DEVELOPMENT OF A DIDACTIC MICROCONTROLLED THREE-PHASE EQUIPMENT FOR AUTOMATIC CORRECTION OF RMS VOLTAGE AND/OR POWER FACTOR

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***Abstract* - This work describes the microprocessor control system in closed loop that measures the module and angle of the phase voltage and line currents. It triggers groups of monophase capacitors with the objective of automatically correcting the rms voltage and/or the power factor of each phase of the low voltage power system within the limits established by the electric energy concessionaire or by the user. A didactic prototype of 5 KVAr has been built with serial communication and a program for MS-Windows. Practical results of the developed strategy for correction are presented with the goal of validating the proposed methodology and the developed logical algorithms.**

***Keywords* - capacitors, didactic equipment, rms voltage, microcontroller, power factor correction.**

I. INTRODUCTION

According to the DNAEE standard 1.569 of23 December 1993(starting from march/96), the minimum power factor demanded is 0.92, measured in agreement with the hourly average, imposing penalties for the users that are not in agreement with this norm. Besides the power factor [1-2], other aspect that should be taken into account in an electric power system is the quality of the voltage supplied to users [3-4]. The electric energy concessionaire adopts the range of ± 5% with respect to the nominal voltage as the acceptable variation of the voltage of the electric power system.

Taking into account the aspects mentioned above, a three-phase didactic prototype was developed that automatically connects groups of monophase capacitors in order to keep the rms voltage and/or the power factor of each phase of the power system into the limits of quality of energy specified by the electric energy concessionaire or for the user. The control system of this equipment should make possible a balanced distribution of the rate of use of the capacitors of each group. Its dynamic behavior should also be capable of accomplishing the corrections of the rms voltage and/or the power factor in real time (through microcontrollers).

II. DESCRIPTION OF THE DIDACTIC EQUIPMENT

The developed equipment, Figure 1, consists of a system of microprocessed control, sensors of current and voltage, human-machine interface (HMI), trigger circuits and power circuit. The voltage and current sensors are voltage transformer and current transformer, respectively. They provide signals for a circuit that contains analog filters (with the objective of removing the high frequency components). Those signals are transformed from the analog domain to discrete domain by analog-to-digital converter, multiplexing the inputs. The microcontroller (AduC841, of Analog Device @ 24MHz) calculates the values of magnitude and phase for each phase of the power system, using the Fourier transformer algorithm. With the calculated values, the microcontroller decides if it connects or disconnects the next capacitor of each group.

The control system keeps monitoring the power factor and the rms voltage for each cycle of the power system, and correcting it when necessary. This system admits a stabilization time in cycles of the power system, avoiding to put or push capacitors in transitory load (value adjusted by the user).

Furthermore, this system has serial communication, storage of data in no-volatile memory and a clock of real time, with own battery, to store the dates and times when the main events happen, with the objective of accomplishing a subsequent evaluation of the whole behavior of the system.

The command circuit of the capacitors is made with solid-state relays (SCRs), which trigger the capacitors in zero voltage. This procedure increases the lifetime of the SCRs and also of the capacitors, avoiding a high current in the starting. The turn-off of the capacitors is made in zero current, because SCR turns off naturally in zero current. Therefore the commutation in SCRs is ZVS in the starting and ZCS in the blocking.

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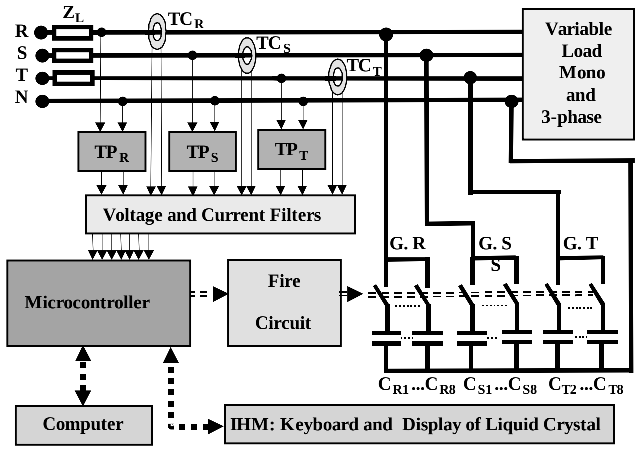

Fig. 1. Block Diagram of the system

Figure 2 shows a diagram relating the electronic circuits: control, human-machine interface (HMI) and sources. Figure 3 shows a layers diagram of the software acquisition and control of the analog-to-digital converter, plus the calculation of digital Fourier transform (DFT).

