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COMPARING CONTROL PERFORMANCES OF MRAC AND PID APPLIED ON A BRUSHLESS DC MOTOR

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Abstract- Brushless DC motors are powered by a DC electric source and are used widely used in appliance, automotive, aerospace, medical and industrial equipment due to their compact size and light weight. Parallel to improvements in semiconductor industries the operating frequency of semiconductor switches and microcontrollers are getting improve and this provides conditions to use different algorithms in motor control. In this study the reference model adaptive control of a DC brushless motor will be studied. Brushless DC motors have some advantages such as long working life, high efficiency, and low maintenance requirements; however their control is a bit complicated. For this reason, there have been published many studies in relative with speed control of brushless DC motors. Classical or modern control methods can be used for this purpose. In this study, BLDC motor is controlled with firstly classical PID controller and secondly model reference adaptive control (MRAC) based on MIT law method and the results are compared.

Keywords: Brushless DC Motors, BLDC, Model Reference Adaptive Control, MRAC, MIT Rule.

1. INTRODUCTION

Brushless DC motors (BLDC) are one of the special purpose electric motors. These types of motors are powered by a DC electric source and are used widely in appliance, automotive, aerospace, medical, and different branches of automated industries. The main advantages of this type motor are their compact size and light weight. In conventional direct current motors, commutation is carried out using brushes so; friction, electric sparks (arc) and noise occur. They shorten the life of the device. Therefore; new high-performance motors are needed for small and medium-sized applications [1].

BLDC consists of rotor, stator, feedback units, inverter - drive layer and controller [2] illustrated in Figure 1.

Looking at the parts of the brushless direct current motor; the rotor is the rotating part of the motor and consists of a permanent magnet. The number of poles ranges from two to eight. The appropriate magnetic material is selected depending on the magnetic field density required for the rotor. The magnets used for this purpose may be ferrite (ceramic) magnets or alloy materials such as Neodymium (Nd), Samarium cobalt (SmCo) and Neodymium, Ferrite and Boron mixture (NdFeB).

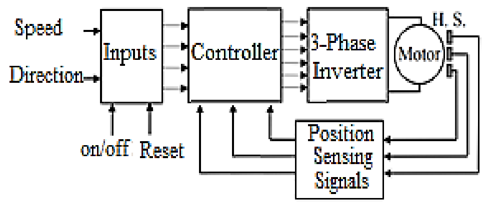

Figure 1. Drive system of BLDC

The stator is the stationary part of the motor. The stator winding of the BLDC motor may be trapezoid winding and the sine winding. The main difference between them is different connection methods of the winding. Depending on the winding connection the generated back emf waveforms of motor may be sine or trapezoidal wave. The back electromotive waveform generated by the trapezoid and sine winding is shown in Figure 2 [10].

Feedback control method is used to control the positon and speed of motor and this is achieved by comparing the signals measured through sensors mounted on the motor with the reference signals. The errors of the comparisons are used by controllers through which the signals applied to gates of inverter switches are generated.

Rotor position information is needed to understand which winding to be energized in the stator. The stator is energized according to the rotor position information transmitted through the feedback units. Today, various sensors such as electromagnetic, electromechanical and optical sensors are used in BLDC. Field effect sensor and optical sensor are commonly used in feedback units [1, 6]. Sensorless control approach is also one the control methods used in BLDC motor control [3].

The DC voltage of inverter input may be derived using single phase or three phase rectifiers. For the cases where the rectifiers are uncontrolled type a DC regulator may be used between the rectifier and the inverter to control the DC inverter input voltage. In some applications single phase or three phase power factor corrections are used.

These types converters both adjust the output dc voltage and increase the rectifier input current to unity [4]. With the controller, parameters such as current, torque, rotor position and speed of the motor are controlled using various control methods.

