AN AUTOMATED NOVEL SYSTEM FOR DETERMINING THE CHARACTERISTICS, LOSSES AND EFFICIENCY OF DC MOTORS

Puneet KAUR* **S.CHATTERJI****
* Assistant Professor, Department of Electrical & Electronics Engineering, UIET, Panjab University, Chandigarh, India.
E-mail: puneet2379@yahoo.com
**Prof & Head, Department of Electrical Engineering, NITTTR, Chandigarh, India.
E-mail: chatterjis@yahoo.com

Abstract: *This paper provides essential information on a research completed with the aim to develop a 'dc motor test and analysis platform' which can be used to provide motor characteristics, calculate losses and efficiency, and also work as a dc motor speed controller. User can test a given dc motor for these analyses by practicing different conventional methods, but, the concept discussed in this paper, reveals how intelligently integration of all these analyses can be done with a single user friendly automated setup. Integration has been accomplished by a technique that can accommodate all types of dc motors with different ratings at various loading conditions. The embedded platform has been developed using an external interface hardware based on AVR microcontroller, a data acquisition circuit, and a graphical programming environment (visual basic).Experimentally measured results on 0.5HP dc motors using the same platform are also presented in this paper. With successful development of 'dc motor test and analysis platform', authors, through this paper aim to extend an overview on this novel concept.*

Key words: *data acquisition, electrical loading of dc motor, efficiency, losses, motor torque, performance-index of dc motor, speed-torque characteristics*

1. Introduction

Whenever the application of any dc machine is considered, its operational performance along with its economical and technical viability is the essential criteria behind its selection. Compatibility of a dc motor for any type of application can be best understood by analyzing their speed-torque characteristics. Idealization of the speed-torque characteristics will result in a model which will not be able to provide an insight to motor's behaviour under different operating conditions. Correct and accurate calculation of losses and efficiency has been established as an important means for detection of faults in the dc motors. Therefore, an essential criterion for deciding the performance-index for dc motors is the knowledge of their speed-torque characteristics, losses (constant and variable) occurring in the motor and measurement of their efficiency.

Review of the conventional methodologies practiced in this field, reveals, that user needs to perform lot of complex analytical and numerical computations to acquire all these performance parameters of the dc motor. Not only this, multiple tests at different loads and different speeds of dc motor is essential to cover the complete operating range of the dc motor with use of such conventional techniques. As the measuring instruments used in the set-up are chosen according to the rating of dc motor, for testing higher (or lower) rating of dc motor, the entire set-up needs to be modified. Similarly, there cannot be universal platform for different types of dc motors. Incorrect manual monitoring and intervention during testing can result in less precise calculations. As a result, if one tries to determine characteristics, losses and efficiency of a dc motor with the existing techniques, the process becomes time-consuming, cumbersome, error prone and tedious[1-4].

In this paper, concept of PC based automated acquisition of characteristics in real-time, calculation of losses, efficiency versus torque curve and closed loop speed control of dc motor is discussed. By practicing this single automated method, various parameters of dc motor e.g. speed, torque, armature current, field current, armature voltage, field voltage, winding temperature variations and dependency of these parameters on each other is closely monitored with help of control hardware and application software. The control hardware presented in this paper is an AVR based embedded system, dedicatedly designed for providing complete automation for evaluation of dc motors. It has been programmed with a firmware, which performs all the tasks necessary to execute a dc motor control application. The developed 'dc motor test and analysis platform' controls the motor input dc voltage/s through SCR bridges, electrically load the dc motor through a dc generator, collect the motor parameters at each loading condition and manipulate the acquired data in PC based software to arrive at the parameters which will define the motor performance[5,6].

2. An automated design of dc motor test and analysis platform

The platform for automating the process of testing of any given dc motor consists of dc motor (under test) coupled with a separately excited dc generator, which is interfaced with the control hardware and PC. The generator itself is electrically loaded by connecting suitable fixed resistance at its terminals. Concept of controlled electrical loading of the dc motor with help of dc generator has been utilized in this research scheme. Authors have utilized the microcontroller's processing power to achieve a precise PID control of motor shaft loading by manipulating the generator field voltage. In this case electrical load on the generator armature is fixed whereas the field voltage of generator is varied by a fully controlled SCR bridge. Any change in motor shaft loading caused by reduction in speed can be compensated by increase in generator field voltage (magnetic field strength) and vice versa.

