The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)

Volume 1, Pages 123-130

ICONTES2017: International Conference on Technology, Engineering and Science

LOW COST AND PRECISE ELECTRONIC TACHOGENERATOR FOR SPEED CONTROL APPLICATIONS OF BLDC MOTOR DRIVE WITH 150-DEGREE CONDUCTION MODE INVERTER

M. Cihat Ozgenel
Erzincan University

Abstract: This experimental study presents a precise speed control scheme for Brushless Direct Current (BLDC) Motor which is fed three-phase inverter implemented 150-degree commutation mode. In 150-degree commutation mode, four rotor position signals are required. From these four position signals can be attained pure analogue rotor speed information. Because there are four position signals, it can be easily obtained analogue rotor speed signal by implementing frequency to voltage converter. So, low cost and further precise electronic tachogenerator (ETg) can be put into practice in order to perform closed-loop precision speed control for BLDC motors.

In this study, 150-degree commutation technique has been applied a BLDC motor and four rotor position signals have combined properly to attain higher frequency than one position sensor's frequency to acquire pure analogue rotor speed information. After converting four positions signals to pure analogue rotor speed information signal by frequency to voltage converter circuitry for manufactured this study, it has been applied to a PI speed regulator in order to obtain constant rotor speed versus changing load.
BLDC motor driven 150-degree commutation has been run under various loads and speeds and performance of the BLDC motor and ETg have been examined.
Furthermore, a high resolution electro mechanic tachogenerator is used in experimental setup in order to compare the performances with proposed ETg.

Keywords: 150-degree commutation mode, electronic tachogenerator, frequency to voltage converter, speed control of BLDC motor

Introduction

Brushless Direct Current (BLDC) motors are increasingly used in a wide range of applications such as medical, industrial, robotics, and aerospace applications day by day. Speed and torque of BLDC motors can be easily and precisely controlled due to the fact that their structures are suitable for control. In applications where speed control of BLDC motor is important such as industrial, medical, household applications, small moveable devices, textile machines and many of applications, BLDC motors are equipped an electro mechanical tachogenerator on the motor shaft by their manufacturers. Attaching electromechanical tachogenerator on the motor shaft increases cost and volume of BLDC motor.

BLDC motors need rotor position sensors in order to implement commutation. Commutation is performed according to the rotor position information received from the rotor position. Rotor position information is generally sensed three position sensors which ensure 120-degree commutation placed on the stator in BLDC motors. Position signals from these three position sensors are logic high and logic low. These logic high and logic low position signals which are apart from 120-electrical degree each other can be used to obtain analog rotor speed signal to input a PI speed controller in order to obtain constant speed from BLDC motor. In March 2017, M. Cihat Özgenel, Gungor Bal and Durmus Uygun obtained a pure rotor speed analogue signal from three position sensors signals in 120-electrical degree commutation mode controlled BLDC motor. In their study, they have obtained a higher frequency square wave signal one of three position signals. Then this higher frequency

- Selection and peer-review under responsibility of the Organizing Committee of the conference
*Corresponding author: M. Cihat Özgenel- E-mail: mcozgenel@erzincan.edu.tr

signal which is three times one position signal has been used to achieve pure analogue rotor speed signal by frequency to voltage converter. The higher frequency to frequency to voltage converter, it is obtained the purer analogue signal. If the motor is controlled by 150-degree commutation method, four position sensors should be used. In 150-degree commutation method for BLDC motors, from the four position signals, it can be obtained a square wave which is two times frequency than those of 120-degree commutation mode. So, pure analogue speed signal can be obtained from frequency to voltage converter and BLDC motor can be controlled both at low and high speed ranges.

In 2009, Hung-Chi Chen, Chih-Kai Huang and Tzu-Yang Tsai studied 150-degree commutation mode using sensorless algorithm, they used a 16 bit MCU . Srivichai Promthong and Mongkol Konghirun controlled BLDC motor by using 150-degree conduction mode implementing 16-bit, 40 MIPS dsPIC33F controller in order to minimize torque ripple. Mayur H. Maheswari, Madhusudan V. Gohil and Mayuri Tahilramani implemented 150-degre conduction mode to BLDC motor in order to reduce harmonics using AT89C51 8-bit microcontroller in 2015. Mohamed H. Saied, M.Z. Mostafa, T. M. Abdel-Moneim and H.A. Yousef implemented PIC16877 micro controller to reduce harmonics contents in both current and voltage by controlling BLDC motor with 150-degree conduction mode in 2006. In 2016, Rishabh Shah, Dhairya Shah, Priyank Shah and Sanket Thakur carried out 150-degree conduction mode in order to reduce harmonic distortion by implementing Matlab/Simulink toolbox.
As explained above, 150-degree commutation mode used to carry out reduction torque ripple and harmonics. But speed control applications of BLDC motors have an important area in the industry. In this study, a precise closed loop speed control of BLDC motor with 150-degree conduction mode without using electro mechanic tachogenerator as speed feed back device has been implemented.

