IMPROVEMENTS AND GAINS ON THE POWER FACTOR CORRECTION IN LOW VOLTAGE

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Abstract. The correction factor of power became necessary for Brazilian industries due to the number of expenses applied in this area. Power consumption must occur efficiently, avoiding waste, because this is an element that triggers losses in the electrical system and an increase in electricity costs. This work aims to find generated earnings power factor correction in transformers and motors, depicting the differences in the consumption of apparent and reactive power, reducing heat losses in conductors and busbars, besides the improvement of automatic controllers power factor making the most efficient equipment.

Keywords: Power Factor Correction, automatic power factor controller, Joule losses.

1 INTRODUCTION

Currently, many devices need to generate reactive power so that they can perform their duties. Normally, the equipment that generates reactive power has Copper coils internally, such as transformers, electric motors, generators, among others.

The reactive power generated by asynchronous electric motors, transformers, etc. are of the inductive reactive power, generates an inductive reactive power factor, but synchronous motors and capacitors generate capacitive reactive power. In this case, these charges/equipment generates a capacitive reactive power factor.

In industrial plants, the predominance of loads that operate in the electrical system (motors, transformers, etc.) generates inductive reactive energy, as these devices originate electromagnetic field by having internal coils of copper. This electromagnetic field generates reactive power to maintain the exciting copper coils. In an asynchronous motor, the stator excited produces an electromagnetic field which assists the rotor core to perform a rotational movement, resulting in revolutions per minute, among other benefits.

According to the Ministry of Mines and Energy (2015) engines makeup about 68% of all electricity consumed by industry. Because the engines generate a considerable amount of reactive power, this phenomenon on a large scale, triggered considerable demand for reactive power by industries. So demand is largely reactive energy scale generates a low power factor.

Decree # 479 of March 20, 1992, states that all energy consumers should keep the power factor of your electrical system and its wiring as close to the value defined by the National Department of Water and Power (DNAEE). So began a new way of performing the billing electricity.

DNAEE made the following changes:

- The increased power factor of 0.85 to 0.92 inductive;
- It started surplus reactive energy billing;
- Filed performing the measurement of the power factor every time instead of performing measurement of an average monthly power factor;
- A new measurement and power factor limit from 6 am to 24, that it should be at least 0.92 inductive reactive. And from 24 till 6 am and received energy demand must be at least 0.92 capacitive reactive.

One of the solutions developed for the transformer power factor correction is the installation of fixed or automatic capacitor banks on the side of these, being a valid alternative with low installation complexity, affordability and generating significant gains for businesses.

However, performing a more efficient installation of this equipment in the electrical system, enhances the reduction in the consumption of electrical quantities, further increasing the ecological gains.

2 THEORETICAL FLAMEWORK

Power factor

According to Mamede (2010), the Power Factor can be defined as a ratio of the active power and the apparent power circuit (1) shows this.

$$Fp = P\ ativa \div P\ aparente \qquad (1)$$

FP = Power factor;

P ativa = Active circuit power which is represented by kW;

P aparente = Apparent power or full power to the circuit is represented by kVA;

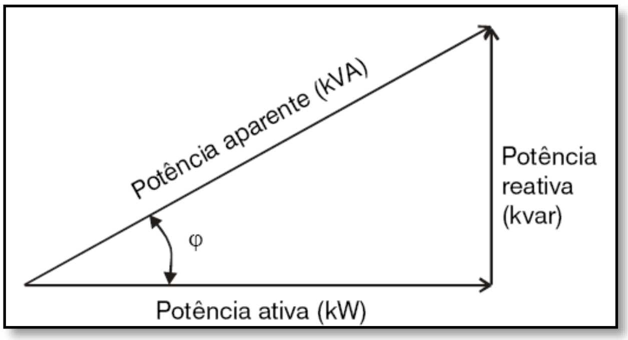
The power factor is the ratio between two components that have the same unit of measurement in this way does not have a unit of measure. The power factor can also be sized as the cosine of the angle between the active power and apparent power:

$$Fp = \cos\varphi \qquad (2)$$

This angle is formed by the fact that the active power is the work requested by the electrical system and so does not include losses in the existing electrical system. Already apparent power, equivalent power encompasses all existing losses in the electrical system."φ"

Figure 1 shows symbolically the powers of the triangle, which are representing the apparent, real and reactive power.

Figure 1 - Diagram of Powers.



Source: Collection of the author.

In an electric system that has non-linear loads such as frequency inverters, rectifiers, soft-starters, etc. need to conduct another assessment to determine the actual value of cos, ie:

$$Cos\varphi \ = \ Pat \div Pap \qquad (3)$$

Pat = Active power of the electric circuit, but taking into account the harmonic components of "n" orders.

Pap. = Apparent power of the circuit, but taking into account the harmonic components of "n" orders.

According to Mamede (2010), there are some factors that help gain knowledge on the electrical system or has no harmonic components, some of these factors are:

- Developing a calculation using (1) the installation to determine the power factor and the value obtained using the formula is different to what is being measured at that point in the installation, it means that it has harmonic components;
- Effect installation of the panels multimeters. For energy multimeters perform measurements of various electrical parameters in the system, some of these quantities are the harmonic components;
- Perform installation of equipment called a power analyzer. The same holds measurements of electrical quantities of the electrical system, but the measured values vary according to the location of the equipment in the electrical system, for example, in the panel input circuit breaker, secondary power transformers, motors, among others.