The control hardware for this system is designed around AVR ATMega32 [7]. It communicates to the PC via RS232 UART(programmed in 115200 bps, 8 bits, no parity, 1 stop bit configuration[8]), acquires different analog inputs e.g. motor current, motor voltage, generator field voltage, speed and winding temperature signals at its 10-bit ADC port after being filtered and conditioned by analog and digital conditioning circuits[9].It drives two fully controlled SCR bridges comprising of 8 thyristors (to generate a controlled dc voltage for motor armature and generator field), has the capability to acquire/drive digital signals and implements PID algorithm for speed control of dc motor[10].Digital outputs of the hardware can be used to drive PWM control or relays. At the same time digital input pins can acquire signals from limit switches, proximity switches or push buttons.

Block level illustration of control hardware [11] is given in Fig.1.

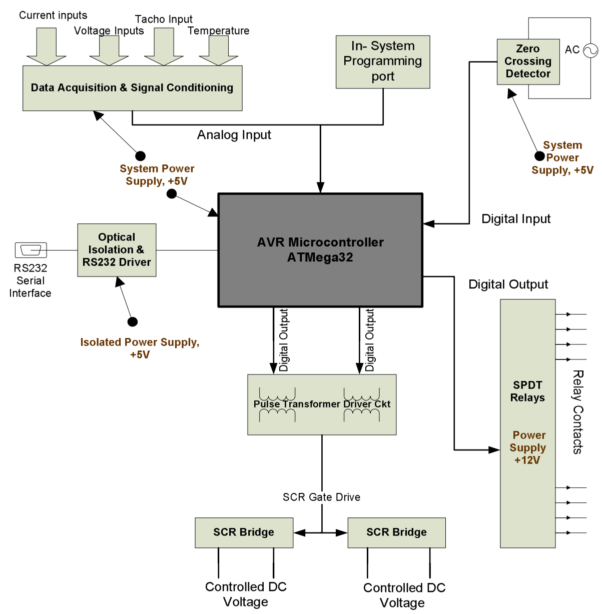

Fig. 1. Block level illustration of design of control hardware

Firmware library designed for the control hardware is a cross platform application and can be easily ported and reused on different microcontroller architectures. Algorithms and peripheral controls have been programmed in discrete functions in order to ease the future expansions and modifications [12]. The three layer architecture of the firmware is shown in Fig. 2.

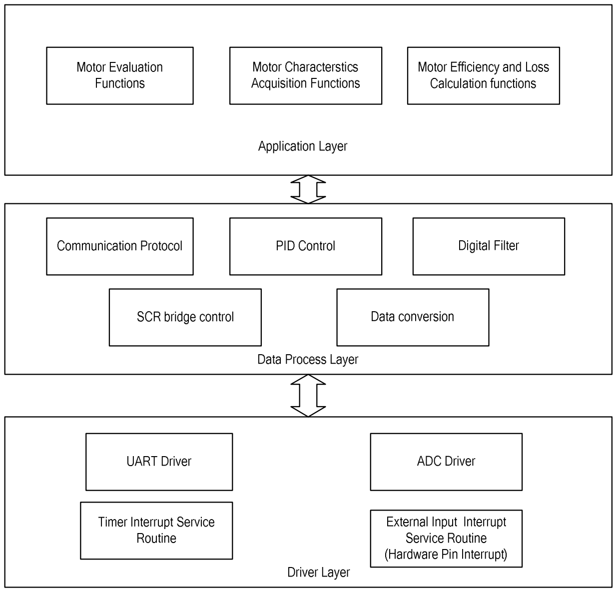

Fig. 2. Modular design of Firmware

A PC program based on Microsoft Visual Basic is designed to provide the necessary interface to the user and also interaction with the hardware [13]. This PC based application software provides graphical user interface(GUI) for choosing different type of tests to be performed, editing/updating information regarding motor set-up, data storage and processing the data received from control card/hardware .Application software has been designed and developed in a two layer model as shown in Fig. 3.

