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A CASE STUDY ABOUT LOW–VOLTAGE POWER FACTOR CONTROLLER IN TEXTILE INDUSTRY

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Abstract: The paper presents a power quality analysis in a textile plant. A practical solution to improving the power factor was implemented, using a power factor controller equipped with capacitor banks, connected to the low–voltage power substation. Experiments were carried out to measure the power quality indices at various time moments, as well as monitoring them over a week. Experimental data revealed that the use of six capacitor banks with the same value is not a suitable method to adjust the reaction power in low–voltage systems. By using capacitor banks of different capacities in the power factor controller, a finer adjustment of the power factor is achieved.
Keywords: power factor; controller; capacitor banks; power quality analyzer

1. INTRODUCTION

In many industrial facilities, electric loads consume electrical energy from the network and convert it into other forms of energy (e.g. mechanics, light, heat). Single– or three–phase electric motors represent one of the most used loads in industry. Electric motors require inductive reaction energy, which is essential for their operation, but increases the total electrical energy of the electrical loads. Most industrial electric motors operate at variable speeds. Therefore, electric motors are no longer directly connected to the electrical network, but to electrical equipment (static frequency converters). The motor itself represents a linear load, because if the voltage applied to the motor has a sinusoidal waveform, the current through the motor will have an approximately sinusoidal waveform. But, the power electronics (static frequency converters) and motors connected to the network become non–linear loads (current and voltage waves sometimes differ more from sinusoidal forms). In the textile industry, there are nearly four decades of sewing machines connected to low–voltage networks via static frequency converters or variable–voltage regulators for variable–speed drives.

Energy factors (PFs) are important parameters in power engineering. A lower PF causes overheating and excessive voltage drop, which leads to power losses, thermal stress of the equipment, and finally to the decrease in their lifespan and reduction of system's capacity. For these reasons, it is necessary to increase PF above the neutral value (0.9 for low voltage). Artificial solutions to increase PF include connecting capacitor banks (CBs) to electrical loads, creating capacitance–reactive power (in contrast to inductive–reactive power), thereby reducing the total reactive power. The CBs can be connected to low–voltage (LV) or medium–voltage (MV) [1–4].

To improve the PF using CBs (for a single high–power motor or a group of motors), the nonlinear effect becomes important and current waveforms are less sinusoidal [5–7]. The distorted waveforms (current or voltage) can be decomposed into fundamental frequencies (50Hz) and harmonics (using fast Fourier transformation). To improve the power quality indices, passive, active, or hybrid filters can be used with CBs and power factor controllers (PFC) [5,8,9].

This paper presents a power quality analysis in a textile plant. To increase the power factor, a PFC in the low–voltage power substation were installed and experimental analysis are performed [10–12]. The PFC, the connection method, the data on the low–voltage power substation, and experimental measurements (voltage and current shapes and spectra, Fresnel diagram) at an initial

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moment of time and over a week (line voltage, line current and neutral current, powers, power factors) are presented further.

2. POWER FACTOR IMPROVEMENT IN INDUSTRY

Increased industrial PF can be achieved by natural means (e.g. selecting the right motor and transformer, reducing free time, repairing high–quality electrical equipment, adjusting the inductive motor with synchronous motor) and/or by artificial means (using synchronous compensation, static VAR compensation, PFC controlled CBs). CBs represent the common solution to increase PF in low–voltage power stations [4,6,9].