By the time a lot of loads that generate reactive power are installed in an electrical system, begins a large reactive power demand in the system, in this way, cables, transformers, etc. give way to the reactive power through this space but could be in use for the passage of active energy. So to solve this problem are installed capacitor banks near the loads. The capacitor bank has the goal to inject reactive power capacitive electrical system, decreasing the amount of inductive reactive power being generated by the electrical system (improves the power factor of the electrical system).

Causes of Low Power Factor

The main causes of a low power factor in an industrial electrical installation are:

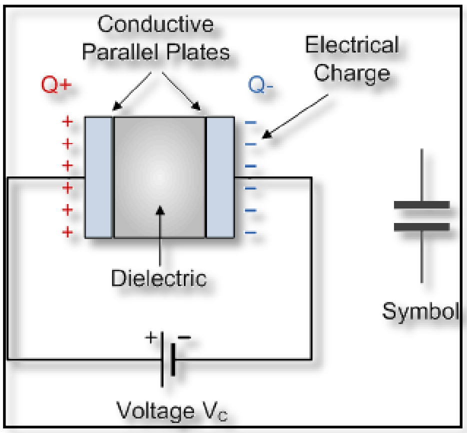
- According to Kosów (1982), transformers that are oversized or operating in a vacuum or with low demand, for power transformers have a certain power factor curve, that is, the transformer needs to realize the transformation of a certain amount of power so that it achieves optimum values for loss and power factor;
- According to the author, induction motors oversized because engines need to obtain a shipment of approximately 75% of its nominal power in achieving optimal values of losses and power factor;
- Engines that have low power, as they have a low yield value and power factor;
- Arc furnace;
- Welding machines;
- Electronic equipment;

General characteristics of capacitors

As Mamede (2010), the capacitor is a device designed to collect electricity. The same is basically constructed of two conductive plates installed one in front of another in parallel and between the plates is installed a dielectric. The dielectric can be paper, air, plastic, among others. In both conductive plates are connected to a power supply that has the function of generating an electrostatic field within which the dielectric is installed.

Figure 2 shows how the capacitors are constructed, that is, the position of the metal plates (conducting plates), and the dielectric voltage source ("E").

Figure 2 - Capacitor



Source: ElectronicsTutorials.

In the capacitor, the power supply starts an electrostatic flow between a metal plate and the other. With this, a load is generated from the electrostatic flow between the conductive plates.

The electric charge is measured in coulomb (symbol C) and is defined by the electric charge carried by 1 second with a current of 1 Ampere.

Applications for Capacitor

In industrial and commercial facilities capacitors are installed to perform the correction of the power factor because this usually has a lower value than required by legislation. The capacitor is also used in industries to perform voltage increase and reduction of circuit losses.

In an industrial plant, the capacitors are installed near the loads that need your power factor is corrected, such as transformers and asynchronous motors.

To perform the correction of the power factor in power transformers need to install a bank of the capacitor. However, for this to have a great performance, it needs to be provided with the following equipment:

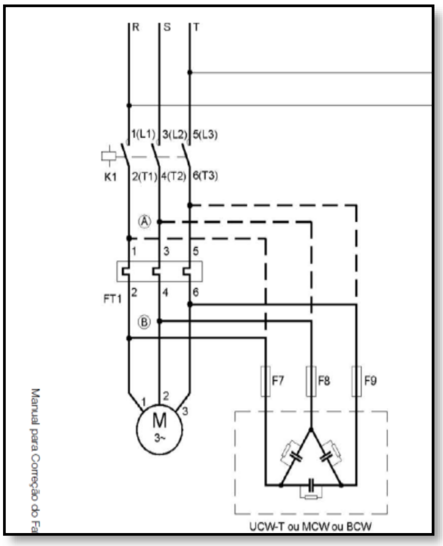
- Automatic power factor controller has the objective of carrying out a sweep of the capacitor bank to select which sets capacitor must be connected as the active power demand of the transformer. Automatic power factor controller checks the reactive power or the capacitance of each capacitor and carries out the maneuver of the same on demand. This equipment is widely used for capacitors are connected as the need for reactive power demand of the electrical system, because if there is a reactive power excess the power utility carries out the collection of this excess;
- The circuit breaker has the objective to realize the protection of drivers and capacitor short circuit and overcurrent. For the circuit breaker perform these protections, it must be installed in series with the capacitor;
- Contactor for capacitor maneuver is responsible for performing the maneuver/sectioning of the capacitors, it must be installed in series with the capacitor. Contactors also perform protection against surge current of the capacitors, as they are provided with preload resistors to perform is protection;
- The anti-surge inductor has the function of performing the protection of the capacitors against surge currents. For the same conduct is protection, it must be installed in series with the capacitor;
- The dessintonazided filter has the function to carry out the protection of the capacitor against the harmonic current circuit. If 20% of the charges the capacitors made the correction of the power factor is the non-linear type (frequency inverter, UPS, switching power supplies, welding machines, DC drives, etc.) must be performed at the installation of filters dessintonazided. For the filter does not allow resonance to occur in series or parallel between the capacitor and the transformer;
- The resonance in series between the capacitor and the transformer is very dangerous, because it carries out the reduction of circuit impedance, thus increasing the short-circuit current system.

