ISSN 1974-9821
Vol. 6 N. 6
December 2013

International Review on Modelling and Simulations (IREMOS)

PART **A**

Contents:

(continued on inside back cover)

Praise Worthy Prize

International Review on Modelling and Simulations (IREMOS)

The ***International Review on Modelling and Simulations (IREMOS)*** is a publication of the **Praise Worthy Prize S.r.l.**.
The Review is published bimonthly, appearing on the last day of February, April, June, August, October, December.

Published and Printed in Italy by **Praise Worthy Prize S.r.l.,** Naples, December 31, 2013.

International Review on Modelling and Simulations (I.RE.MO.S.), Vol. 6, N. 6
ISSN 1974-9821 December 2013

BLDC Motor Control Using Simulink Matlab and PCI

Bambang Sujanarko[1], Bambang Sri Kaloko[1], Moh. Hasan[2]

Abstract – *This paper presents the control of BLDC motor using Simulink Matlab and PCI as interfacing to hardware. The control based on six step method that have certain relations among rotor positions and winding currents. These relations convert to digital functions and simplify using K-Map. The result then implemented by basic digital elements on Simulink Matlab and used to trigger the inverter through PCI interfacing to produce six step waveform. Before feed to inverter, a PWM added to these signal as speed control of BLDC motor. Test experiment results show that the control can produce variable speed, voltage and current.*

***Keywords**: BLDC, Control, Karnaugh, Simulink, PCI, Six Step, PWM*

Nomenclature

B	Friction coefficient
B_x	Fux density vector
D	Duty cycle (Ton/T)
E, E_a, E_b, E_c	Back-EMF in winding, in winding A, in winding B, in winding C
H_A, H_B, H_C	Hall A, Hall B, Hall C
I, I_a, I_b, I_c	Motor Current in winding, in winding A, in winding B, in winding C
J	Moment of inertia
L, L_a, L_b, L_c	Self inductance in winding, in winding A, in winding B, in winding C
L_x	Length of the core
N_p	Number of active phases
N_{spp}	Number of slots per pole per phase
N_t	Number of turns per slot per phase
N_t	Number of turns per slot per phase
P	Number of magnet poles
$Q_n, Q_1, Q_2, Q_3, D_4, Q_5, Q_6$	Inverter switch in n-th, in switch 1, switch 2, switch 3, switch 4, switch 5, switch 6
R, R_a, R_b, R_c	Resistance in winding, in winding A, in winding B, in winding C
R_x	Outer radius of rotor (moment arm)
T_e	Electric Torque
T_F	Friction Torque
T_J	Inertia Tourque
T_L	Load torque
V_s	Voltage supply

Abbreviation

BLDC	Brushless Direct Current
CCW	Counter Clockwise
CW	Clockwise
EMF	Electric Motion Force
K-Map	Karnaugh Map
PCI	Peripheral Component Interconnect
PWM	Pulse Width Modulation

I. Introduction

BLDC motors have many advantages over other types of motors. These advantages are high torque, low maintenance, high efficiency, long life operating, low noise, high density power and high reliability [1].

Due to their properties and the evolution of low-cost power semiconductor switches and permanent magnet materials, BLDC motors are widely used in automotive, robotics, industrial automation equipment, machine tools, medical, instrumentation and so on [1], [2].

In order to produce good performance, BLDC motor require particular control for specific system. Many designs and methods have been created for this purpose. Some of the controls use the Field Programmable Gate Array, Digital Signal Processor, Application Specific Integrated Circuit, and the most is using a microcontroller [3]-[7].

But these controls is not flexible, because it is not possible to change easily, such as exchange PWM frequency, current limitation, type of closed-loop control and others. To solve this problem, this research will be build BLDC motors control using computer, which based on Simulink Matlab and PCI 1711 L interfacing.

This control is expected to gain control system that easily modeled and modified, so that it can be used to obtain the optimal control system, only by changing the software.

This research is a continuation of previous research, which has resulted in digital circuits represent logic functions among the sensor signals to triggers of the inverter [8].

II. BLDC Control Fundamental

II.1. Basic Structure

A BLDC motor is a synchronous electric motor powered by DC power and is electronically

Manuscript received and revised November 2013, accepted December 2013

commutation. To realize electronic commutation and synchronization, A BLDC motor system usually consist of five main parts, power inverter (1), inverter drive (2), logic circuit (3), positions sensor (4) and BLDCmotor (5), as shown at Fig. 1 [1], [8].

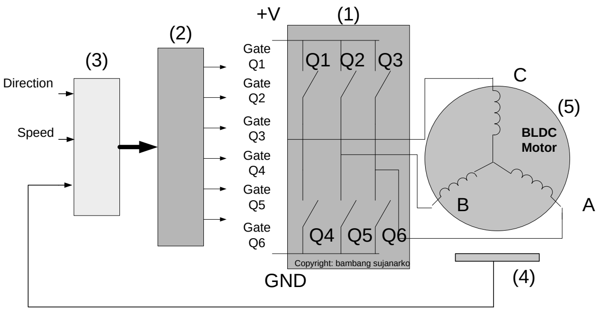


Fig. 1. Basic block diagram of BLDC motor

The basic principle of a BLDC motor is brief as follows. The position sensor (4), usually Hall sensor or Back EMF detection, will give sign of place mark the permanent magnet against the winding. These sign generally in the three bits data.