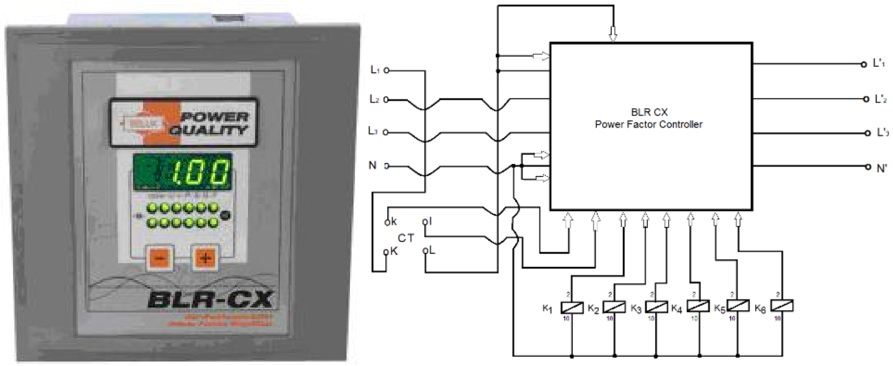
In sinusoidal regime, the reaction Qc of the CBs is determined based on the active power P of the consumers and the phase shift between voltage and current before (φ_1) and after (φ_2) the use of the CBs (φ_2 depends on the neutral value of PF), according to the relationship [4]:

$$Q_c = P \cdot (tg\varphi_1 - tg\varphi_2) \quad (1)$$

To increase PF in low–voltage power stations, the connection of CBs can be done manually or automatically (e.g. using PFCs). If the electrical cables of the plant are wide and the development of new electrical loads increases, it is recommended to improve the PF in one sector of the plant. In the design phase of electrical network, the required reaction energy can be determined in the same way as the apparent energy. The active and reactive power values of the network loads can be determined at each level. The best compensation capacity of existing power stations is determined based on the following main considerations [5]: the electricity bill before the installation of a PFC in a CB; the cost reduction when the PFC is installed; initial measurement value of the energy supply and the energy supply. When installing equipment to improve energy factors, the following costs should be taken into account: CBs and control equipment (PFCs, fuselage, contactors, cables, connectors, equipment boxes, etc.); installation of equipment and maintenance costs; thermal losses of CB dielectrics relative to thermal losses of cables, transformers, etc.

3. PFC AND CBs USED IN LV POWER SUBSTATION

In the analyzed textile plant was used the PFC BLR–CX Belux to control six CBs (Figure 1) [13,14]. This PFC measures only the current (L1) and voltage (L23) of one line. The PFC input current ranges are 10 mA to 5 A (current measurements are performed using CT current transformers, Figure 1), and the voltage ranges are 50 V to 530 V (Figure 2). This type of PFC can ensure automatic self–adjusting and connections to different sizes of capacitor banks (with six outputs) through electrical contacts. The CB is connected to the PFC by continuous rotation (uniform operation) and PFC operates simultaneously to connect and disconnect the CB. The PFC detects errors with an internal algorithm and chooses the best CB connection (if different capacitor values are used). The connection of the cables is done by means of mechanical clamps. The power factor value is displayed on the LED screen. Each connected CB is displayed by LEDs [11].

(a)


(b)

Figure 1. a. Belux BLR–CX power factor controller; b. principle diagram

Since in textile factories most electrical loads are single–phase (supplied between phase and neutral), it is difficult to achieve the phase balancing, as the RMS current values are different on the three phases. The PFC only needs a single–phase to measure the current (Figure 2). Current

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transformers (CT, Figure 1) are connected to the average load phase. The conversion ratio for CT was 150/5 (e.g. the line current was reduced 30 times to PFC input). The CB was connected to six contactors of the 230 V AC voltage coil [12]. The PFC–containing electrical equipment box (electric bars, fuselage, contactors, CBs) is shown in Figure 3.a and the CB in Figure 3.b. Dry CBs are used with gas, composed of two rolls of polypropylene paper that are automatically self–healing (in the case of dielectric collapse). Previous MKPg 275 CB used electronic devices with the following characteristics [9]: 20 kVAR, 400 V, 50 Hz, Delta connection, 3 x 137 μF, 3 x 29 A.

