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Open-loop BLDC motor simulation using the Motor Control blockset from Matlab library

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Abstract

Special electrical machines play an increasingly important role in modern applications. They are designed to address situations that were previously handled by conventional machines, offering improved efficiency and sustainability. The growing need to save resources and protect the environment has encouraged the development of new strategies in motor design and control. This paper presents a BLDC behaviour using datasheets obtained from a PMSM motor. Both BLDC (Brushless DC) and PMSM (Permanent Magnet Synchronous Motor) are permanent magnet machines and their mathematical models are closely related, differing mainly in how the back-EMF is shaped (trapezoidal for BLDC, sinusoidal for PMSM). Key parameters like stator resistance, inductance, and permanent magnet flux linkage are common to both machines. This means PMSM data can be repurposed for BLDC simulations without needing a completely separate dataset. MATLAB/Simulink, provide PMSM blocks that can be adapted for BLDC by changing the EMF profile. This paper presents an open-loop control scenario for simulating the BLDC motor performance using the Motor Control Blockset from the MATLAB/Simulink library starting from a PMSM open loop control strategy.

Keywords: Brushless DC Motor (BLDC), Permanent Magnet Synchronous Motor (PMSM), Open-loop control, MATLAB/Simulink, Motor Control Blockset, Back-EMF, Torque ripple.

1 Introduction

Electric drives based on permanent magnet (PM) machines have become increasingly popular in modern applications such as electric vehicles, robotics, and industrial automation. Among these machines, the Brushless DC Motor (BLDC) and the Permanent Magnet Synchronous Motor (PMSM) are two of the most widely used types due to their high efficiency, compact size, and excellent dynamic performance. Although they share a similar construction—both having a permanent magnet rotor and a three-phase stator—their electrical characteristics and control strategies differ significantly.

However, their behaviour differs significantly due to the type of supply current and the shape of the Back-EMF waveform. Consequently, the control methods also differ: the BLDC motor by using electronic commutation based on Hall sensors [1], while the

PMSM employs vector control (Field-Oriented Control) [2] or sinusoidal PWM. These differences notably affect the torque ripple, noise and overall efficiency [3].
An open loop speed control of BLDC represents an important step in obtaining a model which contains less switching action and a sensorless control technique applied in electric vehicle drives [4].
The BLDC motor is more efficient, requires less money, has a large ratio of torque to weight and it is easy to at all speeds. Hall sensors are used to determine the rotor's position. In an open loop, BLDC motor the control technique involves voltage control, pulse-width modulation, and frequency control. The open-loop control is more accurate than the closed-loop speed control as external factors like temperature and load variations are included [5].
To reduce the ripple torque commutation, a strategy of direct torque control (DTC) is used for a dual inverter-fed three-phase BLDC motor drive with open-end stator winding [6]. Another possibility of reducing the ripple torque is to connect each phase winding of the winding BLDC to an H-bridge inverter, so its phase voltage and current could be controlled independently [7].
MATLAB and its Simulink environment provide a powerful platform for modelling, simulation, and analysis of electrical machines and control systems. The Motor Control Blockset within MATLAB offers prebuilt models, parameterized motor components, and control algorithms that significantly simplify the development and testing of motor control strategies. These tools enable the accurate simulation of both BLDC and PMSM motors under various operating conditions, allowing designers to evaluate torque, speed, current, and efficiency characteristics without the need for physical prototypes. Furthermore, MATLAB's flexibility in integrating mathematical models with control algorithms facilitates a deeper understanding of system dynamics and the impact of different control techniques such as electronic commutation (BLDC) and field-oriented control (PMSM). As a result, MATLAB serves as an essential tool for validating motor performance and optimizing design parameters in a cost-effective and time-efficient manner.
Motor parameter estimation is the key element for implementing motor control algorithms with good results. Accurate motor parameters enable the algorithm to compute the control parameters with precision. Therefore, accurate representation of motor parameters is necessary for a finer speed and torque control when you run PMSMs using control techniques such as field-oriented control (FOC). Motor parameter estimation also enables you to verify the parameter values provided by the motor datasheet. In addition, it enables you to accurately replicate the plant model in Simulink® using which you can simulate real-world scenarios and tests that are difficult to execute using a physical hardware setup.[8]
The paper presents the behavior of a BLDC motor using a PMSM parameters offered by MATLAB library "Motor Control Blockset" and the tutorial applications. From a PMSM datasheet, the most useful parameters for BLDC motor simulation are electrical constants (resistance, inductance), mechanical constants (inertia, friction), and motor ratings (voltage, current, torque, speed, poles). These values allow to build an accurate open-loop strategy of the motor for control and performance analysis.
The objective of this paper is to analyze the behavior of a BLDC motor using 'Motor Control Blockset toolbox and highlight the impact of control method (open-loop speed by VbF control) on Back_ EMF waveform and dynamic response if the procedure starts with data sheet provided by a PSMS motor. It's should be a starting point in developing

a complex strategy in BLDC drive simulation using Motor Control Blocks toolbox developed by MATLAB platform.