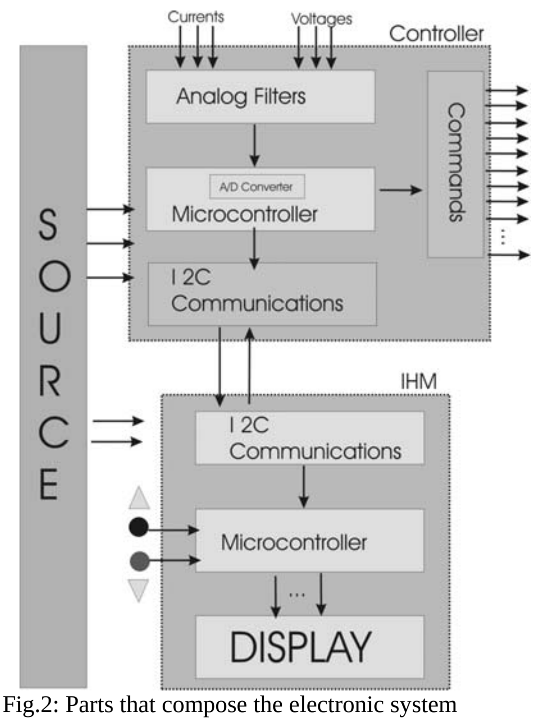

Fig.2: Parts that compose the electronic system

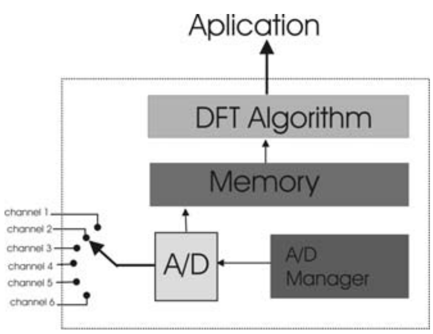

Fig. 3. Detection of magnitude and phases of current and voltage

The control block is responsible for the acquisitions and for commanding the capacitors of each group, besides sending the relevant information of the system for a display. For that we have used a bus I2C (serial) of high-speed of data transfer. In the interface block HMI the user can visualize two screens containing the information of voltage, current and power factor, and the states of the capacitors. The basic circuit of the signals filter (fourth order) with "antialiasing" functions is shown in Figure 4.

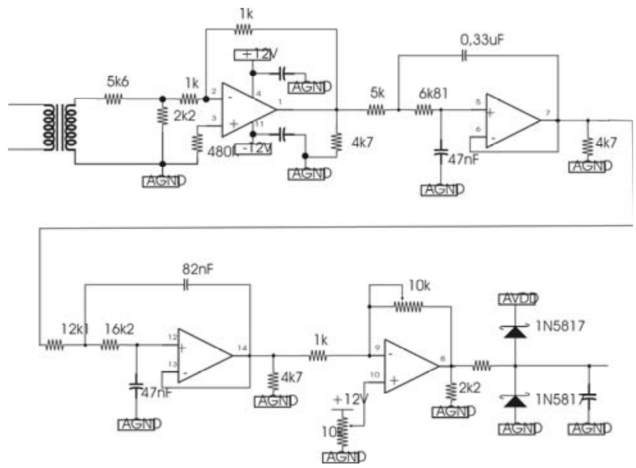

Fig. 4. Passive filter.

The control routine is simple. In the beginning the user is recommended to initialize the checkup routine the monophase capacitors to ensure that all groups of capacitors are working properly. In case some monophase capacitor doesn't work, it will be marked as "capacitor in fault". The user determines the control limits of the power factor and of the rms voltage of each phase. He also determines the system operation mode: automatic control, disabled or manual command.

Besides correcting the rms voltage, the control system maximizes the use of the banks. For that, it uses the logic known as FIFO - First In First Out - ensuring that the first capacitor to enter in action is also the first capacitor to be turned off. This system makes possible the rotation of the capacitors in each group, distributing the rate of use among all the capacitors, increasing the lifetime and avoiding the excessive use of the first capacitors of each group.

The signal stabilization routine only commands the input of a monophase capacitor if and only if the mesured value was stabilized by a certain time, established in power system cycles for the user, avoiding the input of capacitors when it is in power system transitory. The basic block diagram of the control software is shown in the Figure 5.