To perform the correction of the power factor located in engines, you need to install a capacitor bank next to them. To implement this adaptation, one needs to perform the installation of the following equipment:

- The circuit breaker has the purpose of making the protection of conductors, capacitors, and motor against short circuit and overcurrent. In this type of application, you need to pay attention to the nominal current of the circuit, as with the improvement of the motor power factor ends up circulating less current in the system. Therefore, to achieve adequate protection carried out a finer calculation for circuit breaker sizing, or carried out a search in catalogs and manuals capacitor manufacturers, as they usually indicate which circuit breakers to be installed, according to the application;
- The contractor in this type of application has the purpose of carrying out maneuvers both on the engine and the capacitor at the same time. This contactor also need to get preload resistors to perform the same protection against surge currents;
- The thermal relay has the function of performing motor protection against overcurrent. When is the use of the thermal relay, but there is a capacitor installed close to the engine, you need to pay attention in relation to the rated current of the system for the design of the relay as the capacitor performs the correction of the power factor, thus reducing the amount of current is passing through it;
- Fuse makes the protection of the capacitors, motors, and conductors against short circuit current;
- The conductor will perform the power transmission needs to be dimensioned to withstand the motor and the capacitor.

Figure 3 shows one of the methods used to correct the engine power factor, installation of capacitors next to them. Furthermore, the picture shows the difference from the capacitor installation position (dashed line and continues) which influences the dimensioning of the thermal relay.

Figure 3 - Power Factor Correction engines.



Source: Manual for Power Factor Correction - WEG Automation.

Location of Capacitor Banks

According to WEG Automation (2015), the position in the electrical system for the installation of a capacitor bank is an important factor, since the installation of the same in the correct system location enhances the savings and adds advantages over the power flow system.

To perform the correction of the power factor of a step-down power transformer (HV / LV), carried out the installation of a capacitor bank at low voltage in the secondary of the transformer. Typically, the capacitor bank is installed as if it were the last load of the General Framework for Low Voltage (QGBT) of the transformer because, in this way, it generates improvements in relation to the electrical system of power flow.

The location of the capacitor bank in the electrical system varies depending on the need for power factor correction, such as the capacitor bank can be installed on the bar of a Motor Control Center (MCC), for the same conduct correction power factor in a larger electrical system, thus generating further improvements and gains in the electrical system.

To perform the correction of the power factor in some specific load, such as an asynchronous motor, you need to pay attention to the following criteria:

- The power capacitor should be determined from 20 to 30% of the rated power of an IV pole motor;
- If the capacitor switching key is different from the motor maneuvering key, you must first turn off the capacitor and after that switch off the engine;
- If the capacitor and switching the engine key is the same as Figure 3, the motor becomes a generator excited by the capacitor. Therefore, by turning off the engine/capacitor and its rotor keeps spinning for some time, because

of the inertia of the motor and the load on its axis, it generates a residual voltage in the electrical system during a given period;
- The conductor connecting the capacitor terminals at the motor section must not get lower than the third conductor that carries the motor connection.

Power Factor Correction

The correction of the power factor has become very important in the industry because it was highlighted generating many gains, such as reduction of Joule losses of the electric system, the release of power transformers, reducing electrical system voltage drop, etc. Currently, there are strict laws regarding the value and billing power factor, if these are not met, it ends up generating excessive fines and / unnecessary costs for industry.

To perform the installation of equipment that performs power factor correction (capacitors and capacitor bank) is necessary to evaluate the loads that require its power factor is corrected because if 20% of these charges are non-linear type, consider It is known that there will be harmonic components in the electrical system. However, if the amount of non-linear loads is less than 20% of the total installed loads, it is recommended to consider the correction of the power factor of only linear loads.

Power Factor Correction in Linear Loads

The correction of the power factor in linear loads obtained a wide application in the industrial electrical system. However, to minimize the amount of capacitive reactive power to be used to correct the power factor should be made the following changes:

- Keeping engine operating at full load and disconnect motors that operate at or empty load factor less than 75%, for engines that operate to empty or low load factor their performance and cos φ decrease, thus increasing the amount of power consumption and losses in the motor;
- Develop energy efficiency plans in the company so that loads are turned off in periods that they are no longer useful, for example, shut down transformers on weekends, turn off lights and unnecessary fixtures, develop a better central air-conditioning operation, among others;
- Resize and replace pumps, fans, etc. oversized and have low efficiency.

When these measures are carried out, there is an improvement in the system power factor and reduction in active power consumption, thus reducing the amount of capacitive reactive power required to perform power factor correction.

Bank Fixed Capacitors

Fixed capacitor banks are used in industrial and commercial buildings. This type of correction should be used only in loads that get a fixed reactive power demand or low range, such as an industry does not produce on the weekends, but its power transformer is still connected during this period. In this way, the transformer ends up generating a certain amount of reactive power, thereby decreasing the power factor of the installation on the weekend. To solve this problem, you need to perform the installation of a fixed capacitor bank to correct the power factor of this transformer weekend.

Scaling Bank Fixed Capacitors

As Mamede (2010), to scale a bank fixed capacitor performs the resolution of the triangle of powers. But, using equation (3) to determine the reactive power required to perform power factor correction.