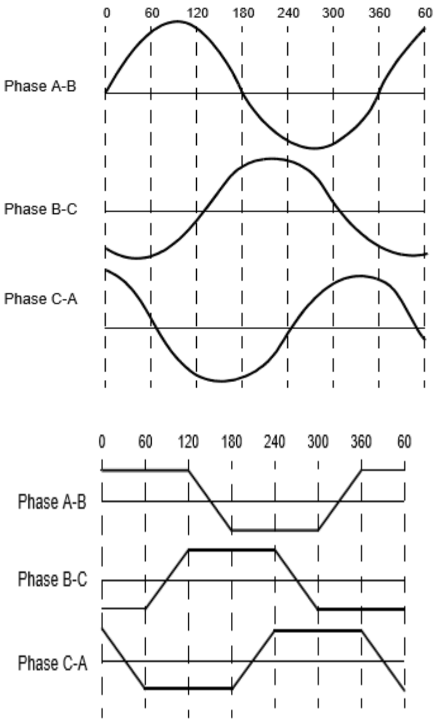

Figure 2. Trapezoidal back EMF and sinusoidal back EMF

BLDC is used in domestic appliances, heating, cooling and ventilation systems, civil and military robotics industry, health industry, aerospace industry, automotive industry [1]. BLDC has some advantages as relatively high efficiency, long working life, low maintenance or no maintenance, very small RF noise compared to brushed direct current motor. The complexity and costly of the control of BLDC with respect to brushed DC motor can be considered as disadvantages of BLDC motors [2].

2. MODELING OF BRUSHLESS DC MOTOR

The mathematical model of a BLDC motor is derived in this section. The mathematical models of different parts of the system are derived and combined. The formulas obtained from circuit diagram of system shown in Figure 3 are used to get the mathematical model of BLDC motor as shown in Figure 4 [5, 6].

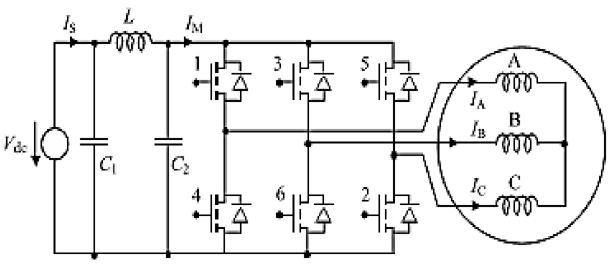

Figure 3. The circuit of BLDC

$$v_{dc} = 2[R_s i_a + (L-M)\frac{di_a}{dt} + e_1 - e_2 \quad (1)$$

$$v_{dc} = R_a i_a + L_a \frac{di_a}{dt} + e_1 - e_2 \quad (2)$$

$$T_e = T_L + Jm\frac{d\omega}{dt} + Bm\omega \quad (3)$$

$$v_{dc} = R_a i_a + L_a \frac{di_a}{dt} + K_b \omega \quad (4)$$

$$T_e = K_b i_a \quad (5)$$

$$T_L = K_t \omega \quad (6)$$

$$K_b i_a - K_t \omega = J_m \frac{d\omega}{dt} + B_m \omega \quad (7)$$

The block diagram of BLDC can BE obtained as illustrated in Figure 4 which is based on Equations (4) and (7). The parameters of the motor considered in this study are given in Table 1.

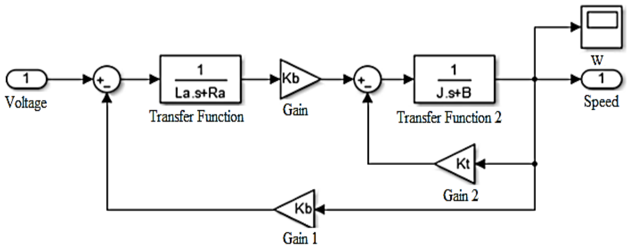

Figure 4. The block diagram of BLDC

Table 1. Parameters of BLDC motors

Parameters	Values
R_a	1.4 Ω
L_a	0.00244 H
K_b	0.0513 V.sec
B_m	0.002125 N.m.s/rad
J_m	0.0002 kg.m^2
gamma	0.1

3. CONTROL

There have been developed many control methods used to control BLDC motors. Each method has advantages parallel to disadvantages that it may have. The preference of the usage method depends mainly on the application where the motor is used. Control methods can be studied under two different groups as classical control (CC) and modern (intelligent) control (IC) [7].

