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MEASUREMENT OF A DC SERIES MOTOR TORQUE BASED ON PLC TECHNIQUES

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ABSTRACT:

In this paper, a system is established and designed for DC series motors torque measurement based on PLC (Programmable Logic Controller) techniques instead of using old traditional mechanical methods. The researchers tried to exploit the techniques available in PLC type LOGO! ® V6 to design the above mentioned system which measures the torque with a simple method. Measuring the torque in this system is based on two parts, the first part is to measure the supply voltage, current and speed of the DC series motor by Hall Effect sensors, then enters these values to the PLC. The second one is to calculate and process the torque of the motor depending on the mentioned above values by building a representative model based on mathematical equations representing the operation of the DC series motor. By comparing the results of both methods, it shows that the results are approximately the same but our system is much easier than the traditional systems. Our system contains a subsystem which enables the operator to monitor the mechanical output power and the percentage efficiency of the motor during its operation. To protect the operator and the motor from the risky situations of overload and over speed, which often happens when operating DC series motors, an overload and an over speed protections were included in our system.

KEYWORDS:

DC Electrical Machines, PLC, Hall Effect sensors.

قياس عزم محرك التوالي للتيار المستمر بالإعتماد على تقنيات المتحكمات المنطقية القابلة للبرمجة

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المستخلص:

تم في هذا البحث تصميم وتنفيذ منظومة لقياس عزم محركات التوالي للتيار المستمربإستخدام تقنيات المتحكمات المنطقية القابلة للبرمجة بدلا من إستخدام الطرق الميكانيكية التقليدية. قام الباحثان بالإستفادة من التقنيات المتوفرة في المتحكم المنطقي القابل للبرمجة نوع LOGO! V6.0 في تصميم المنظومة المذكورة والتي تمتاز بدقّة وسهولة القياس.إن قياس العزم في هذه المنظومة يكون بجزئين، الجزء الأول يتم فيه قياس قيم تيار وسرعة المحرك وجهد المصدر بإستخدام متحسسات HALL EFFECT، وإدخال هذه القيم الى المتحكم المنطقي القابل للبرمجة، أمّا الجزء الثاني فيتم فيه حساب قيم العزم إعتمادا على هذه المتغيرات من خلال بناء أنموذج تمثيلي مبني على معادلات رياضية تمثل عمل محرك التوالي للتيار المستمر، وقد تمت مقارنة نتائج قياس عزم المحرك لهذه المنظومة مع نتائج القياس بالطرق الميكانيكية التقليدية لنفس المحرك، فأظهرت نتائج هذه المنظومة تقارباً كبيراً مع نتائج الطرق التقليدية مع سهولة واضحة في القياس. تحتوي هذه المنظومة على نظام يمّكن المستخدم من معرفة قيم القدرة الميكانيكية الخارجة للمحرك وكذلك كفاءة المحرك آنياً أثناء دوران المحرك. ولحماية المستخدم والمحرّك من أخطارحالتي تجاوز الحمل وإنفلات سرعة المحرك- والتي غالبا ما تحدث عند إستخدام محركات التوالي للتيار المستمر- فقد تم تجهيز المنظومة بنظامين للحماية من السرع العالية وحالة تجاوز الحمل.

1. INTRODUCTION

With the rapid changes in the industries and information technologies during recent years, control, monitoring and calculations of all information have been performed through the use of computers. PLCs are widely used in industrial fields because they are inexpensive, easy to install and very flexible in applications. A PLC interacts with the external world through its inputs and outputs [1]. In this research, a laboratory solution was provided for estimating the torque of a DC series motor without using the classical mechanical methods, but implementing the programmable control devices. In such cases, a control unit involving a PLC must be added to the system structure in order to make it a PLC-based monitoring and control system for estimating the torque of a DC motor. It describes the design and the implementation of the configured hardware and software. The test results obtained on DC motor performance show improved efficiency and the accuracy is increased in torque measurements. Thus, the PLC correlates and controls the operational parameters requested by the user and monitors the DC motor system during operation [2, 3].

DC machine model:

A theory is a general statement of principle abstracted from observation. And a model is a representation of a theory that can be used for control and prediction. For a model to be useful, it must be realistic and yet simple enough to understand and manipulate.

