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A Novel Virtual Instrumentation based method for Automation of Electrical Machines

Gundeep Singh Saini
Department of Electrical & Electronics
Manipal Institute of Technology
Manipal University, Karnataka, India

P.N. Hrisheekesha
Associate Professor,
Department of Electrical & Electronics
Manipal Institute of Technology
Manipal University, Karnataka, India

ABSTRACT

Electrical Machines areintegraland key equipments for engineering undergraduate, graduate, research scholars& for any processing industries. The modernization & automation of these machines are very much necessary in todays computer based environment. The available techniques for automation are very costly & unaffordable. This paper presents a new low cost, accurate & effective method for the automation of machines. The proposed method has been designed, developed & evaluated at Manipal Institute of Technology, Manipal University, Manipal, India. The results are accurate & promising. This work could be one of the major steps towards total system automation.

General Terms

Electrical Machines, Instrumentation, Embedded System, Control Systems.

Keywords

Automation, Data Acquisition System, LabVIEW, Machines, Microcontroller, Sensors, Virtual Instrumentation

1. INTRODUCTION

Electrical Machines (EM) is an imperative part of engineering studies and is one of the core subjects of electrical engineering. Furthermore, Electrical Machines Laboratory Course consolidates the theoretical concepts by means of practical and hands on approach to various machines such as Transformers, AC and DC Motors, Generators, etc.

However there is a great need to change &modernize the society perception about the subject. This can only be addressed by the use of modern equipment and computer-aided tools. A paper by Nehrir, Fatehi and Gerez [1] also observes that a wrong impression of the subject on the students deters them from taking any further courses in the subject. Therefore, it is necessary to complement the theoreticalknowledge with proper simulations and the use of digital interface integrated with computer-aided tools in the laboratory.

The incorporation of computers in the laboratory courses of universities & in industries has been reported in the literature[4,5,6,7,8,10,11,12],Krein and Sauer [2] at the university of Illinois at Urbana-Champaign, Mohammed and Gorden [3] at Florida International University and many others including Krishna Vasudevan of Indian Institute of Technology, Madras have proposed techniques for modernization of machines. But such process and techniques require a high initial investment, which is not affordable to majority of engineering universities & industries to incorporate. Normally, in machine laboratory environment, the students and operators invariably have to work with live terminals including high voltage, which is very risky & for this reason many engineers hesitate to work with electrical machine environment.

In this age of modernization, the transformation from analog to digital has resulted in more accurate and precise measuring devices. In this work, an in-house data acquisition module (DAQ) has been developed to sense &measure the parameters of the test machine,like armature and field current, voltage, speed of the machine set and the rise in temperature of the machine. The proposed method ensures isolation of person working in the machine environment, which ensures safety of the operating personnel.

In this paper a novel methodology has been proposed to design, develop and evaluate a low cost solution for automation in Electrical Machines Laboratory environment. This new method has been developed & tested at the Department of Electrical & Electronics, Manipal Institute of Technology, Manipal University, India. The test results are promising & this work could be a very useful step towards the automation of the system.

2. SYSTEM ARCHITECTURE

In the initial setup, a DC Shunt Motor coupled with a DC Shunt Generatorhas been chosen as the test machine. Multiple experiments/testing can be done on the same setup, viz. load testing on motor or generator and Hopkinson’s Test (Regenerative Test).

The parameters to be measured during the testing are armature and field current, the field and armature voltage, the speed of the motor-generator set and the temperature rise of the machine. These parameters have been measured using individual modules developed for the same.

The hardware modules have been classified as Data Acquisition Card (DAQ), CT & PT Module, Digital Tachometer and Temperature Sensor.The software involves the development of LabVIEW based Virtual Instrumentation (VI)System [9]. The block diagram of the system is shown in fig 1. The DAQ is based on the Atmega328 microcontroller, which has a 10 bit, 6 channels Analog to Digital Converter (ADC) on board. The ADC senses the voltage and current from the transducers and sends it to the VI. It also communicates with the temperature sensor and the tachometer over I^2C protocol. With I^2C, multiple devices can be connected on the same bus. The VI communicates with the DAQ to acquire the data and displays it.

