# Brushless direct current (BLDC) motor driving experimental set

**Article** · February 2011



2 authors:

YASİN BEKTAŞ
Aksaray Üniversitesi


Necibe Fusun Oyman serteller
Marmara University

*Energy Education Science and Technology Part A: Energy Science and Research*
**2011** Volume (Issue) **27(2)**: 455-466

# Brushless direct current (BLDC) motor driving experimental set

**Yasin Bektas, N. Fusun Oyman Serteller***

*Marmara University, Kadikoy , Istanbul, Turkey*

Received 28 November 2010; accepted 29 December 2010

**Abstract**

The aim of the present study is to familiarize students with the parameters of a brushless direct current (BLDC) motor and its driving circuits, with particular emphasis on the dynamic motor behavior from stable working to the transient operating phase. A BLDC motor experimental set and MATLAB real time simulation program are designed and improved to control a BLDC motor's parameters in a laboratory environment. The characteristics of the operating parameters are mathematically and graphically presented in a trial. BLDC motor driving characteristics are given in detail to support students' theoretical understanding. This study is intended to provide to students with all the necessary theoretical knowledge including MATLAB real time simulation program, with the best practical observation on the subject. Furthermore, the driving circuit card is designed and constructed to provide to the students simple, clear and easily understood data for a general overview of BLDC motors.

*Keywords:* BLDC motor; Driving circuit design; Experiment set; MATLAB


## 1. Introduction

Conventional direct current (DC) motors are highly efficient and they can effectively be used as motors. However, due to the presence of commutation and brushes it is subjected to mechanical wear and hence requires maintenance. As time passed the functions of commutation and brushes were implemented by solid-state (semi-conductor) switches, thus maintenance-free motors were realized. These motors on further development gave birth to a special electrical machine known as brushless dc motors. Actually, the usability of BLDC motor has increased for last ten years due to rapid development in semi-conductor and permanent magnetic material technology. The BLDC motors increasingly are being used in computer, automotive, industrial and household products because of its high power density, compactness, high efficiency, low maintains and its common control technology. In this paper the subjects are explained that students are familiar with the basic knowledge of electric motor, driving circuits and computer using skills.

*Corresponding author. Tel.: + 90-216-336-5770; Fax: + 90- 216-337-8583.
*E-mail address*: fserteller@marmara.edu.tr (N. F. Oyman Serteller).

The brushless direct current motor is constructed with three stator or armature windings and a set of pole paired permanent magnet on the rotor (fig. 1(a) and (b)). As the BLDC motor is inherently electronically controlled it is required control and driving unit. The motor drive unit regulates the switching of the direct current supply voltage to the stator winding of the motor. Basically, the motor requires a driving system to supply commutated current to the motor stator windings synchronized to the rotor position. Rotor position is knowable with or without sensor. In these study hall sensors are used [1-5]. In general, BLDC motors are started through two kinds of driver unit, like other small and medium-sized powerful motors: bipolar and unipolar. Some applications a bipolar driver is suggested such as loaded starting. But some application unipolar drive is needed such as high speed requirements. Also some application two circuit driving feature can be needed. In this paper all of them have been taken into consideration. These circuits are quite complex and puzzling to understand electronic devices and their features. In this study both drive application are implemented in the same electronic card to prove and compare the circuit's features in the laboratory environment. The developed driving circuit card has a capability so that it can be used either unipolar or bipolar or both together to understand the each driving effect on the BLDC motor [8].

The laboratory studies in electric machines courses have a great importance because of constructing an active and permanent learning environment. The purpose of this study is to determine encountered difficulties during matching knowledge of electric machines laboratory with electrical machine theoretical information. The purpose of this study is to determine encountered difficulties. A new driving design requirement is prepared to overcome the difficulties of complex theoretical knowledge of BLDC motor faced by students using evaluation of experiences of the teacher, observation of lecturer and background information from students [6, 9, 10].

The experiment set has been developed as possible as simple and understandable and motor parameters have been analyzed to give the ideas for motor operation performances, control and command. In addition all the relationship of the motor parameters is given and an experiment set are realized to show all the control effects on motor [14].

## 2. Mathematical explanations of driving of a BLDC motor

Here, a three phase, star connected and sole wound BDCM was utilized and its required plate values were given Table 1. The BLDC motor uses three winding stator structure and permanents magnets mounted on the rotor (Fig.1 (a) and (b), respectively). The detailed explanation for stator and rotor windings is given in section 3 and 4. The rotor or rotating part of the BLDC motor has high resistivity of both magnet and stainless steel.

