Development of a Platform with Induction Motors for Control Tests

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Abstract: This article describes the design and construction of a control test platform, intended for research and laboratory practices at the Universidad Politécnica Salesiana. The application fields for the platform are Power Electronics, Electrical Machines and Control Theory. The work includes the construction of the mechanical system, which consists of two three-phase induction motors, an incremental encoder and a torque sensor; also the assembly of the power system, which consists of two three-phase inverters, each with three IGBT modules mounted on a heat sink; and the implementation of the control system, which combines a FPGA with an DSP to generate the PWM switching pulses of the IGBT, depending on the control technique used.

Keywords: platform, induction motors, inverters, control.

I. INTRODUCTION

In recent years, the Energy Research Group (GIE) of the Universidad Politécnica Salesiana has been designing control systems for three-phase converters[1][2][3], which can be used in applications with electrical machines, reactive power compensators, active filters, wind and solar energy generators, electric vehicles, among others. However, it is necessary to implement this type of systems and to provide students and researchers the practical resources to apply these technologies in the laboratory. Currently, it is not easy to get such kind of platforms in the marketplace, with the academic benefits of using common electrical machines in the industry. For this reason, there is interest in designing and developing a platform to implement control systems in commercial motors. Three-phase induction motors have been chosen because they are the most widely used electrical machines in the industrial sector, due to their high performance and robustness, as well as their low purchase and maintenance costs [4].

The power circuit is mainly composed of a three-phase inverter for each motor, the used topology is a two-level voltage source converter (2L-VSC), as it is the most common for low voltage applications in the industry (400 V line to line), due to the fact that it requires fewer components and simpler control[5]. The ideal elements for the construction of the inverters are the IGBT transistors because they can manage high voltage and current levels, and a high switching frequency, which allows a higher rate of voltage increase and better current waveforms [6].

The control system is in charge of generating the PWM pulses for the activation and deactivation of the IGBTs. Considering that this task demands a lot of processing time for the processor, an FPGA is used to carry out the IGBT switching operations and the serial to parallel conversion of data obtained from the sensors. The DSP is used only to implement the various control techniques since it provides high processing speed [2].

II. DESIGN STANDARDS

Standards are a set of rules that establish specifications, instructions and techniques that institutions must follow to guarantee the quality of their products [7]. Internationally there are several regulations that establish the minimum quality levels that must be met for the manufacture of electrical equipment.

A. International Standards for Electric Motors

The main standards for the manufacture of electric motors are IEC and NEMA, which focus on the quality and efficiency of motors, in order to ensure energy savings that benefit the planet [8]. In Tab.1 a comparison of the efficiency classes between these two standards is shown.

IEC 600034-30-1:2014	**NEMA** MG-1-2009
IE1	Standard
IE2	High
IE3	Premium
IE4	Super Premium

Tab. 1: Comparison of efficiency classes between IEC and NEMA [8].

The motors used in this project meet NEMA MG-1 High Efficiency standard, which provides 87.5% efficiency.

B. International Standards for Electrical Cabinets

The main standards for the manufacture of electrical cabinets are IEC 60526, NEMA 250 and UL 50-50E, which focus on safety, design efficiency and product performance [9].

The NEMA 250 standard indicates the degree of protection of the cabinets against ingress of people, tools, moisture, dust or dirt, and provides specifications detailing the minimum requirements for electrical cabinet design (strength, sealing, material, ventilation, mounting, etc.) [9].

The cabinet constructed in this project meets NEMA 250 Type 2, which provides a degree of protection against access to hazardous parts and against the ingress of solid foreign objects (dirt), and also provides a degree of protection against the ingress of water (dripping and splashing) [9].

III. MECHANICAL STRUCTURE

The first part of the project is the design and construction of the mechanical structure of the platform, this part consists of a cabinet in which the elements of the power circuit and the control system are placed. It also includes the metal table on which the motors, the rotary sensors and the bases for these elements are placed. The design of the 3D representations of all elements is done with Autodesk Inventor Professional 2015 software; this allows knowing the structural dimensions of the whole platform. Fig. 1 shows the diagram of the mechanical parts that compose the platform and based on this diagram the design, and later the construction, is carried out.