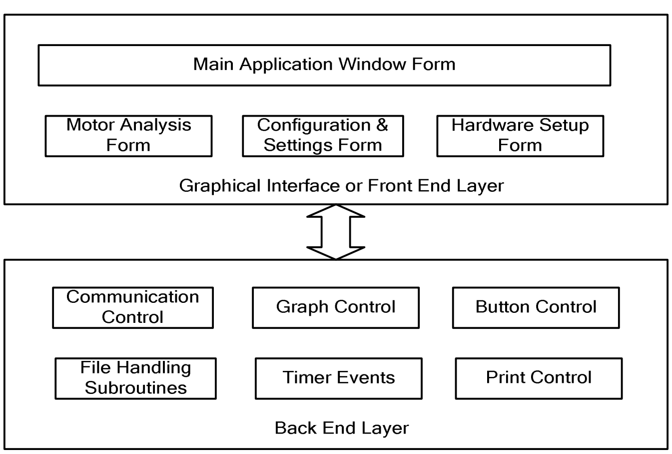

Fig. 3. Software Structure

Complete block diagram for illustration of the discussed automated scheme is given in Fig. 4.

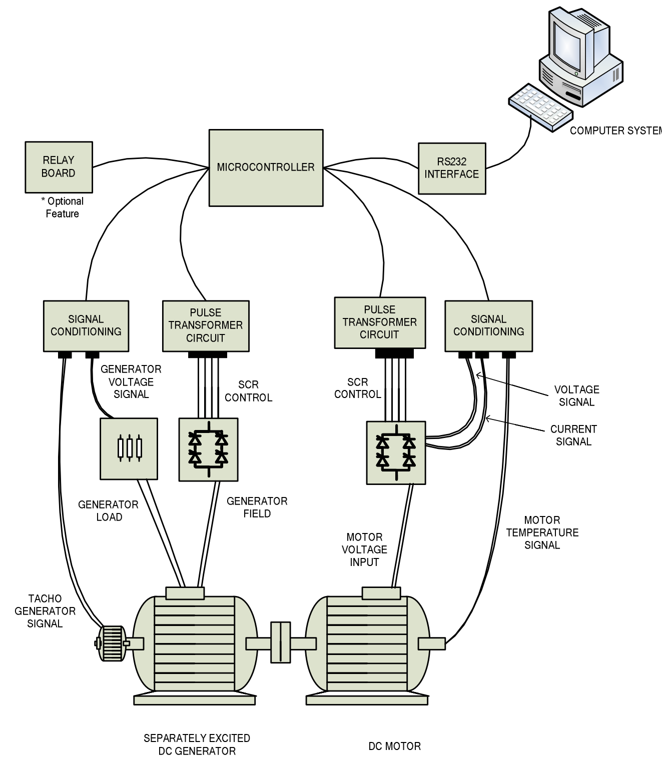

Fig. 4. Block Diagram of the Automated Scheme

3. Execution of various tests

a) Characteristics of dc motor: Initially dc motor is run at maximum speed (rated voltage) and at no-load (generator field turned off). Gradually mechanical load on the motor shaft is increased by increasing the reference (target value) input to the PID control algorithm which controls the generator field. PID algorithm output manipulates the firing-angle of the SCR bridge which in turn controls the voltage being fed to the generator field. Voltage across the armature terminals of the generator (armature terminated with fixed resistor) acts as the feedback signal for the PID control algorithm. The motor parameters e.g. voltage, current, speed, winding temperature, etc. acquired by the microcontroller at predefined intervals during the test, are sent to the PC, where storing in the log file for analysis and plotting of the characteristics are carried out. Calculation of the motor torque from the data provided by the microcontroller is carried out in the PC software using the torque equation.

A common flow chart which describes the functioning of acquisition of all the characteristics is provided in Fig. 5.