$Q = P * ((tan(arccos\ FP1)) - (tan(arccos\ FP2))$ (3)

Q = Reactive power required to perform power factor correction [VAr];

P = Active power [W];

FP1 = Current power factor;

FP2 = Desired power factor.

Example: A dry to 1000kVA transformer, has a demand of about 570kW and a power factor of 0.80. The reactive power required to perform power factor correction is:

Transformer data:

The primary voltage 3,45kV =;

Secondary voltage = 380V;

Rated Current = Primary 167,34A

Rated Current = Secondary 1519,34A

Impedance Percentage% = 5.89.

Power factor = 0.96 Desire

Q = 570 000 * ((tan (0.80 arccos)) - (tan (0.96 arccos))) = 261,25kVAr

Therefore, to install exemplified capacitor bank is convenient to consider a capacitor bank with a total power of 350kVAr, because if realize the capacitor bank installation with this power will be possible to perform the correction of 80% of the rated power of the transformer (about 800kVA). Recalling that it is appropriate to maintain the transformer loaded with up to 80% of its rated power because in this way the transformer reaches a good amount of your income and increases its useful life.

Example:

Q = 800 000 * ((tan (0.80 arcs)) - (tan (0.96 arccos))) = 366,66kVAr.

Automatic Capacitor Bank

According to Mamede (2010), the method to scale an automatic capacitor bank is the same as a bank fixed capacitor. However, you need to evaluate some criteria, such as reactive power of the capacitor bank, reactive power of the installed capacitors, power demand variation, among others.

Normally, banks of automatic capacitors are installed in electrical systems that have a wide range of active power and require an adjustment/power factor control.

Power Factor Correction for nonlinear loads

To correct the power factor of non-linear loads must be taken into consideration that there are harmonic components in the electrical system. Thus, this may end up generating the following problems:

- Increased percentage of errors on energy meters;
- Increased Joule losses in cables and busbars;
- Overloaded electrical motors;
- capacitors burning in the electrical system;

- Generates resonance (frequency) series and parallel;
- Performance protection devices such as circuit breakers, protection relays, among others.

This occurs by the fact that harmonic components generate overcurrent and variations in the electrical system voltage.

Automatic Power Factor Controller

According to Schneider Electric (2003), automatic power factor controller has the aim to control and reduce any reactive power parts of the electrical system (controlling the amount of reactive power from the active power demand of the system). Therefore, it eliminates the possibility of charging reactive power spare conducted by power utility and helps in automating the power factor correction system.

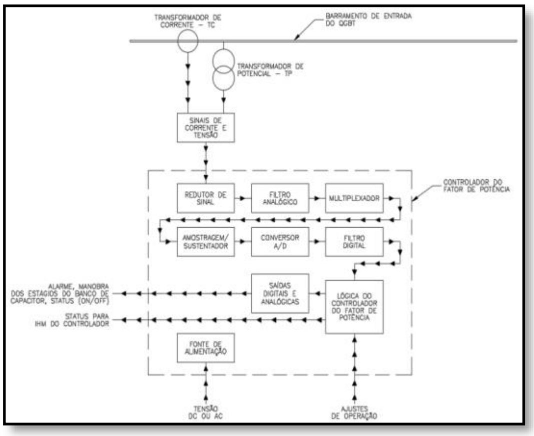
To perform the power factor control of the controller uses signal processing techniques. The same can be programmed with the buttons on the front of the machine and with the aid of a liquid crystal display can read measurements and controller parameters. Information can also be sent through serial communication.

Generally, the automatic controller of the power factor works from a number of logical blocks. Figure 4 shows this block diagram but in a summarized manner.

Below is a description of the function of each block composing the automatic controller of the power factor:

- Voltage and current signals show the analog signals input current and voltage, using current transformers and voltage transformers.
- Reducing signal performs an adjustment in the signals entering the automatic power factor controller. The same accomplishes this with the help of auxiliary transformers.
- The Analog Filter filters out unwanted signals to the controller, for example, high-frequency signals.
- multiplexer performs multiplication of the input signals.
- Sampling / Sustainer Samples and preparing input signals for conversion from analog to digital signals.
- The Digital Filter extracts the signal of the fundamental quantities so that it can be transmitted to the next block.
- Automatic Controller Logic Power Factor performs controller operating logic. It is logic varies by the manufacturer of the equipment and also according to the user's schedule. For example, some algorithms are based on functions of approaches, Discrete Fourier Transform, among others.
- The Digital Outputs and Analog help the controller carry out the maneuver in the capacitor bank stages and send the same status of the capacitor bank (alarms, quantities measurements, controls, etc.).
- HMI realizes the man-machine interface and aids in the settings made by the user in the automatic power factor controller.
- Power supply necessary for the operation of the controller.

Figure 4 - Automatic Controller Block Diagram of Power Factor.



Source: Collection of the author.

The power factor controller performs voltage measurements (RMS), current (RMS), apparent power, reactive, active, frequency, THD (total harmony distortion) and odd harmonics up to the eleventh order. The current measurements and electrical system voltage are carried through and current transformers or voltage transformers.

It uses user programming criteria to perform power factor correction. The capacitor steps are triggered by dry driver contacts, but without pre actuation time given and the number of stages in operation depends on the user-made programming.