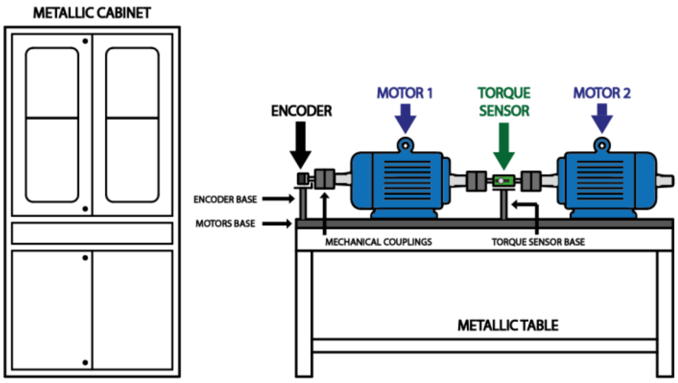


Fig. 1: Scheme of the mechanical structure.

The body of the metal table is constructed with a structural steel channel-type profile, recommended for metal furniture [10], which is 10 cm wide by 5 cm high, with a thickness of 2.5 mm. In addition, the UPN100 beam, recommended for supports and rails [11], is used for the motor bases; the beam is 10 cm wide by 5 cm high, and 8.5 mm thick. The total dimensions of the metal table are 150 cm long by 60.5 cm wide, and 60.5 cm high. In addition, the type of material used is ASTM A-36 steel, which guarantees strength, stability and safety in the structure to support the combined weight of the engines, which is 148 kg.

The bases that support the encoder and the torque sensor are made of steel plate and square tube, the height of the shaft of both sensors must coincide with the height of the motor shaft, which is 133.35 mm from the base. In addition, flexible Lovejoy L100/L099 [12] crosshead type couplings are used to connect the movement between the axes. Acrylic protections for the moving parts of the encoder shaft connections and the torque sensor are also included. Fig. 2 shows the final modeling of the table with all the elements.

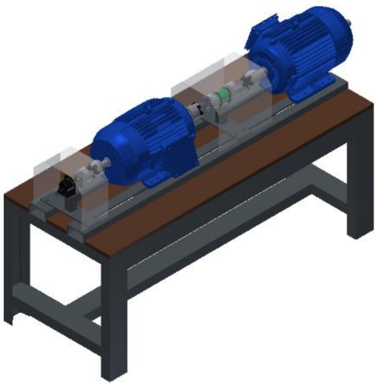


Fig. 2: 3D representation of the metal table with all elements.

The cabinet is made with sheet steel of 2 mm tickness and coated with white anti-corrosion paint. The cabinet is divided into three sections, the upper section being the most important, as the elements of the power circuit and control system are installed in it, having the control panel on a side. The other two cabinet sections are used to store additional elements of the platform. The cabinet also has holes for mounting a fan FP-108EX [13] to help in the cooling of the power stage heatsink. Fig. 3 shows the final modeling of the cabinet.

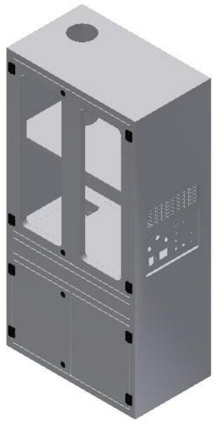


Fig. 3: 3D representation of the cabinet.

IV. CONTROL STRUCTURE

The design of the control structure is based on the diagram shown in Fig. 4. The power circuit is one of the most important parts, so it is necessary to make a correct sizing of the power elements based on the characteristics of the actuators.