Methods

In order to implement 150-degree conduction mode to BLDC motor, rotor position information should be sensed four-bit as binary high and binary low. These four bit rotor position information data are used to obtain a square wave which is higher frequency than rotor position signals. High frequency square wave is given to frequency to voltage converter in order to achieve an analogue signal proportional to rotor speed. Then this analogue rotor speed signal is used as rotor speed feedback signal to PI speed regulator. PI speed regulator keeps the rotor speed constant against load changes. The PID controller has found a very wide application area in the industry, due to its simplicity, stability and easy applicability, Vinod KR Singh Patel and A. K. Pandey, 2013. Linearity and resolution of frequency to voltage converter is important to attain successful results from the proposed system.
Figure 1 shows the conventional BLDC motor drive system. In conventional BLDC motor driver, in order to get stable speed an electro mechanic tachogenerator (T_G) is used to measure rotor speed. Measured rotor speed by electro mechanic tachogenerator is applied to PI speed controller for comparison with reference speed.

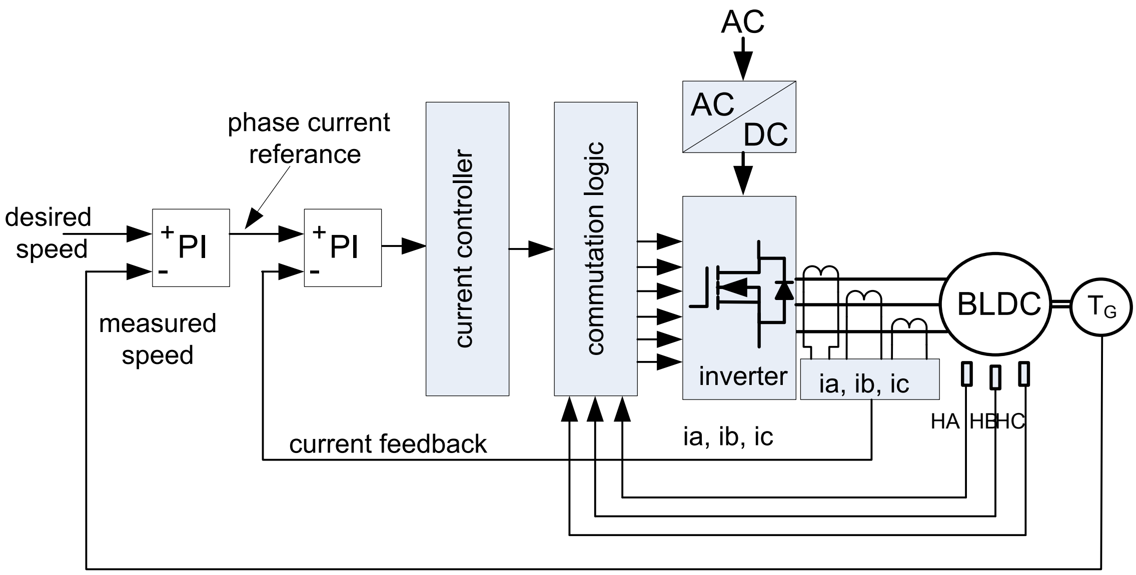


Figure 1. Conventional BLDC motor driver

Then, phase the current reference is obtained from output of PI speed controller. Measured phase currents by current sensors are applied to PI current controller for comparison with reference of phase current. The output of PI current controller is inputted current controller block. In this current controller block, PWM signal produces according to output of PI current controller. Commutation logic unit produces appropriate gate signals for inverter transistors according to the state of rotor position signals HA, HB and HC which are inputted commutation block.

Figure 2 shows the proposed driver system. The main difference between two control schemes is measured speed signal obtained electronically without using electro mechanic tachogenerator resulting in reduced cost and volume of BLDC motor.