According to the author, the drivers can enter the capacitor bank stages in the sinusoidal passage at zero voltage and current. For so it generates a small amount of noise in the electrical system.

Controller programming Input Stages

As Schneider Electric (2003), the automatic controller of the power factor has an internal algorithm which performs calculations to reach the value desired, while retaining certain criteria necessary for the electrical system, ie to keep the inductive and less capacitive system. This algorithm determines the input and/or output capacitor bank stages.

Most controllers use a linear program or normal for the input/output stages. The linear parameter uses the criterion that the first stage connected will be the last to be disconnected and vice versa. In addition, the normal or linear parameter prioritizes the entry of stages that have the lowest reactive power to perform power factor correction. Figure 5 shows how the input stages are performed by the controller.

Figure 5 - Stages input sequence.

Chamada do escalão	Nº do escalão					
	1	2	3	4	5	6
+	X					
+	X	X				
+	X	X	X			
+	X	X	X	X		
+	X	X	X	X	X	
+	X	X	X	X	X	X
-	X	X	X	X	X	
-	X	X	X	X		
-	X	X	X			
-	X	X				
+	X	X	X			
+	X	X	X	X		
+	X	X	X	X	X	
-	X	X	X	X		
-	X	X	X			
-	X	X				
-	X					

Source: Installation Manual Varlogic NR12 - Schneider Electric.

However, the controller has a parameter called optimized method parameter.

As Schneider Electric (2003), the optimal parameter of the automatic controller power factor performs the input stages, like normal or linear parameterization, but the function of this parameter is to reach the value desired with the shortest time possible and with the smaller number of linked stages. Cosφ

The same also uses more power stages to achieve the value of the desired cos, thus, reduces the response time, especially on systems that have large power factor correction of errors and, as well as when the electrical system becomes capacitive.

Economic sizing conductors/losses in conductors

According to Hilton Moreno (2010), drivers and copper or aluminum buses have the aim of carrying the power of the best technical and environmental way possible, since the power supply to the point of use. However, both the driver and the bus have certain inductive reactance and resistance due to copper or aluminum are manufactured. Therefore, to carry power, as both the bus conductor, joule losses obtained, consuming part of the power being transmitted.

During the lifetime of an electrical conductor the most significant CO_2 emission occurs in the transmission of electric energy, since, in the manufacture of electrical conductors occurs CO_2 emissions, however, it is not very significant in relation to the emission generated in transport electricity. The CO_2 emissions from the electric power transmission are due to the fact that the extra electricity generation to compensate for the Joule losses that occur in transport.

The power consumed by the driver or bus adds the real value consumed by the loads, thus this power consumed by the driver or bus needs to be generated and contributes to the value of electricity costs.

So, when we perform power factor correction diminish the demand for active power and apparent power system. Thus, this makes it possible to observe reduction compared to the Joule losses occurring in power transmission in the electrical system. However, it should be noted this type of gain/improvement in an electrical system having a constant electricity demand.

According to Hilton Moreno (2010), to demonstrate the Joule losses occurring in an electrical system, apply (4).

$E = R * I^2max$ (4)
E = Energy dissipated in the conductor [Wh]
R = Electrical conductor resistance [ohm]
I^2max = Maximum current consumed squared [A]

According to the author, to determine the reduction of CO_2 emissions in power generation with the capacitor bank installation applies (5).

$Z1 = N [Np * Nc * I^2 * R * T * G * K1]$ (5)
Z1 = Annual amount of reducing CO_2 emissions [kg-CO_2]
np = Number of phase conductors per circuit;
nc = Number of circuits that take the same type and load value;
I = Consumed current [A];
L = Cable length [km];
R = Conductor resistance [Ohm / km];
T = Operating time per year [h / year];
K1= CO_2 emissions per kWh when the generated power generation [kg-CO_2 / kWh]. In Brazil, according to 2006 data, K1 = 0.081 kg-CO_2 / kWh.

3 RESULTS AND DISCUSSIONS

The results were obtained from studies conducted in the field using a power analyzer for measuring electrical parameters the values of the electrical system. These results are directly linked to the values measured before and after the power factor correction.

Operating test - Power Factor Controller

This operational testing aims to test and verify the actual operation of the parameterization methods, thus carried out a test to observe the behavior of the automatic power factor controller, Varlogic NR12 model, installed in one of the capacitor banks of Ajinomoto's Brazil - Unit Limeira / SP.

The test consists in carrying out the reading of the electrical system power factor, using an energy analyzer at the time that the bank effectively capacitor input stages, applying both parameterization methods, in order to measure the time entry of stages to confirm the effectiveness of the optimized parameter, because according to Schneider Electric (2003), it uses an algorithm that performs more efficiently scan the need for power factor correction.

Figure 6 shows how the readings are performed using a system of electric energy analyzer.

Figure 6 - Energy Analyzer.

Source: Ajinomoto in Brazil - Unit Limeira / SP.

Table 1 shows the entry of capacitor bank stage, however applying the straight-line method in the parameterization of the automatic power factor controller.

Table 2 expresses the entry time of each capacitor bank step but using the optimized method in the parameterization of the power factor controller.

Traffic 1 - Entry Delay of each stage of the Bank of Capacitor - Parameter in Linear Method.