3.1. Classical Control

If the mathematical model of the system to be controlled is fully known and control is not very sensitive, classical control methods with simpler and cheaper structure may be preferred. Classical control methods commonly used in brushless direct current motors; proportional-integral control (PI), proportional-derivative control (PD), proportional-integral and derivative control (PID). The desired operating performances can be obtained by adjusting the proportional gain (K_p), integral gain (K_i) and derivative gain (K_d) in these controllers.

3.2. Modern Control

This type of control is used where the mathematical model of the system cannot be determined exactly or there is needed for a sensitive or accurate control. The most commonly used methods are; fuzzy logic control, artificial neural networks, neural fuzzy control, genetic algorithm, particle flock optimization, wavelet technique, extended Kalman filter and adaptive control. In this study the adaptive control is studied.

3.3. Adaptive Control

Adaptive control is a control method used when the parameters of the process are not known or change over time. Model reference adaptive system (MRAS) is one of the main approaches of adaptive control. The MRAS consists of the reference model, controller, adaptation mechanism and plant as illustrated in Figure 5 [8].

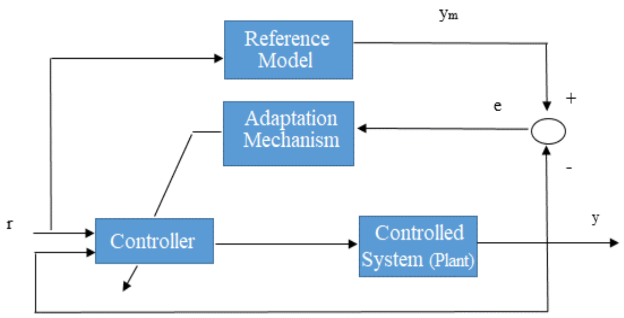

Figure 5. Block Diagram of model reference adaptive system

The block diagram of MIT rule, which is one of the main approaches of MRAC is shown in Figure 6. It was originally designed for autopilot in aircraft. Today, the MIT rule can be used to design a controller for any system with MRAC. The usage of this approach in driving of BLDC motor is illustrated [11, 12].

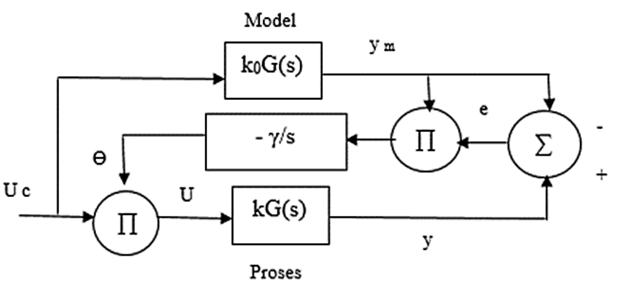

Figure 6. MIT rule

The formulas are:

$$U = \theta U_c \quad (8)$$

$$\theta = \frac{k_0}{k} \quad (9)$$

$$e = y - y_m = kG(s)U_c - k_0G(s)U_c \quad (10)$$

$$de/d\theta = kG(s)U_c = k/k_0 y_m \quad (11)$$

$$d\theta/dt = \gamma k/k_0 y_m e = -\gamma' y_m e \quad (12)$$

4. SIMULATION

This study was conducted in the Simulink application of the MATLAB program.

4.1. Control of the System Using the Classical Method of PID

In this section, the control of BLDC is done with PID controller which is one of the classical control methods. In this step of simulation the performance of the controller for three different input signals are studied separately. Firstly, a pulse function, then a sine function and finally a step function is applied to input of the system. The results of output for the given inputs are given separately in the following Figures. The circuit of the BLDC controlled by the classic PID controller is illustrated in Figure 7.

