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A MATLAB application for monitoring the operation and power quality of electrical machines

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Abstract— Efficient simulation and control tools for electrical machines is an important issue for engineering education and research. This paper presents a MATLAB application to characterize and analyze the electrical-mechanical behaviour of electrical machines. The study is carried out in the laboratory of the University of Almeria (Spain) and has been specifically designed to monitor the operation and power quality of electrical machines. It consists of several test benches that allows different configurations for the electrical machines in the laboratory. The electrical machines are controlled using an automated and adjustable frequency AC drive. The MATLAB application communicates with the adjustable frequency AC drive via standard industrial communication protocols and opensource libraries in real-time in order to adjust some input parameters (start, stop, motor speed, etc.) Furthermore, the application displays some important output parameters, such as the RMS voltage, RMS current, active power, speed and torque. In addition, this framework is also designed to monitor power quality and to analyze the operation of the electrical machines, including the chance of applying advanced techniques for prediction and correction of rotating electrical machines maintenance.

Index Terms— Electrical machines, PQ monitoring, Power quality, MATLAB.

I. INTRODUCTION

High-voltage transmission lines transport electricity from the power generation plants to secondary nodes, while low-voltage distribution networks deliver electricity to end consumers. Rotating electrical machines are widely known electromechanical energy converters that transform mechanical power into electrical power (generators) and vice-versa (motors). The economic importance of electrical machines is considerable since they provide, transform and consume a high percentage of the available electrical energy. In fact, they are currently present in all activity areas including domestic and industrial facilities. For example, some studies have shown that the average modern home (in the developed countries) has between 20 and 30 electrical motors in the range 0-1 kW for domestic appliances, air conditioning, heating systems, etc [1].

The analysis of electrical and mechanical features of electrical machines is a critical issue to ensure flexibility and safe operating of a test stand system. Obtaining these characteristics in practice, involves the interpretation of changes in the operating regime, so it is suitable to establish a control system that governs the electrical machine (starting, stopping, retarding, accelerating, braking, reversing, etc.). A common way to control electrical machines is to use variable speed drives, which can smoothly change the speed to any value within their design operating range, optimizing the processes in which the electrical machines are involved. Direct Current (DC) drives and adjustable frequency Variable Frequency Alternating Current Drives (VFD) are used according to the characteristics of the machine. The main function of variable speed drives in rotating electrical machines is to control speed, acceleration, and direction of movement. Three elements are involved in electrical variable speed drives [2], namely the high-level controller used to enable the use of buttons, switches and potentiometers to start, stop and change speed; the drive controller to convert fixed voltage and frequency of an AC power source into adjustable power output to control the electric drive motor over the allowed range of speeds; the drive motor to transform electrical energy into motor movement.

Data acquisition software for electric machines allows to perform the test automation and to provide the user interface to monitor and execute the experiments. Most commercial electrical variable speed drives allow direct communications from computers using ethernet, serial port Modbus protocol, etc., in a way that it is possible to read electrical and mechanical data from instruments. These data can be also used to analyze the power quality of the signal received by these devices. In fact, electrical devices, including rotating generators and motors, transformers and other electronic devices, react adversely with variations that appear on an ideal waveform of current and voltage in a generic electric power network. Therefore, continuous condition-based monitoring of electrical machines is an effective way to reduce required cut operating costs and prevent unplanned shutdowns. Moreover, monitoring electrical machines to acquire and processing valuable data for predictive maintenance of electrical machines (fault detection, diagnosis and prognosis) becomes an important research topic.

This paper presents a MATLAB application to control and characterize the main variables of rotating electrical machines. Section II describes the test benches and the characteristics of electrical machines available in the experimental laboratory in which this investigation has been carried out. Section III describes the MATLAB application that has been implemented to control and characterize the electrical machines and presents some graphical results related to the variables analyzed through the software application. Finally, Section IV presents the conclusions derived from this study.

II. LABORATORY DESCRIPTION

As commented above, the aim of this paper is to present a software application to control and characterize different rotational electrical machines, including the possibility of monitoring power quality parameters in real time. This software together with some test benches give students and researchers in Electrical Engineering the opportunity to train with modem control systems for industrial automation such as Programmable Logic Controller (PLC). With this aim, several low cost independent benches for testing rotating electrical machines have been designed and built at the laboratory of electrical machines of the University of Almería (Spain), which contains several AC and DC electrical machines, including single-phase induction motors, three-phase squirrel cage induction motors, slip ring motors, three-phase Dahlander motors, separately excited DC motors, compound DC motor, and universal motors, all them in the range 0.40-0.60 kW. The design of the benches makes it possible to analyze not only single electrical machines, but also electrical machines coupled in series.