Method Parameter linear		
DATE	**Time [min: sec, msec]**	**Power factor**
01/12/2016	41: 30.9	0842
01/12/2016	41: 39.8	0859
01/12/2016	41: 51.3	0894
01/12/2016	42: 03.9	0913
01/12/2016	42: 17.7	0935
01/12/2016	42: 32.7	0954
01/12/2016	42: 48.9	0973
Mean Time Input Stages [min: sec, msec]		00: 13.8

Source: Collection of the author.

Table 2 - Input time of each stage of the Bank of Capacitor - parameterization in Best Method.

Parameterization with Optimized Method		
Date	**Time [min: sec, msec]**	**Power factor**
01/12/2016	33: 48.0	0.84
01/12/2016	33: 59.8	0.87
01/12/2016	34: 11.7	0891
01/12/2016	34: 23.8	0913
01/12/2016	34: 35.7	0.93
01/12/2016	34: 47.7	0952
01/12/2016	34: 59.8	0971
Mean Time Input Stages [min: sec, msec]		00: 12.0

Source: Collection of the author.

With the analysis of the tables, I concluded that the optimized method is 4 seconds faster than the straight-line method, ie, the stage input capacitor bank, the optimized method performs the entry of stages 0.571 seconds faster than the method linear. Therefore, the test was carried out in an electrical system with low variation in active power demand, but if the electrical system has a wide variation in active power demand is advisable to carry out parameterization of the power factor controller in the optimized method, as this conduct a scan faster and more efficiently if you need the input or output capacitor bank stages. Additionally, it assists in the development of finer control over the reactive power consumption of the system.

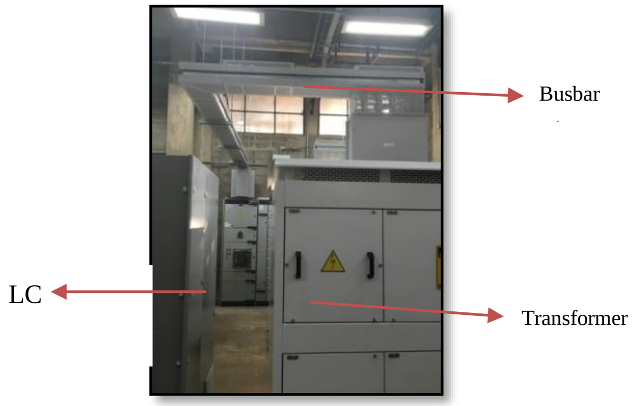
Operating test - Power Factor Correction

This operational test has the purpose test and proves the gains earned on active and apparent power consumption with the correction of the electrical system power factor, through readings using an energy analyzer.

The test consists of performing a reading of the electrical system of a Load Center (LC) that is powered by a 1000kVA transformer, dry, three-phase, installed in Ajinomoto in Brazil - Unit Limeira / SP. With the measurement, it was found that it has an average demand of approximately 540kWh and a power factor of 0.82. The power transformer for LC occurs through an armored bus that connects the low bus voltage transformer with the input of LC, as shown in Figure 7. The correction of the power factor is affected via an automatic capacitor bank installed in an LC of outputs.

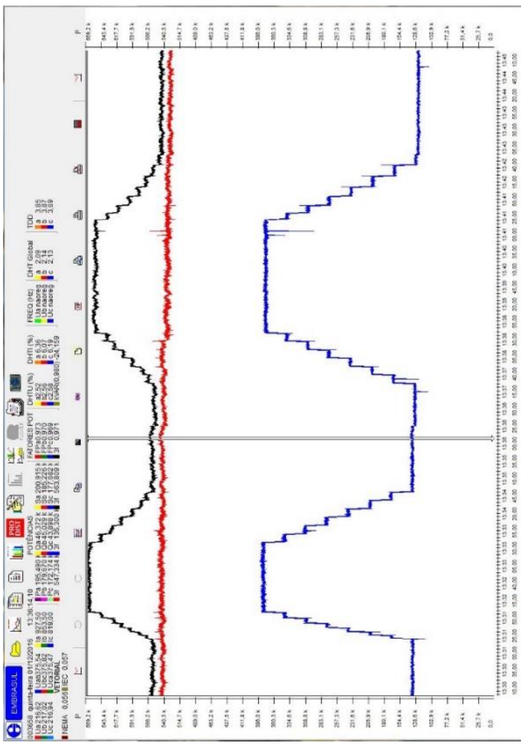
Figure 7 illustrates a shielded low-voltage bus interconnecting LC with the transformer.

Figure 7 - Armored Bus Low Voltage.



Source: Ajinomoto in Brazil - Unit Limeira / SP.

Figure 8 - Leitura do Quadro Geral de Baixa Tensão com Analisador de Energia.



Source: Ajinomoto do Brasil – Unidade Limeira/SP

Figure 3 shows the differences between the electrical parameters (apparent power, active and reactive) before and after correction. Due to the fact that it is an extracted reading of the electrical system with the aid of an energy analyzer.

Developed calculations and data extracted from the reading of the energy analyzer show the results of the gains before and after the power factor correction.