**Table 1. Specifications and parameters of BLDC motor**

| Working Voltage | 220 | V |
|---|---|---|
| Power | 550 | W |
| Working current | 2 | A |
| Number of phases | 3 | - |
| Insulation class | F | - |
| Return direction | Clockwise/ visaverse | - |
| Stator | 3 Phased Star con. 2p=4 | - |
| Rotor | 4 Piece and 2p=4 Ferrit | - |
| Weight | 6.5 | kg |

The basic equations of the BLDC motor equations can be explained as follows:

$$T = K_T I_a \quad (1)$$

$$V = I_a R_a + K_E \omega \quad (2)$$

$$T = -\frac{K_T K_E}{R_a}\omega + \frac{K_T}{R_a}V \quad (3)$$

where $K_T$, $K_E$, $R_a$, $I_a$, $\omega$ and $V$ are torque constant, back emf (electro-motive force) constant, resistance and current of the energized windings, rational speed and supplied voltage respectively[5,16]. Table 2 shows the major variables of the BLDC motor driven by a bipolar or unipolar drive in the case of the application same voltage.

(a)

(b)

Fig. 1. BLDC motor stator winding (a) and permanent magnet rotor (b).

It shows the major variables relationship of the BLDC motor driven by a bipolar or unipolar in the case of the application same voltage which is of 33V.

**Table 2. motor design variables of a BLDC motor operated by unipolar and bipolar**

| Motor parameters | Bipolar Drive | Unipolar Drive |
|---|---|---|
| Torque constant | $K_T$ | $(1/2)\, K_T$ |
| Resistance | $R_a$ | $(1/2)\, R_a$ |
| Torque-speed relation | $T = -\frac{K_T^2}{R_a}\omega + \frac{K_T}{R_a}V$ | $T = -\frac{K_T^2}{2R_a}\omega + \frac{K_T}{R_a}V$ |
| Starting torque | $\frac{K_T}{R_a}V$ | $\frac{K_T}{R_a}V$ |
| No-load speed | $\frac{V}{K_T}$ | $\frac{2V}{K_T}$ |

Torque constant and back emf constant of a unipolar drive are half of those of a bipolar drive. This makes the unipolar drive has an advantage over the bipolar drive in the high speed applications. Whereas if the same voltage is applied to motor and operates in the linear range the former input current is larger and the starting torque of the unipolar drive is much smaller than that of the bipolar drive in practice[16].

## 3. Experimental set of the driving circuit of the BLDC motor

The realized education tool of the BLDC motor is shown schematically in Fig. 2. The real set is shown in Fig.3 (a) and (b). The development and prevalence of computer technology and usability for multi purpose aims provides not only speed and economy but also visual and sound opportunity. Especially learning the difficult concepts like motor and motor driving, it is important to use the visual materials effectively, besides educational strategies such as seeing, hearing and talking [17-19].

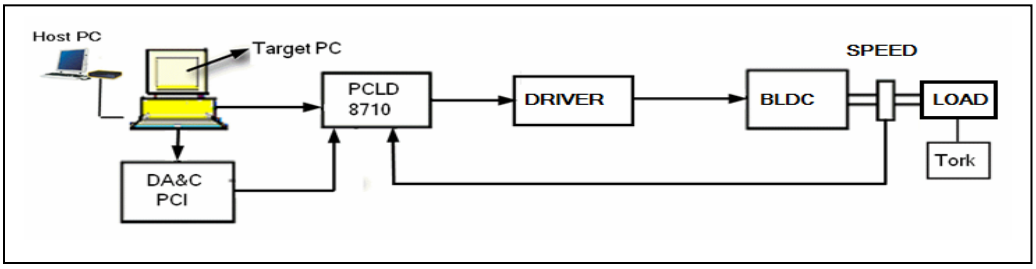



Fig. 2. Schematic diagram of the BLDC motor with its driving circuit and other auxiliaries.

The experiment set of BLDC motor including the loading equipment as an educational tool is presented in Fig.2. Computer assistant learning is a method used to increase the efficiency of traditional educational approaches (lecturers, exercises and laboratories) it is used in a great number of applications in electrical machine education and training [20]. The simulation is used in this study as a type of computer assistant. Simulations provide a model in which the students play a role and interact with the computer. Simulations provide a model in which the student plays a role and interacts with the computer. They are applicable to any field however it is very vital for teaching electric machine drive and can be of significant help in illustrating concepts, in helping students to develop problem solving techniques or in allowing students to explore complex interactions [26-28]. Here, MATLAB software program and PCI data acquisition card (PCI-1711) are used to simulate and to run the motor operating parameters. It also controls motor speed rate and current oscillation as a computer assistant [30 -35]. The developed flow diagram is given in Appendix. Fig. 3 (a) shows complete part of the experiment set and Fig. 3 (b) shows the main components of the experiment set.

One of the most powerful aspects of MATLAB functions is to present useful functions package which are called toolbox. Toolbox covers wide range of application areas such as mathematics, analysis, modeling, data collection, control, signal and image processing and cost modeling so on. These are additional functions and enable us to run in real time on our laptop PC for rapid prototyping or hardware-in-the-loop simulation of control system.