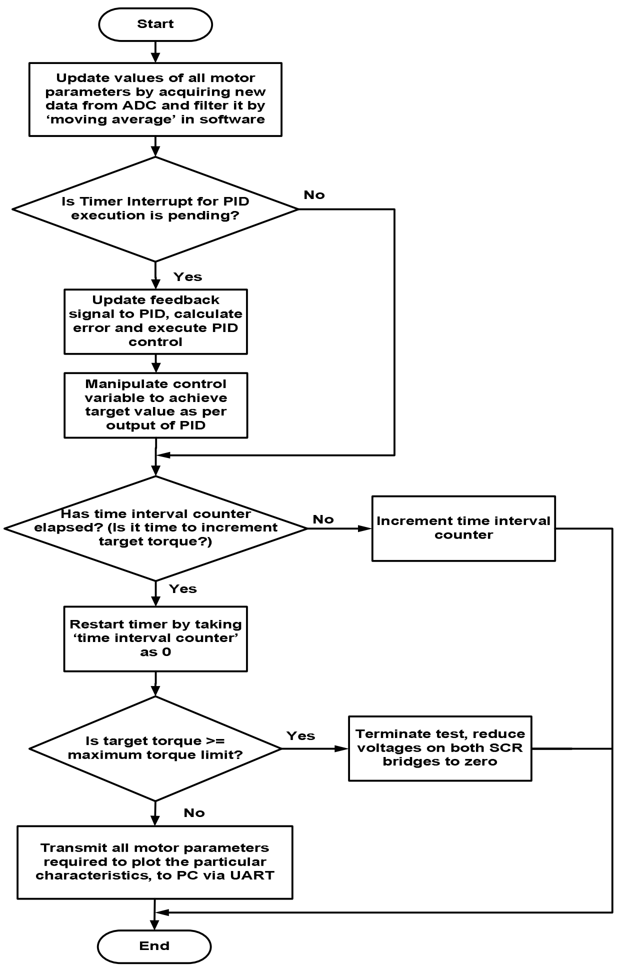

Fig. 5. Flow Chart for Motor Characteristics Acquisition

b) Motor Efficiency and Copper loss: After acquisition of motor parameters e.g. motor voltage, current, speed, winding temperature etc. at predefined intervals of the test; they are sent to the PC for storing in the log file. Calculations for motor torque, copper loss of the motor, power input, power output and efficiency are carried out in the PC software. In this process, losses occurring in the dc generator are also considered to calculate the motor efficiency. This is done in order to ensure correct calculation of the mechanical power delivered by the motor. This is achieved by carrying out the generator calibration (process in which generator constant losses are calculated for different speeds) before conduct of the tests.

Flow chart to describe the calculation of losses and efficiency of dc motor is provided in Fig. 6.

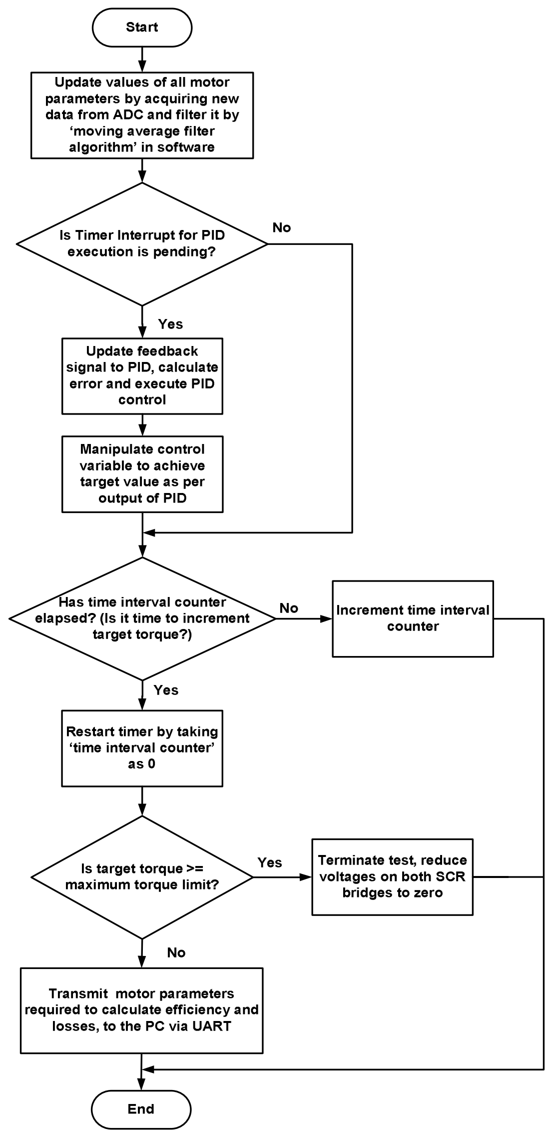

Fig. 6. Flow Chart for Calculation of Motor Losses and Efficiency

c) Motor speed controller: In this mode, feedback signal is acquired from the tachogenerator and the value of firing-angle of the SCR bridge for motor voltage control is manipulated to achieve the desired speed. In this mode a graph is plotted over the time scale along with the motor armature current. Motor shaft loading can also be controlled in this test.