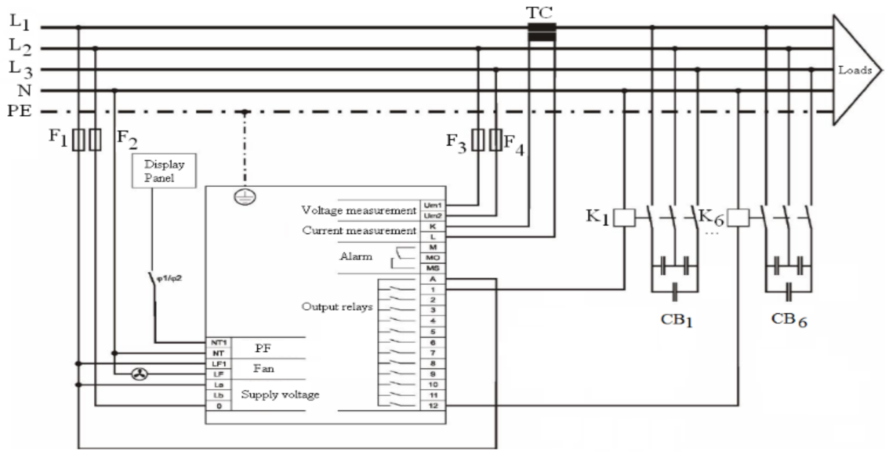

Figure 2. Usual connection diagram of the Belux BLR–CX power factor controller


(a) (b)
Figure 3. a. The electric box with PFC (on the front side); b. capacitors banks installed in PFC

For a three–phase CB delta connected, the capacitor is determined according the relationship [4]:

$$C_{\Delta} = \frac{P}{2 \cdot 3 \cdot \pi \cdot f \cdot U_l^2} \cdot \left(\frac{\sqrt{1 - \cos\varphi_1^{\,2}}}{\cos\varphi_1} - \frac{\sqrt{1 - \cos\varphi_2^{\,2}}}{\cos\varphi_2} \right) \tag{2}$$

where f represents the frequency (50 Hz) and U_l represents the line voltage. The capacitors are installed in an insulated box, with double insulation, thus eliminating the need for grounding. In order to discharge the capacitors, resistors are permanently connected inside the CBs.

4. EXPERIMENTS CONDUCTED IN TEXTILE PLANT

This section presents the experiments carried out in a textile plant. In order to improve the PF, the PFC was connected in the LV power substation of textile plant; power substation is compact air types, being mounted on supports outside the plant (Figure 4). The support is of type SC 15015 type, with a casting base. The power transformer has the following features: transformation ratio 6/0.4 kV, the active power 250 kVA, and the phase current In=360 A. The transformer's primary winding is supplied by an underground 6 kV transmission line (connected to a 110/6 kV high–voltage substation). The transformer is provided with zinc oxide arresters BMD 24 kV that ensure protection against overvoltages caused by lightning strikes, SFEN 6 kV, FEN 63 A medium–voltage fuse for the short–circuit protection, a distribution box CD 1.2 and a low–voltage circuit breaker USOL 630 A (with current overload of 320 A) [10–12].


Figure 4. Low–voltage power substation placed outside from textile plant

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There are more than 350 sewing machines in the textile plant, most of which are single–phase and run intermittently on a single shift. Although each sewing machine has low power (300–450 W), their number being large, they consume a lot of electricity. Other electrical consumers include elevators (up to 1000 kg capacity, 7 kW induction motors, 940 rpm, 240/400 V, 29.5/17.2 A), compressors (up to 10 bars, induction motors, 11 kW induction motors, 2870 rpm, 20.5 A, 400V), packaging machines (11.5 kVA, 15.5 A with two–stage heating tunnel, 90 W electric motors), and irons (0.5–2 kW). Electric lighting is supplied with low–pressure fluorescent mercury lamps and inductive ballasts (classical version). As many single–phase consumers operate intermittently, the three–phase electricity network is most often unbalanced. The plant staff work in one shift from morning to afternoon (6–15 hours), Monday to Friday (sometimes Saturday). All measurements were made with the CA 8334B [15] power quality analyser at the USOL 630 A LV station. The voltage measurement was performed using four conductors (three phases and a neutral phase). For phase current measurements, three current transducers (AmpFLEX, 3000A) are used which can be easily mounted on a substation pole [15–17].