Since control technology of BLDC motor is predominantly explained in this study, special interest is given to driving circuit. It can be explained in three main parts in general. In the first section, a controller that processes the position information coming from the sensors is available with electronic component (MC33035). The position information processed by the controller is used to trigger the six switching element (IRF720) for the bipolar working mode

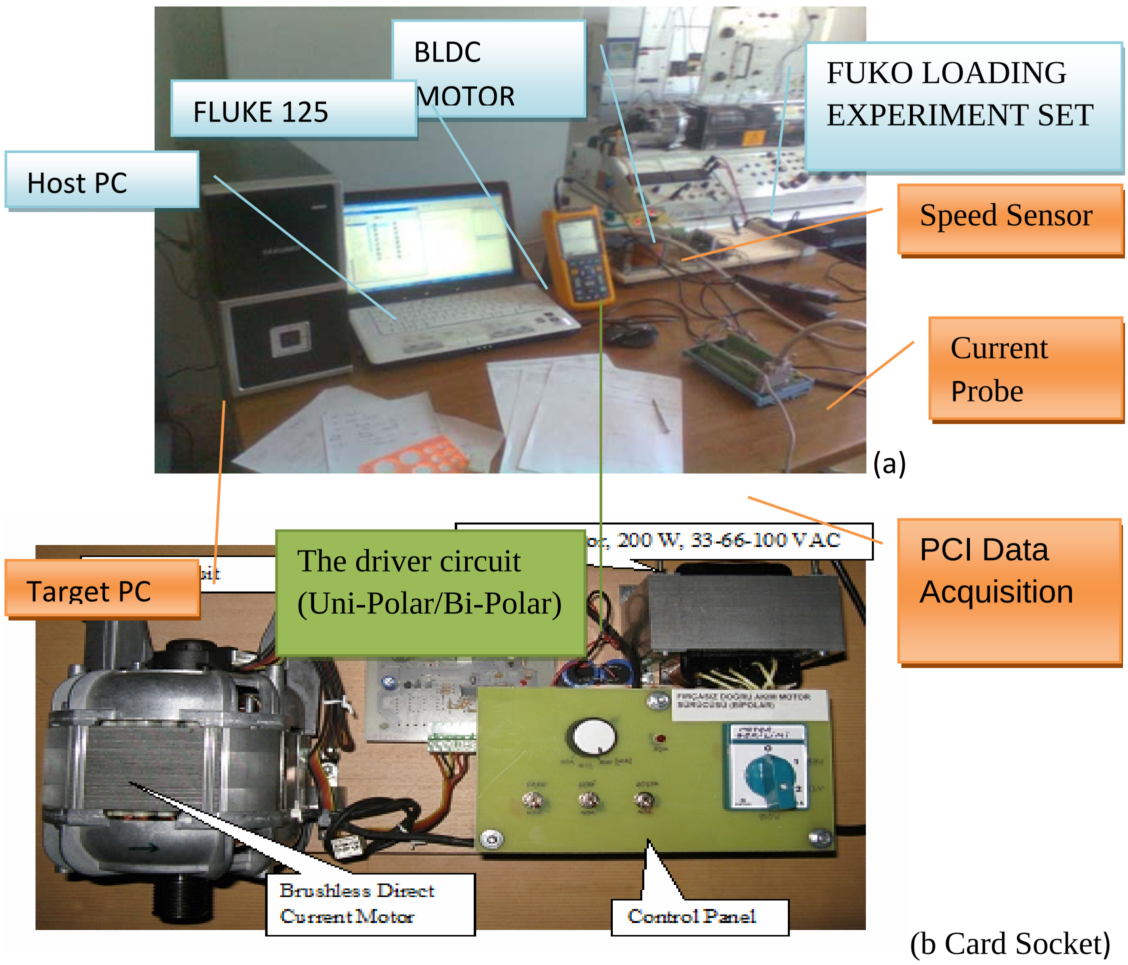



Fig. 3(a). The whole experimental set which includes loading equipment and other auxiliaries, (b) BLDC motor with its driving unit.

and three switching (in some cases this number can be increased) that can be named as second section. The third section in the circuit consists to ensure the insulation of MOSFET drive circuit elements (IR2113) between the section that belongs to the keying elements where the high source voltage is available and the section that belongs to the controller where low voltage is available [21-25] and hall sensors to define rotor position($S_A$, $S_B$, $S_C$).

Terminal voltage is distributed to the motor over the switching elements (MOSFETs) determined and triggered by the controller according to the position of the rotor (Fig. 4).

### *3. 1. Bipolar and unipolar circuit driving system*

Three- phase stator windings (A, B, C) star -connected BLDC motors (Figs. 5 and 6) can be categorized as bipolar or unipolar driving systems like identical other type of motors. Unipolar and bipolar driving methods energize one phase and two phases out of three phases at each commutation period, respectively. Their commutation periods are 60 and 120 electrical degrees, respectively. The unipolar driving system has fewer electromagnetic switches (Fig 1) and a simpler driving circuit and the commutation frequency is half that of