Flow chart to describe the closed loop speed control of dc motor is provided in Fig. 7.

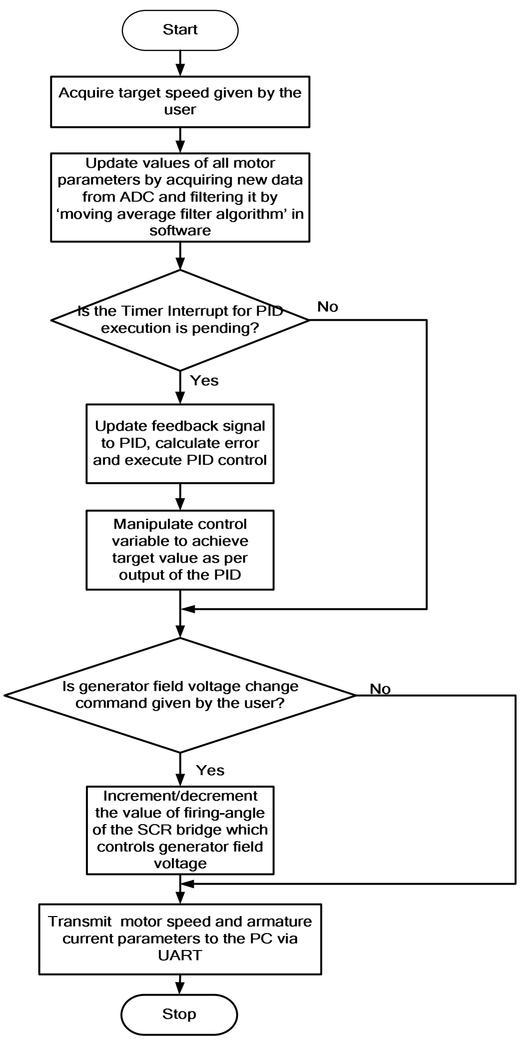

Fig. 7. Flow Chart for Speed Control of DC Motor

3. Automated test results

The system presented in the paper after fabrication was tested and validated using 0.5 HP dc motor-generator (MG) sets. Different analyses (viz. to obtain speed-current, torque-current and speed-torque characteristics curves, to calculate dc motor losses and obtaining efficiency curve, to run dc motor in speed controller mode) were carried out on 0.5HP dc shunt, series, compound and separately-excited motors (practical set-up shown in Figure 8). Results were captured on PC using Visual Basic Application software in form of curves as well as in tabular form so that practical performance of dc motor can be verified with data derived from theoretical calculations and equations. For illustration of the results, sample graphs have been presented in screen shots shown from Fig.9 to Fig. 20.