Data:

- Bus length: 10 meters;
- Model: KLF-28 - Schneider Electric;
- Material: Aluminum;
- Bus Current Nominal: 2500A;
- average resistance per conductor: 0.027 mΩ / m;
- Voltage Transformer Secondary: 380V;
- active power demand: 540kW / h;
- power factor before correction: 0.82;
- power factor after correction: 0.97;

Formulas used in the calculations:

$E = R * I^2 max$ (4)

$Z1 = N [Np * Nc * I^2 * R * T * G * K1]$ (5)

*Nominal current [A] = P [W] / (Voltage [V] Power Factor * * 3)*√(6)

*Apparent power [VA] = Rated Current [A] Voltage * [V] * 3*√(7)

Reactive Power [var] = (apparent power [VA] ^{2} *- Active Power [W]* ^{2}*)* √(8)

Tables 3 and 4 and Figures 1 and 2 show the changes in the values of the electrical, briefly, before and after the power factor correction.

Table 5 presents the summarized data from the reading of the power analyzer so that we can prove the real differences that occurred in the electrical system.

Table 3 - Values of Quantities Power Before the Power Factor Correction.

Before the values of Power Factor Correction	
Active Power [kW]	540.00
Reactive Power [kVAr]	390.94
Apparent power [kVA]	666.66
Current [A]	1012.89
Power factor	0.82
Power Dissipation by bus [kW]	0.831
CO2 emission [kgCO2 / Year]	0.453

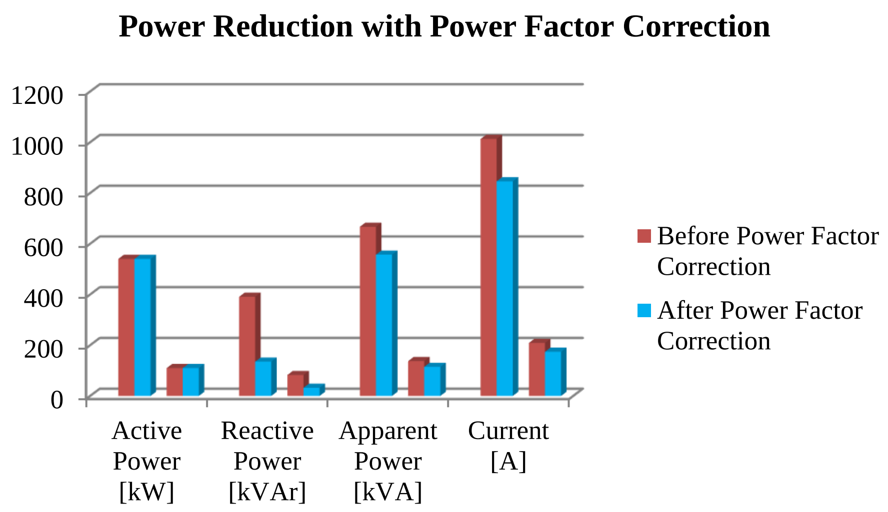
Source: Collection of the author.

Table 4 - Values of Electrical Quantities after Power Factor Correction.

Values After Power Factor Correction	
Active Power [kW]	540.00
Reactive Power [kVAr]	135.33
Apparent power [kVA]	556.70
Current [A]	845.82
Power factor	0.97
Power Dissipation by bus [kW]	0.579
CO2 emissions [kg-CO2 / year]	0.157

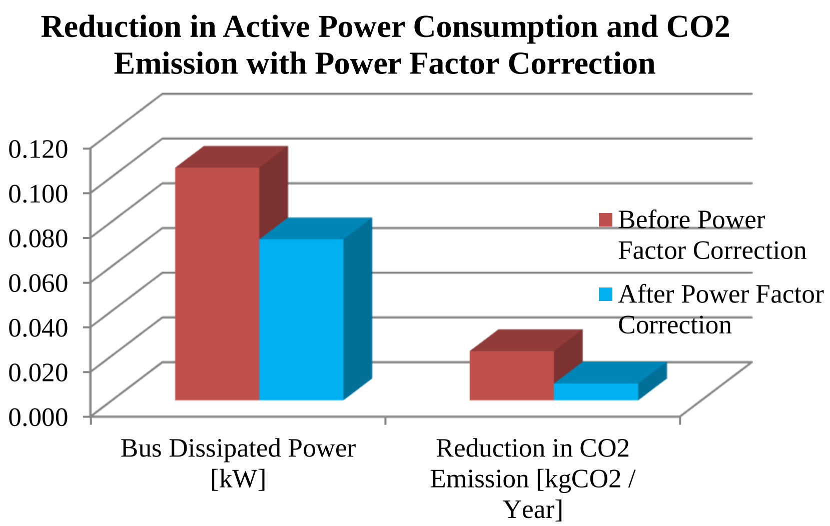
Source: Collection of the author.

Figure 9 - Power Consumption Reduction with Power Factor Correction.



Source: Collection of the author.

Chart 10 - Reduction of Active Power Consumption and CO2 emissions with Power Factor Correction.



Source: Collection of the author.

Table 5 - Energy Analyzer Data Before and After Power Factor Correction.

Time [min: sec, msec]	**Active Power [kW]**	**Reac-tive Power [kVAr]**	**Appar-ent power [kVA]**	**Power factor**
32: 21.9	540.434	376.942	658.904	0.82
30: 22.0	540.033	134.370	556.499	0.97

Source: Collection of the author.

Example 2 (suggestive): A Motor Control Center (MCC) is powered by its QGBT, has a demand of about 110 kW / h. So, what is the power dissipated by the drivers before and after the correction of the power factor?