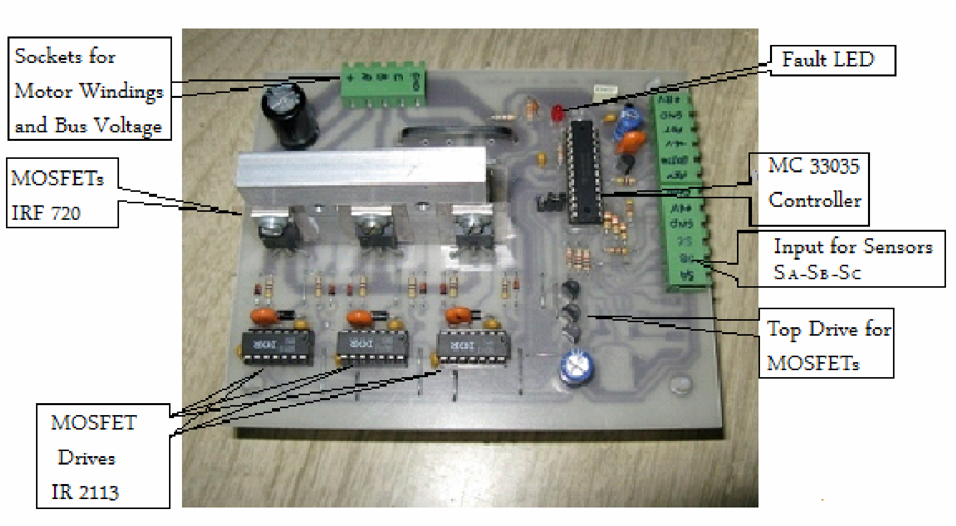



Fig. 4. Driving card of the BLDC motor with its all equipments.

the bipolar driving circuit. A unipolar drive appears to offer advantageous over the bipolar drive. However, during start up operation, magnetic saturation appears due to huge current values, and this causes high torque ripple and lower starting torque. Additionally, it has dead spots like a single phase motor, because the direction of current flows through the phase windings can not be inverted so that it needs more switches to overcome the problems which is being explained next section [16, 29].The current flow direction and current values are given Figs. 6(b) and 7(b). The graphical results of speed of concerning driving circuits are given with comparison in section 4.

*3. 2. Hybrid (Bipolar- starting and unipolar-running) driving system*

The bipolar-starting and unipolar-running method is used to provide high speed with high starting torque, especially when the motor is loaded. As a result, a bipolar starting and unipolar-running driving circuit is thought to combine advantages of bipolar and unipolar driving. In Fig. 7 shows another topology of a unipolar drive with six switches (transistors). Since the unipolar drive use three switches and they can't invert the direction of the current flow with the application of two additional switches current flow can be inverted. These two switches ($N_+$ and $N_-$) are connected to a neutral point and they are off using bipolar drive (stating time). In the case of operating unipolar drive two additional switches play role on flowing the positive or negative current in the given single phase.

The graphical results are given in Section 4. Although hybrid driving has more electronic switches than other configurations, it is more stabile and more convenient for various application (Figs. 8 (a) , (b) ,(c),(d) and 9). In particularly, a BLDC motor operating at load regime, using hybrid driving looks more effective [16, 30-33].

## 4. Discussion and result

This research has prepared the effects of the computer assistant method and laboratory work on students' success in teaching of the subject of a BLDC motor and it's driving in the Electrical machine course of electrical education. The BLDC equipment set and computer

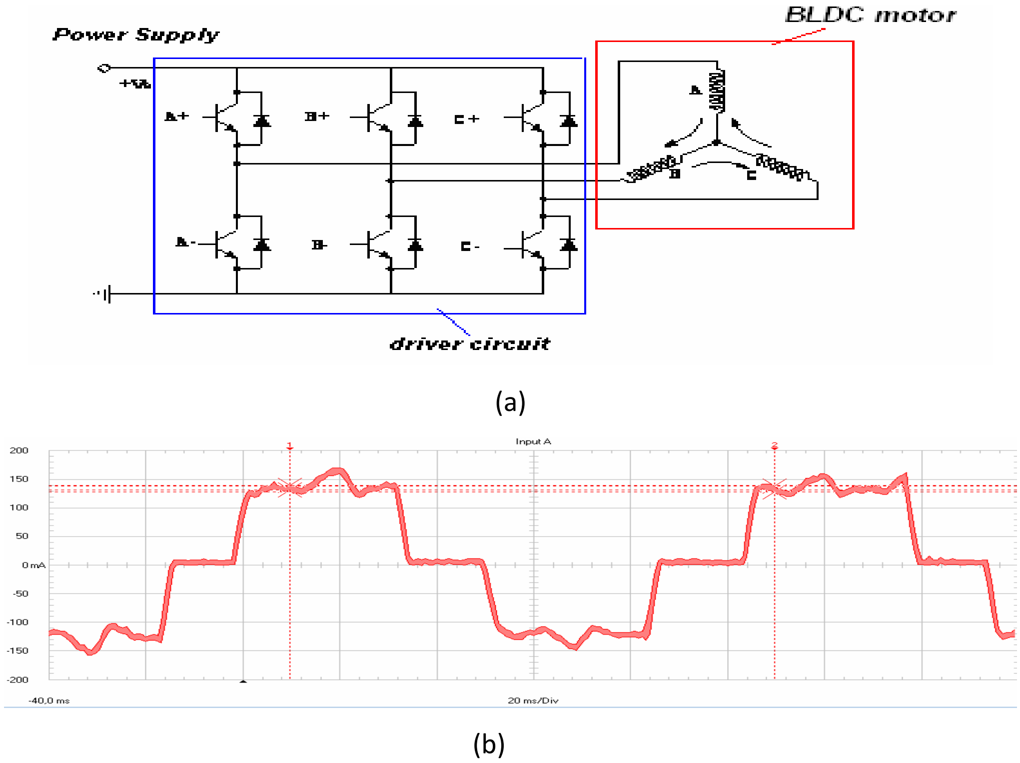



Fig. 5. Bipolar driver circuit and stator windings of motor (a), stator current values for phase A (b).