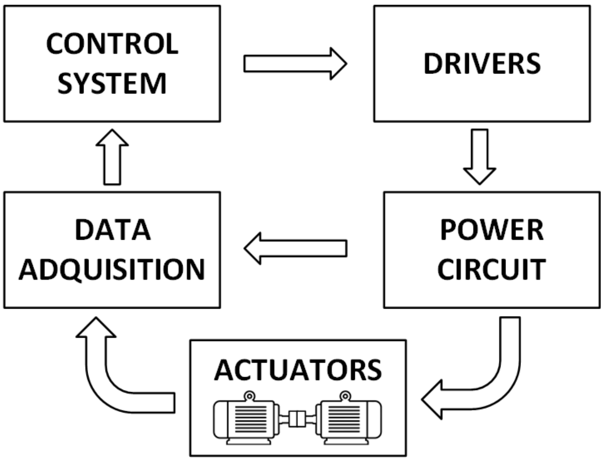


Fig. 4: Diagram of the control structure.

A. Actuators

The three-phase induction motors used as actuators have 5 HP, belonging to the TEFC - W22 - High Efficiency line of the WEG company and are manufactured under the requirements of the NEMA MG-1 standard. Among the advantages offered by these motors is the reduction of energy losses between 10% and 50% compared to other commercial motors [14]. The motors are of “B” category, characterized by generating normal torque and current during starting, this represents between 5 or 6 times the nominal current [15]. The type of insulation is class F that allows the motors to withstand a maximum operating temperature of 155°C.

B. Rotary Sensors

For speed measuring, an Autonics E50S8-3600-3-T-24[16] incremental rotary encoder is used, which can operate with a maximum frequency of 300 Hz and hold a speed of 5000 rpm. The encoder’s resolution is 3600 pulses per revolution.

For the acquisition of the torque generated in the motor shaft, a Burster 8645-5075[17] torque sensor is used, which can withstand a maximum torque of ±75 Nm and up to 3000 rpm, generating an output voltage of ±2.5 V depending on the applied torque.

C. Power Circuit

The inverters are sized taking into account a power of 5 HP that each motor consumes. The diagram in Fig. 5 shows the complete power circuit. The circuit consists of a SKD 82 rectifier [18], that converts the three-phase input voltage to a continuous one; next are connected two ALS30/31 capacitors [19] of 2200 uF and 400 V, which stabilize the input voltage and minimize voltage ripple. Finally the three-phase inverters that feed the motors are connected. These inverters are composed of three SKM50GB063D modules [20] each one containing two IGBTs. An important part of the power circuit is the MM12878 heatsink [21], which is responsible for dissipation of the heat generated by the IGBT modules and the rectifier.

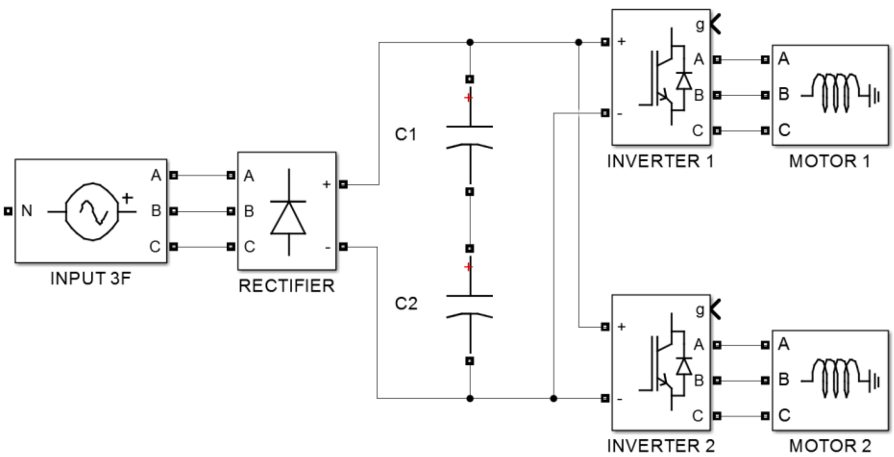


Fig. 5: Diagram of power circuit.

D. Control System

The control system is composed by an embedded circuit FPGA XC3S500E [22] responsible for generating the PWM signals to activate the IGBT and convert from serial to parallel the signals acquired from the sensors through the fiber optic, this integrated works in conjunction with the digital processor ADSP-21369 [23] that provides faster signal processing, this algorithm is also loaded with the control technique developed in the Visual DSP++ software.