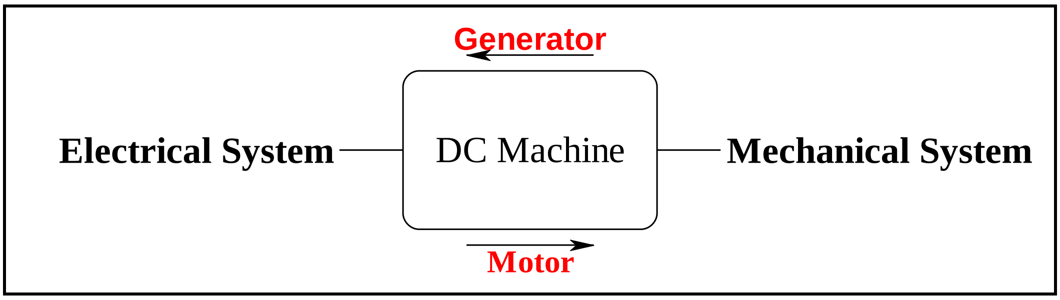

Fig. 1. DC Machine model

The equations of motion for DC motors are as follows [4]:

$$V = L\, dI/dt + RI + K_b\, w \quad (1)$$

$$J\dot{w} = K_T I - v\, w - T \quad (2)$$

Where:

V - the voltage applied to the motor (volts).

L - the motor's inductance (mH).

I - the current through the motor's windings (Amperes).

R - the motor's winding resistance (Ohms).

K_b - the motor's back electromagnetic force constant.

w - the rotor's angular velocity.

J - the rotor's moment of inertia.

K_T - the motor's torque constant.

v - the motor's viscous friction constant.

T - the torque applied to the rotor by an external load (N.m).

The set of equations here, constitutes a model of the DC motor, which may be represented as a linear dynamic system [4, 5].

For DC series motor, the field coil and armature windings are connected in series to the power source. The field coil is wound with a few turns of heavy gauge wire. In this motor, the magnetic field is produced by the current flowing through the armature winding, with the result that the magnetic field is weak when the motor load is light (the armature winding draws a minimum current). The magnetic field is strong when the load is heavy (the armature winding draws a maximum current). The armature voltage is nearly equal to the power source line voltage (just as in a shunt wound motor if we neglect the small drop in the series field). Consequently, the speed of the series wound motor is entirely determined by the load current. The speed is low at heavy loads, and very high at no load. In fact, many series motors will, if operated at no load, run so fast that they destroy themselves. The high forces, associated with high speeds, cause the rotor to fly apart, often with disastrous results to people and property nearby. The torque of any DC motor depends upon the product of the armature current and the magnetic field. For the series wound motor this relationship implies that the torque will be very large for high armature currents, such as occur during start-up. The series wound motor is, therefore, well adapted to start large heavy-inertia loads, and is particularly useful as a drive motor in electric buses, trains and heavy duty traction applications. Compared to the shunt motor, the series DC motor has higher starting torque and poorer speed regulation.

The power output of the motor is defined by the following relation [6]:

$$P_{out} = (1.4 * n * T)/10000 \quad (3)$$

Equation (3) was simplified and approximated as in equation (4)

$$Pout = n * T/9.55 \quad (4)$$

Where:

P_{out} - Output Power in (KW).

n - Speed of motor in (rpm).

T -Torque of the motor in (N.m).

From equation (4), the shaft torque was calculated as shown in equation (5)

$$T_{shaft} = (9.55 * P_{out})/n \quad (5)$$

Implementation of PLC

PLC is a microprocessor-based control system, designed for automation processes in industrial environments. It uses a programmable memory for the internal storage of user-orientated instructions for implementing specific functions such as arithmetic, counting, logic, sequencing, and timing [1, 2]. A PLC can be programmed to sense, activate and control industrial equipment, incorporates a number of I/O points, which allow electrical signals to be interfaced. Input devices and output devices of the process are connected to the PLC and the control program is entered into the PLC memory [3] as shown in Fig. 2.