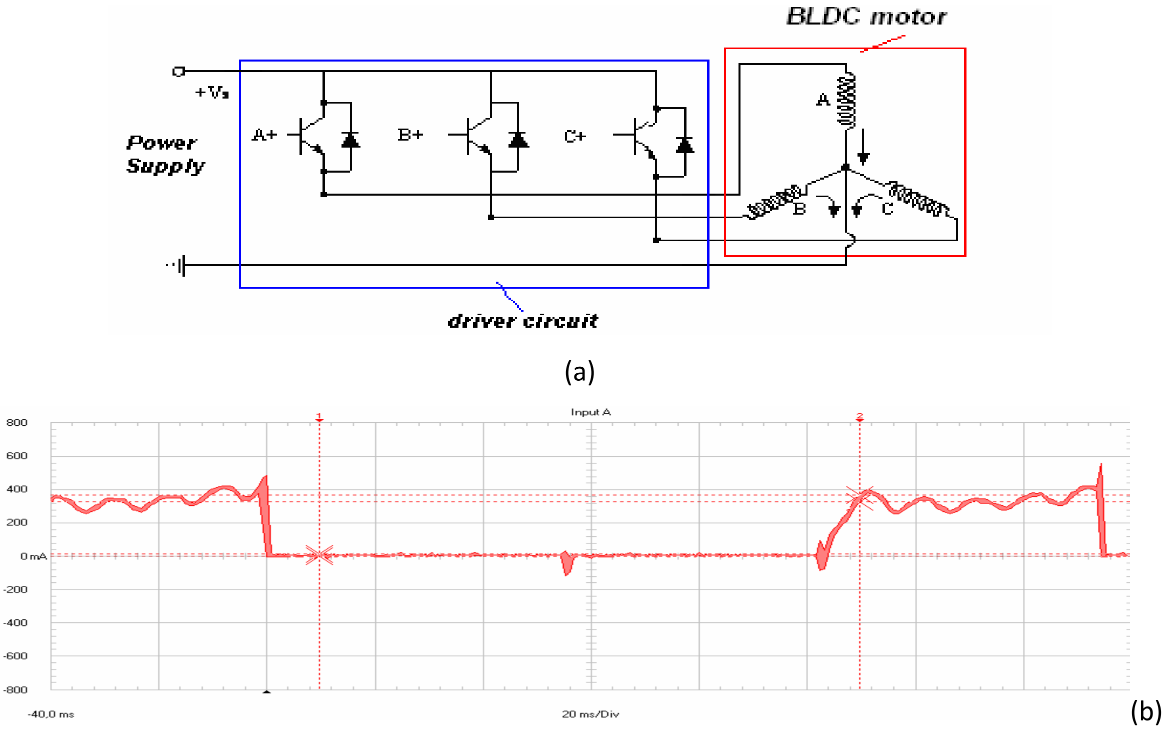
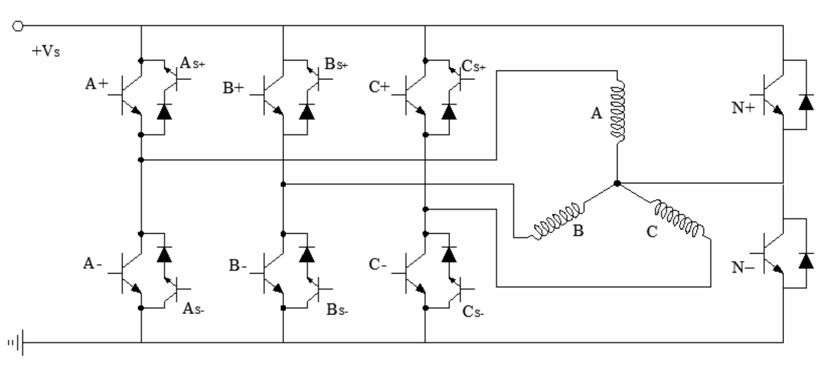
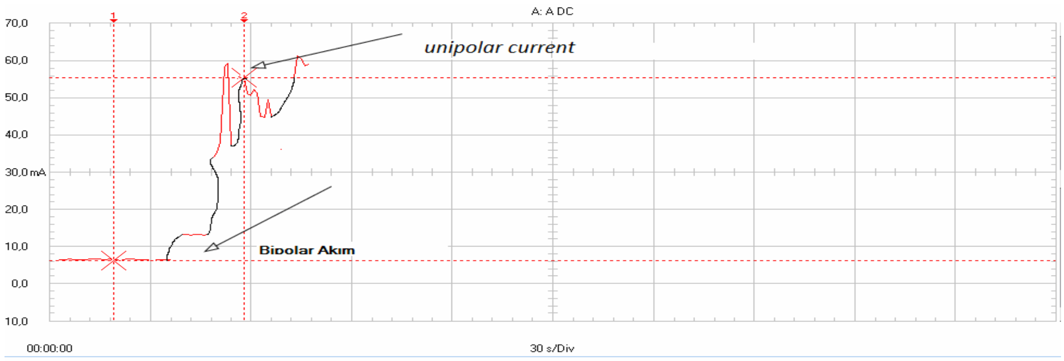