Figures 5–7 show experimental measurements of certain electrical parameters at different times. In principle, the voltage harmonic spectrum does not change (the most significant harmonics are 5 and 7), but the current harmonic spectrum can change. The predominant current harmonics are 3, 5, 7, 11, 13 (Figure 5). Line currents can be balanced and deformed, and neutral current can reach 20 to 30% of the line currents (Figure 6.a). Consumers distributed in phases have an inductive character (Figure 6.b). Active and apparent powers can be compared during PFC operation.

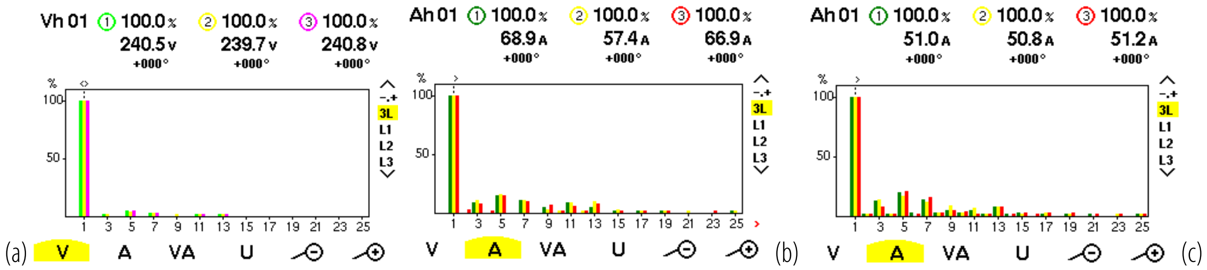

Figure 5. a. Spectrum of phase voltages; b.c. Spectra of line currents at different moment of time

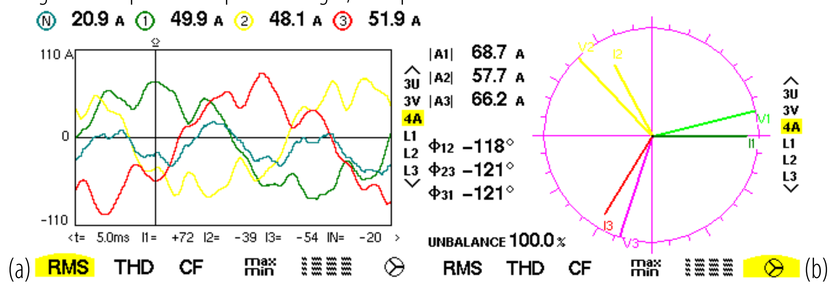

Figure 6. a. Line and neutral currents; b. Fresnel diagram for currents and voltages (fundamentals, 50 Hz)

Figure 7. Powers on three phases at one moment of time

In Figures 8–14 measurements were made over the course of a week (approx. 3/4 a day between Tuesday and Wednesday no recordings were made). The recordings were made with a period of 10 min (average values for 10 min represent a point). Days of the week were represented on the graphs. The company only works in shift 1. The line voltage (Figure 8) drops by 10–12 V when working and increases when there are fewer consumers (after dinner, evening, and night). The line currents (Figure 9) obviously have high values, from Monday to Friday, the phases are slightly unbalanced. During the weekend, the currents are reduced to 20–30%, and the neutral current becomes important during the weekend (especially on Sundays).