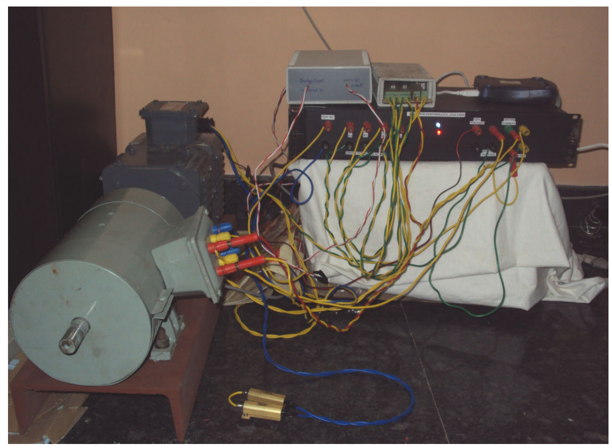

Fig. 8. Practical Set-up for Testing DC Motors

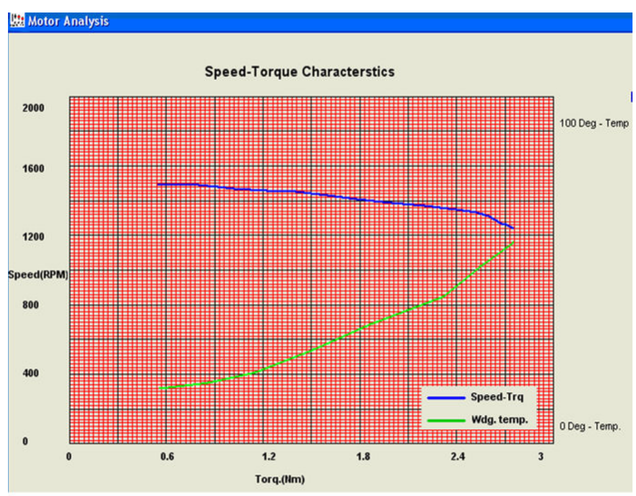

Fig. 9. Screen-shot of Speed-Torque Characteristic of DC Shunt Motor

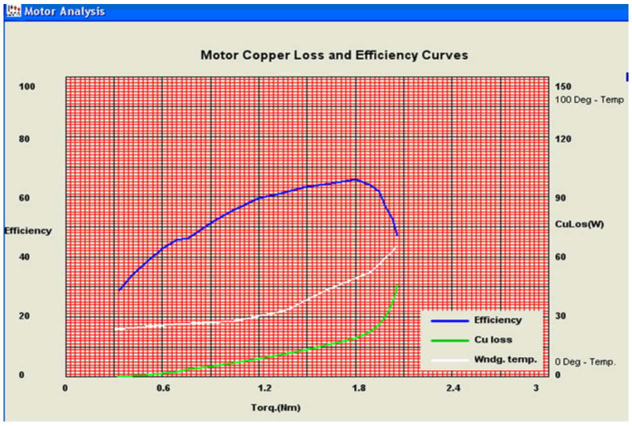

Fig. 10. Screen-shot for Calculation of Losses and Efficiency of DC Shunt Motor

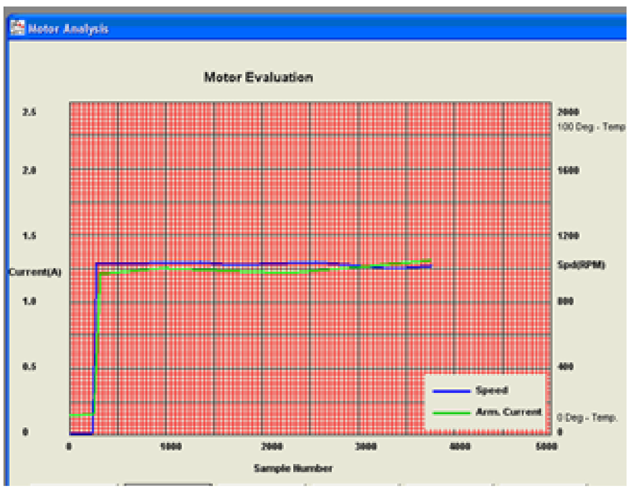

Fig. 11. Screen-shot for Speed control of DC Shunt Motor

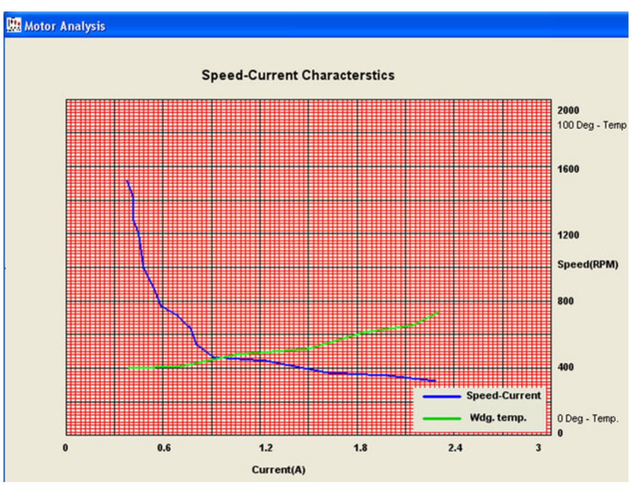

Fig. 12. Screen-shot of Speed-Current Characteristic of DC Series Motor