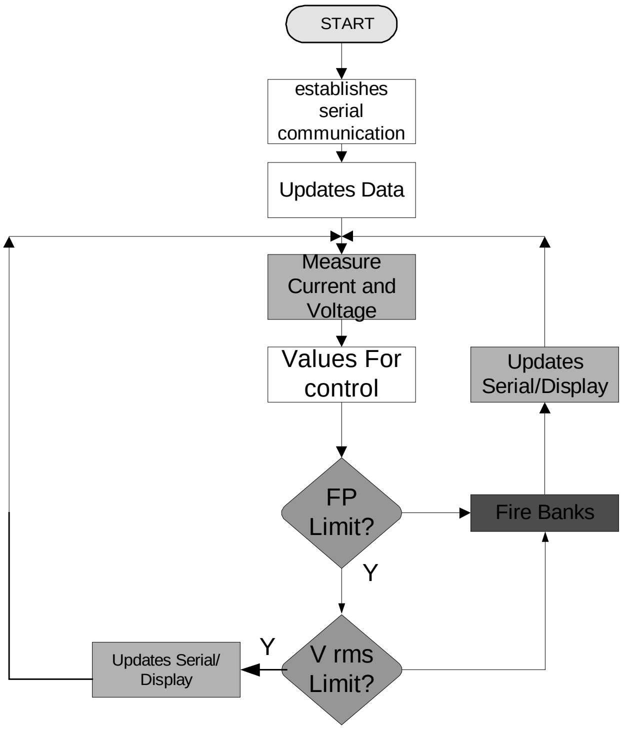

Fig. 5. Block diagram of the developed program.

A three-phase equipment was built, with a group of eight monophase capacitors of 11.4uF/440V for phase, with a simple serial passive filter for avoiding noise when the current is only capacitive. This prototype also has a load with inductive characteristics composed of three monophase motors of 1/3 HP, three three-phase motors of 1HP and three resistive loads of 600W.

In this didactic equipment we can vary the load and the phase where the load will be put to verify the dynamics of the correction, in other words, as the load is tied through keys, the capacitors are worked or turned off automatically to maintain the rms voltage and the power factor inside of the limits imposed by the user. Figures 6 and 7 show the external part and the internal part of the developed equipment respectively.

The first experiment was in open loop, in an increasing way. In this situation, the whole load of the equipment was used in a balanced load in the phases of the power system; it remained constant during the whole time of the experiment.

Figures 8 and 9 show that the rms voltage and the power factor (three phases) are out of the acceptable range (209 V to 231 V for the rms voltage and 0.92 as minimum value for the power factor), when the capacitors are not active.

Fig. 6.External part of the equipment.

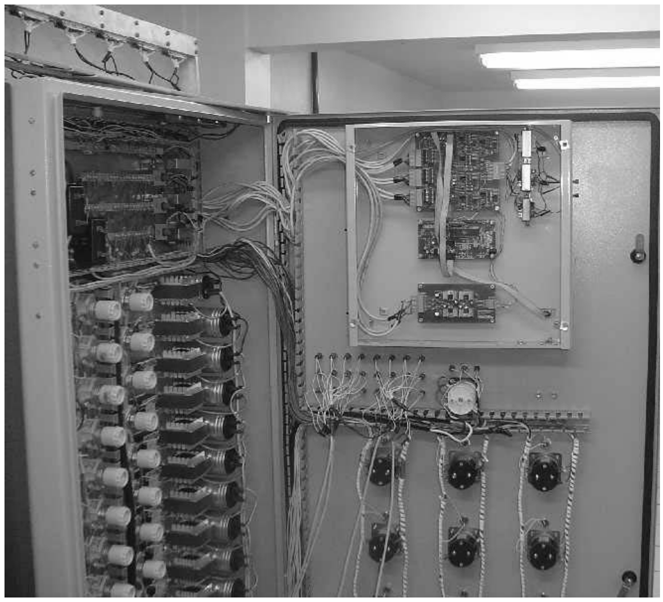

Fig. 7. Internal part of the developed equipment.

The graph of Figure 8 shows the evolution of the phase voltage in function of the amount of capacitors put in each group. It is observed in this graph that the rms voltage of the phases R, S and T enter into an acceptable range after the connection of the fourth, fifth and third capacitors, respectively.

