivalent power grid.

The first thing that has to be done is to feed the system with real values; preferably obtained with a reliable energy quality meter, the requested data are those shown in the following lines of code:

```

clc
clear
v=128.6 ;%Measured voltage of the system.
f=60; %Line frequency.
I=14; %Measured rms current, without
compensation.
fp=0.24; % System power factor.

```

Subsequently to have the possibility of making a calculation from 0.24 with increments of 0.01 until reaching 1 of the PF value; this is done by declaring a vector, similarly it is done to obtain resistance, capacitance, inductance and power. This can be seen in the part of the code below.

```
theta=acos(fp);
m=fp:.01:1; % Power factor vector for capacitor calculation.
[r1 c1]=size(m);
c= zeros(size(m)); % Vector for capacitor results of the same size as the previous vector.
l=((v/I)*sin(theta))/(pi*2*f); % Calculation of the inductance that occurs with the conditions described.
r=(v/I)*cos(theta); % Calculation of resistance according to the previous conditions.
p=v*I*cos(theta); %vrms*irms*fp=P,
```

Subsequently, all desired values were calculated, emphasizing that all these data must be based on real values measured in a single phase electrical system. The computation of the data is observed in the following lines of code.

```
for n=1:1:c1
fpd=m(n); % Desired power factor.
thetad=acos(fpd); % Desired angle.
Id=I*cos(theta)/cos(thetad); %Irms*cos(theta) by cos(desired theta).
Ic=I*sin(theta)-Id*sin(thetad); %capacitor current.
c(n)=Ic/(2*pi*f*v); %Capacitor.
End
```

Another feature of the tool is the visualization of the data in graphic form of a fair spectrum of power factor values, together with corresponding capacitance values, according to the required value of the power factor.

For the particular case of  $v=128.6$  volts,  $f=60$  Hz,  $I=14$ A and a  $pf=0.24$ ; however, Figure 1 shows a large number of values together with the capacitance value corresponding to the PF value, although the resulting graphs will always start from the measured PF value.

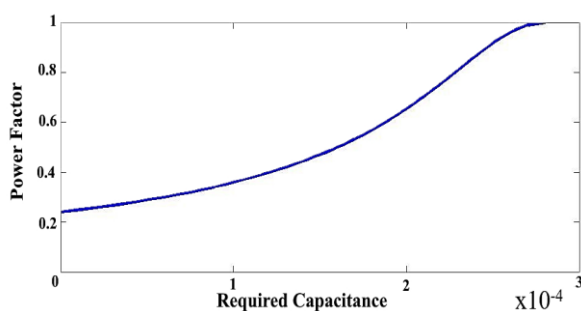


Figure 1 PF measured from 0.24 with capacitance

In order to verify the value of the PF at any of the points on the graph, a diagram was made in Simulink. The capacitance is related in vector form to the Matlab calculation; in the case of the example, it starts from 0.24 with increments of 0.01 to 1. This results in 77 different capacitance values, in which the value number 77 is the one corresponding to the result of a PF equal to 1. The corresponding diagram is shown in Figure 2.

### Diagram for graphical display of power factor variables

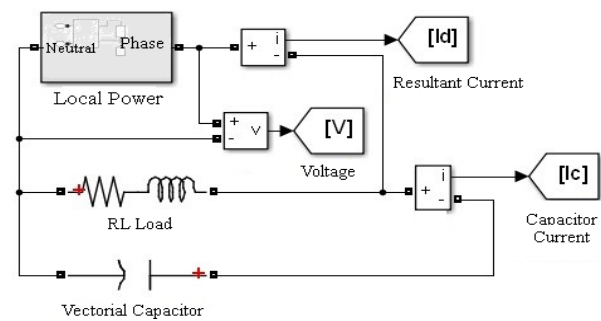


Figure 2 Diagram with vector capacitor

After a simulation of two seconds and placing the number 77 element in the vector capacitor, the result is the PF of the line shown in the green graph, as well as its comparison with the original PF which is observed in blue. These results are shown in figure 3.

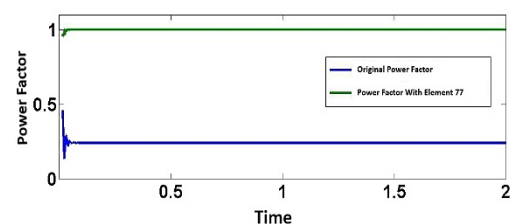


Figure 3 Power factor with element 77

The graphic result with the calculation of element 75 is exemplified in Figure 4, which is further from the ideal PF that is 1. It should also be noted that calculating an ideal PF could cause the power grid to come into resonance because in practice all the elements have both positive and negative tolerances.