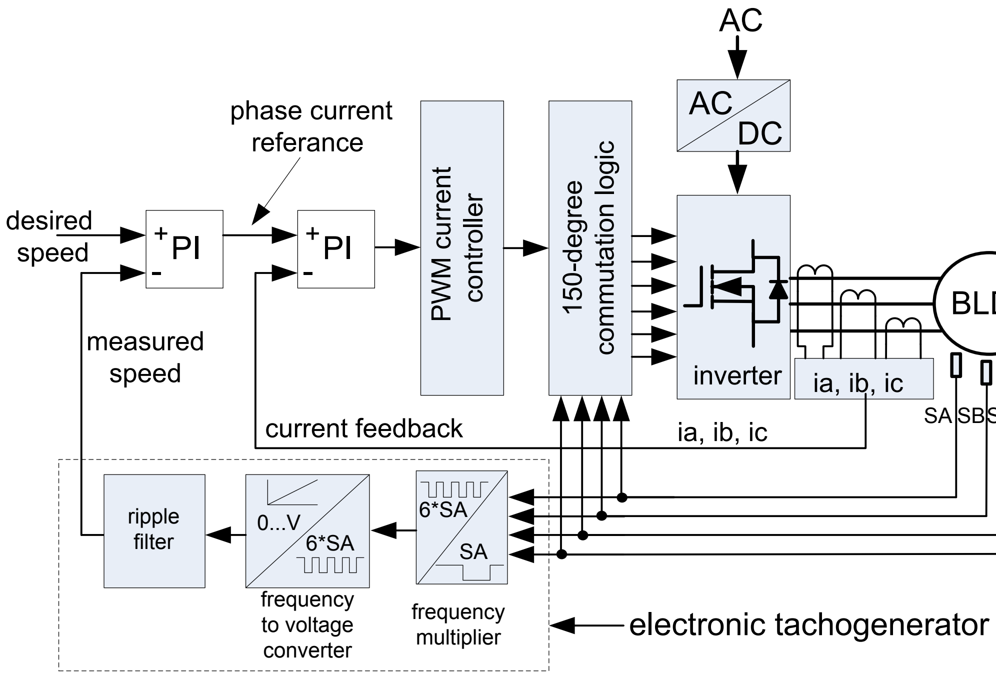


Figure 2. BLDC motor driver using proposed electronic tachogenerator as a speed sensor

In Figure 2, four-bit position information is used to provide both commutation and to obtain analog speed information. Four-bit binary high and binary low position data is input 150-degre commutation block and electronic tachogenerator. Electronic tachogenerator consists of three parts. These are frequency multiplier, frequency to voltage converter and ripple filter.

Frequency Multiplier

Frequency multiplier that has four-bit input and one-bit output functions to increase the frequency. Rotor position is sensed by four switches SA, SB, SC and SD. The frequency of output signal of the frequency multiplier is 6 times the frequency of SA switch (Figure 3). This process is performed using basic logic gates.