The signs then entered in a logic circuit (3) to convert into 6 trigger signals for each switch of inverter (1), which usually composed from power device like MOSFETs or 6 IGBTs. In the logic circuit, the trigger signals also regulate to desire direction and speed of rotation. The result depend on direction signal and the setting of speed. Before enter to the inverter, the trigger signals entered to the driver circuit (2). In this circuit, the signals will be matching to the specification of the switch devices.

Finally, by condition of switch of inverter, an example, the power flow from +V to switch (Q_1), winding (C), winding (A), switch (Q_5) and Ground.

And then position sensor detect sign of place mark the permanent magnet against the winding again in the different condition, and the process will be return to logic circuit.

II.2. Six Step Commutation

As seen in Fig. 1, BLDC motors using a three phase power inverter that commute sequentially every 60 degrees. These commutations produce six different in one cycle as shown in Fig. 2.

This figure show the waveforms of Back-EMFs (E_a, E_b, E_c), current (I_a, I_b, I_c) and Hall position sensors (Hall A, Hall B and Hall C) [1]-[8]. Back-EMFs in this figure is the trapezoidal type. Other type of Back-EMFs is Sinusoidal [1]-[7].

Because there are six pattern of commutation, so it called six step commutation. The first commutation occurs in 30^o until 90^o, the 2th in 90^o until 150^o, the 3th in 150^o until 210^o, the 4th in 210^o until 270^o, the 5th in 270^o until 330^o and the 6th in 330^o until 30^o.

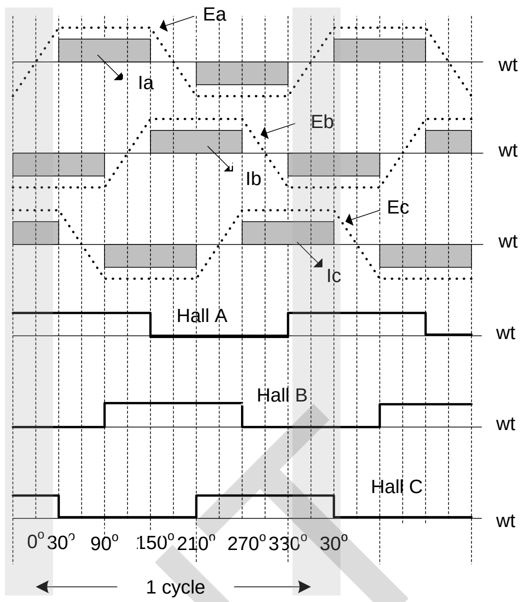


Fig. 2. Back-EMFs, current and Hall position sensors waveform of BLDC motor

If the presence of currents in the winding, Hall sensor detection and direction of rotation is converted to a digital logic 1 and 0, then the relationship of these variables can be expressed by Table I [8]. From this table, if the direction is CW rotation, there are six possible of Hall position and in the switch condition of inverter (Q_1 to Q_6). If the direction is CCW, the possible also in six too.

An example, using Fig. 1, Fig. 2 and line 1 of Table I, if direction is CW that means the digital logic in the Table I is 1, and the Halls (H_A, H_B and H_C) detect value 1 0 1, so the logic circuit produce signal triggers 1 0 0 0 1 0 for Q_1 until Q_6.

This triggers cause Q_1 and Q_5 switch on as shown in Fig. 1, and produce current from +V though Q_1, the winding C in the positive polarity, the winding B in the negative polarity, and finally though Q_5 to flow to GND. Waveform of this example shown in the first commutation that occurs in angle 330^o until 30^o.

TABLE I
RELATIONSHIP AMONG DIRECTION, THE POSITION OF HALL SENSOR AND SWITCHING IN THE INVERTER

	Dir	H_C	H_B	H_A	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
CW	1	1	0	1	1	0	0	0	1	0
	1	1	0	0	0	0	1	0	1	0
	1	1	1	0	0	0	1	1	0	0
	1	0	1	0	0	1	0	1	0	0
	1	0	1	1	0	1	0	0	0	1
	1	0	0	1	1	0	0	0	0	1
CCW	0	0	0	1	0	0	1	1	0	0
	0	0	1	1	0	0	1	0	1	0
	0	0	1	0	1	0	0	0	1	0
	0	1	1	0	1	0	0	0	0	1
	0	1	0	0	0	1	0	0	0	1
	0	1	0	1	0	1	0	1	0	0

II.3. Logic Simplification with Karnaugh Maps

If Table I convert to digital logic function, Eq. (1) is the general form of this correlation. In this function Q_n is inverter switch n-th, where n is 1 until 6. Eq. (2) up to Eq. (7) show the functions in the single form:

$$Q_n = f\left(Dir, H_C, H_B, H_A\right) \tag{1}$$

$$\begin{aligned} Q_1 = {} & Dir H_C \overline{H_B} H_A + Dir \overline{H_C}\,\overline{H_B} H_A + \\ & + \overline{Dir}\,\overline{H_C} H_B \overline{H_A} + \overline{Dir} H_C H_B \overline{H_A} \end{aligned} \tag{2}$$

$$\begin{aligned} Q_2 = {} & Dir \overline{H_C} H_B \overline{H_A} + Dir \overline{H_C} H_B H_A + \\ & + \overline{Dir} H_C \overline{H_B}\,\overline{H_A} + \overline{Dir} H_C \overline{H_B} H_A \end{aligned} \tag{3}$$