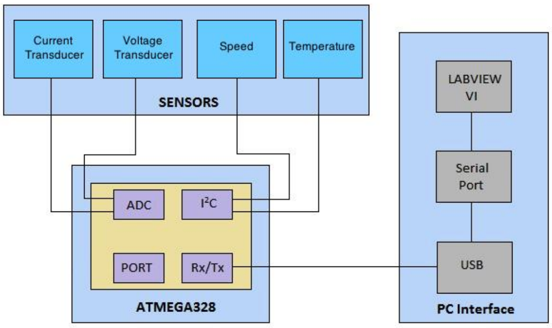

Fig 1: System Block Diagram

2.1 Data Acquisition Module (DAQ)

The Data Acquisition Module (DAQ) is centered on the Atmel's micro-controller, Atmega328. It acts as an external USB Instrument, using the predefined LabVIEW(LV) protocols for communication. It was custom developed for the setup.The micro-controller communicates at 115200 bits per second with 8 data bits, no parity and 10 stop bits with checksum.

It communicates with the computer via the USB port and FTDI's FT232RL USB to Serial Chip. It converts the USB signals to serial TTL that the micro-controller can read. It acts as a virtual COM port over RS-232. A VISA Resource (in LV) is made for the communication with the micro-controller and this is used as a sub VI in the main interface. The block diagram of LVDAQ module is shown in fig 2.

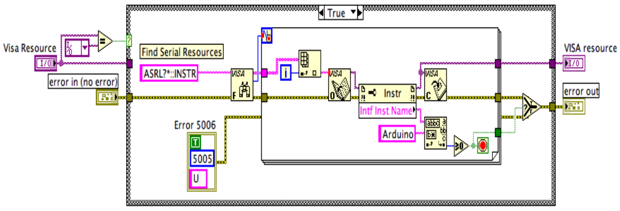

Fig 2: LabVIEW DAQ Module

2.2 Digital Tachometer

The Digital Tachometer is also based on Atmel Micro-controller (ATMEGA328). It acts as a contactless digital tachometer, and sends the speed data directly to the DAQ, communicating over I^{2}C protocols.

The principle used is to count the pulses coming from a sensor and measure the duration between them to find the corresponding rpm. In this case, the counted pluses come from Infrared photo-sensor, which detects a reflective element passing in front of it, and thus, will give an output pulse for each and every rotation of the shaft, as show in fig 3.The pulses are fed to the microcontroller and counted with the use of Interrupts.The mounting arrangement of the developed module is shown in fig 4.

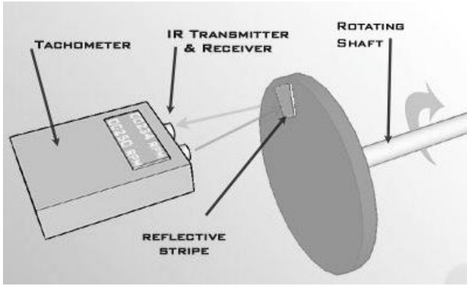

Fig 3: Tachometer Illustration

There are two external interrupt pins on the ATmega328 INT0 and INT1, and they are mapped to pins 4 and 5. These interrupts can be set to trigger on RISING or FALLING signal edges, or on low level. In the proposed setup, a falling edge was used to trigger the interrupt.

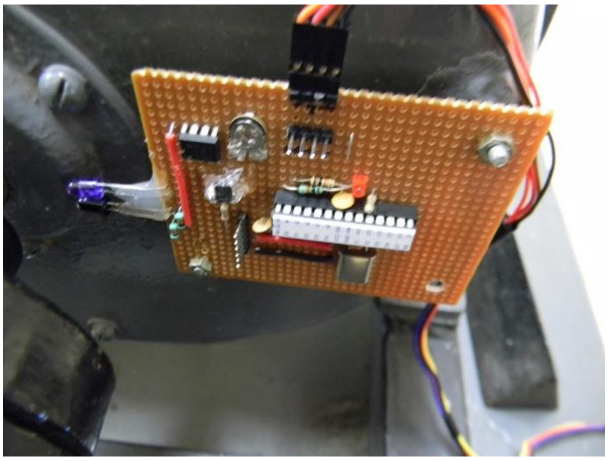

Fig 4: The developed tachometer mounted on the motor

The formula used to calculate the RPM is as follows:

$$RPM = \frac{RPM_{counter} * 60 * 10^6}{(Up\_time - Loop\_Time)} \quad (1)$$

where, the RPM$_{counter}$is incremented everytime the Photo-sensor picks up a rotation of the shaft. Up_time returns the running time of the system in microseconds and Loop_time returns the time elapsed since the last calculation of RPM.