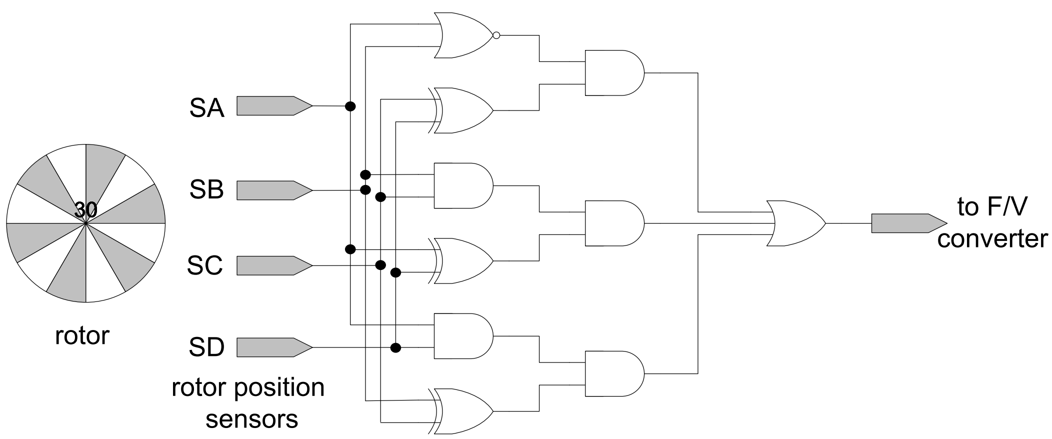


Figure 3. Frequency Multiplier

Frequency to Voltage Converter

The frequency to voltage converter generates an output voltage that is proportional to the input frequency. The output of frequency multiplier is inputted frequency to voltage converter (F/V). Processing of frequency to voltage converting is implemented by KA331 chip in this study. There are numerous F/V converter chips used in frequency to voltage converting applications such as LM2917, LM2907, TC9400, RM4151, NTE995, VFC32, LM331, KA331 and etc. The KA331 is preferred in this study due to the fact that it requires few components, it is low cost and easily available and it has excellent electrical characteristic. In F/V converters, the higher frequency of input to F/V converter is the purer analogue signal is obtained. This means that F/V converter gives good result even at low rotor speeds. Figure 4 shows F/V converter that is used KA331 from Fairchild Semiconductor Co. The output voltage of KA331 frequency to voltage converter chip is expressed as follows;

$$V_{out} = F_{in}.(2.09).\frac{R_L}{P}.R_t.C_t \tag{1}$$

Where F_{in} is the output frequency of frequency multiplier that is proportional to rotor speed, P is the value of P_1 potentiometer. P, R_L, R_t and C_t are 5.117KΩ, 19.21KΩ and 47nF respectively.

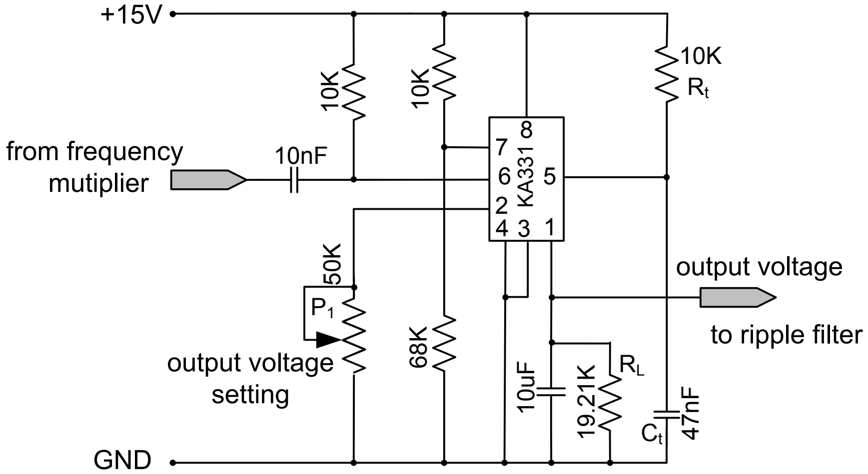


Figure 4. Frequency to voltage converter

Ripple Filter

Ripple filter is need due to eliminate the ripples in the output of F/V converter. When the BLDC motor rotates at low speed ranges, input frequency to F/V converter is low and the output voltage of F/V converter may have fluctuation. This fluctuation or ripple can cause fluctuations at BLDC motor speed. In order to input pure and without ripple speed feedback signal to speed controller PI, the speed feedback signal should be pure and without ripple. This can be easily accomplished with TL081 operational amplifier from ST Microelectronics. Figure 5 shows ripple filter implemented TL081 working in the common mode. Ripple removes from fundamental signal and pure analogue speed signal is available at the output of TL081. Although there are many schemes of ripple removal, Figure 5 gives excellent result and is carried out with very few components.

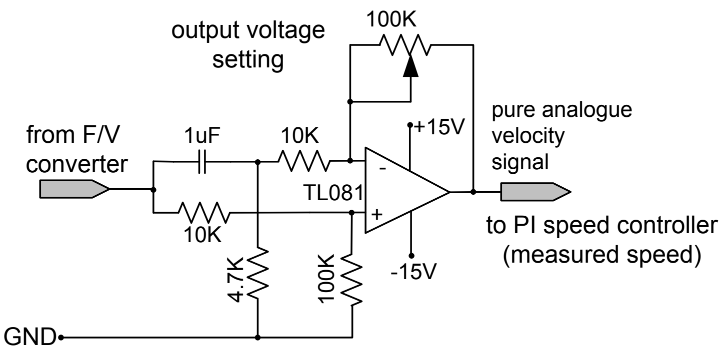


Figure 5. Ripple Filter

Testing Part of Electronic Tachogenerator

The parts of electronic tachogenerator have been tested one by one. The frequency multiplier is the first part of ETg which is tested. The task of the frequency multiplier is to increase the frequency of the SA (F_{SA}) switch to six times. Figure 6 clearly shows that the output frequency of the frequency multiplier is 6 times the SA switch measured by logic analyzer. In the same time the output frequency of frequency multiplier is 2 times of SB switch.