$$\begin{aligned} Q_3 = {} & Dir H_C \overline{H_B}\,\overline{H_A} + Dir H_C H_B \overline{H_A} + \\ & + \overline{Dir}\,\overline{H_C}\,\overline{H_B} H_A + \overline{Dir}\,\overline{H_C} H_B H_A \end{aligned} \tag{4}$$

$$\begin{aligned} Q_4 = {} & Dir H_C H_B \overline{H_A} + Dir \overline{H_C} H_B \overline{H_A} + \\ & + \overline{Dir}\,\overline{H_C}\,\overline{H_B} H_A + \overline{Dir} H_C \overline{H_B} H_A \end{aligned} \tag{5}$$

$$\begin{aligned} Q_5 = {} & Dir H_C \overline{H_B} H_A + Dir H_C \overline{H_B}\,\overline{H_A} + \\ & + \overline{Dir}\,\overline{H_C} H_B H_A + \overline{Dir}\,\overline{H_C} H_B \overline{H_A} \end{aligned} \tag{6}$$

$$\begin{aligned} Q_6 = {} & Dir \overline{H_C} H_B H_A + Dir \overline{H_C}\,\overline{H_B} H_A + \\ & + \overline{Dir} H_C H_B \overline{H_A} + \overline{Dir} H_C \overline{H_B}\,\overline{H_A} \end{aligned} \tag{7}$$

This digital logic function can simplify. One method for simplification is K-Map. The result of this simplification is digital logic function in Eq. (8) up to Eq. (13) [8]. Implementating these function using basic digital logic gate can produce digital circuit in Fig. 3:

$$Q_1 = Dir \overline{H_B} H_A + \overline{Dir} H_B \overline{H_A} \tag{8}$$

$$Q_2 = Dir \overline{H_C} H_B + \overline{Dir} H_C \overline{H_B} \tag{9}$$

$$Q_3 = Dir H_C \overline{H_A} + \overline{Dir}\,\overline{H_C} H_A \tag{10}$$

$$Q_4 = Dir H_B \overline{H_A} + \overline{Dir}\,\overline{H_B} H_A \tag{11}$$

$$Q_5 = Dir H_C \overline{H_B} + \overline{Dir}\,\overline{H_C} H_B \tag{12}$$

$$Q_6 = Dir \overline{H_C} H_A + \overline{Dir} H_C \overline{H_A} \tag{13}$$

III. BLDC Modelling

III.1. Electric Modelling

Trigger signals (Q1 to Q6) cause the current to the winding and generate electric phenomenon. It can be analyzed by BLDC motor modeling.

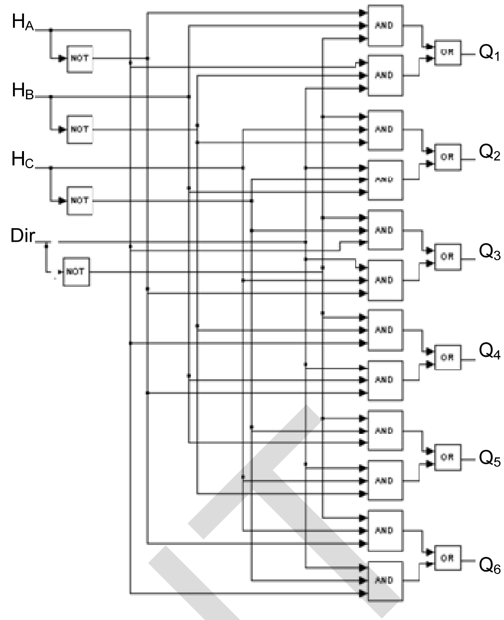


Fig. 3. Digital circuit of relationship among direction, Hall sensor signals and trigger of switches

This modeling can be developed as a three phase synchronous machine, but since rotor is mounted with a permanent magnet, some dynamic characteristics are different [9]. Fig. 4 show BLDC model, where the winding will be represented using inductance (L), resistance (R) and Back EMF (E).

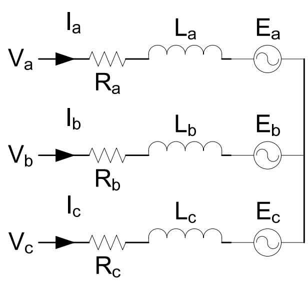


Fig. 4. BLDC motor model

If the circuit is balance, the circuit of BLDC motor model has Eq. (14). This mathematical model using assumption that the magnet has high sensitivity and current induced of rotor can be neglected. It is also assumed that the stator resistances at all the windings are equal ($R=R_a=R_b=R_c$). Therefore the rotor reluctance does not change with angle. Eq. (15) show the consequence of this assumption. Finally, the voltage equation become (16):

$$\begin{aligned} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = {} & \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \\ & + \frac{d}{dt} \begin{bmatrix} L_a & L_{ba} & L_{ca} \\ L_{ba} & L_b & L_{ca} \\ L_{ca} & L_{ba} & L_c \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \end{aligned} \tag{14}$$

$$L_a = L_b = L_c = L \qquad L_{ab} = L_{bc} = L_{ac} = M \tag{15}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \tag{16}$$

III.2. Torque and Speed Modelling

Fig. 5 shows a cutaway view of a BLDC.motor. This motor is a three-phase, 4-pole, 12-slot, full-pitch, surface mounted permanent magnet, trapezoidal Back EMF BLDC.