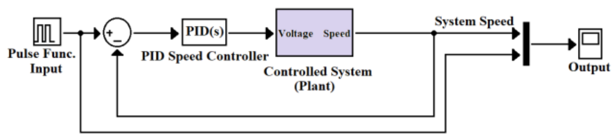

Figure 7. Circuit of BLDC controlled by a classic PID controller

4.1.1. Application of Pulse Function Input

The reference speed in the form of a pulse function is applied to the circuit in Figure 4. The results of simulation are given in Figure 8.

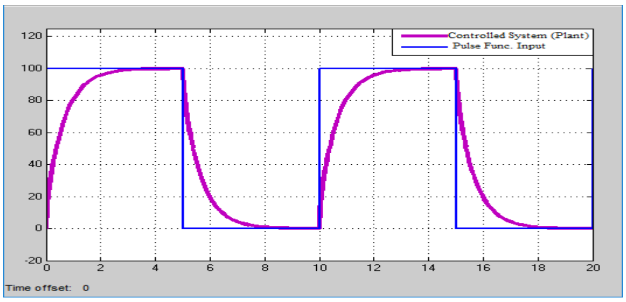

Figure 8. Output of BLDC with PID control applied as pulse function

4.1.2. Application of Sine Function Input

The reference speed in the form of a sine function is applied to the circuit in Figure 4. The results of simulation are given in Figure 9.

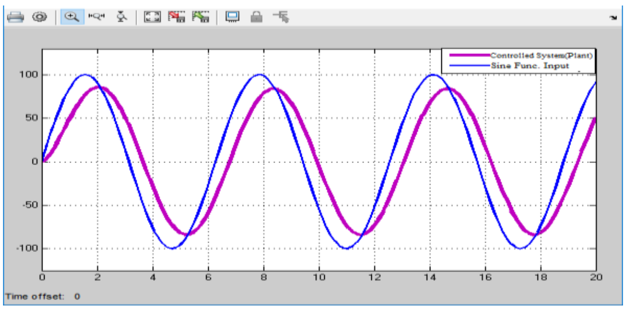

Figure 9. Output of BLDC with PID control applied as sine function

4.1.3. Application of Step Function Input

The reference speed in the form of a step is applied to the circuit in Figure 4. The results of simulation are given in Figure 10.

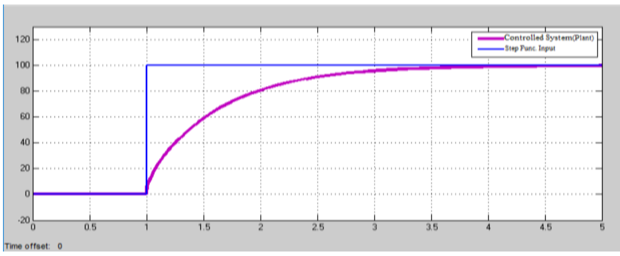

Figure 10. Output of BLDC with PID control applied as step function

4.2. Control of the System Using Model Reference Adaptive Control - MIT Method

The block diagram of the system using Model Reference Adaptive System is shown in Figure 11 [9].

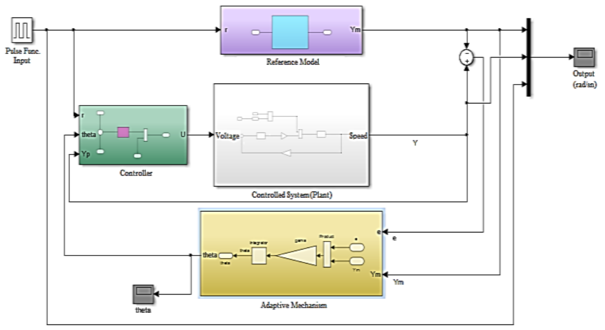

Figure 11. BLDC circuit diagram applied to MRAC

This system consists of reference model, plant, controller and adaptive mechanism. This study was conducted in the Simulink application of the MATLAB program. The reference model that was used in simulation is a 2nd order transfer function. The plant component of the model reference adaptive system is the mathematical model of the motor illustrated in the Figure 4. The controller component of the model reference adaptive system is theta, which varies according to the gamma (adaptation gain) variable in the adaptation mechanism. The adaptive mechanism of the model reference adaptive system is formed according to structure given in Figure 6.