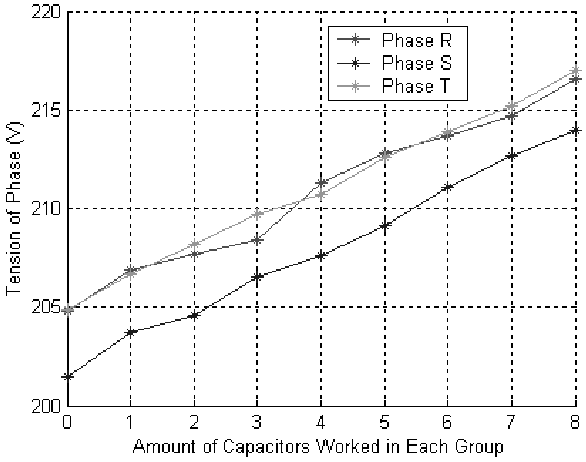

Fig. 8. Phase voltage in function of the capacitors number.

The graph of Figure 9 shows the behavior of the power factor of each phase in function of the amount of capacitors put in each group. It is observed in this graph that the power factor of the three phases enters into the acceptable range after the connection of the fourth capacitor of each group and that the power factor of the three phases leaves this acceptable range after the connection of the last capacitor of each group.

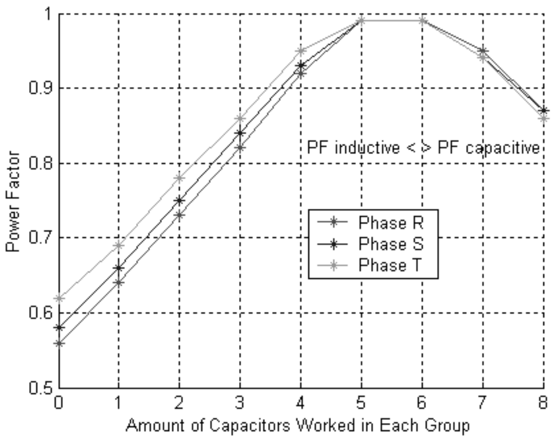

Fig. 9. Power factor in function of the capacitors number.

In this load situation, the equipment operating in the automatic correction of rms voltage and power factor should activate seven capacitors of each group to guarantee that the rms voltage by phase reaches the closest level to the nominal voltage (220 V) and that the power factor lies inside the acceptable range (more than 0.92).

The behavior of the line currents is presented through the graph of Figure 10 where an accentuated decrease of these currents is measured, indicating that the number of capacitors in the power system is increased. This decreasement is only observed until the value of the power factor reaches a value close to one. These currents grow again when the power factor becomes more capacitive.

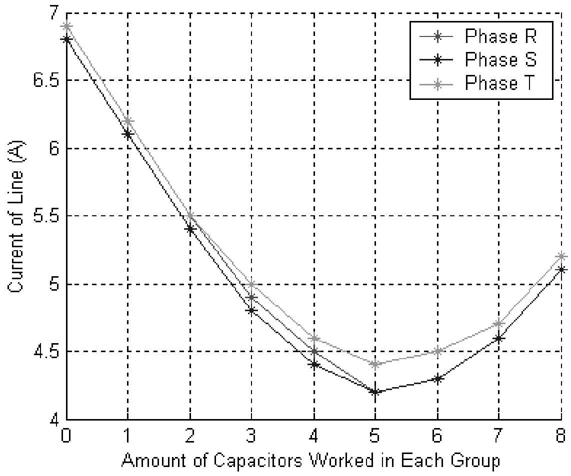

Fig. 10. Behavior of the line currents in function of the number of triggered capacitors.

In the second experiment the whole load of the equipment was used in an unbalanced mode as shown in the first line of Table I (without any capacitors triggered). It was observed that both rms voltage and power factor of all three phases are out of the acceptable range.

The second line of Table I was generated when the equipment was running in an automatic way only for the correction of the power factor. To put the power factor of the three phases inside the acceptable range, it was necessary to put four capacitors in the phase R, five capacitors in the phase S and two capacitors in the phase T. However, the rms voltage of the phase S is out of the acceptable range.

When the equipment was running in automatic mode to correct rms voltage and also power factor (see the third line of Table I), it was necessary to put five capacitors in the phase R, seven capacitors in the phase S and three capacitors in the phase T. In this situation, both the rms voltage and the power factor of the three phases were put inside the acceptable range.

TABLE I
Connection of the monophase capacitors in automatic mode.