2 System modelling

2.1 The structure of BLDC diagram

Several types of electric motors are commonly used in EV applications, including permanent magnet synchronous motors (PMSMs), brushless DC (BLDC) motors, induction motors, and synchronous reluctance motors. Due to its characteristics, BLDC motors are preferred because could achieve precise speed control and reducing torque ripple, particularly under varying load conditions, remains a significant challenge that requires advanced control strategies. BLDC motor control techniques are primarily categorized into sensor-based and sensorless methods.[9]
The sensorless method estimates position by analyzing the back-electromotive force (back-EMF) waveform and identifying zero-crossing points. While sensorless control offers advantages such as reduced hardware complexity and cost, it struggles with rapid variations in load and speed, which can lead to misinterpretation of rotor position and potential system failure. Due to these limitations, sensor-based control techniques are commonly preferred in EV applications to ensure reliable and precise motor operation.[10]
A typical structure for supplying and controlling a BLDC is presented in fig. 1 [9], Where is illustrates a simplified configuration of a BLDC motor drive system, wherein a battery serves as the power source and delivers energy through a three-phase inverter composed of six MOSFET switches. The rotor, embedded with permanent magnets, directly contributes to the flux linkage, making magnetic flux saturation a prominent aspect of the motor's dynamic behavior. The analysis is carried out under the following assumptions:

1. To prevent magnetic core saturation, the motor is regulated to operate within its nominal current rating.
2. The 3-phase windings are symmetrically arranged.[9]

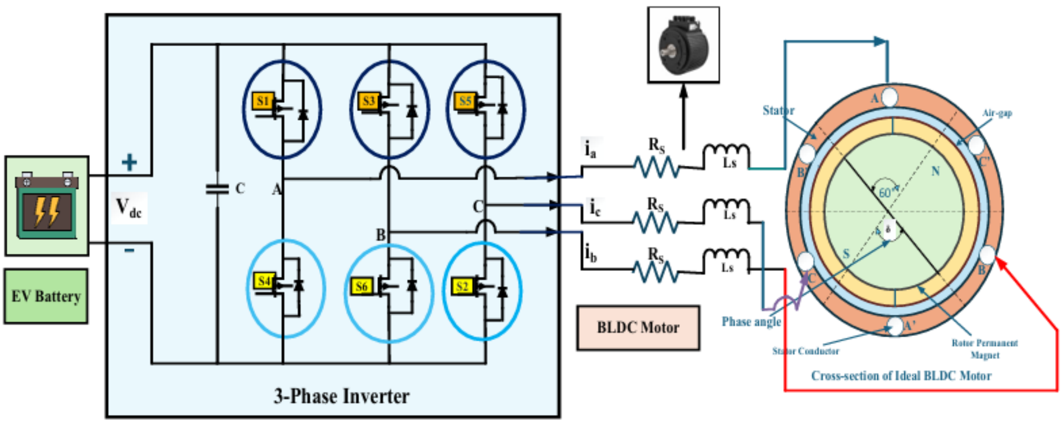

Figure 1. Simplified layout of a BLDC motor drive

The stator windings are a star connection and the voltage relations are the next expressions:

$$V_a = Ri_a + e_a + L_a \frac{di_a}{dt}$$
$$V_b = Ri_b + e_b + L_b \frac{di_b}{dt}$$
$$V_c = Ri_c + e_c + L_c \frac{di_c}{dt}$$

Where, $L_a = L_b = L_c = L_S - L_M$ [Henry]
And $R_a = R_b = R_c = R$

R, L_M, and L_S, are armature resistance in ohms, the stator mutual inductance, and self-inductance.
An example of control of BLDC motor without position sensor created in MATLAB/Simulink blocks are presented in fig. 2. [8]
The system describes a simulation for a BLDC motor, to control the speed in open loop electric drive. The system is feeds by a DC voltage source through a controlled three-phase inverter. The Control subsystem implements the sensorless speed control strategy. A hysteresis controller controls the phase currents.
The model is done by Simscape blocks from electrical and mechanical area. The model proposed uses dedicated blocks for each element like: inverter (with ideal semiconductor switch), ideal torque sensor, inertia, dc sources etc. The load torque is done through a step time source. The BLDC has a star stator winding connection with 4 number of pairs.