Fig. 6. Unipolar driver circuit and stator windings of motor (a) stator current values for phase A(b).




(a)




(b)

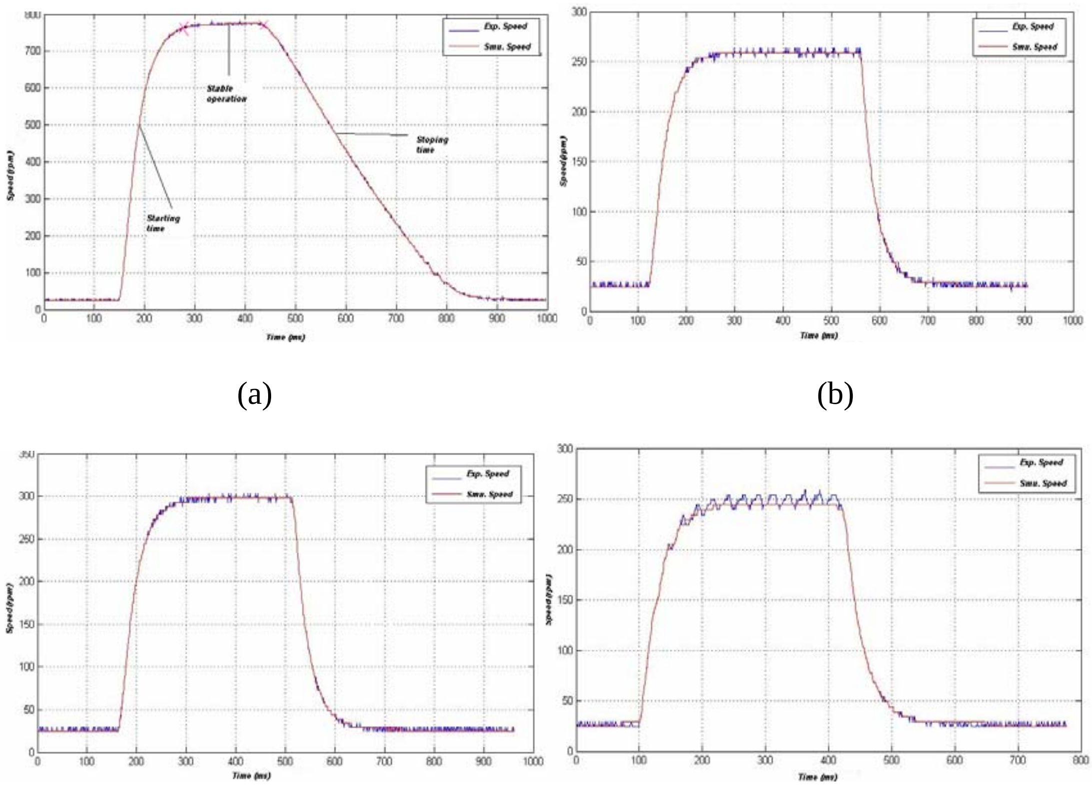
Fig. 7. Hybrid driver circuit and stator windings of BLDC motor (a), bipolar starting unipolar running driver current variation (b).

visualization was found very effective in teaching the features of the driving units of a BLDC motor. Operation of the drive system can be observed on a PC monitor and can be modified by choosing appropriate functions. The contents of the control functions do not change while the program is running [16, 20]. Figs. 8 (a), (b), (c) show results of the experiment on the relationship between speeds versus time (ms). The graphs indicate that the experimental results are almost in good agreement with the simulation results (reference results). The experiment was realized of 33V at load of 0.5 Nm.

A detailed understanding of these driving circuits and motor parameter's role for motor operation is an essential first step towards improved performance. This paper clearly shows that students can easily understand the operation of the driving circuit and can conclude that the hybrid method has low torque ripple when the motor is running at high speed and large starting torque which provides advantages over the bipolar and unipolar drives (see the comparion of Figs. 8 (b), (c), (d))[18,30-33] .