Data:

- Conductor Length: 10 meters or 0.010 kilometers;
- Gauge Conductor: # 240mm²; (One (1) per phase conductor)
- Material: Copper;
- Resistance per phase at 35 ° C (ambient): 0,0801Ohm / km;
- Power Voltage Motor Control Center (MCC): 380V;
- active power demand: 110 kW / h;
- power factor before correction: 0.80;
- power factor after correction: 0.96;
- Electrical system: Three-phase + PE (earth);

Tables 6 and 7, and graphics 3:04 show the changes in the values of the electrical, briefly, before and after correction of the power factor in the CCM.

Table 6 - Values of Quantities Power Before the Power Factor Correction in CCM.

Before the values of Power Factor Correction	
Active Power [kW]	110.00
Reactive Power [kVAr]	82.5
Apparent power [kVA]	137.5
Current [A]	208.91
Power factor	0.80
Power Dissipation by bus [kW]	0.104
CO2 emission [kgCO2 / Year]	0.022

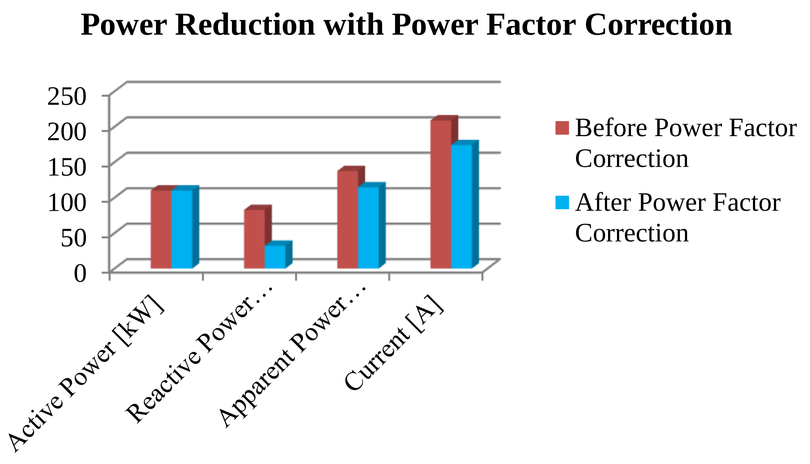
Source: Collection of the author.

Table 7 - Values of Electrical Quantities after the Power Factor Correction in CCM.

Values After Power Factor Correction	
Active Power [kW]	110.00
Reactive Power [kVAr]	32.07
Apparent power [kVA]	114.58
Current [A]	174.09
Power factor	0.96
Power Dissipation by bus [kW]	0.072
CO2 emissions [kg-CO2 / year]	0.0075

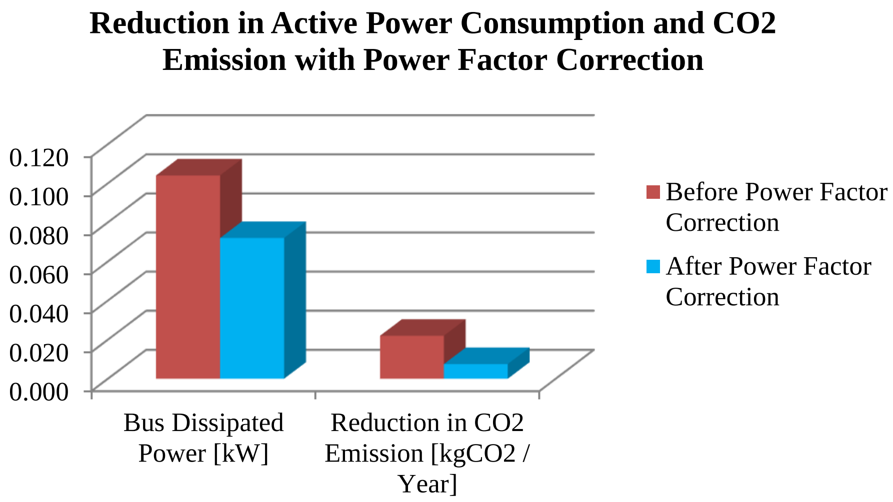
Source: Collection of the author.

Figure 11 - Power Consumption Reduction with Power Factor Correction.



Source: Collection of the author.

Graph 12 - Reduction of Active Power Consumption and CO2 emissions with Power Factor Correction.



Source: Author's Collection

4. CONCLUSION

Automation of power factor correction in electrical systems allows us to develop a more efficient and speedy correction. The use of an automatic controller to correct the power factor proves to be effective in electrical systems that have active power demand variation and for systems that require control in relation to the power factor. Thus preserving the value required by regulatory agencies and assisting in measuring/charging excess reactive power held by utilities.

The Power Factor Correction reduces the apparent power consumption of the electric system and thus helps reduce thermal losses in conductors and buses. Is reducing heat loss considerably reduces the active power consumption and thus reducing CO2 emissions that would occur to compensate for this extra active power consumption.

This project states that the correction of the power factor has become indispensable in electric power systems. Because become a valuable application to observe the difference from reduced consumption of electrical quantities, reducing CO2 emissions, reducing thermal losses and energy efficiency. In addition, the power factor correction interferes directly in the operating costs of companies.

5. REFERENCES

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