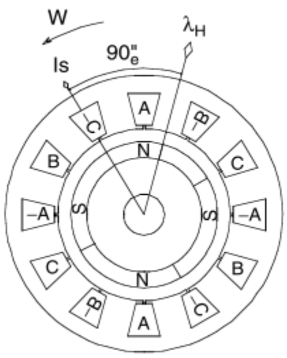


Fig. 5. Cutaway of BLDC motor

To drive the maximum torque/ampere motor, it is desired that the line current pulses be overlapped by the line-neutral Back EMF voltages of the particular phase.

This allows a maximum torque output by the fundamental physical principle of torque generation, i.e., Torque = Total Force × Moment Arm, where the force is produced by the interaction of the flux produced by the rotor magnets and the current in the stator coil sides.

From the Lorentz force equation is (17) [1]:

$$Force_{1\,coil\,side} = \int_L N_t \left(I \times B_x \right) dl \tag{17}$$

In the running condition, two phases are excited with DC current in the same direction, and a radially magnetized magnet in the certain polarity was appeared overlap at two adjacent slots.

The flux magnetic in these part then force rotor to rotate. The total force is the sum of the forces of all of the active poles.

In a BLDC with radially magnetized magnets and full-pitched windings, the number of stator slots = (number of phases)×(number of poles). There are two phases simultaneously active with square wave excitation and in the magnet distance approximately equal to the pole arc, the electric torque (T_e) is given as (18) [1].

The most accurate static torque for a specific machine geometry is determined by using a finite element software package that uses numerical methods:

$$T_e = N_p \; N_t \; N_{spp} \; P \; I \; B_r \; L_x \; R_x \tag{18}$$

This torque is equal to the peak or maximum torque, which can also be calculated by the load torque, torque due to inertia, the torque required to overcome the friction, the windage loss which is contributed by the resistance offered by the air in the air gap ant others. Eq. (19) shows the relation of these factors with k caused unknown factors [10].

In the dynamic model or if current supply of BLDC cause motor rotates in ω angular velocity, this torque also can be represented using equation (20) [9]. In this equation k is a constant.

Equation (19) can be modified using angular velocity ω as shown in (21):

$$T_e = \left(T_L + T_J + T_F \right) \times k \tag{19}$$

$$T_e = k \frac{E_a I_a + E_b I_b + E_c I_c}{\omega} \tag{20}$$

$$T_e = \left(T_L + J \frac{d\omega}{dt} + B\omega \right) \times k \tag{21}$$

III.3. Speed Regulating Using PWM

Subtitute Eq. (18) to (20) and using assumption the current and Back EMF in three windings are in balance and using consideration that E is proportional to supply voltage, the angular speed of BLDC motor can can be arranged into (22). If V produce from voltage supply (V_s) using PWM method [11], [12] as illustrated in Fig. 6, the voltage (V) can calculate using (23). Finally, if (23) substituted to (22), angular velocity become (24):

$$\omega \cong k \frac{3EI}{N_p \; N_t \; N_{spp} \; P \; I \; B_r \; L \; R} \cong kE \cong kV \tag{22}$$

$$V = DV_s \tag{23}$$

$$\omega \cong kDV_s \tag{24}$$

PWM circuit build using compare a triangle wave and variable DC signal and then implemented to trigger signal by using AND digital logic [8].

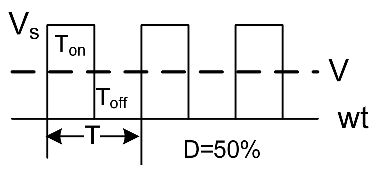


Fig. 6. PWM signal

IV. Matlab/Simulink and PCI

The modeling, simulation and the real plant are three separated fields. The deep gap among these become a problem in practice, research and education.

This problem can be bridged through the use of special hardware and software directly in MATLAB/Simulink environment. In this environment, to build a dynamic system there is two-step process with Simulink. First, creating a block diagram using the Simulink model editor, in the graphical form and constitue time-dependent mathematical relationships among the inputs, model and outputs. The second, running the Simulink model in the certain time using start and stop command [13]. Simulation circuit in the Simulink can be implemented in real time, using Real-Time Workshop (RTW). RTW is an extension of capabilities of MATLAB/Simulink that can automatically generates, packages, compiles and builds source code from Simulink models to real-time software applications. The code generates in C language [13]. Fig. 7 shows RTW code generation process.

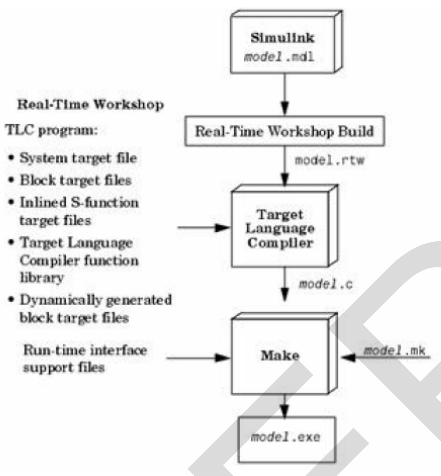


Fig. 7. RTW code generation process [13]

Using External mode, the system enables communication on a real-time, between Simulink and a real equipment through an interfacing component. One of interfacing components is PCI. PCI is a local computer bus for attaching hardware devices in a computer.

The devices in PCI slot will be connected to the processor directly to the processor bus in assigned addresses of the processor's address space [14]. PCI1711 L is a type of PCI that used in this research.