E. Drivers

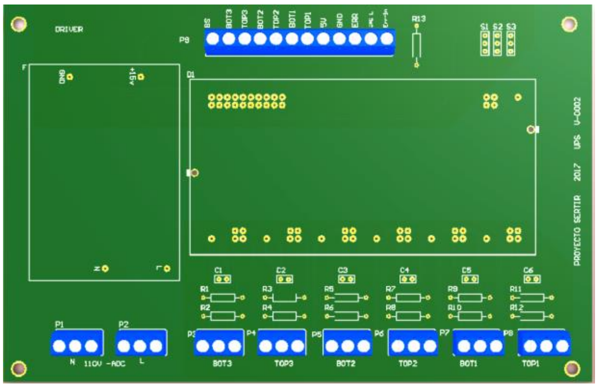
The driver circuit consists mainly of the SKHI 61 driver [24], in charge of receiving the PWM pulses of the control circuit and generating a PWM output of +15V and -7V necessary for the correct activation and deactivation of the IGBTs.

F. Data Acquisition

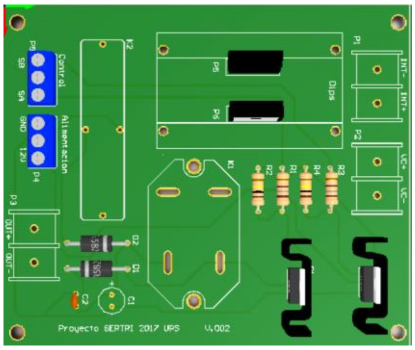
The data acquisition circuit uses an AD7607 converter [25] to convert the signals obtained by LA 55-P current sensors [26] and LV 25-P voltage sensors [27], and then transmit them to the control board via fiber optics.

V. CONSTRUCTION AND ASSEMBLY

The sensor and control board designs developed by the GIE are used to produce the sensor and control boards. These designs were used in a multilevel electronic converter [1]. However, for this project the SKHI 61 drivers are used, so a separate card is made for each driver. In addition, to ensure controlled charging and discharging of the capacitors, a board is designed to regulate this action by means of resistors, which are activated by relays. The finished designs of these cards are shown in Fig. 6.



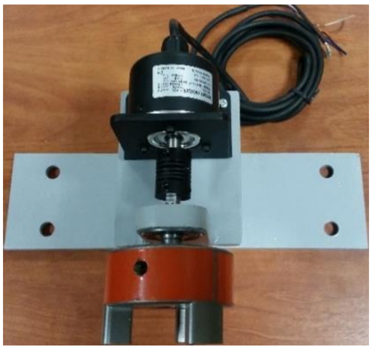
(a) Drivers board.



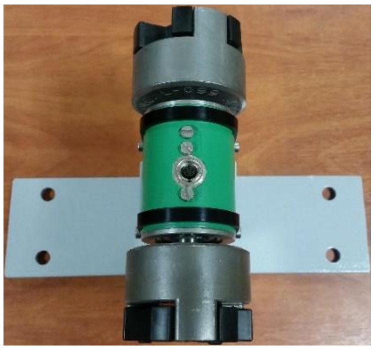
(b) Load/unload resistors board.

Fig. 6: Electronic board designs.

The bases of the rotary sensors are elaborated according to the previous designs, later the sensors are fixed to the bases by means of the supports that come included by the manufacturer, and finally are assembled with the mechanical couplings.



(a) Encoder incremental.



(b) Torque sensor.

Fig. 7. Assembly of the rotary sensors.

Once the rotary sensors have been assembled, they are placed on the metal table together with the two induction motors. It should be noted that the axes of all the elements are well aligned and that there are no mechanical stresses when the motors are started, the final prototype of the mechanical part of the project is shown in Fig. 8.

Fig. 8: Final assembly of all elements on the metal table.

Finally the assembly and wiring of the control system elements inside the cabinet is carried out. This includes electronic cards, inverters, protections, power supplies and control devices. The final assembly of the entire control system is shown in Fig. 9.