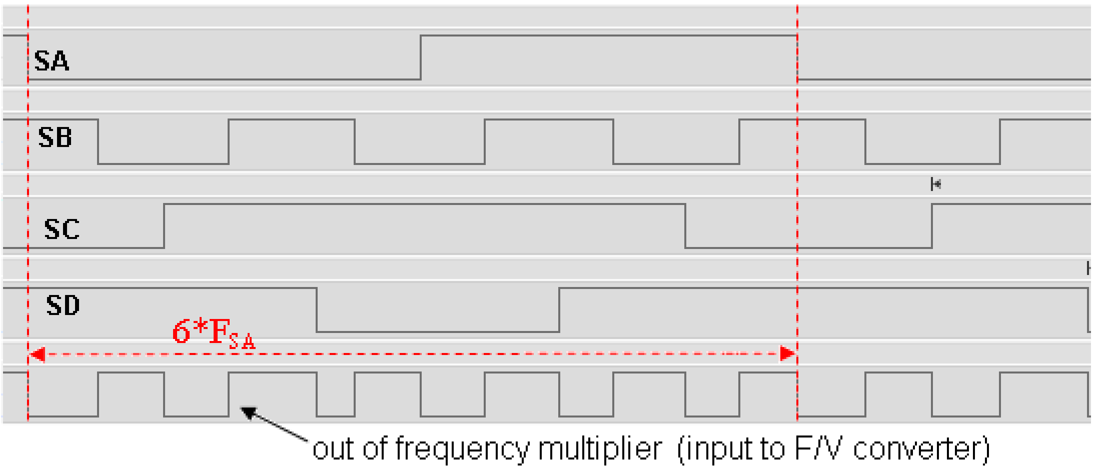


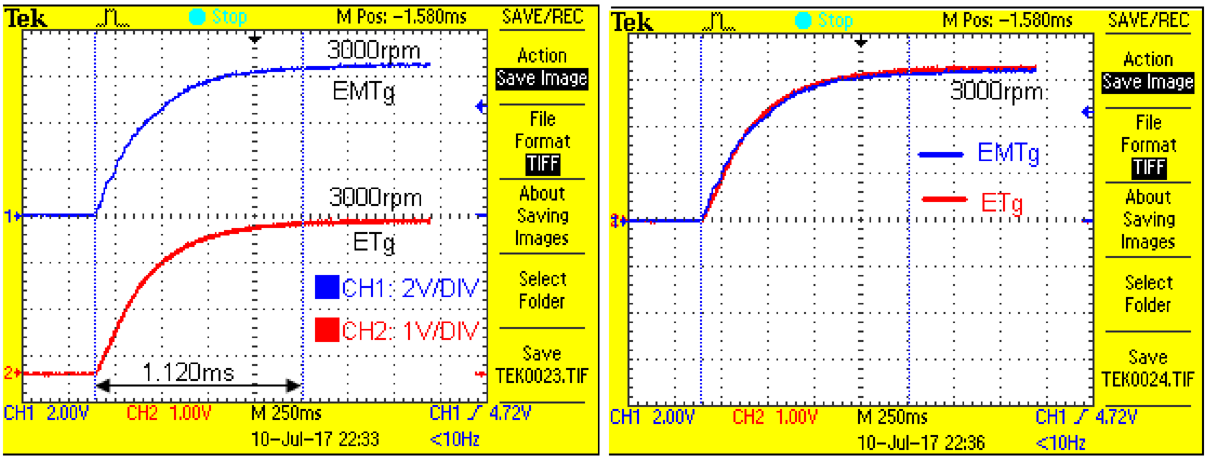
Figure 6. Tested of frequency multiplier

Then, F/V converter has been tested for linearity and accuracy. For this test, various values of frequencies have been applied to F/V converter and measured the out of ripple filter. In addition, the frequency value applied to F/V converter is also calculated according to formula (1). Table 1 shows that F/V converter and ripple filter have excellent accuracy and linearity. When Table 1 is examined, it can be clearly seen that there is no difference between the calculated value according to formula (1) and the measured values.