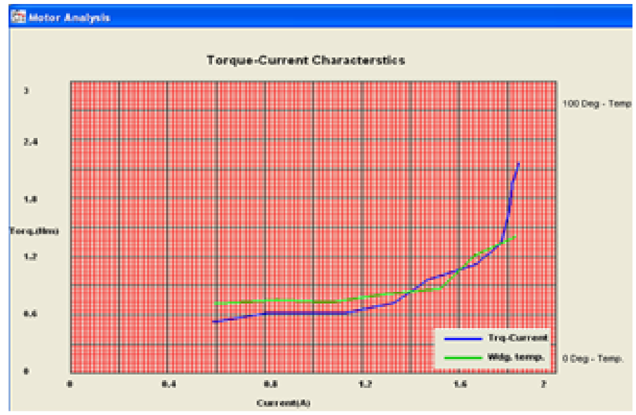

Fig. 13. Screen-shot of Torque-Current Characteristic of DC Series Motor

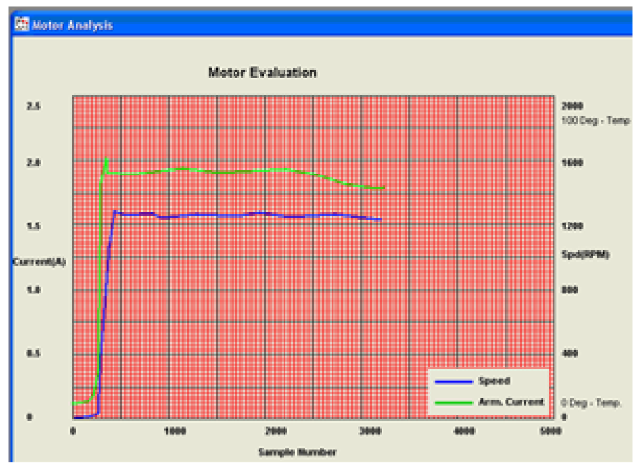

Fig. 14. Screen-shot for Speed Control of DC Series Motor

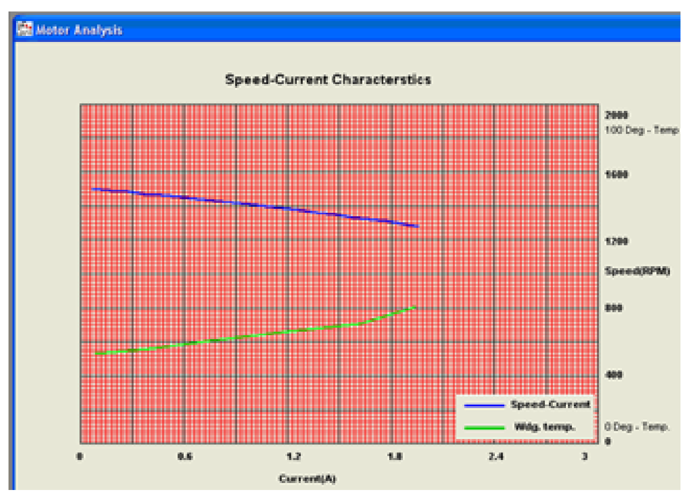

Fig. 15. Screen-shot of Speed-Current Characteristic of DC Compound Motor

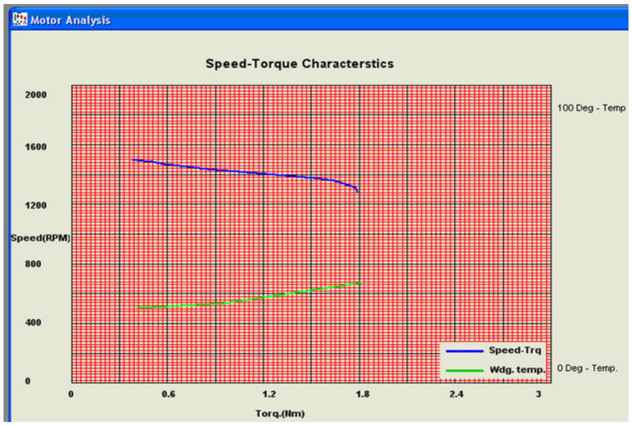

Fig. 16. Screen-shot of Speed-Torque Characteristic of DC Compound Motor

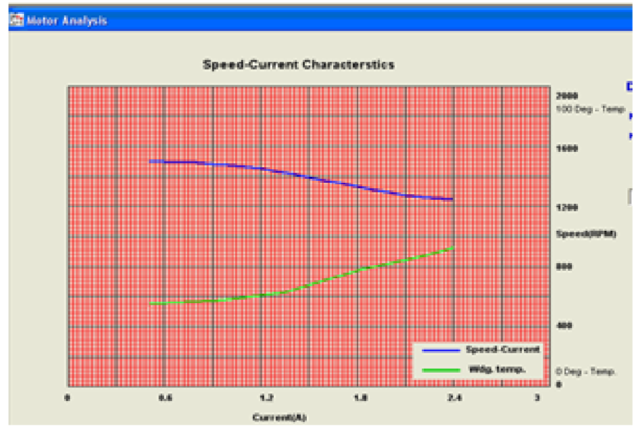

Fig. 19. Screen-shot of Speed-Current Characteristic of DC Separately-excited Motor