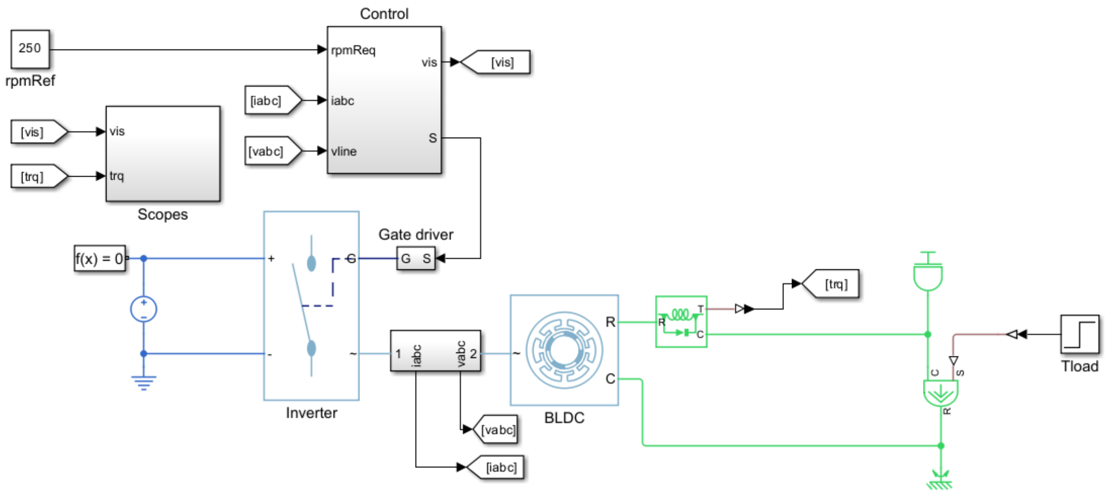

Figure 2. Physical system model of BLDC motor

2.2 The structure of PMSM diagram

In a small commercial application where not much precision is required, open-loop or voltage/frequency (Volt/Hz) control is used, due to their easy calculation and implementation and becomes a low-cost product for PMSM. [11]
Open-loop speed control for a PMSM (Permanent Magnet Synchronous Motor) involves controlling motor speed by adjusting the applied voltage and frequency

without using a speed sensor for feedback. The most common method is V/f constant, where the voltage-to-frequency ratio is kept constant to maintain magnetic flux. This is often used for starting the motor before transitioning to a closed-loop system.
Scalar Control controls only magnitudes. The simplest method to control a PMSM is scalar control, where the relationship between voltage or current and frequency are kept constant through the motors speed range. The frequency is set according to the wanted synchronous speed, and the magnitude of the voltage/current is adjusted to keep the ratio between them constant. No control over angles is utilized, hence the name scalar control. The method uses an open-loop control approach without any feedback of motor parameters or its position.[12]
Scheme presented in Fig. 3 is an open-loop PMSM electric drive. [14]
In this situation, the system does not measure or adjust based on rotor position or speed and have a fixed input: the controller sends a predefined signal to the inverter.
Sensorless control strategies for PMSM eliminate the need for physical position sensors by estimating rotor position and speed using mathematical models and observers. These methods improve reliability, reduce cost, and are widely used in automotive, industrial, and consumer applications. The simulation is realized with Simscape Electrical Specialized Power Systems Blocks types of blocks which will be not sustained by the versions of MATLAB anymore.

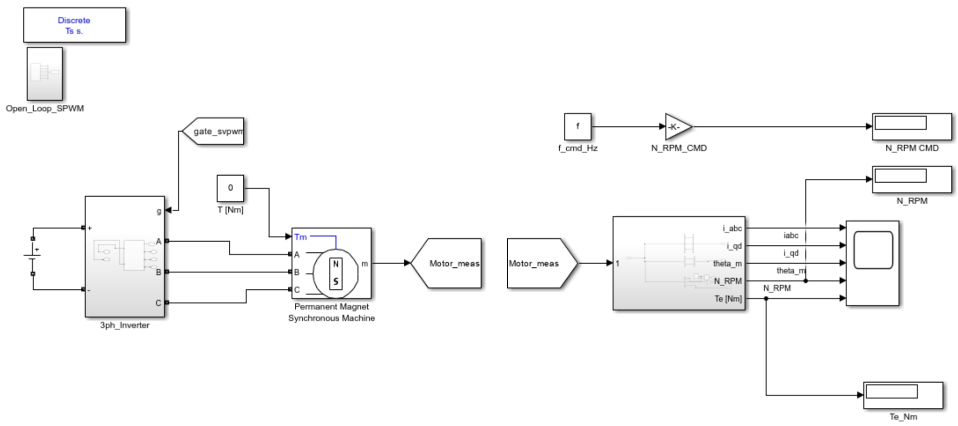

Figure 3 An open-loop PMSM control.