## 5. Class assignments

This experimental set was prepared and implemented for graduate level students, so it was therefore assumed that students already know the basic principles of the motor technology, power electronics and computer software. The developed experiment set was designed to




(a) (b)

(c) (d)

Fig. 8. Experimental and Simulation results: (a) no load hybrid driving circuit; (b) bipolar starting hybrid driving circuit at 0.5 Nm ;(c) unipolar driving circuit at 0.5 Nm ;(d) Bipolar driving circuit.

encourage students to learn the concepts of the methods presented at lectures, based on the standard textbooks, and information about the lesson provided by the lecturer. The electrical machine’s course module progresses should be planned so that the new technologies included into the course such as BLDC motor. The course should therefore be divided into two parts, dealing with conventional and new technologies, respectively. At the end of each theoretical section of the course, students test their knowledge on the experiment sets [34]. During laboratory work, the students should be divided into the smallest possible groups, such as a maximum of two persons and each student has his computer and student is watched and guided while working with the computer to effectively improve their knowledge. Assignments should also be set, to test students’ knowledge themselves. In the meantime, their questions are answered and assistance is given when required. The authors believe that this study demonstrates highly effective results in assisting students to understand the course content [26-28, 35-39].

## 6. Conclusion

The presented brief, graduate level driving methods and their experimental results are of value for teaching the control of brushless motor designs, driving circuit features and analysis, which are necessary for students to develop knowledge of electrical machines and driving circuits. Implementations and suggestions are offered within the trial, to teach students the concepts step by step.

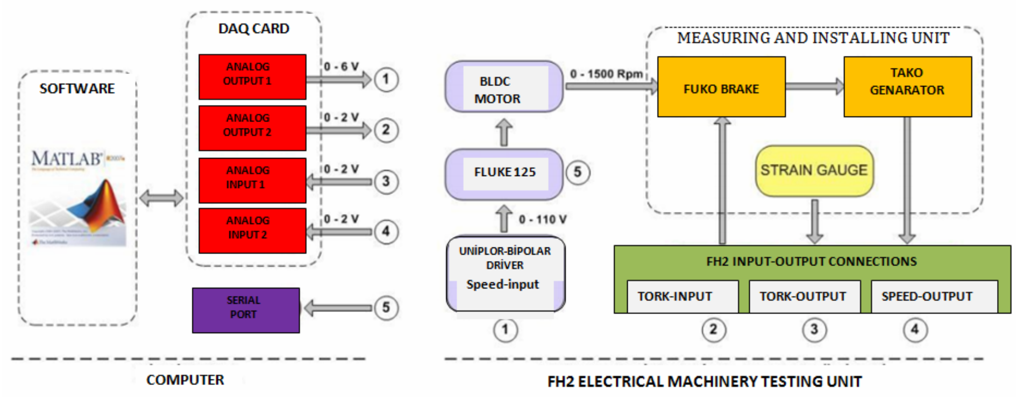
In this paper, a basic knowledge, precluding complex algorithms, of BLDC motor performance and driving circuits are explained. Students are particularly encouraged when they can observe the open circuit, control the motor themselves and use the real time simulation program; since they have all the necessary theoretical and practical data, they can perform quite complex tasks, achieved from the experimental experience.

## Acknowledgements

This work was supported by the Scientific Research Project Commission of Marmara University Project No FEN-C-YLP- 0105080100. We thank to the Scientific Research Project Commission so that we have achieved a chance to study at laboratory environment.

## Appendix

**Matlab Programme**




FH2: Brand code of the loading unit.

## References

[1] Niasar AH, Moghbelli H, Vahedi A. A low costsensorless control for reduced-parts Brushless DC motor drives. IEEE Int Symp Ind Electron ISIE 2008;662-667.

[2] Pillay P, Krishnan R. Modelling, simulation and analysis of permanent magnet motor drives.II: The brushless drive. IEEE Transac Ind Applic 1989;25:274-279.

[3] Wildi T. Direct Current Motors Electrical Machines Drives and Power Systems 5th Edition, Laval University Press, Canada, 2002.

[4] Lee BK. Kim TH. Ehsani M. On the feasibility of four switches three phase BLDC motor drives for low cost commercial applications: topology and control. IEEE Transac Power Electron 2003;18:164-172.

[5] Fitzgerald A. Kingsley C, Umans SD. Permanent Magnet DC Machines, Electric Machinery 6th Edition, Cambridge Press, United States, 2003.

[6] Demirbas A. Energy concept and energy education. Energy Educ Sci Technol Part B 2009;1:85-101.

[7] Karamustafaoglu O. Active learning strategies in physics teaching. Energy Educ Sci Technol Part B 2009;1:27-50.