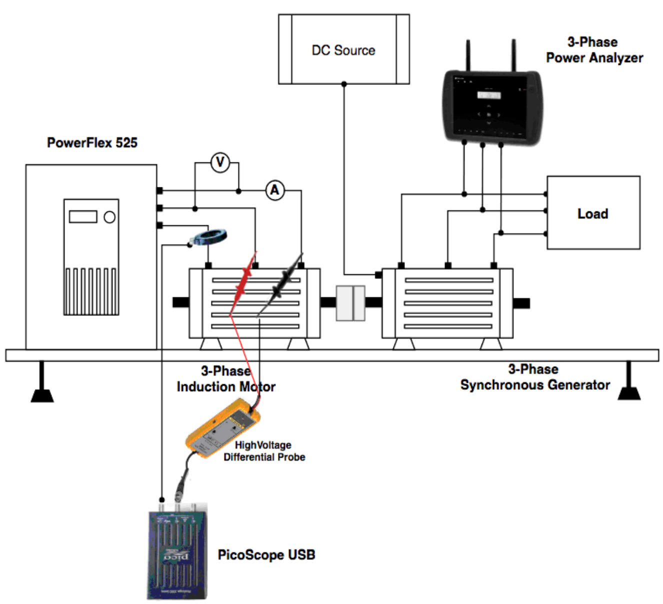

Figure 1. Configuration of a test bench with a 3-phase induction motor coupled with a 3-phase synchronous generator.

Figure 1 shows a schematic description of one of the test benches that can be configured. Each test bench is formed by two parallel rails to fix the electric machines and a variable speed drive. In this study, the PowerFlex 525 (Allen-Bradley) is used to control AC electrical machines. This drive offers a power rating ranging from 0.4 kW to 22 kW, voltage ranging from 100V to 600V, and provides a variety of motor control and flexible mounting options, and offers embedded EtherNet/IP communications and USB programming. EtherNet/IP is one of the leading industrial network protocols that adapts the common industrial protocols to standard Ethernet. Therefore, the bench is controlled by dials with variable speed, or by external signals received from a given computer control software. A three-phase power analyzer and an oscilloscope are also used to analyze the power quality. Figure 2 presents a real image of one of the test benches, while the variable speed drive is shown in Figure 3.

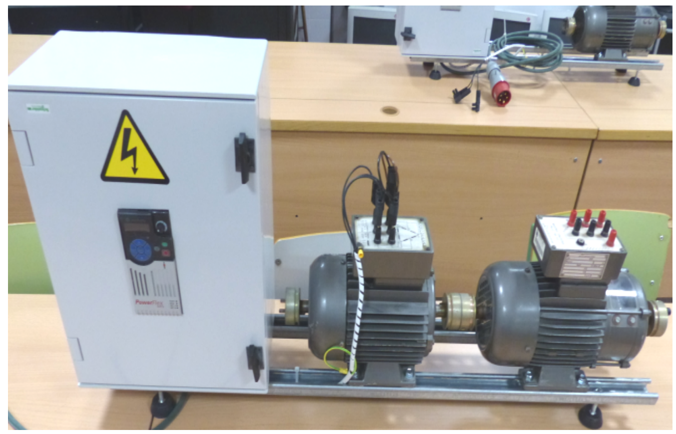

Figure 2. Configuration of the test benches.

Figure 3. PowerFlex 525 AC drive (Allen-Bradley).

Table 1 shows the main values assigned to the PowerFlex 525 speed drive to control the motor.

In order to setup the variable speed drive, it is also necessary to set the IP address, net mask and gateway (internal parameters #129 to #132). The setup of the net protocol is configured automatically and, in the case of communication errors, the system will rise an alert causing the motor to stop.

#item	Name	Value	Unit	Int. Val.	default	Min	Max
31	Volt motor	400	V	380	460	20	460
32	Hz motor	50	Hz	50	60	15	500
33	Current SC motor	2.3	A	23	2.3	0.0	4.6
34	Amps motor	1.6	A	16	1.5	0.1	4.6
35	Poles motor	4		4	4	2	40
36	RPM NP motor	1400	RPM	1400	1750	0	24000
37	Power NP motor	0.75	kW	75	0.75	0.00	655.35

Table 1. PowerFlex motor configuration.