The following algorithm has been developed for the tachometer module:
Step 1: Start a timer (Up_time) to measure the running time of the module.
Step 2: Initialize the interrupt counter (RPM$_{counter}$)to count the pulses and a timer (Loop_Time) to measure the loop time between calculations of RPM.
Step 3: When the RPM$_{counter}$reaches 10, stop the interrupt counter and calculate the RPM by using equation 1.
Step 4: Reset the RPM$_{counter}$ and set the Loop_Time = Up_time.
Step 5: Send the RPM over the I^{2}C Bus to the DAQ and wait for the response from DAQ.
Step 6: If response is true reinitialize the interrupt counter and goto step 3.
Step 7: If response is false, stop.

2.3 Temperature Sensor

The Temperature Sensor used in this work is Texas Instrument's high precision sensor, the TMP175. It has a two-wire interface, and comes in a small SOIC package. It requires no external components and is capable of reading temperature with a resolution of 0.0625°C or 12 bits.

The TMP175 is I^2C configurable with 3 address bits as user settable. This allows interfacing of upto 27 devices on the same bus. It is specified for operation over a temperature range of −40°C to +125°C. The block diagram of the sensor is as shown in fig 5.

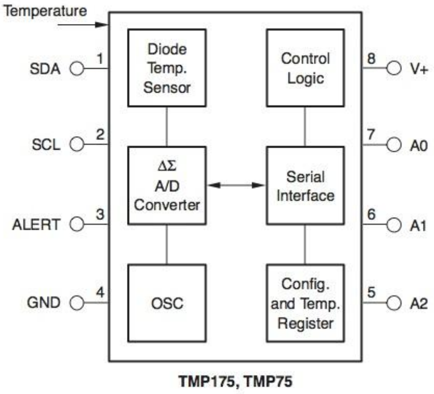

Fig 5: Block diagram of TMP175 Temperature Sensor

The plots of the conversion time versus temperature and the accuracy versus temperature are shown in fig 6a & 6b respectively. It can be seen that the conversion time is very fast (less than 250 ms) and the accuracy (99%) is also constant over a range of temperature.

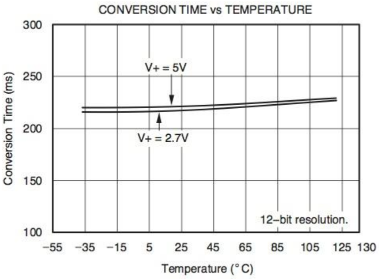

Fig 6a. Plot of conversion time versus temperature

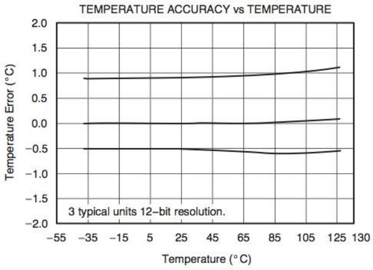

Fig 6b. Plot of temperature accuracy versus temperature

Two Sensors have been used in the proposed setup, one for motor temperature and the other for ambient temperature. The Motor temperature sensorhas been placed inside the motor, next to the stator windings as shown in the fig 7.

Fig 7: The temperature sensor inside the motor

2.4 CT and PT Module

The CT Module makes use of Hall Effect Sensors to monitor all the currents of the test set up. Two different sensors have been used, one for the field current with a maximum current rating of -5A to +5A, and the other sensor with a rating of -30A to +30A.

The block diagram of the hall-effect sensor is shown in fig. 8.The sensor device (ACS712) consists of a precise, low-offset, linear Hall circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which the Hall IC converts into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for a specific accuracy.

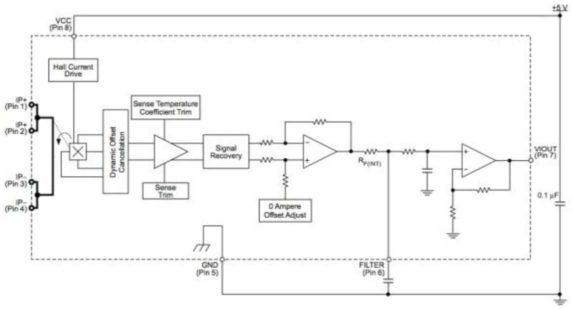

Fig 8: Block diagram of the Hall Effect Sensor

The output of the device has a positive slope ($>V_{IOUT}$) when an increasing current flows through the primary copper conduction path, which is the path used for current sampling. The internal resistance of this conductive path is 1.2 mΩ, providing low power loss. The thickness of the copper conductor allows survival ofthe device up to 5 times the rated conditions. The terminals of the conductive path are electrically isolated from the signal leads. This allows the sensor to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques. The output of the Hall sensor is fed to the ADC of the micro-controller.