4.2.1. Application of Pulse Function Input

At this stage, the pulse function is applied to the system input. The control of the system was performed using Model Referance Adaptive Control using the MIT rule. The simulations were carried out for the same inputs used in part A for PID control approach. The output results for different input functions are derived and are compared with ithe input ones. The results of the simulations are given in Figures 12 and 13.

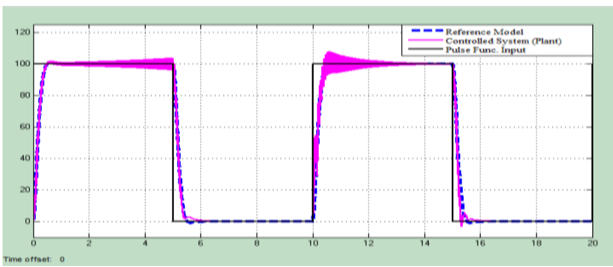

Figure 12. The output of the BLDC controlled in rad/sec by MRAC-MIT rule (Pulse function input)

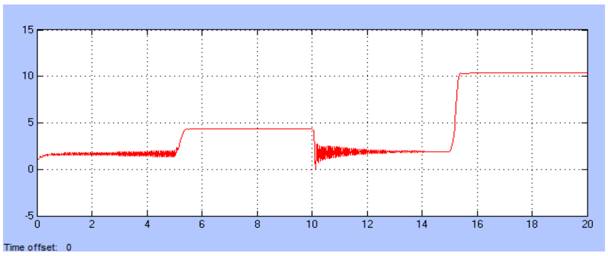

Figure 13. Theta graph of the BLDC controlled by MRAC-MIT rule (Pulse function input)

4.2.2. Application of Sine Function Input

At this stage, the sine function is applied to input of system. The output results for different input functions are derived and are compared with ithe input ones. The results of the simulations are given in Figures 14 and 15.

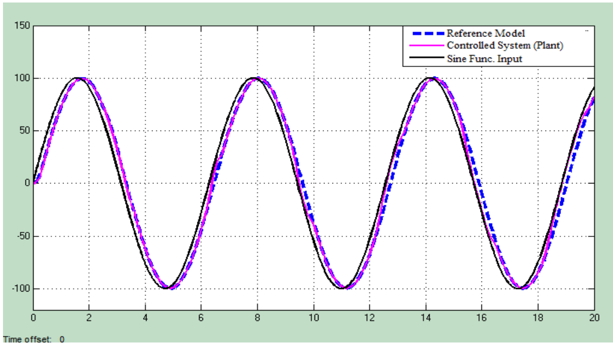

Figure 14. The output of the BLDC controlled in rad/sec by MRAC-MIT rule (Sine function input)

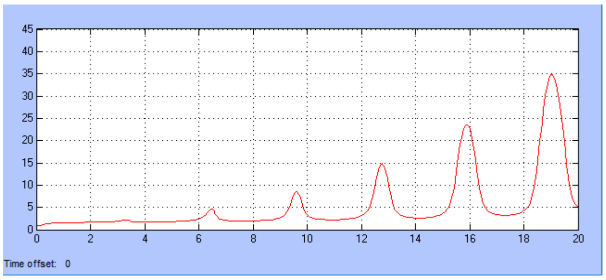

Figure 15. Theta graph of the BLDC controlled by MRAC-MIT rule (Sine function input)

4.2.3. Application of Step Function Input

At this stage, the step function is input is applied to the system input. The output results for different input functions are derived and are compared with ithe input ones. The results of the simulations are given in Figures 16 and 17.