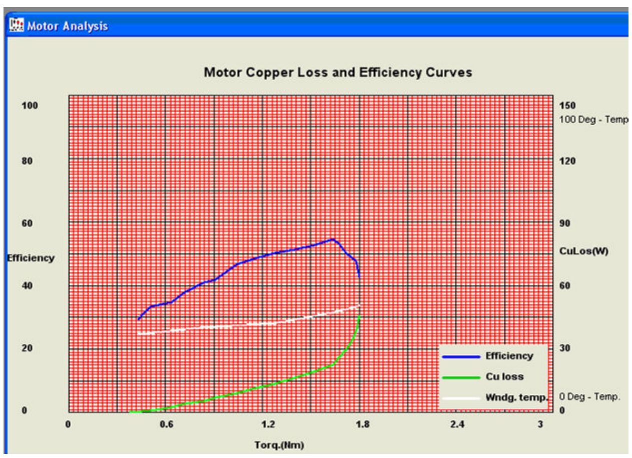

Fig. 17. Screen-shot for Calculation of Losses and Efficiency of DC Compound Motor

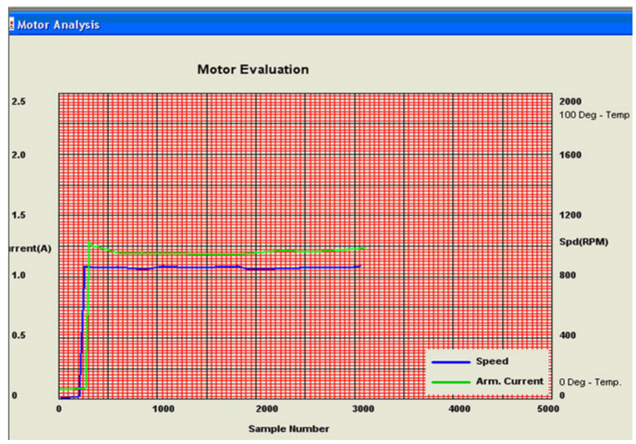

Fig. 20. Screen-shot for Speed control of DC Separately-excited Motor

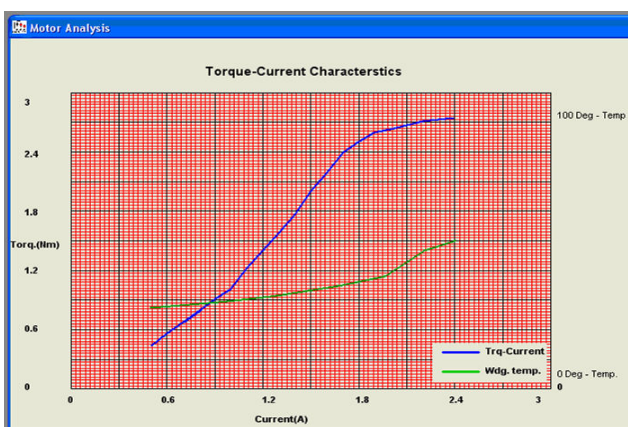

Fig. 18. Screen-shot of Torque-Current Characteristic of DC Separately-excited Motor

4. Discussion

The validity of the test results can also be checked by comparing the test results obtained from this automated procedure with experimentally measured speed-torque characteristics using a conventional set-up. Because of the real time data acquisition and communication capabilities of the control hardware, same set-up delivered successful results for all types of dc motors. The effectiveness and flexibility of technique stands unmatched with other methodologies due to the fact that the same platform can be utilized to automate the process of testing different ratings of dc motors also. Authors have tested dc motor of ratings up to 5HP using the same platform. This justifies the universal behaviour of the novel technique being implemented by the authors in this paper.

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