2.3 MATLAB simulations of BLDC motor

2.3.1 Motor Control Blockset toolbox

The Simscape library contains dedicated blocks in electrical and mechanical area for simulating the behavior of PMSM/BLDC motors in different situations with appreciate results. In many applications simulations part and practical determination are separately created and the aim is to validate simulation results with practical one.
Control Motor blocks are the building blocks of modern motor control systems. They abstract complex math and hardware interactions into manageable modules, making it easier to design safe, efficient, and scalable robotics or automation solutions.
Motor Control Blockset™ is a MATLAB/Simulink toolbox designed to help engineers design, simulate, and deploy advanced motor control algorithms on real hardware. It

provides ready-to-use blocks, reference examples, and automatic code generation for microcontrollers, FPGAs, and SoCs.
Motor Control Blockset bridges the gap between motor control theory and real-world deployment, making it easier to move from simulation to hardware implementation.
This toolbox includes prebuilt Simulink blocks for common motor control techniques like Clarke and Park transforms, six-step commutation, lookup table or sensor support. It's able to use encoders, Hall sensors, and resolvers. More offers to users sensorless estimators for rotor position and speed and generates different types of codes.
This toolbox supports popular hardware platforms such as Texas Instruments C2000, STM32G4 boards and enables both open-loop (scalar control) and closed-loop (vector control) methods, including Field-Oriented Control (FOC). The toolbox is focused on PMSM structure but it could be extended to other motor types also.
Thus, using the block named "Interior PMSM" from "Motor Control" toolbox, is possible to simulate the behavior of a PMSM only introducing the motor parameters for start an application. These parameters describe the physical properties of the motor and help the built-in blocks build accurate models and design effective controllers.
The toolbox permits to observe how motors behave—speed, torque, position—by combining sensor inputs, mathematical transforms, and control strategies into modular blocks that can be reused and deployed on hardware.
MATLAB datasheet is a very useful tool in observing the motor behavior in several situations, starting for simple to complex, without using very complicated formula and calculus.
Unfortunately, in practice are just few manufacturers who will supply a datasheet that provides information on the motor's properties and performance. For this particular reason in this paper the parameters described in MATLAB tutorial are used for implementing an open-loop speed strategy for BLDC using comparable parameters from PMSM. This should be the first step in designing a model for BLDC drive and then to extend the research to complex strategies, like: closed-loop control speed, using Hall sensors to determine exactly the rotor position.
The motor parameters offered by MATLAB simulation are done in Table 1.

Table 1 PMSM motor parameter

Description	Variables	Values
Number of Pole Pairs	pmsm.p	4
Rotational Inertia	pmsm.J	0.0227 kg*m^2
Stator Resistance	pmsm.Rs	0.02 Ω
D-Axis Inductance	pmsm.Ld	61.31 μH
Q-Axis Inductance	pmsm.Lq	122.63 μH
Permanent Magnet Flux	pmsm.FluxPM	0.0725 Wb
Rated Voltage	pmsm.V_rated	325 V
Rated RPM	pmsm.N_rated	500 RPM
Rated Current	pmsm.I_rated	200 A

These tools will output a data structure containing the estimated parameters, which can then be loaded into a MATLAB® workspace.

2.3.2 BLDC block from Motor Control Blockset

This toolbox contains a BLDC block which implements a three-phase brushless DC (BLDC) motor with a trapezoidal back electromotive force that remains constant for a position range of 120 electrical degrees. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed. The motor parameters are taken from Table 1.
In many situations the values of inductance after both axes are equal for a BLDC, but when you want to assure a good balance between torque and speed control different values are recommended and exploited in advanced control methods like field-oriented control. Thus, the motor datasheet plays a very important role in motor's behavior and in choosing a control strategy.
This strategy is used into a testing procedure, when the motor doesn't have any load and it will be connected into a larger structure after that.
The MATLAB block used in applications is presented in fig.4. It has 2 inputs, LdTrq (load torque on motor), PhaseVolt (stator terminal voltages) and 3 outputs Info (contains the block calculations), PhaseCurr (phase a, b, c current, i_a, i_b, and i_c) and MtrSpd(angular speed of the motor). Being on the testing phase the value of load torque on motor is setting to zero.