[8] Serteller NF, Yan G. Bipolar suruculu fircasiz dogru akim motoru analizi ve calisma parametrelerinin incelenmesi. Otomas Derg 2010;3:216-228 [in Turkish].
[9] Demirbas A. Concept of energy conversion in engineering education. Energy Edu Sci Technol Part B 2009;1:183-197.
[10] Matthews MR Constructivism and science education: A further appraisal J Sci Edu Tech 2002;11:121-134.
[12] Kurnaz MA, Calik MA thematic review of ‘energy2 teaching studies: focuses needs, methods, general knowledge claims and implications Energy Edu Science Technol Part B 2009;1:1-26.
[13] Cepni S. Effects of computer supported instructional material (CSIM) in removing students misconceptions about concepts:” lights, light source and seeing” Energy Educ Sci Technol Part B 2009;1:51-83.
[14] Akcayol MA, Cetin A, Elmas . An educational tool for fuzzy logic-controlled BDCM. IEEE Transac Edu 2002;45:33-42.
[15] Pillay P, Krishnan R. Modeling of permenant magnet motor drives. IEEE Trans Ind Electron 1988;35:537-541.
[16] Jang G, Kim MG, A bipolar starting and unipolar running method to drive a hard disk drive spindle motor at high speed with large starting torque IEEE Trans on Magnetic 2005;41:750-755.
[17] Akcayol MA,Cetin A, Elmas C, An educational tool for fuzzy logic-controlled BDCM IEEE Trans on Edu 2002;45;33-42.
[18] Gotou M, Ochi M, A new drive system of a brushless motor reducing power consumption and motor vibration simultaneously IEEE International Conference on power electronics and drive systems, PEDS'99, July 1999, Hong Kong.
[19] Sway CLP, Singh B, Singh BP, Murty SS, Experimental investigations on a Permanent Magnet Brushless DC motor fed by a PV array for a water pumping system Journal of Solar Energ 2000;122:129-130.
[20] Karady GG, Heyt GT Increasing student interest and comprehension in power engineering education at the graduate and undergraduate level IEEE Trans on Power Systems 2000;15:16-21.
[21] Park SJ, Park HW, LeeMH, Harashima F, A new approach for minimum torque- ripple maximum efficiency control of BLDC motor IEEE Trans on Industrial Elec 2000;47:109-114.
[22] Bolton HR, Ashen RA. Influence of motor design and feed-current wave form on torque ripple in brushless DC drive. Proc Ins Elec Eng 1984;131:82-90.
[23] Haskew T A, Schinstock DE, Bredeson JG, Salem E T, brushless machine monitoring and simulation Proceedings of the Intersociety Energy Conversion Engineerin Conferenc, Washington DC USA, Agust 11-16, 1996
[24] Haskew TA, Jackson DJ. Real-time simulation methods for a six-pulse converter. Elec Power Syst Res 1995;33:69-75.
[25] Bodner GM. Why good teaching fails and hard working students do not always succeed. Spec 1990;28:27-32.
[26] Chambers SK, Andre TG. Prior knowledge, interest and experience in electricity and conceptual change text manipulations in learning about direct current. J Res Sci Teac 1997;34:107-123.
[27] Demirbas K, Demirbas A Technical assessment of different biorenewable wastes into energy solutions by briquetting. 97-106. Energy Edu Sci Technol Part A 2011;22:97-106.
[28] Gibson HL, Van Strat GA, A longitudinal study of the impact of constructivist instructional methods on pre- service teachers’ attitudes toward teaching and learning mathematics and science. Paper presented at the annual meeting of the national association of research in science teaching St Louis, MI, 2001.
[29] Zhong, MP, Zheng SY, Pan XH. Design of direct-drive air compressor drived by permanent magnet brushless DC motor Engineering Science 2009;43;495-499.
[30] Niasar AH, Moghbelli H; Vahedi AA, Low-cost sensorless control for reduced-parts, Brushless DC motor drives IEEE International Symposium on Industrial Electronics, ISIE, June 30-July 2, Cambridge, England 2008.

[31] Liu Y, Zhu ZQ, Howe D. Commutation-torque-ripple minimization in direct-torque-controlled PM brushless DC drives IEEE Transac Ind Applicat 2007;43:1012-1021.
[32] Hansen H B, Kallese CS, Bendtsen JD. A hybrid model of a brushless DC motor Proceedings of the IEEE International Conference on Control Applications, October 1-3, Singapore, 2007.
[33] Bektas Y, Oyman Serteller NF. Fircasız DA motorun kontrolunde PWM ve histerisiz bant kontrolünün karsilastirilmasi. SDU, Ulus Teknol Bil Derg 2010;2:31-45 [in Turkish].
[34] Karakas E, Tekindal S. The effects of computer-assisted learning in teaching permanent magnet synchronous motors. IEEE Transac Educ 2008;51:448-455.
[35] Tatli ZH. Computer based education: Online learning and teaching facilities. Energy Educ Sci Technol Part B 2009;1:171–181.
[36] Turhan K, Kurt B. Computer based medicine education: Improved skin segmentation using YCbCr color space. Energy Educ Sci Technol Part B 2010;2:1–20.
[37] Yesilyurt M. Meta-analysis of the computer assisted studies in physics: A sample of Turkey. Energy Educ Sci Technol Part B 2011;3:173–182.
[38] Koral O. The effectiveness of problem-based learning supported with computer simulations on academic performance about buoyancy. Energy Educ Sci Technol Part B 2011;3:293–304.
[39] Saidur R, Lai YK. Parasitic energy savings in engines using nanolubricants. Energy Educ Sci Technol Part A 2010;26:61-74.