Number of fired Capacitors			Rms Voltage of Phase (V)			Power Factor		
R	S	T	R	S	T	R	S	T
0	0	0	205,5	197,5	207,4	0,57i	0,56i	0,80i
4	5	2	211,5	206,6	211,4	0,99i	0,97i	0,99i
5	7	3	212,6	209,6	213,1	0,99c	0,98c	0,97c

Furthermore, figures 11 and 12 show the control action with maximum load. Observe that the control system maintains the power factor among the established control limits (in this case, minimum of 0.92).

Besides, we see in figures 13, 14 and 15 the graphs that can be generated by the program MS-Windows developed to receive the data of the microcontroller, with a sampling time of the one second.

Figure 13 shows the power factor and the rms voltage of the three phases and their respective acceptable range.

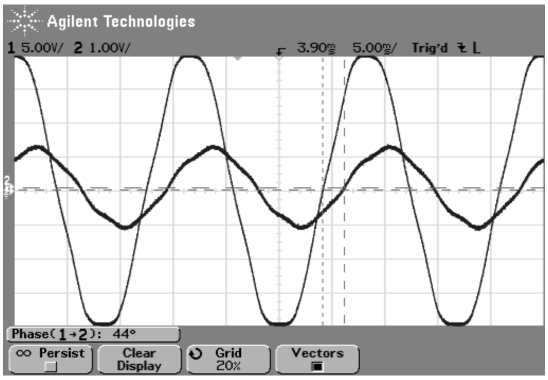

Fig. 11. Behavior with maximum load in the equipment, cosϕ is inductive (CH1 :75V/DIV; CH2: 2A/div).

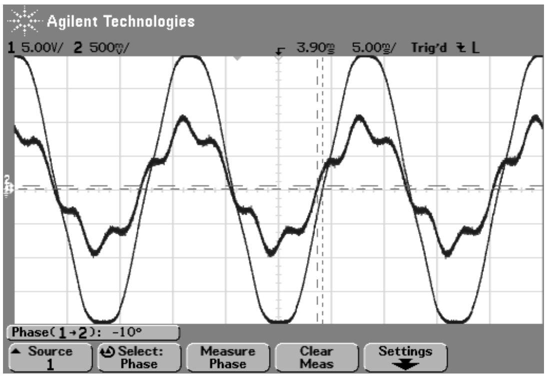

Fig. 12. Correction with the automatic connection of capacitors, cosϕ is 0.96 capacitive (CH1 :75V/div ; CH2: 5A/div).

In Figure 14 the rms voltage of each phase are presented while in Figure 15 the fasor diagram is shown containing the voltage and the line currents fasors, showing the power factor displacement and the limits of control (real time behavior).

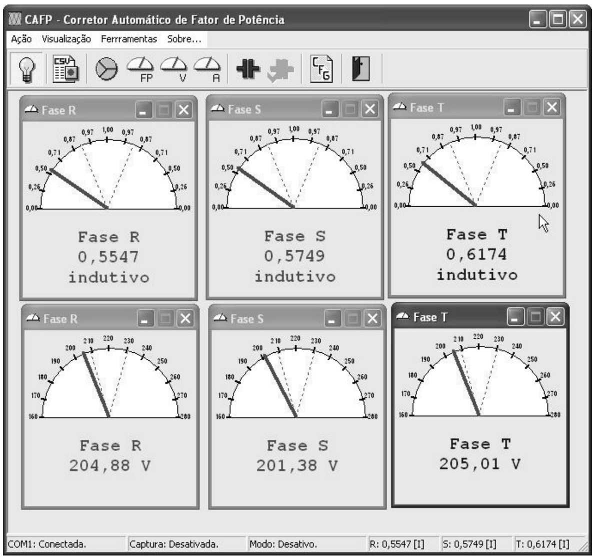

Fig. 13. Displays of power factor and phase voltage.

In figures 16 and 17 we have a general view of the interface between the user and the equipment, allowing configuring it, to store and to visualize the main data of the control system.