This PCI have 16 digital outputs, 16 digital inputs, 2 analog outputs, 16 analog input and 3 channels Timer [15].

V. The Proposed Control

Refer section II.3 and III.3, control modelling using Simulink can build as shown in Fig. 8.

In this picture, Hall sensors connect to Digital Input (DI) component of RTW. The DI should be preceded by setting the channels used, time sampling and voltage levels. The same setting also need for Digital Output (DO), which used to connect the trigger output signal Q_1 to Q_6 to the driver circuit. These connection through a wiring board PCLD 8710AI.

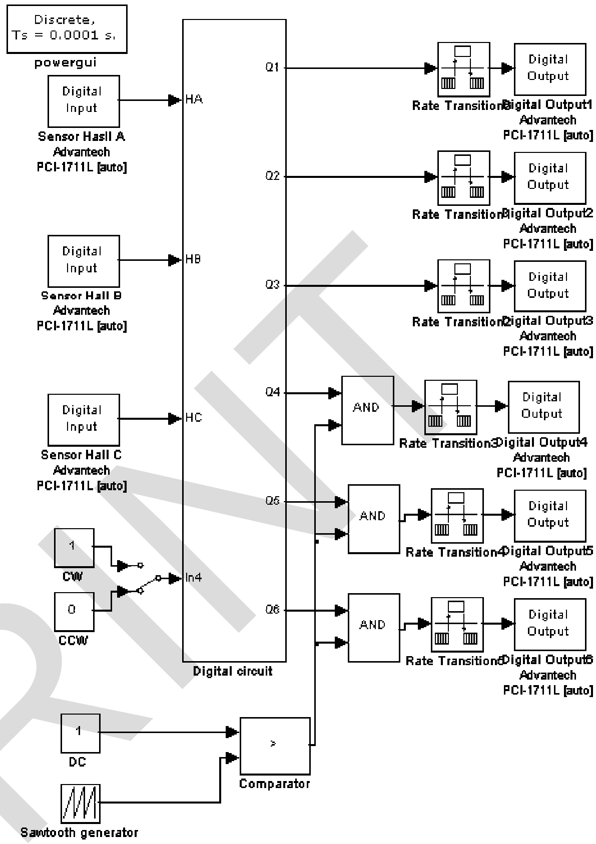


Fig. 8. Control modelling using Simulink

Trigger signals from the DO, before enter to the inverter circuit, will be entered to driver circuit.

This circuit must have the ability to isolate the PCI from the inverter. Therefore, the driver circuit use optocouplers and separate voltage supplies. After experiencing the formation in the driver circuit, trigger signals which had dv/dt, di/dt and amplitude voltage that corresponding to specification of the power devices used [12] the signals then entered to power device gate of inverter. Fig. 9 shows schematic of the driver circuit and inverter, while Fig. 10 shows experiment setup scheme and Fig. 11 shows photograph experiment setup in this research. Some variables such as voltage, current, RPM, PWM frequency and duty cycle, measured and captured.

Some of these measurements and figures, will be taken by toolboxes in the sink group of Matlab/ Simulink.

VI. Result and Discussion

VI.1. Simulink Control Model Verification

The first control testing is verify the logic truth of Simulink control model.

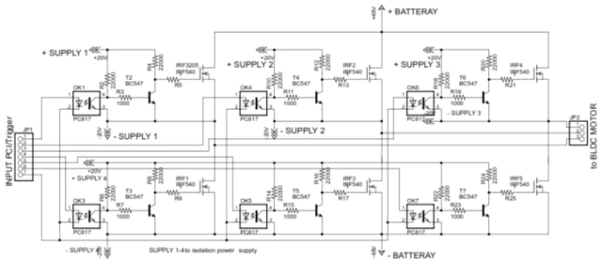


Fig. 9. Driver and Inverter circuit

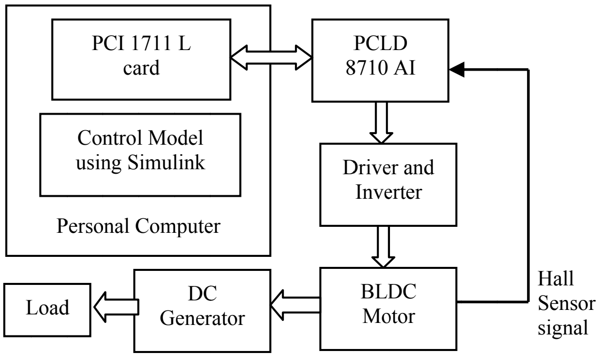


Fig. 10. Experiment setup scheme

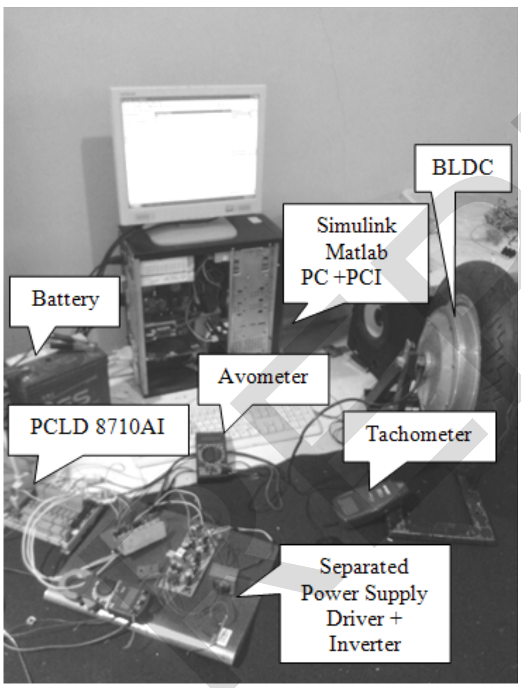


Fig. 11. Experiment setup scheme

Fig. 12 the result of this testing in the CCW direction.