Table 1. Response of F/V converter according to various input frequencies

No	Input Frequency (Hz)	Measured Output of F/V Converter (V)	Calculated Value According to Formula (1)
1	50	0.1841	0.18435
2	100	0.3688	0.3687
3	150	0.553	0.553
4	200	0.738	0.737
5	250	0.921	0.92175
6	300	1.10	1.106
7	350	1.293	1.2904
8	400	1.479	1.4748
9	450	1.660	1.659
10	500	1.847	1.843
11	550	2.025	2.0278
12	600	2.213	2.2122

It is also ETg has tested for time response. For this test, ETg has been compared with a high resolution mechanical tachogenerator. The results of the tests are satisfactory. Figure 7 shows that there is no difference for the time response between electro mechanic tachogenerator and purposed ETg.



(a) (b)

Figure 7. Time response for both tachogenerators

As seen Figure 7(a), the BLDC motor has been started up both speed curves have started at the same time and both speed curves have the same changing (Figure 7(b)). When the two-speed curve overlaps it is distinctly seen that the two curves are the same and the ETg speed curve is ripple free.

Results and Findings

After these satisfactory tests, the BLDC motor has been run closed loop speed control system according to Figure 2 using 150-degree conduction mode and ETg has been used a speed feedback device. The BLDC motor has been run under load and without load and performance of ETg has been analyzed. In Figure 8, BLDC motor running 150-degree conduction mode runs at 1515.2 rpm without load, after 750ms, 130mNm load is applied to motor. When motor is loaded, motor speed is decreased very small value then PI speed controller is increased the motor speed 1515.2 rpm again. This process takes place at 250ms. The BLDC motor runs under 130mNm load then the load is removed from the motor suddenly. When the BLDC motor is suddenly unloaded, speed of BLDC motor is increased to 1761.86rpm then decreased to 1374.2rpm. After a small change in BLDC speed, rotor speed is reached its reference speed value that is 1515.2rpm. The purposed electronic tachogenerator has responded very quickly and it has quickly sensed changing of the speed and given it input to PI speed controller that keeps the speed constant. After BLDC motor is unloaded, the BLDC motor speed has reached its reference value within 570ms after carrying out a small oscillation. From Figure 8, it is easily seen that steady state error is zero. Figure 8 also compares the time response of two tachogenerators.

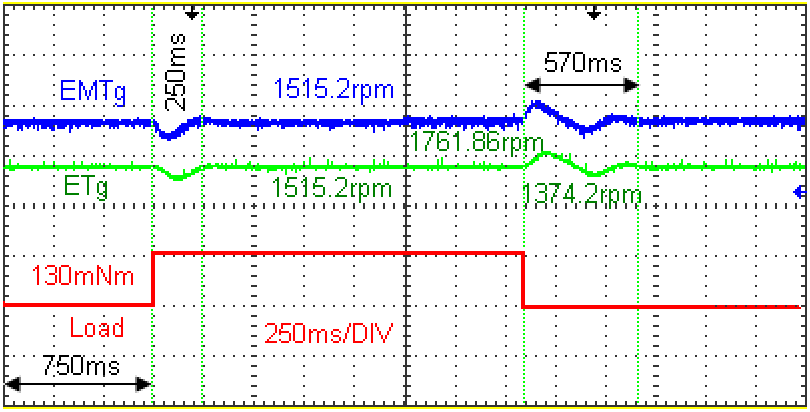


Figure 8. Speed response of BLDC motor loaded and unloaded

In Figure 9, Speed reference has been changed randomly and BLDC motor has accomplished following this change in speed without delay thanks to quickly response of PI and ETg.