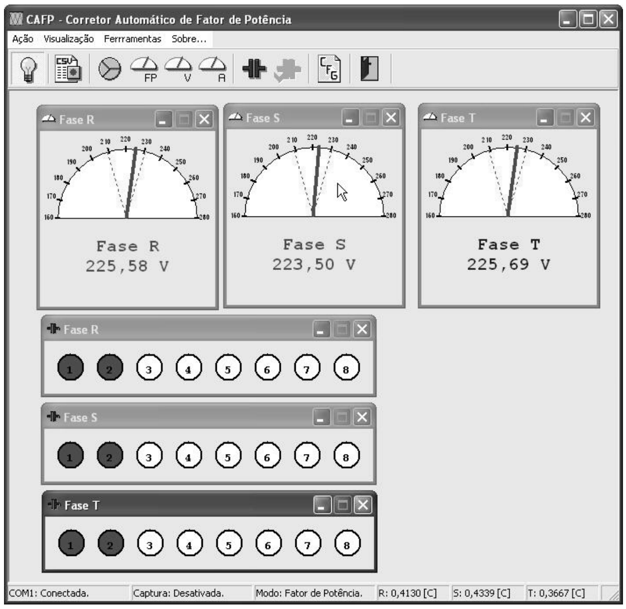

Fig. 14. Displays of rms voltage and capacitors actived in the three groups.

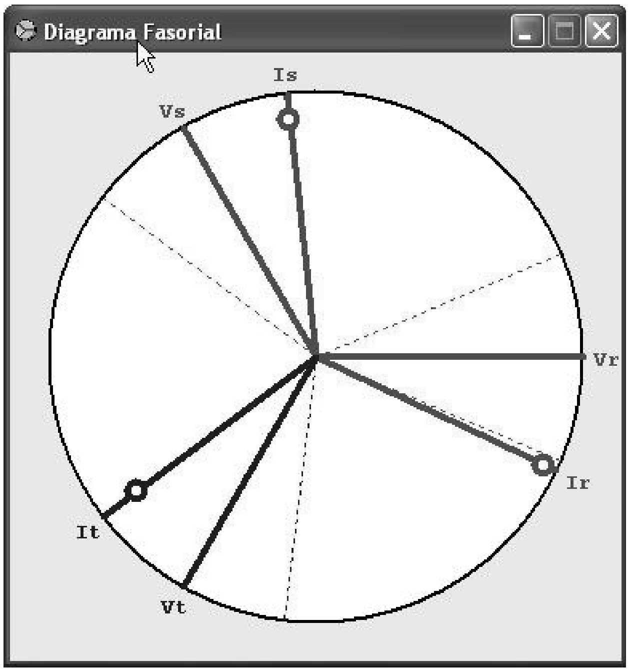

Fig. 15. Three-phase fasor Diagram of the voltage and current showing the power factor, and the limits of control.

Fig. 16. Main screen of the program.

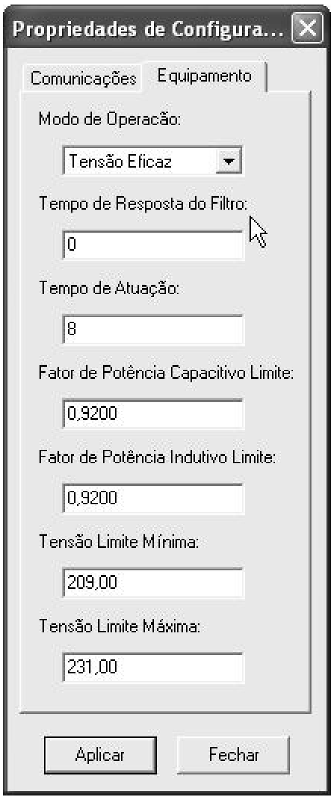

Fig. 17. Configuration Menu of the equipment.

III. CONCLUSION

This system allows the automatic correction of the rms voltage and the power factor of an electric power system (low voltage), maintaining the rms voltage and the power factor inside of the range specified by the user, also optimizing the use of the monophase capacitors, for the best lifetime of each capacitor.

The use of microcontrolllers for the control turns the system flexible, didactic, with low cost, reconfigurable by software, allowing to see all parameters of didactic interest, such as values of power factor, rms voltage and current, dinamics control behavior under variable loads (mono or three phase) and variable situations of the power system. Besides, it is possible, through the Liquid Crystal Display or through a computer connected to the equipment, to obtain at any moment the information about the situation of an electric power system by serial protocol.

The developed equipment is rich in didactic resources, especially in the graphic visualization in real time, and the possible variations of load by phase. Also, it is possible to keep it registering all variables into a file, using a programmable time stamp for future use in behavior analysis of the power system.

A video showing the dynamics behavior can be found in http://planeta.terra.com.br/educacao/valdirnoll, inside the link “pesquisa&desenvolvimento”.

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