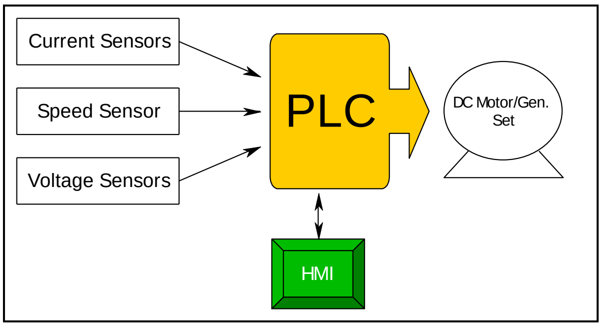

Fig. 2. Schematic of PLC control

In our application, it monitors, calculates and controls through analog/digital inputs and outputs, the varying shaft torque and speed operations of a DC series motor. Thus, the PLC continuously monitors the inputs and activates the outputs according to the control program. This PLC system is of modular type composed of specific hardware building blocks (modules), which plug directly into a proprietary bus, a central processor unit (CPU), a power supply unit, input/output modules and a program terminal. Such a modular approach has the advantage that the initial configuration can be expanded for other future applications such as multi machine systems or computer linking [1]. Fig. 3 shows a section of the PLC simulation of the main program.

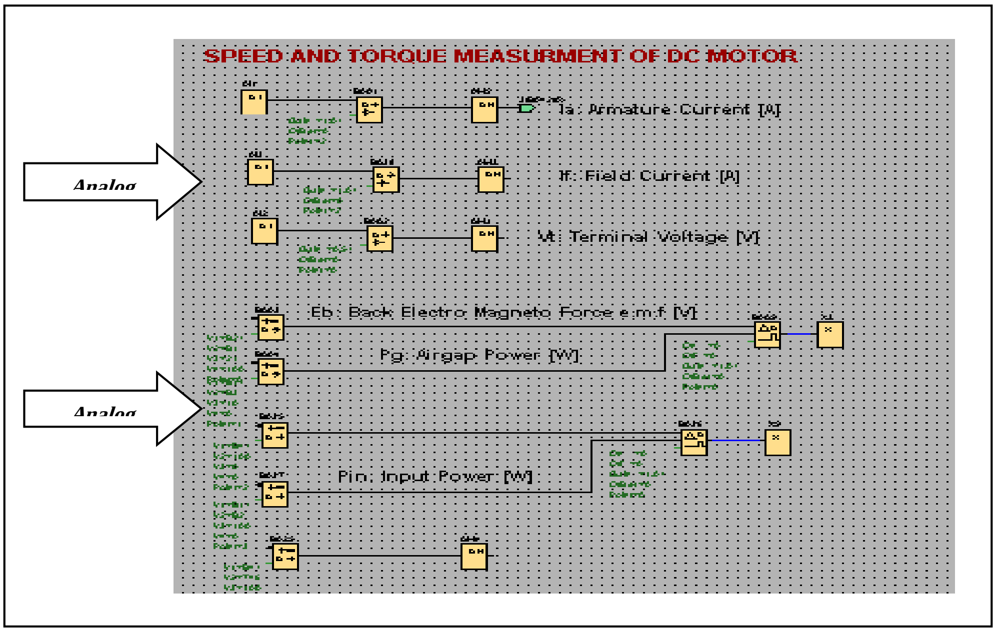

Fig. 3. PLC simulation

As shown in Fig. 3, analog inputs of the PLC are utilized to receive data (I_a , I_f , V_T) collected from Hall effect sensors [9] in the range of (0-10 volts). These data are used to calculate the parameters needed in order to get the values of shaft torque, efficiency and output power of the series motor under test. The speed of this motor is collected from a speed encoder [10] connected on the motor's shaft which its signals, in the range of (0-10 volts) were received also by an analog input of the PLC. The Analog Math Function (available in PLC LOGO! V6) is used to apply the above calculations.