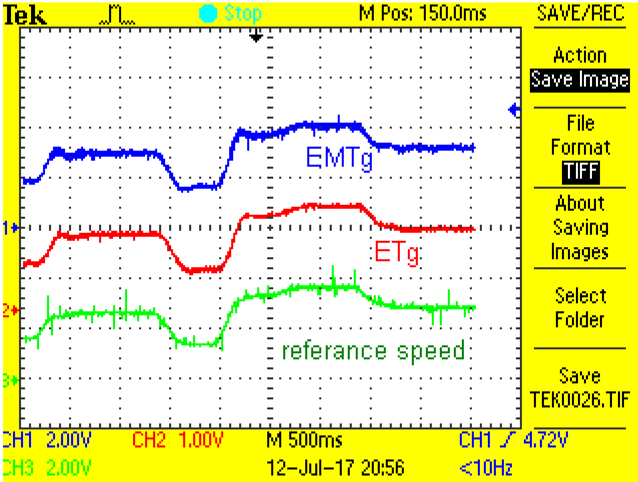


Figure 9. Response of both tachogenerators versus random speed change demand

Conclusion

In this study, an electronic tachometer is purposed and it is used instead of electro mechanic tachogenerator in order to implement closed speed control of BLDC motor with 150-degree commutation mode operation. For this purpose, a 150-degree commutation mode BLDC motor driver has been designed and implemented. Rotor position is sensed by four position switches. A pure rotor speed signal has been obtained using these four bits of information. So, rotor speed is sensed without using an external rotor speed sensor. Position switches have also been used as rotor speed sensors. Thus an analog electronic tachogenerator (ETg) has been carried out. ETg has been used a speed feedback device and ETg has given perfect results. Table1 shows that ETg has perfect linearity and very high precision. It was found that there was no time difference between the speed response of the purposed ETg and the speed response of the electro mechanical tachogenerator in Figure 7. In Figure 8, when the BLDC motor runs without load, 130mNm load is suddenly applied to BLDC motor, then the load is suddenly removed the BLDC motor, but the closed speed control system using ETg as speed feedback device keeps the motor speed constant against sudden load changes. Figure 9 shows that reference speed changes randomly, the closed speed control system is followed the changing without any delaying.

Recommendations

From these experimental results, the purposed ETg can be used feed back device instead of electro mechanical tachogenerator in closed-loop speed control applications of BLDC motors. This ETg can be used both conventional 120-degree commutation mode and 150-degree commutation mode. If proposed ETg is combined with the BLDC motor pre-driver in a new chip by the manufacturers, a versatile and more efficient BLDC motor pre-driver chip which, BLDC motor provides higher performance is obtained.

References

Ozgenel M. Cihat, Bal Gungor, Uygun Durmus, (2017). Design an application of a novel high precision and low cost electronic tachogenerator for sensor-based direct current motor drivers, *Rewiew of Scientific Instruments, Vol. 88, issue, 3*,1-7.

MadhusudhanaRao at al, (2010). Speed control of BLDC Motor Using DSP, *International Journal of Engineering Science and Technology, Vol. 2(3)*, 143-147.

Hung-Chi Chen, Chih-Kai Huang, Tzu-Yang Tsai, (2009). DCM Sensorless Control for Twelve-Step Square-Wave PWM, *2009 International Conference on Power Electronics and Drive Systems (PEDS), 2-5 Nov., Taipei*, 511-516.

Srivichai Promthong and Mongkol Konghirun, (2013). Sensorless control of BLDC motor drive with 150^0 conducting mode to minimize torque ripple, *International Conference on Electrical Machine and Systems, Oct, 26-29*, Busan, Korea.

Maynur H. Maheswari, Madhusudan V. Gohil, Mayuri Tahilramani, (2015). Implementation of Three Phase 12-Step VSI With Harmonics Reduction, *National Conference on Recent Research in Engineering and Technology (NCRRET -2015), International Journal of Advance Engineering and Research Development (IJAERD)* e-ISSN: 2348-4470, print-ISSN:2348-6406

Mohamed H. Saied, M. Z. Mostafa, T. M. Abdel-Moneim and H.A. Yousef, (2006). On Three-Phase Six-Switches Voltage Source Inverter: A 150^o Conduction Mode, *IEEE ISIE 2006, July 9-12*, Montréal, Québec, Canada.

Arpit Shah, Divyesh Mangroliya, and Nirav Vaghela, (2013). Simulation and Analysis of an Advanced 150^o Conduction Mode for Three Phase Voltage Source Inverter, *ACEEE, Proc. Of. Int. Conf. on Emerging Trends in Engineering and Technology*.

Rishabh Shah, Dhairya Shah, Priyank Shah, Sanket Thakur, (2016). Simulation and Analysis of 150° Conduction Mode For Three Phase Voltage Source Inverter, *International Journal of Engineering Research and Development (IJERD) ISSN: 2278-067X Recent trends in Electrical and Electronics & Communication Engineering, RTEECE 08th – 09th April* , 05-10.

KA331 V-F Converter, (2001). Fairchild Semiconductor Corporation.