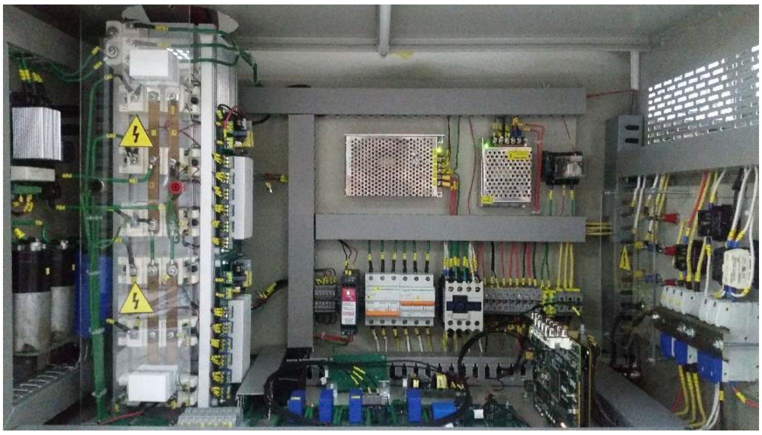
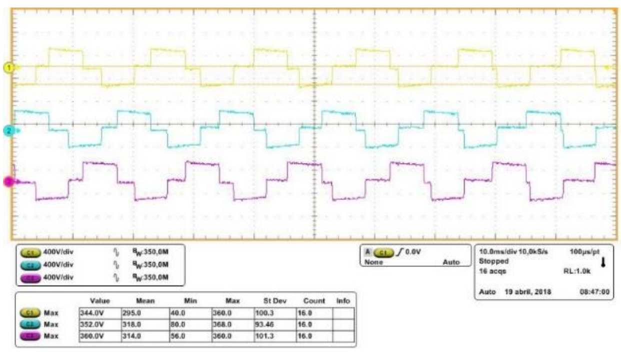


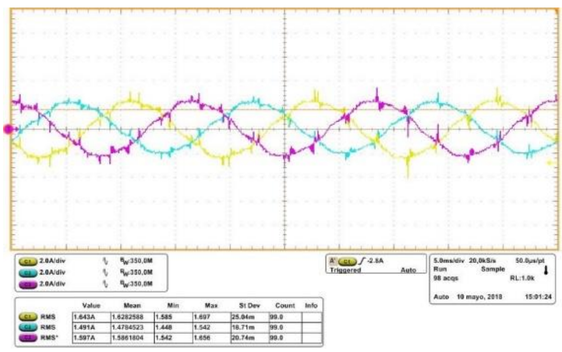
Fig. 9: Assembly and wiring of the control system elements.

VI. RESULTS

By implementing the algorithm of a V/f controller, the platform can be tested and its correct operation can be verified. Fig. 10 shows the voltage and current signals measured at the inverter outputs, which proves that the IGBTs are being switched properly.



(a) Line voltages.



(b) Line currents.

Fig. 10: Measurement of output voltages and currents.

VII. CONCLUSION

The main objective of the project of developing an experimental platform with induction motors to implement any control technique has been successfully achieved. The final prototype has been achieved through several stages, from the design of mechanical drawings to the testing of electronic cards, using equipment and tools available at the university. This shows that it is feasible to design and build platforms with large induction motors for educational applications.

Two algorithms have been implemented to verify the operation of the platform, by means of a V/f scalar control without feedback, the correct operation of the inverters is checked. The performance of the algorithms has a satisfactory response, generating a stabilization time of approximately 5 seconds; however, this time can be improved by changing the control technique.

These types of projects are of great benefit to student learning at the university and generate various research topics for the future.