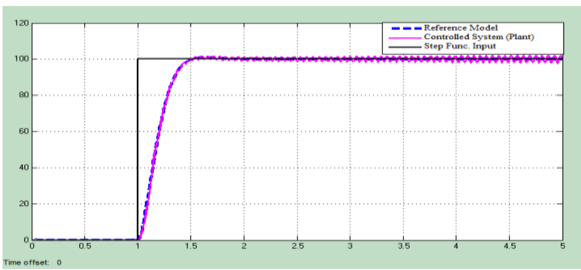

Figure 16. The output of the BLDC controlled by MRAC-MIT rule (Step function input)

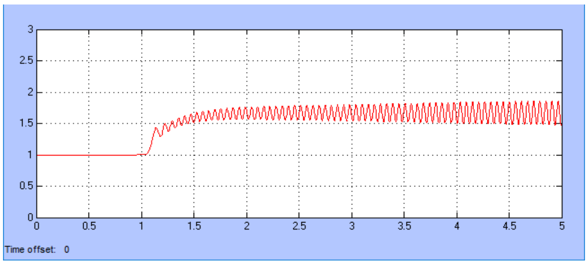

Figure 17. Theta graph of the BLDC controlled by MRAC-MIT rule (Step function input)

5. CONCLUSIONS

In this study, the mathematical model of a brushless dc motor was derived. The control of motor was performed by two different methods of PID and Model Reference Adaptive Control-MIT. To compare the performance of the above mentioned methods different types functions were applied to input of the system. The response of these methods were compared based on the difference between the input and outputs for the different applied functions.

The response of the system of two different methods for the input signal of pulse function are shown in Figure 8 and 12 respectively. Comparing these two figures shows that while in classical control of PID the output capture input in 3 sec in MRAC-MIT Rule method the output captures the input in only 0.5 sec.

Figures 9 and 14 show the control performance for a sine function. Comparing the corresponding outputs show the both response time and accuracy of the results corresponding to MRAC-MIT Rule is better than that for classical method of PID.

Figures 10 and 16 show the control performance for a step function. Comparing the corresponding outputs shows the both response or rise time of the results corresponding to MRAC-MIT Rule (1.5 sec) is better than that for classical method of PID (3.5 sec).

NOMENCLATURES

1. Abbreviations

BLDC Brushless Direct Current Motors
PID Proportional-Integral-Derivative Controller
MRAS Model Reference Adaptive System
MRAC Model Reference Adaptive Control

2. Symbols / Parameters

V_{dc}: Voltage of the DC supply, V
i_a: Armature current, A.
R_s: Stator winding resistance, Ω/ph
$R_a = 2R_s$, Ω
L: Per phase stator winging self-inductance, H
$L_a = 2\,(L-M)$, H
M: Mutual inductance between two stator phases, H
e_1: Back EMF of the first current-carrying phase winding, V
e_2: Back EMF of the second current-carrying phase winding, V
w: Mechanical speed of the rotor, rad/s
K_t: Load torque constant, N.m.s/rad
K_b: EMF constant of the motor, V.s/rad (Nm/A).
T_e: Electromagnetic torque, N.m
T_L: Load torque, N.m
B_m: Coefficient of friction, N.m.s/rad
J_m: Moment of inertia of the motor shaft and attached load, kg.m^2
y: Output of system
ym: Output of reference model
e: Error
θ: Control parameter
γ: Adaptation gain

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BIOGRAPHIES

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Ires Iskender received his Ph.D. degree in Electrical and Electronics Engineering from Middle East Technical University (Ankara, Turkey) in 1996. Prior to joining the Department of Electrical and Electronics Engineering of Cankaya University (Ankara, Turkey), he worked as a Professor at Department of Electrical and Electronics Engineering in Middle East Technical University and Gazi University. His current research interests are energy conversion systems, renewable energy sources, electrical machine and power quality. He participated in and coordinated several research projects and he served as the panelist and referee for many academic or industry projects.

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