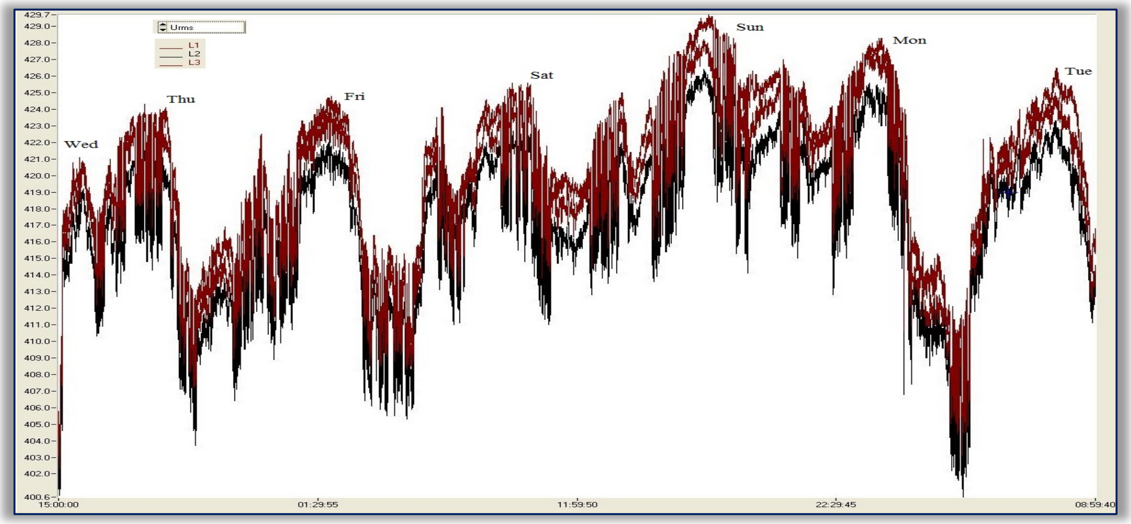

Figure 8. Line voltages (RMS) during one week

Active powers (Figure 10) are high during weekdays (20–25 kW per phase) with lower values on Saturday and Sunday (3–9 kW). Reactive powers have lower values (on weekdays 11–14 kVAR, on weekends 2.5–8.5 kVAR) compared to active powers (Figure 11). Sometimes, the reactive power is also negative because the capacitor banks on a certain stage remain connected (even if it is no longer necessary). The apparent power (Figure 12) has the same evolution (approx.) as the active power, with powers of 22–28 kVA during the week and values of 4–12 kVA at the weekend.