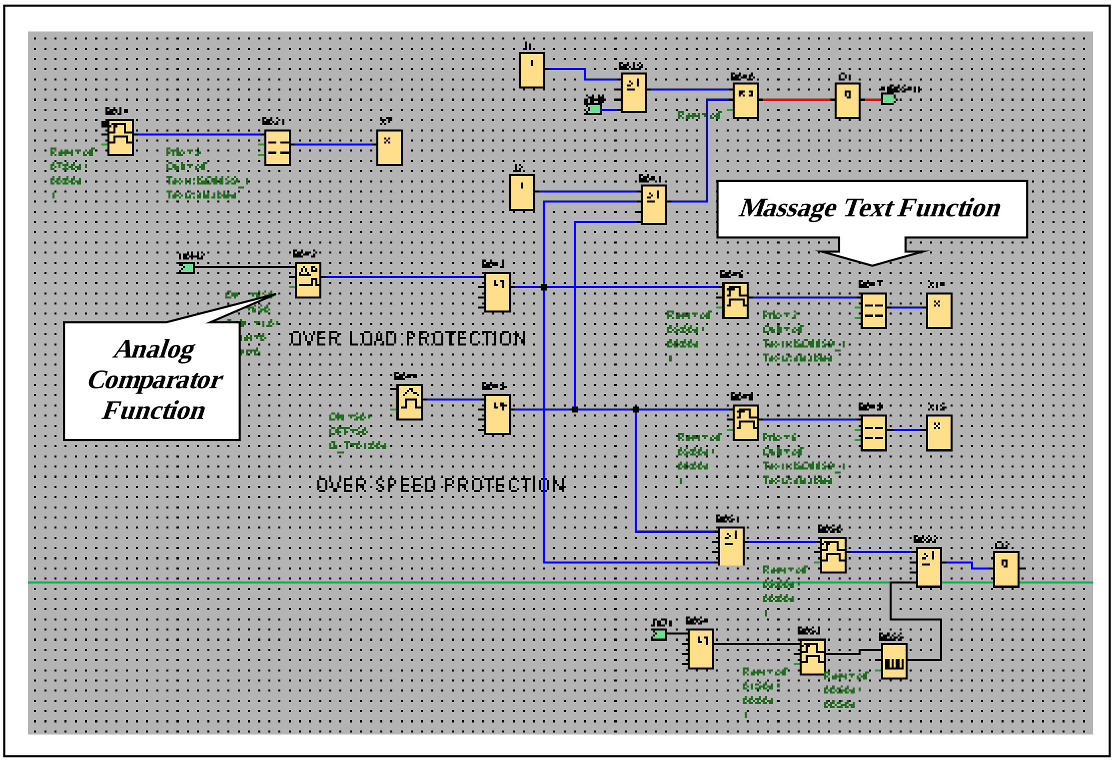

Fig. 4. PLC simulation of overload and over speed protections

Fig. 4 shows two types of protections used in this research:

1. Overload protection.
2. Over speed protection.

These protections are implemented successfully by the analog comparator functions which compare the maximum values of I_a, I_f and N (setting values) with the measured ones by the sensors and operates when they exceed these setting values.

Massage Text function displays massage texts and parameters of other functions on the HMI when PLC is in RUN mode as shown in Fig. 4. It displays also warning massages, flashing signals, date and times of operations and bar curves [1].

The program of the PLC is illustrated by the following flowchart in Fig. 5:

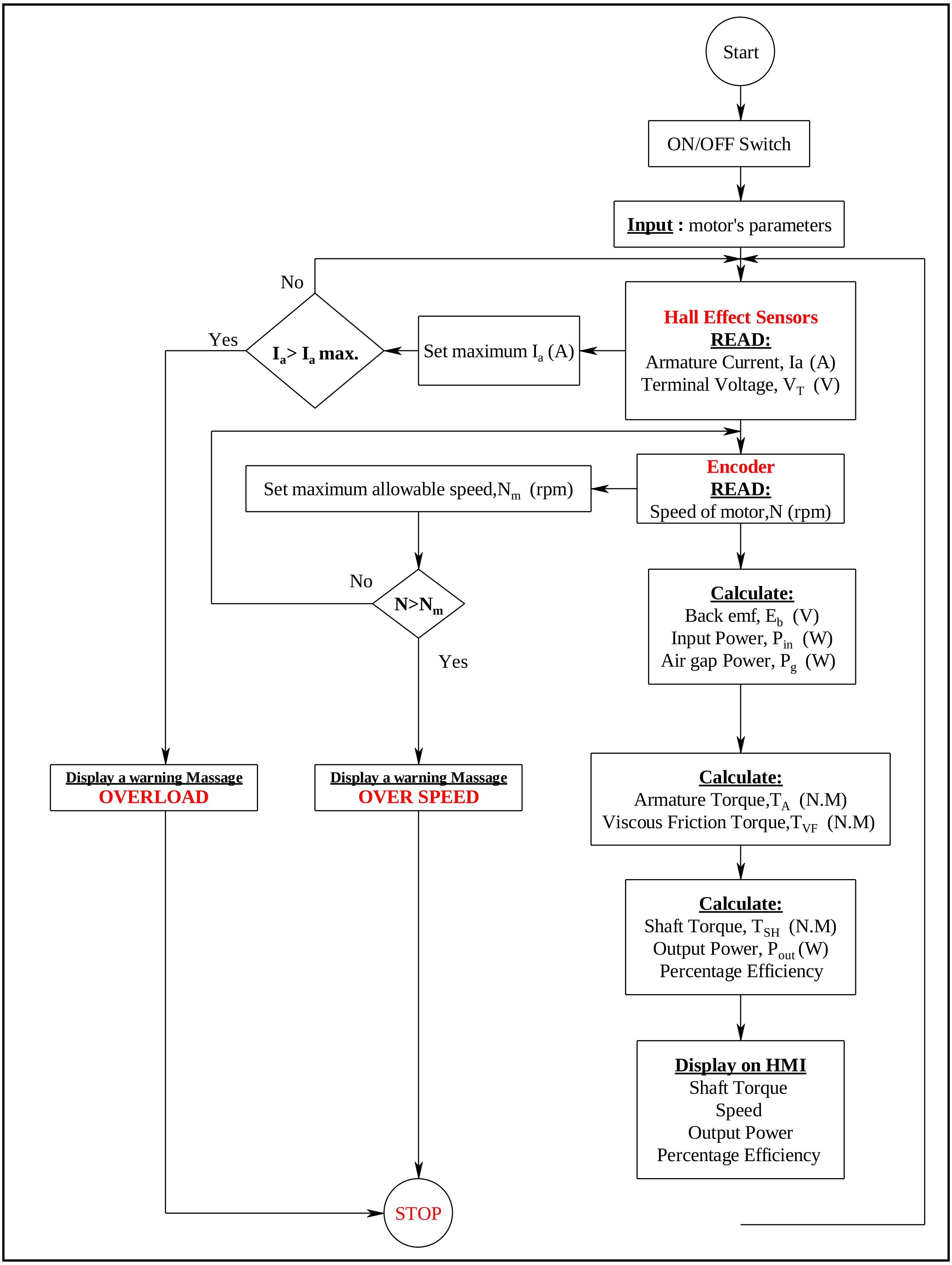

Fig. 5. Flowchart of main program

2. EXPERIMENTAL SETUP

The experimental circuit used to measure the torque of a series D.C. motor is shown in Fig. 6.

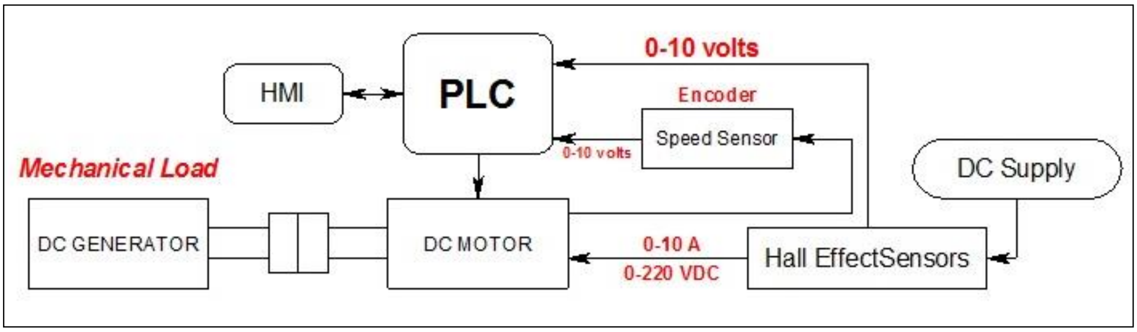

Fig. 6. Schematic diagram of the experimental setup

It consists mainly of:

1. DC series motor whose technical specifications [7, 8] are shown in Table 1.

Table 1. DC motor technical specifications

Name	Rated Value
Power	1KW
Voltage	200 volts
Speed	1500 rpm
R_a	5.975 Ω
L_a	60.79 mH

2. DC generator coupled with the DC motor to apply the mechanical load.
3. PLC LOGO! V6 and its software from SEIMENS with the following technical specifications [1] as shown in Table 2:

Table 2. PLC Technical Specifications

Block type used	Number (used)	Resources (with expansion)
Digital Inputs	2	8 (16)
Analog Inputs	5	2 (8)
Digital Output	2	4 (8)

4. Human Machine Interface (HMI) [1, 3] to establish interaction between the operator and the system.
5. Hall effect sensors [9, 10].
6. Speed encoder [10].