A potential divider is used as a PT to get the values in the range of the ADC (0 – 5Volts). The formula for the calculation is:

$$V_{\text{out}} = \frac{R_2}{R_1 + R_2} \cdot V_{\text{in}} \quad (2)$$

Two voltage ranges have to be taken for the machine system, i.e. for full-scale range of 0-250 V_{DC} and 0-30 V_{DC} for the Armature Resistance calculation.

For 250V_{DC} max, taking R_1 = 47k ohm and R_2 = 1k ohm, gives a voltage range of 0 to 5.2 V. But since the ADC can read max up to 5V, the actual range of measurement is 0 – 240V DC. It has a sensitivity of 20mV output per input voltage.

Similarly for 30V_{DC} max, taking R_1 = 4.7k ohm and R_2 = 1k ohm, gives a voltage range of 0 to 5.263 V. And the actual range of measurement is 0 – 28.5V DC. It has a sensitivity of 175mV output per input voltage.

The advantage with Hall Effect Sensors is its ability to measure both AC as well as DC Currents with negligibleerror, and therefore the same setup can be used on both AC and DC machines.

2.5 Lab VIEW

A VI has been developed in LabVIEW. It makes use of the sub VI developed to acquire data from the custom developed DAQ card. It queries the DAQ for data and further communicates with the devices on the I^2C Bus, namely temperature sensor & the tachometer. The front panel of the VI is shown in fig 9.

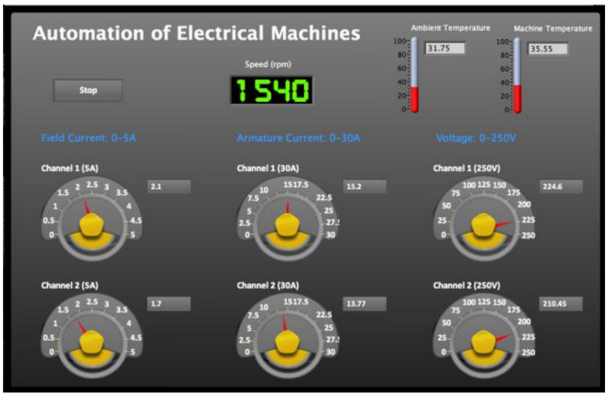

Fig 9: Lab VIEW Front Panel

Various functions have been used in the development of the VI. Since the data is transmitted as 8 bits on the I^2C bus, 2 bytes are read for a single data (integer type). These 2 bytes are then joined by the function Join Number.

The VI displays the speed of the set, the temperature of the machine set and the ambient temperature. It also displays the field current, armature current and voltages (2 channels for each). The block diagram of the VI is shown in fig 10.

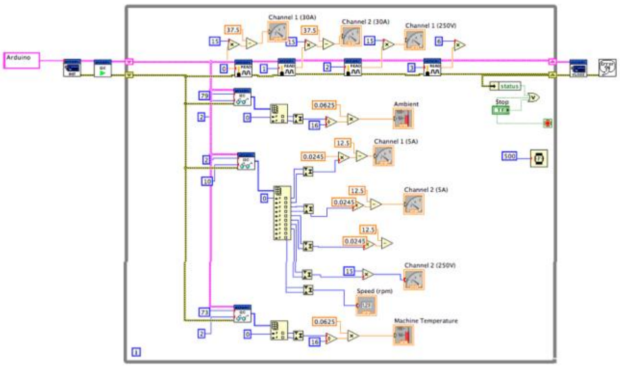

Fig 10: LabVIEW Block diagram

3. RESULTS & ANALYSIS

Hardware has been developed consisting of a DAQ Card to communicate with LabVIEW, CT Module to get the field & armature current, PT module to get load & supply voltage, a contactless tachometer for the speed and temperature sensors for ambient & room temperature.

Input Terminals are provided for easy removal or replacement of the wires coming from the motor-generator set. The complete hardware has been placed in an insulated box and an LCD has also been provided to get the instantaneous readings on the module itself. The developed module is shown in fig 11.