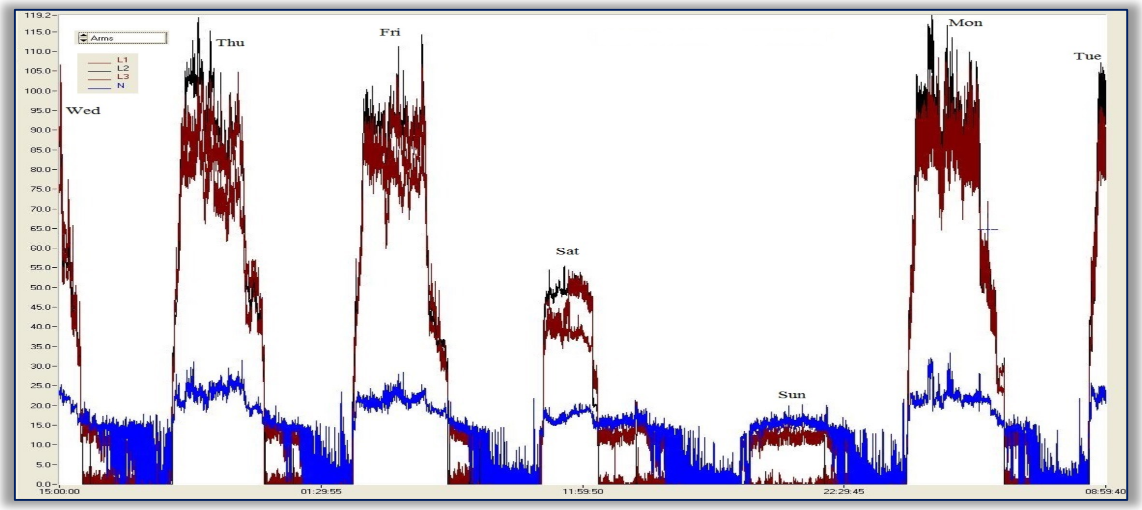

Figure 9. Line and neutral currents (RMS) during one week

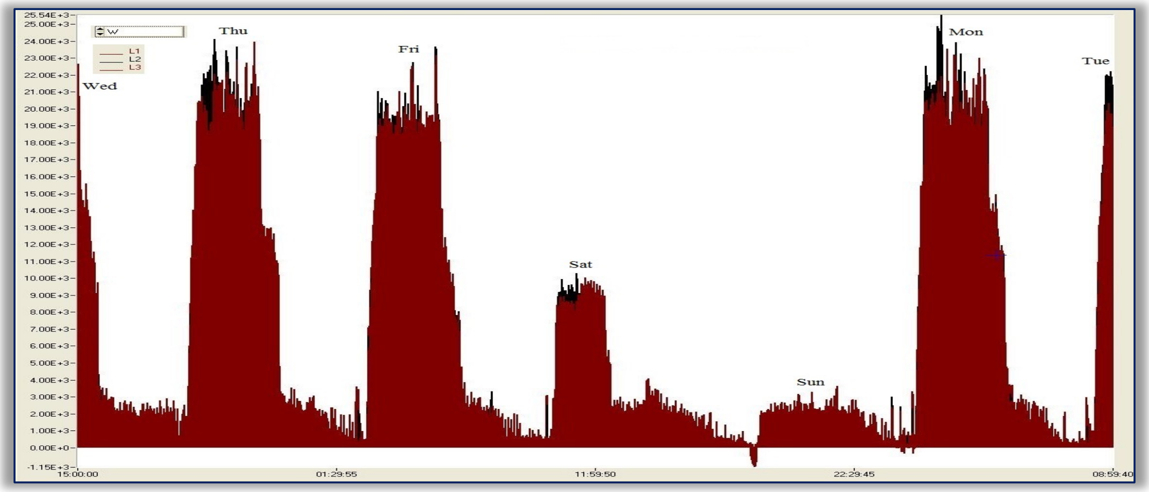

Figure 10. Active powers during one week

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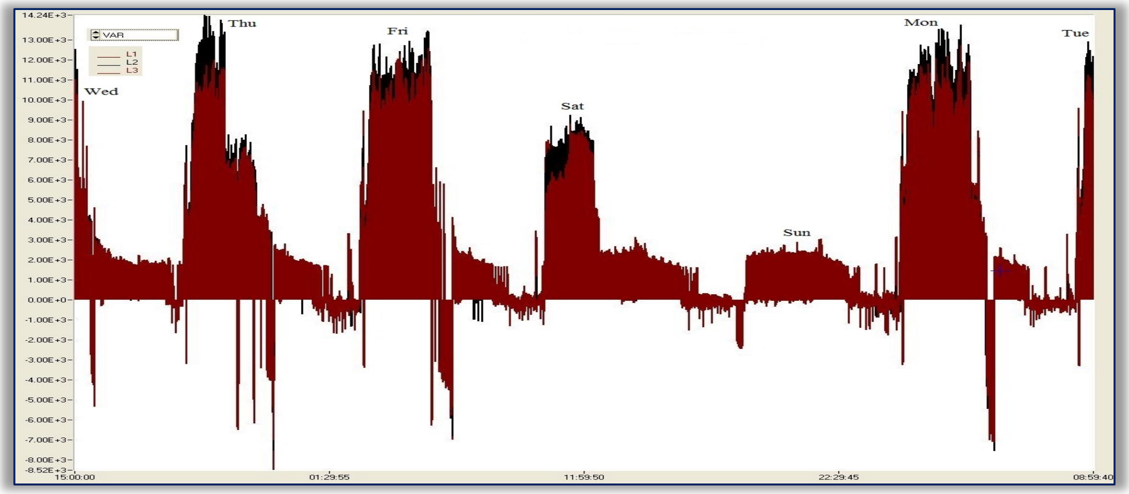