Two operational modes are configured in the drive to the motor. Those modes are called local and remote mode, respectively. The first one allows to start the variable speed drive using the on-board console keyboard and dial to set a speed reference. The second mode allows to start the variable speed drive through the ETHERNET/IP network. This mode is used by the MATLAB application for monitoring and control the operation. Therefore, a wiring selector is connected to digital input number 7 to commute between modes

Some authors have performed experimental investigations of single feedback control based on the analog channel, EtherNet/IP (Allen-Bradley) and OPC (OLE for Process Control) [3]. Allen-Bradley controllers have been widely used in the past for industrial and production environments [4,5], including monitoring and controlling activities of rotating electrical machines [6].

III. MATLAB APPLICATION

The purpose of this document is to provide an explanation based on current facts for the supervision and control of rotating electrical machines that use devices and software tools with which engineers and control engineers are more familiar. This is the case of MATLAB programming language, which provide lot of libraries containing different procedures and routines used in control engineering, enabling the compilation and run of new algorithms and applications created by the user. To compare with the developed MATLAB system, Connected Components Workbench provided by PowerFlex 525 variable speed drive has been used to access the default and non-default parameters. MATLAB communicates with the variable speed drive to read and adjust parameter values via EtherNet/IP thanks to the EEIP java gateway (https://github.com/rossmann-engineering/EEIP.Java).

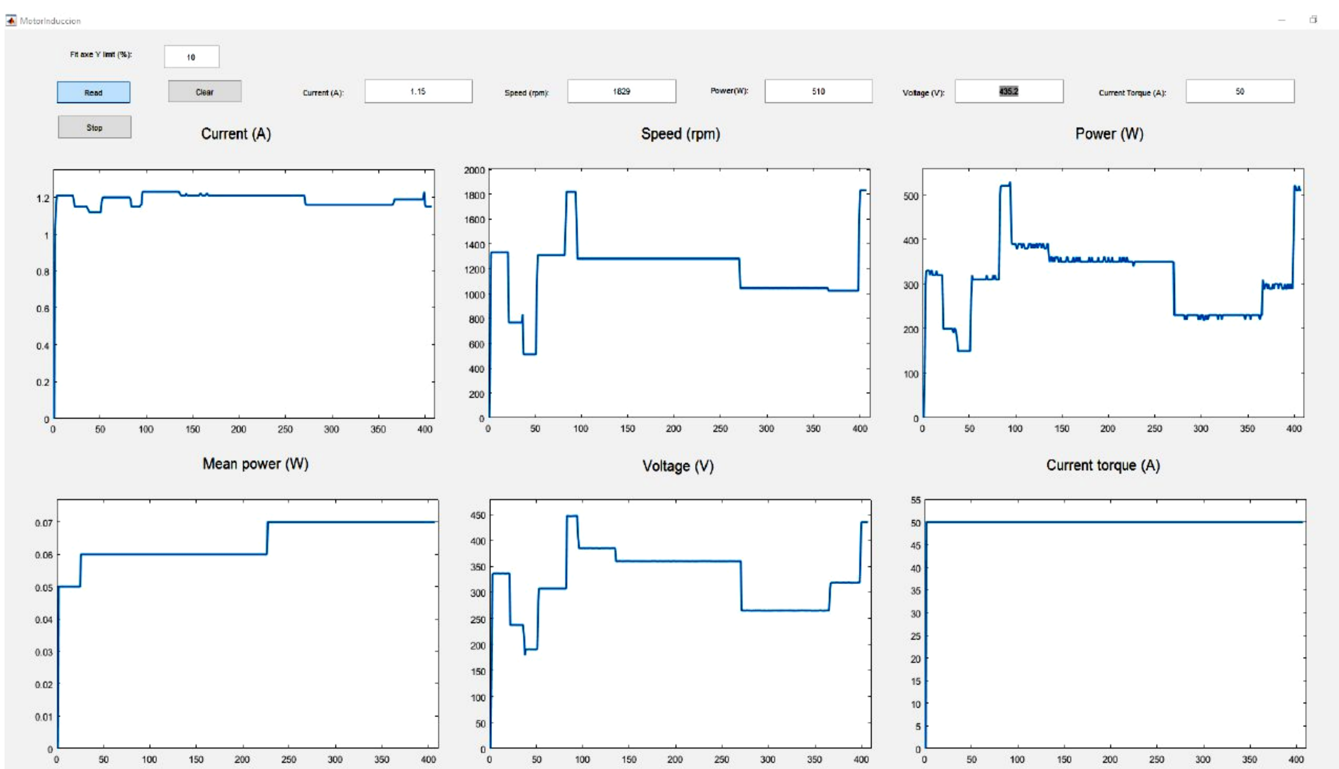

Figure 4. Graphical User Interface of the application developed.