This figure find from scope toll box that connect to DI and DO. DI are represent three Hall sensors in the BLDC motor and DO are bit condition of triggers (Q1-Q6).

These bits condition must be similar with trigger values as shown in Table I.

Comparison between bit values from the picture and bit values in the table show that these values are similar. So it can be concluded that the Simulink control model has been made correctly and accordance to step six principle. This verification has been done in [8].

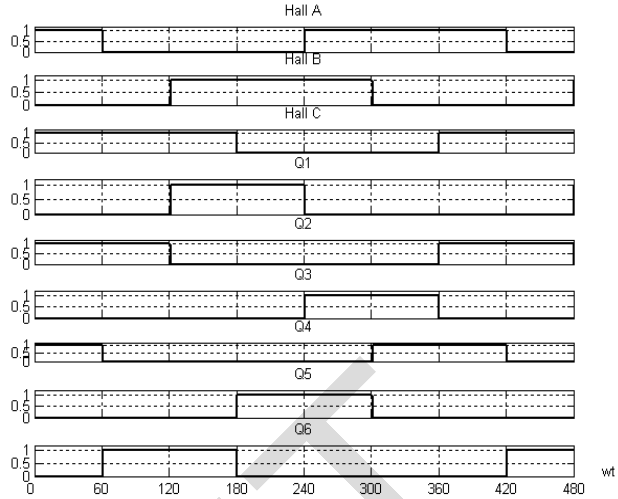


Fig. 12. Logic of Simulink control model in CCW direction

The second control testing is verify the logic truth of Simulonk control using PWM. Fig. 13 shows the result of this testing. In this research only bottom part of inverter or only Q4, Q5 and Q6 that use PWM.

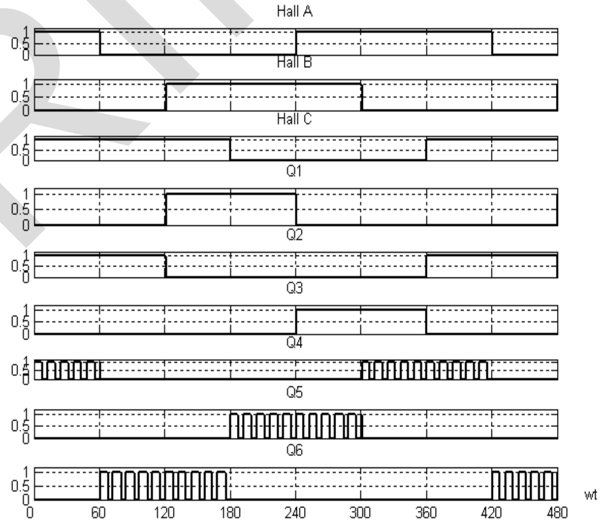


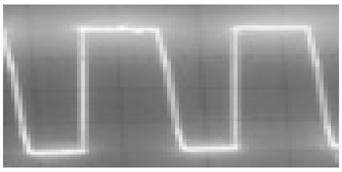
Fig. 13. Logic of Simulink control model using PWM

On state (T_{on}) of this PWM is depend on the duty cycle value. In this example, the duty cycle is 50%. If the duty cycle is small, on state is narrow but if it is big, the on state is width. If duty cycle is 100%, on state become always in the high state. These verifications have been done deeply in [12]. Figs. 14 show oscilloscope capture of PWM signals. Above testings show that Simulink control model has been made correctly and can use as control of BLDC motor.

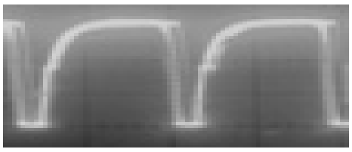
VI.2. Using Simulink Control Model for Motor Respon Testing

This section presents the results of testing the use of the simulink control model to obtain the characteristics of

BLDC motor on duty cycle variation of PWM and frequency.



(a) Tigger signals using PWM from logic circuit



(b) Tigger signals using PWM from driver circuit

Figs. 14. PWM signals [12]

Duty cycle variation can make by fill DC box of control with number 0 to 5, which denote duty cycle in 0 to 100%, while the frequency of PWM can be varied using time determination of sawtooth generator of simulink control model.

This testing use BLDC motor that have nominal power 500 W, rotation speed 500 rpm and 48 V power supply voltage. But in this testing the power supply used in 12 V.

Fig. 15 shows speed responds in this testing on duty cycle variation, while Figs. 16 and 17 show voltage and current responds.