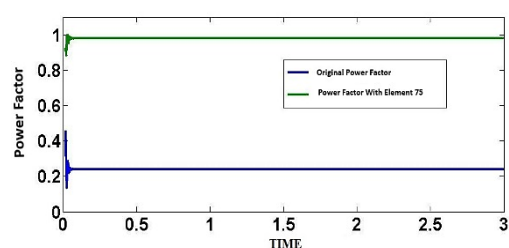


Figure 4 Power factor with element 75

Next, we present a program starting from a measured PF of 0.5, in which the vector will only contain 51 elements, the lines are represented in the following code and the compensation graph in figure 5.

```

clc
clear
v=128.6 ;%Measured voltage of the system.
f=60; %Line frequency.
I=14; %Measured rms current, without compensation.
fp=0.5; %System power factor.
    
```

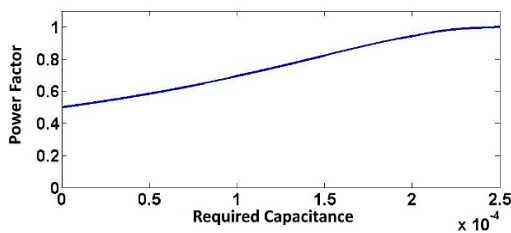


Figure 5 PF measured of 50 with capacitance

This tool also displays the phase shift between current and voltage; first with the power factor measured as shown in figure 6 and then with the PF in the desired element according to the initial values, for element 76 with initial PF of 0.24 is represented in figure 7.

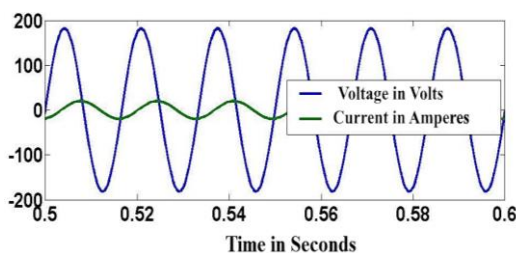


Figure 6 Phase shift with measured FP of 0.24

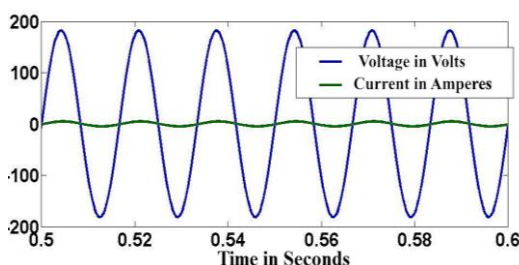


Figure 7 Phase shift with FP with element 76

Something that can be distinguished with this tool is the proximity to the resonance of the system; when the power factor is in the ideal zone or equal to 1, this happens with the vector capacitor in the value 77, as shown in figure 8. It should be mentioned that the measured current was increased up to 60 A for this.

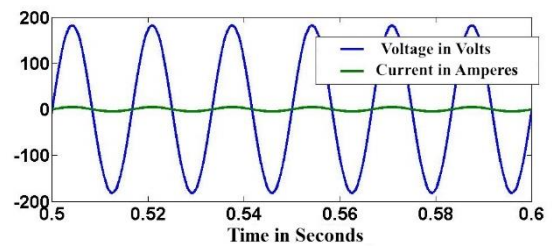


Figure 8 Phase shift with FP with element 77

Finally, another benefit of the tool is the clear understanding of the amount of the system current without compensating as distinguished in Figure 9 and its notable decrease when applying compensation with element 77 of the vector, in Figure 10.

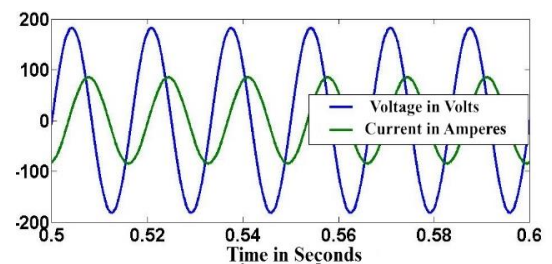


Figure 9 Phase shift with measured current of 60A and without compensation

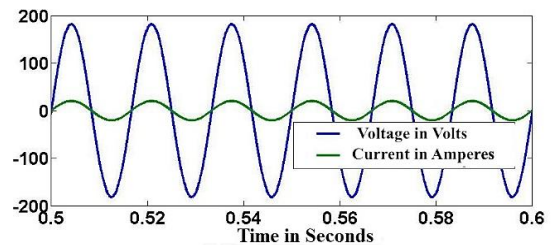


Figure 10 Phase shift with measured current of 60A and with compensation

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**Conclusions**

It is a tool that can help anyone understand the dynamic behavior of the PF according to the compensation that is desired in any single-phase electrical network.

Visualization of the current and voltage phase shift is rather simple depending on the power factor; in addition to giving the convenience to observe the voltage and current signals before and after compensation.

It can compare the original PF and the one that originates after placing the compensatory capacitance.

It is a tool that can be coupled or modified with great ease, according to the requirements of the power grid to be analyzed.

Finally, it is very simple to use, this is because it takes little time to acquire full knowledge of the tool.

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