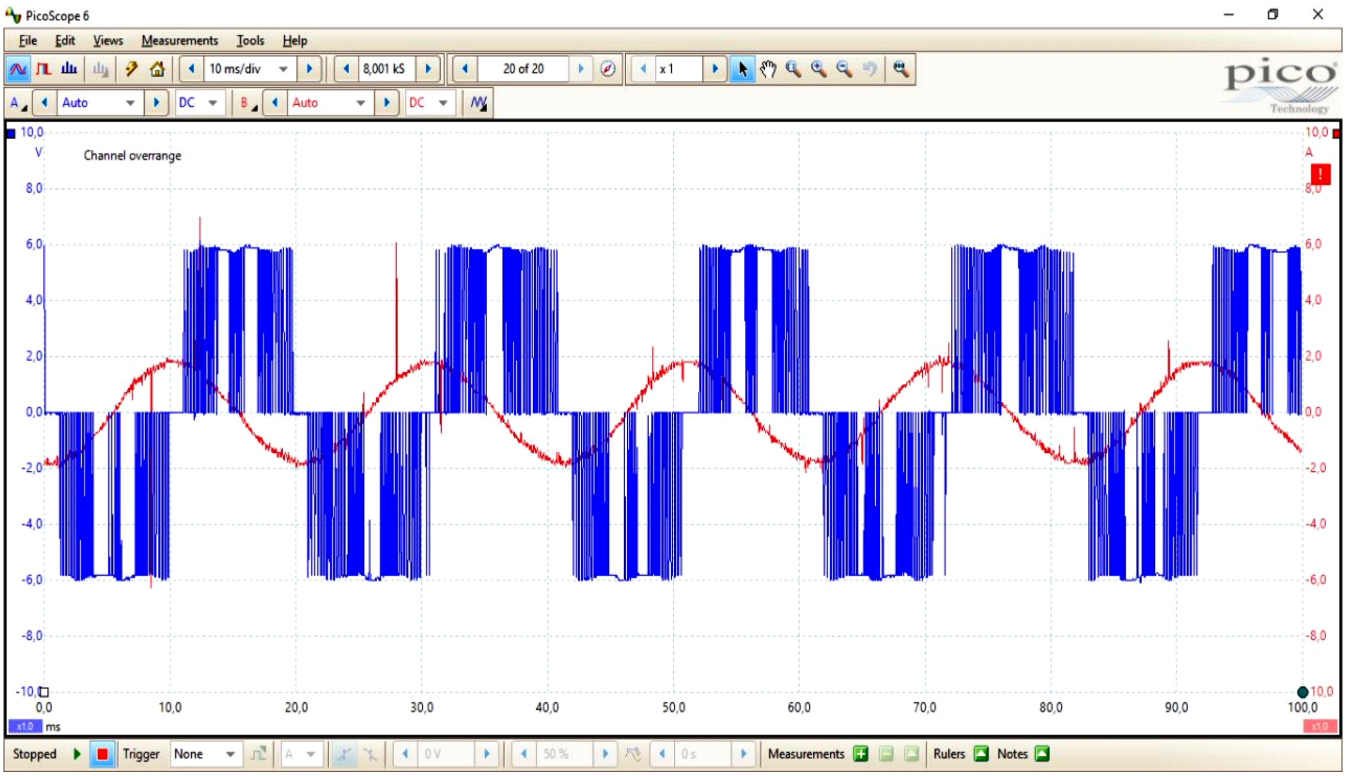

Figure 5. Analyzing the power quality in the induction motor using a digital oscilloscope.