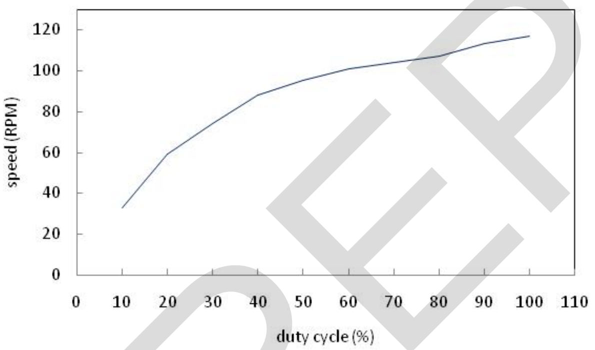


Fig. 15. Speed responds on duty cycle

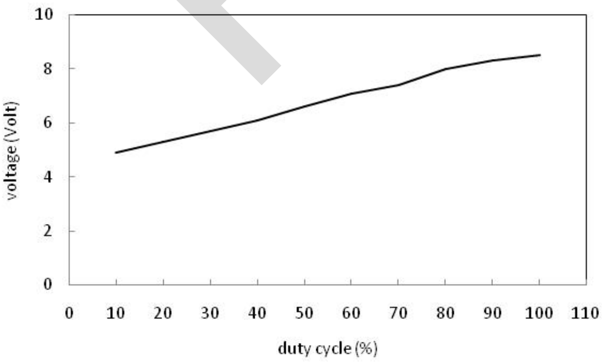


Fig. 16. Voltage responds on duty cycle

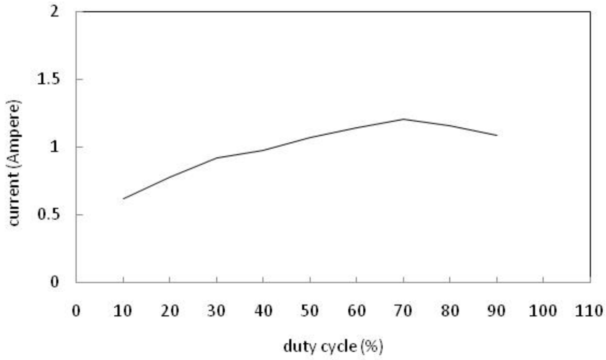


Fig. 17. Current responds on duty cycle

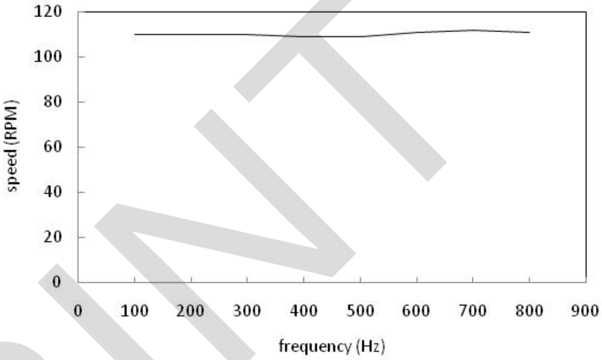


Fig. 18. Speed responds on frequency

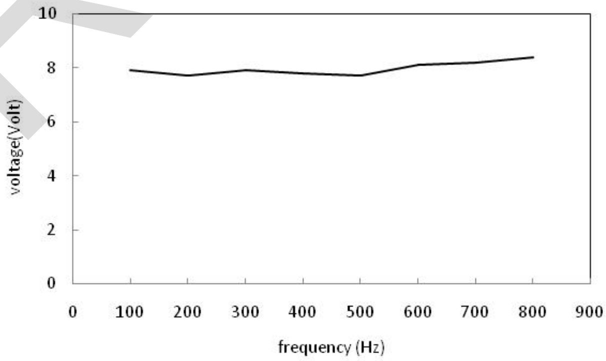


Fig. 19. Voltage responds on frequency

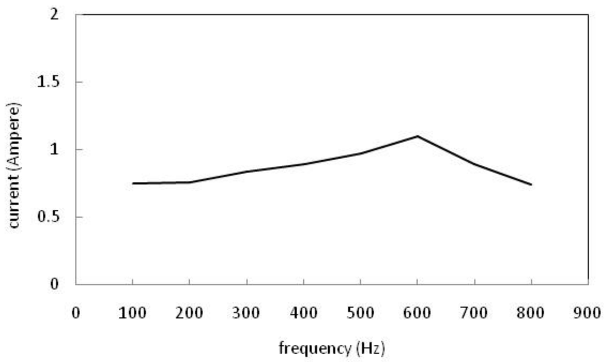


Fig. 20. Current responds on frequency

Experiment result of speed responds is not linear as mentioned in (24), because in this equation some of variable considered in ideal condition. But voltage responds is linear as defined in (23). Non linear correlation also happen on current responds. The non linear function occurred if duty cycle in the duty cycle above of 70%.

These phenomena can be explained using (21), where there is dependency on mechanical properties among speed, load, friction, inertia and electric torque.

Usually BLDC motor use PWM frequency above 6 kHz [10], but since the PCI only has the ability to transfer data at 10 kHz, so in this research the highest PWM frequency is 800 Hz. This frequency obtained from trial and error, wherein the frequency able to give a good shape of PWM. The highest PWM frequency has been used in the duty cycle variation as discussed previously. In the following sections present BLDC motor responds in the PWM frequency variation at 60% duty cycle, particularly to obtain the speed responds, voltage and current of motor.

Figs. 18 and 19 show speed responds and voltage responds of PWM frequency variations. The responds indicate that there is no influence of the PWM frequency to the motor speed and voltage. While for the current responds as shown in Fig. 20, there are non linear correlations, like occurred on the variation of duty cycle.