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REFERENCES

[1] J. Viola, J. Restrepo, F. Quizhpi, M. I. Giménez, J. Aller, V. Guzmán, and A. Bueno, “A flexible hardware platform for applications in power electronics research and education,” in 2014 Electrical Power and Energy Conference (EPEC 2014), Nov. 2014, pp. 226–232.
[2] J. Viola and F. Quizhpi, “Desarrollo de un convertidor electrónico multinivel para aplicaciones de compensación de potencia reactiva,” pp. 96–103, 01 2013.
[3] J. Restrepo, J. Viola, and F. Quizhpi, “Banco de emulación de perfiles de viento para aplicaciones en energía eólica,” pp. 77–84, 01 2015.
[4] J. W. Rengifo Santana, J. Benzaquen Suñe, J. M. Aller Castro, A. A. Bueno Montilla, and J. A. Restrepo Zambrano, “Parameter estimation method for induction machines using instantaneous voltage and current measurements,” Revista Facultad de Ingenier´ıa Universidad de Antioquia, no. 75, pp. 57–66, Jun. 2015.
[5] A. Wilson and S. Bernet, “Comparative evaluation of multilevel converters with IGBT modules for low voltage applications,” in EPE’17 ECCE Europe, Sep. 2017, pp. 1–8.
[6] D.-H. Hwang, D.-Y. Park, Y.-J. Kim, D.-H. Kim, J.-Y. Koo, and I.- G. Hur, “Analysis of insulation characteristics of PWM inverter-fed induction motors,” in ISIE 2001, Pusan, KOREA, Jun. 2001, pp. 477– 481.
[7] L. E. Galicia Moreno, E. A. García Roa, and R. Reyes Chavarría, “Coordinación de protecciones para un sistema eléctrico industrial.” Master’s thesis, Instituto Politécnico Nacional, 2013.
[8] Normativas Globales de Eficiencia para Motores Eléctricos de Baja Tensión, Grupo WEG, 2017.
[9] NORMAS GLOBALES PARA GABINETES EN LA INDUSTRIA ELE´CTRICA, Hoffman Enclosures Inc., 2009.
[10]“Perfiles Estructurales Canales,” IPAC, 2017, [Accessed: 20-nov-2017]. [Online]. Available: http://www.ipac-acero.com/producto-detalle.php?id=32
[11]“Productos Laminados Vigas UPN (Perfil C Estándar),” IPAC, 2017, [Accessed: 20-nov-2017]. [Online]. Available: http://www.ipac-acero.com/producto-detalle.php?id=47
[12]“Tipo L – Acoplamientos de mordaza estándar,” Lovejoy, 2017, [Accesed: 20-nov-2017]. [Online]. Available: http://www.lovejoy-inc.com/product.aspx?LangType=1034n&id=1059

[13]"FP-108EX," EZ FAN, 2017, [Accesed: 20-nov-2017]. [Online]. Available: http://www.ezcfn.com/ac fan/fp108ex ac.html
[14]NEMA Technical Catalog - W22 Three-Phase Electric Motor, WEG Group, 2016.
[15]MotorTico, "Diseño y Categoría en Motores Eléctricos," MotorTico, pp. 1–2, Feb. 2014.
[16]E50S Series, Autonics, 2013. 36
[17]Torque Sensor - Rotating, non-contact transfer, burster, 2016. 37
[18]SKD 82 - Power Bridge Rectifiers, SEMIKRON, 2007.
[19]ALS30/31 Series - Screw Terminal Aluminum Electrolytic Capacitors, KEMET, 2017.
[20]SKM50GB063D - Superfast NPT-IGBT Modules, SEMIKRON, 2010.
[21]"MM12878," Alexandria Industries, [Accesed: 15-sep-2017]. [Online]. Available: http://www.alexandriaindustries.com/product/mm12878/
[22]Spartan-3E FPGA Family - Data Sheet, Xilinx, 2013.
[23]SHARC Processor - ADSP-21367/ADSP-21368/ADSP-21369, ANALOG DEVICES, 2013.
[24]SKHI 61 (R) - Sixpack IGBT and MOSFET Driver, SEMIKRON, 2007.
[25]AD7607 - Preliminary Technical Data, ANALOG DEVICES, 2009.
[26]Current Transducer LA 55-P, LEM, 2015.
[27]Voltage Transducer LV 25-P, LEM, 2012.

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