Figure 11. Reactive powers during one week

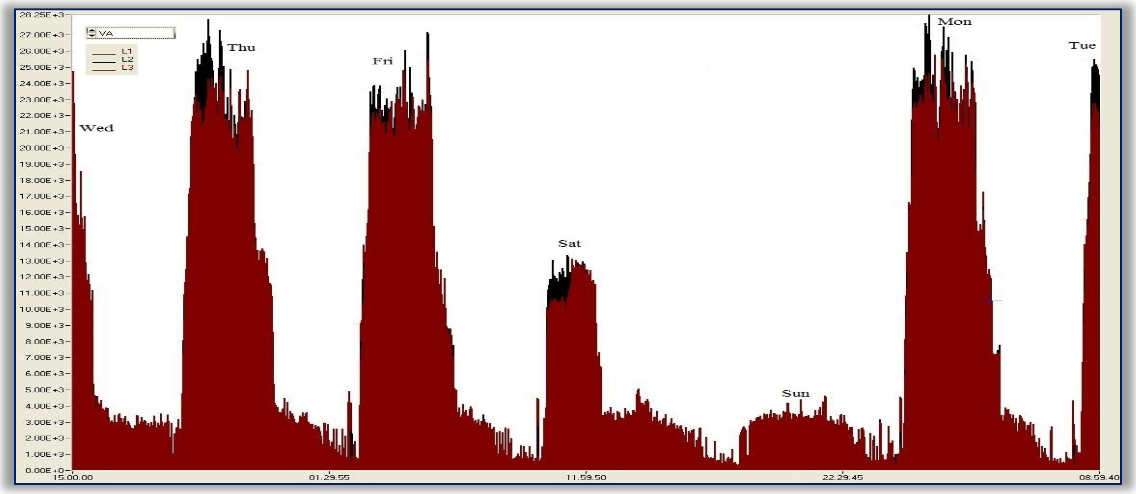

Figure 12. Apparent powers during one week

Since there are many single–phase consumers that start and stop constantly, all powers fluctuate. Power factor PF and displacement power factor DPF (Figures 13 and 14) have high values when working (greater than 0.92) and lower and fluctuating values when not working (0.7–0.8). During the Saturday, there was an intervention on the operation of the PFC, for this reason, there are negative values.