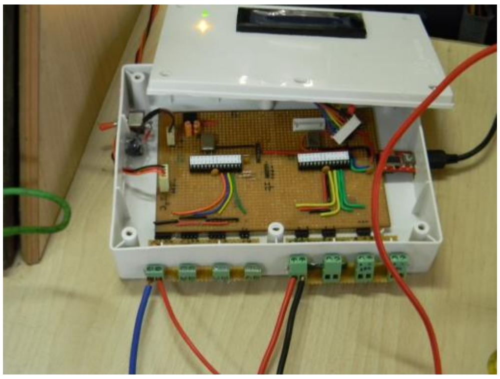

Fig 11: The developed module

The tachometer module has been fully calibrated and tested. It has shown a very low error rate (<1%) as measured against a standard contactless tachometer. The fig 12a & 12b show the deviations and error rate, for the developed digital tachometer.

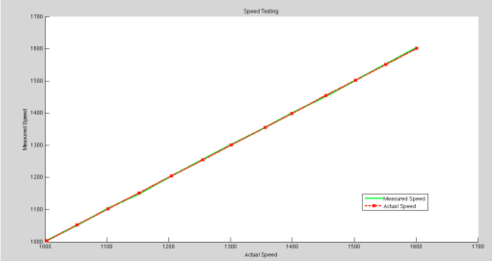

Fig 12a. Plot of Measured Speed versus Actual Speed

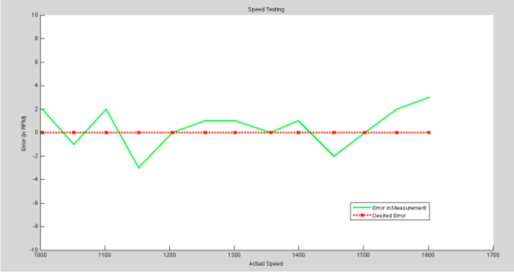

Fig 12b. Error (in RPM) versus Actual Speed

The CT & PT modules have also been calibrated &tested. The plot of output voltage of the sensor versus the sensed current is shown in fig 13 (a). The output voltage varies between +1.5V to +3.5V for a primary current of -5Amp to +5Amp. The sensitivity of the field current sensor is 185mV/Amp and that of armature current sensor is 66mV/Amp as shown in fig13b.

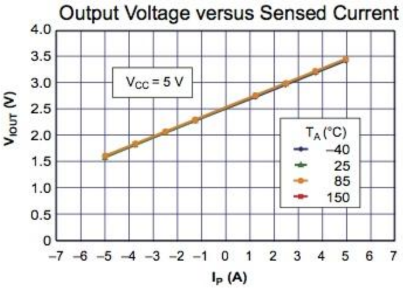

Fig 13a Output voltage versus current

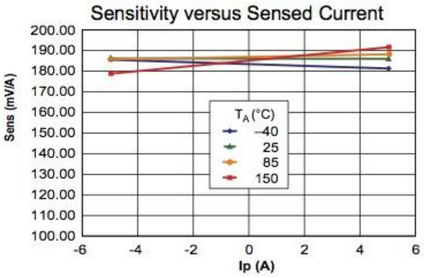

Fig 13b. Sensitivity of the Hall Sensor

The PT module with the selected resistance values has an actual scale of 0-240V and 0-28.5V for the performance testing and armature resistance calculation respectively. It is shown in table 1. It has a sensitivity of 20mV per input voltage. The error in measurement of the CT & PT module has been found to be less than 1% as tested against standard meters.

Table 1: PT Measurement Scales

	Max Scale (Volts)	Actual Scale (Volts)	Resistance (ohms)	Sensitivity (/V_{out})
1	0 – 250	0 – 240	$R_1 = 47k$ $R_2 = 1k$	20mV
2	0 – 30	0 – 28.5	$R_1 = 4.7k$ $R_2 = 1k$	175mV

A comparative study of the previous works[5,7,13,14] has also been done. The in-house developed DAQ Module has the advantage that it has been custom designed to be used in the machines environment and can directly measure the electrical quantities such as current, voltage and other parameters like speed and temperature. Majority of the solutions for the automation of machines cost about $20,000 whereas the proposed method shall cost about $1000, which is just 5% of the cost of the other methods. This justifies thatthe proposed system is the most cost effective solution for System Automation.

4. CONCLUSIONS

This paper presents a novel, accurate and cost effective method for the automation of electrical machines. It introduces electronic measurement and computer-aided tools to the testing of electrical machines.

With the developed system, precise and accurate testing can be performed and the data can be used for analysis or further research. It also allows an individual to work in the electrical machine environment without the risk of any shock or electrocution. The developed hardware follows a modular approach and thus allows for easy expansion and portability to other machines to carry out other test regimes.

This work helps engineers, researchers & industries to incorporate and work with state of art technology, which could be a milestone for the overall progress of the system in the direction of automation.

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