VII. Conclusion

This research has successfully made BLDC motor control using Matlab Simulink, and the interface to the actual hardware using PCI. Control models constructed using simulink element, and this model also can be used as a real control through the RTW facilities used. The experiment results show that the control can be used to control the BLDCmotor, and can generate an appropriate responds within the electrical and mechanical models.

The results of this research are very useful for BLDC motor control modeling and the real testing, easily, quickly and efficiently. It can be helped to generated a better of BLDC motor control.

Acknowledgements

This work was supported by research grant - Riset Unggulan Universitas Jember dana BOPTN, Kementrian Pendidikan dan Kebudayaan Republik Indonesia.

References

[1] Ali Emadi, *Handbook of Automotive Power Electronics and Motor Drives (*Taylor & Francis Group, CRC Press, 2005).

[2] Padmaraja Yedamale, *Brushless DC (BLDC) Motor Fundamentals* (Microchip Technology Inc., 2003)

[3] Sathyan, A. ; Milivojevic, N. ; Young-Joo Lee ; Krishnamurthy, M. ; Emadi, A., *An FPGA-Based Novel Digital PWM Control Scheme for BLDC Motor Drives,* Industrial Electronics, IEEE Transactions on, Vol.: 56 , Issue: 8, 2009, pp.: 3040 - 3049.

[4] Matsui, N. ; Ohashi, H., *DSP-Based Adaptive Control of A Brushless Motor*, Industry Applications, IEEE Transactions on,Volume: 28 , Issue: 2, 1992 , Page(s)*: 448 – 454.*

[5] Semiconductor Components Industries, *MC33035 NCV33035 Brushless DC Motor Controller- Publication Order* (On Semiconductor, 2006).

[6] Atmel Corporation, *AVR498: Sensorless control of BLDC Motors using ATtiny261/461/861-Application Note* (Atmel Corporation, 2009).

[7] Stan D'Souza, *AN957 Sensored BLDC Motor Control Using dsPIC30F2010-Application Notes* (Microchip Technology, 2004).

[8] Bambang Sujanarko, *Brushless Direct Current (Bldc) Motor Controller Using Digital Logic For Electric Vehicle*, National Conference ReTII ke-7 Tahun 2012, STTNAS Yogyakarta, 2012.

[9] Caner, M., Gerada, C., Asher, G., Permanent magnet motor design optimisation for sensorless control, (2013) *International Review of Electrical Engineering (IREE),* 8 (1), pp. 172-181.

[10] Padmaraja Yedamale, *AN885 Brushless DC (BLDC) Motor Fundamentals, Application Notes* (Microchip Technology, 2003).

[11] Mirzaei, H., Pahlavani, M.A., Naderi, P., Comparison of direct torque control of BLDC motor with minimum torque ripple in four and six-switch inverters, (2013) *International Review of Electrical Engineering (IREE),* 8 (3), pp. 971-980.

[12] Bambang Sujanarko, *Desain Kontrol PWM Pengatur Kecepatan Motor BLDC Untuk Mobil Listrik*, National Conference Semantik Tahun 2013, UDINUS Semarang, 2013.

[13] The MathWorks, *Matlab* (The MathWorks, Inc., 2013).

[14] Loeb, M.L. ; Rindos, A.J. ; Holland, W.G. ; Woolet, S.P., *Gigabit Ethernet PCI adapter performance*, Network, IEEE, Vol. 15, Issue: 2, 2001, pp. 42 – 47.

[15] Advantech, *PCI-1711/L Entry-level 100 kS/s, 12-bit, 16-ch PCI Multifunction Card* (Advantech).

Authors' information

[1]Jurusan Teknik Elektro, Fakultas Teknik, Universitas Jember.

[2]Jurusan Matematika, Fakultas MIPA, Universitas Jember.

Bambang Sujanarko received the B.Sc from Universitas Gadjah Mada, Yogyakarta Indonesia, Master from Universitas Jember, Indonesia and Doctor fron Institut Teknologi Sepeluh Nopember (ITS) Surabaya, Indonesia. He is senior lecture of Departement Electrical, Engineering Faculty, Universitas Jember. His research interests included power electronics and renewable energy systems, hybrid power systems, artificial intelligent, electric vehicle and instrumentation.

Bambang Sri Kaloko received the B.Sc and Master from Institur Teknologi Bandung, Indonesia and Doctor fron Institut Teknologi Sepeluh Nopember (ITS) Surabaya, Indonesia. He is lecture of Departement Electrical, Engineering Faculty, Universitas Jember. His research interests included power analysis, battery system, renewable energy systems, artificial intelligent and electric vehicle.

Moh. Hasan received the B.Sc form Universitas Jember, Master from The University of Western Australia, Perth Australia and Doctor fron Wageningen University, Wageningen Holland. He is senior lecture of Departement Math, Math and Science Faculty, Universitas Jember. Now, he is rector of University of Jember. His research interests included modelling of nature phenomena.

International Review on Modelling and Simulations (IREMOS)

(continued from outside front cover)

(continued on Part B)

Abstracting and Indexing Information:

Academic Search Complete - EBSCO Information Services
Cambridge Scientific Abstracts - CSA/CIG
Elsevier Bibliographic Database SCOPUS
Index Copernicus (Journal Master List): ***Impact Factor 6.55***

Autorizzazione del Tribunale di Napoli n. 78 del 1/10/2008

Praise Worthy Prize

This volume cannot be sold separately by Part B

1974-9821(201312)6:6;1-M