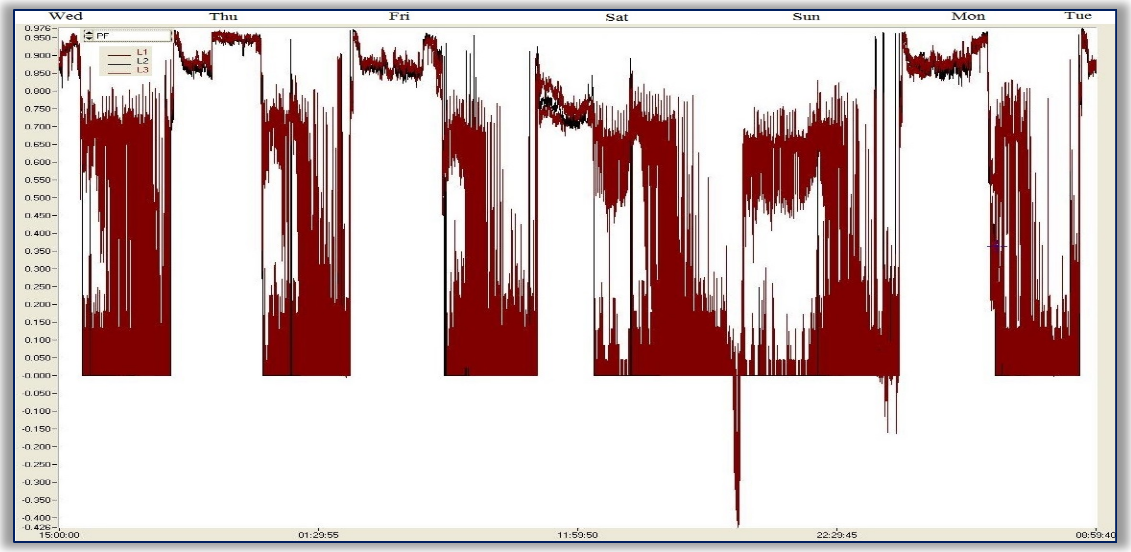

Figure 13. Power factors during one week

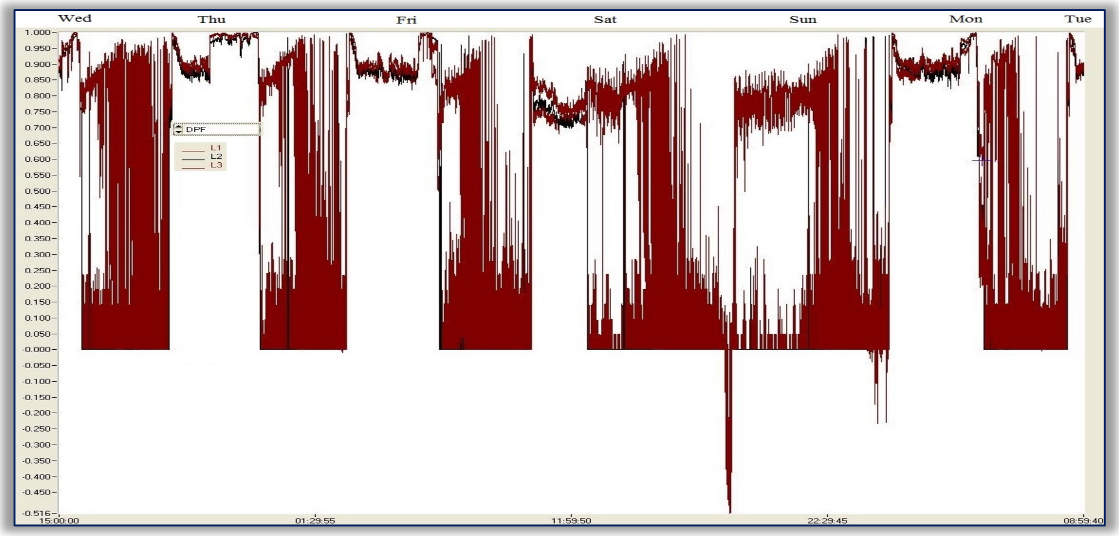

Figure 14. Displacement power factors during one week

Low PF are recorded during the afternoon and night, if the capacitor bank (large value) is not connected. However, this time the current is low. The reaction power is too high (20 kVAR per bank). Currently, the maximum reactive power that can be compensated is 35–40 kVAR. To correct the size of the six capacitor banks, only two (20 kVAR) of the six old ones were retained, the other four were replaced by two 10 kVAR capacitor banks (400 V, 3x68 μF, 3x15 A) and two 5 kVAR capacitor banks (400 V, 3x33 μF, 3x7.5 A) [4]. On the basis of the value of the identification function of the capacitor banks connected to the PFC, replacing the old capacitor bank allows for finer adjustment of the reaction power (and therefore PF) in LV power substation.

5. CONCLUSIONS

In textile plants, to improve and maintain PF above neutral value, can be connected CBs at LV power substations. Due to the large number of single–phase loads, it is necessary to redistribute the consumers on the three phases so as to obtain a balanced three–phase currents system. The correct size and selection of the CB value are solutions for the highest PF values. By replacing the large CB with a fixed value with different CB values, the PF is finer controlled. The connection and disconnection times of the capacitor bank must be changed until 20–30 s, and PFC will react as quickly as possible to the changes that occur in electrical network. CBs are connected to nonlinear consumers with deformed currents, with high harmonic content, which can cause resonances or even explosion of CBs. The analysis and application of CBs linked by coils connected to substation bars will lead to a solution that improves PF and reduces harmonic currents.

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