Our experiment had been applied by a machine laboratory unit equipped with a PLC basic unit, its extension modules and an HMI. This unit was constructed in our institute by the team of machines laboratory as shown in Fig. 7 in order to apply all DC electrical machines experiments.

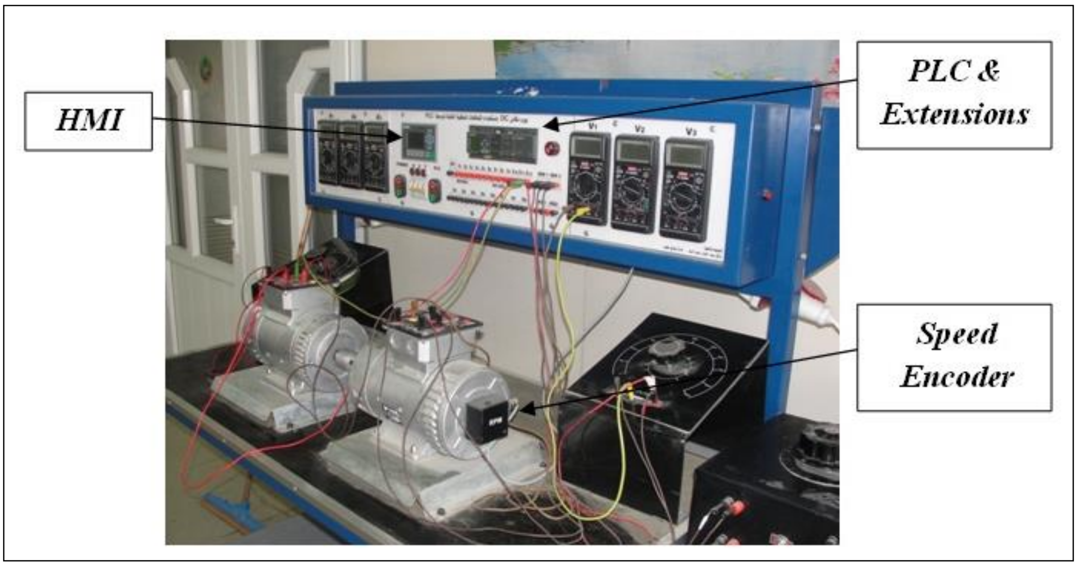

Fig. 7. The laboratory unit

As shown in Fig. 8, the speed in (rpm) and the shaft torque in (N.m) of the motor can be read instantaneously (online) so the operator or the student can read them at any moment during the operation.

Fig. 8. Display output (HMI)

Fig. 9 shows the traditional laboratory unit (from TERCO) [8] available in our electrical machines laboratory which is used to measure the shaft torque of the same DC series motor mechanically and compare its results with the results of our method.

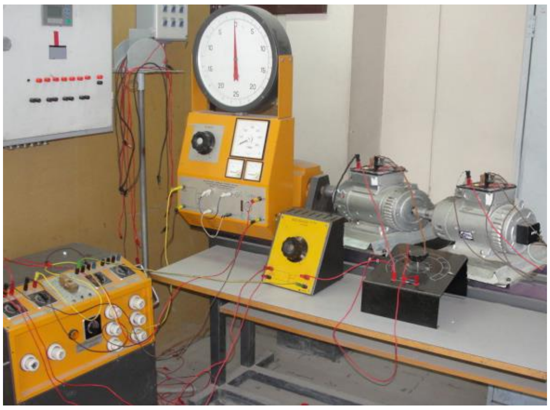

Fig. 9. The traditional laboratory unit

3. EXPERIMENTAL RESULTS

The system was tested during operation at various load conditions, the HMI displays the following variables online:

1. Shaft torque of motor in N.m
2. Speed of motor in rpm
3. Percentage efficiency of motor
4. Output power of motor in KW

Figs. 10, 11 and 12 show the relations between the shaft torque with the speed, output power and efficiency of a DC series motor also comparing the mechanical measurements with PLC ones, sketches of the various values of variables were performed in the Excel environment. Fig. 10 shows higher values of torque in case of PLC system for the same speed.