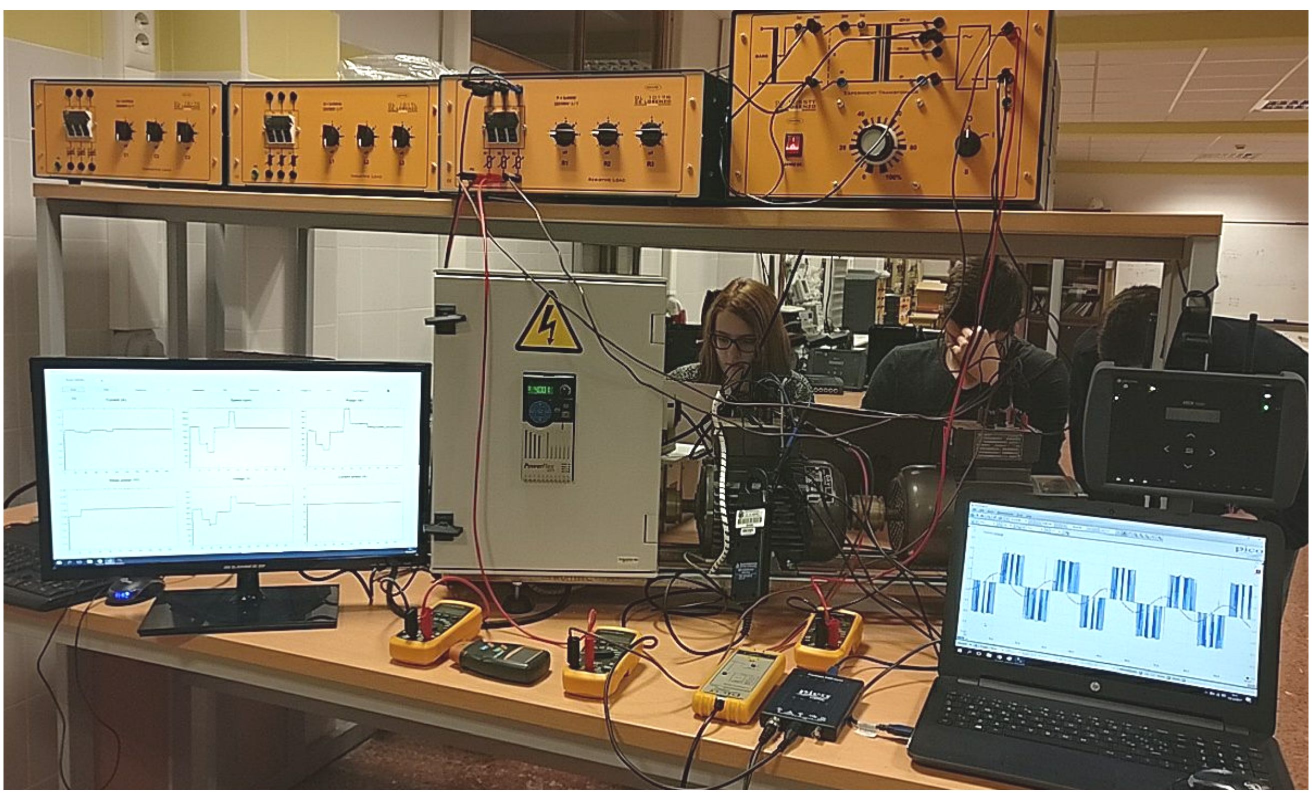

Figure 6. Experiment overview in the laboratory.

Furthermore, the application developed in MATLAB displays and plot some of the main parameters, as showed in Figure 4. From these subplots, it is possible to build an efficiency map that considers torque and speed, describing the maximum efficiency for any speed/torque combination. It is a convenient way to represent the motor drive over a range of operating points defined by a driving cycle [7].

On the other hand, this experimental laboratory has been also designed to analyze the power quality in the motors. With this aim, portable power analyzers and digital oscilloscopes are used, as it is displayed in Figure 5. Pulse-width modulation (PWM) [8] is used to control the average voltage applied to the motor windings in modern three-phase AC electrical machines. The use of PWM is clearly shown in Figure 5, where the blue line shows the PWM signal applied by the Powerflex 525, with an amplitude of 600 V and a frequency of 42 Hz. In addition, the current demanded by the motor is also shown in red line, with a sinusoidal shape as expected. The data confirm the existence of spikes due to the polarity change of the PWM signal.

Figure 6 presents how the real experiments have been carried out in the laboratory. As explained in Figure 1, the configuration is replicated, adding a laptop to the test bench in order to execute the MATLAB application that control the values for the adjustable frequency AC drive. A second laptop was used to display the results provided by the oscilloscope and the portable power analyzer. Other auxiliary components (multimeters, variable resistances, etc.) were also incorporated to modify the basic configuration of the test bench and therefore to characterize the electrical machines under different operating conditions.

IV. CONCLUSIONS

Constructive aspects, operating principles and maintenance operations constitute the main areas of investigation for rotating electrical machines. In this paper, it has been described the main characteristics of a cost-effective laboratory that has been specifically designed to monitor the continuous operation and power quality of rotating electrical machines. Furthermore, it is also presented a MATLAB application that allows controlling, monitoring and characterizing different type of electrical machines.

The simulations and measurements here presented, prove that this experimental laboratory constitutes a good alternative for analyzing and characterizing the behavior, as well as the improvement of the efficiency, of rotating electrical machines in a fast and easy way. Moreover, collecting and analyzing data in real time can alert about problems, which is why the predictive and corrective maintenance of rotating electric machines can be performed in this experimental laboratory.

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