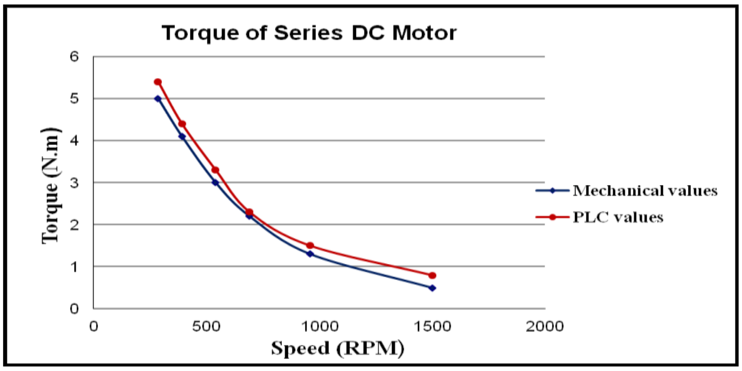

Fig. 10. Torque / Speed Relations

As shown in Fig. 11, power output of the motor in case of PLC system is higher than of those in case of mechanical system.

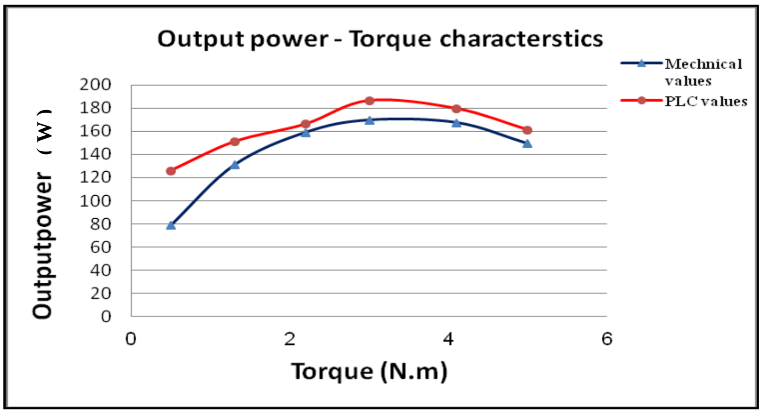

Fig. 11. Power Output/Torque Relations

The relation between efficiency of the motor and the torque is shown in Fig. 12. It shows that the efficiency of the motor increases in case of PLC system. The increasing values in the torque, output power and efficiency of the motor when implementing the PLC system are due to the decreament in the mechanical losses which are avialable in the traditional (mechanical) system for measuring the torque of the series DC motor.

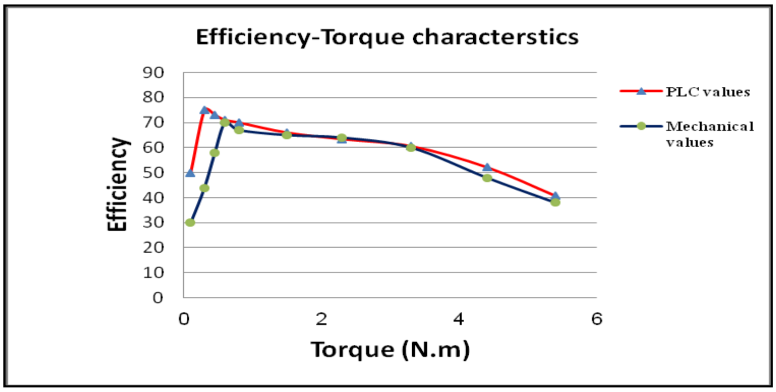

Fig. 12. Efficiency% vs. Torque

4. CONCLUSIONS

Successful experimental results were obtained from the previously described scheme indicate that PLC can be applied in educational laboratories. The recent study revealed that measuring torque with PLC-based control system is affordable and satisfactory. Despite the simplicity of the previous method used, this presents:

1. Measuring the shaft torque of series DC motor by PLC without using any mechanical tool.
2. Higher efficiency.
3. Economically low cost.

5. ACKNOWLEDGEMENTS

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