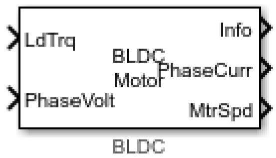

Figure. 4 Three-phase brushless DC motor with trapezoidal flux distribution

The paper presents an open-loop speed control strategy applied on the BLDC motor which have different values for inductances on both axes in several situations:

- 1. The motor is feed with three-phase voltage input.
- 2. The motor is feed by a DC voltage through an inverter.
- 3. To create an open-loop speed control (Vbf controller)

2.3.3 BLDC – speed control strategy using a three-phase AC voltage signal.

The first step in developing a control strategy is to implement the motor data sheet into the model. The three-phase AC voltage signal is the primary driver of the motor response.
The structure builds up with blocks from MATLAB/Simulink are presented in fig. 5.

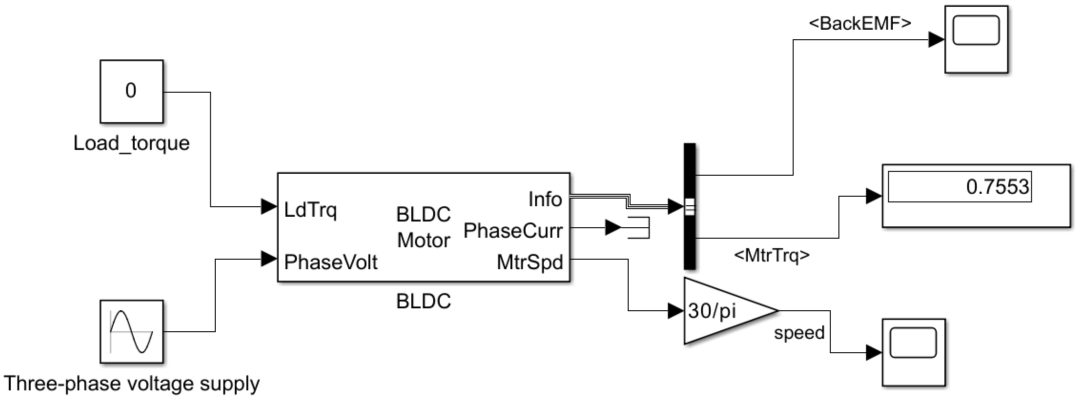

Figure 5. The primary driver of the motor response

The three-phase AC voltage signal is the primary driver of the motor response with the parameters considered: amplitude 50, frequency 60 rad/sec and the phase (rad) [0, -2*pi/3, -4*pi/3].

In the *Display block* connected at the BLDC motor output, the motor torque output doesn't settle quite at zero but rather at a very small number, which represents a good start in developing a testing procedure.

The variation of motor speed and the shape of back EMF in certain conditions is presented in figure 6,7.

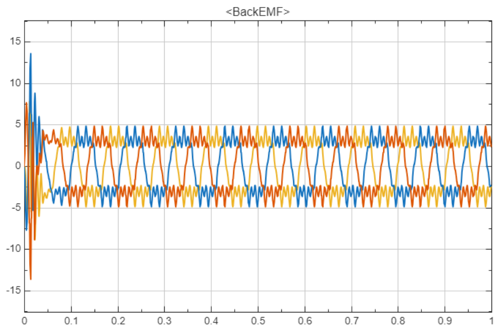

Figure 6. Output of BLDC motor Back_EMF of phases (A, B, C)

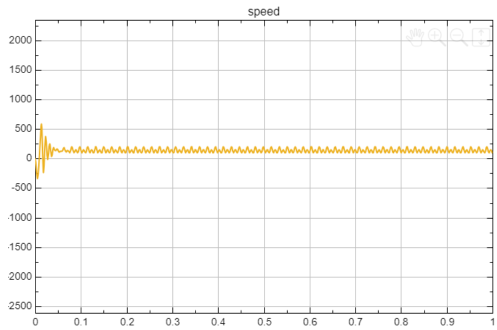

Figure 7. The BLDC motor speed

The motor BLDC has some ripple effects on Back_EMF and speed shapes that could affect torque stability, efficiency, noise, and control accuracy. Higher ripple speed (rapid fluctuations in torque or current) can cause vibration, acoustic noise, and reduced smoothness of rotation, while lower ripple speed improves precision and efficiency.

2.3.4 BLDC inverter solutions.

In electric drive the nature of source plays a very important role due the applications which involved BLDC motors. Most of the applications supposed to have DC sources like electric vehicle for example. In all these situations an inverter is necessary to add. The Average-Value Inverter block provides an easy-to-use inverter model for solving this situation. The diagram control of motors became like in fig. 8.

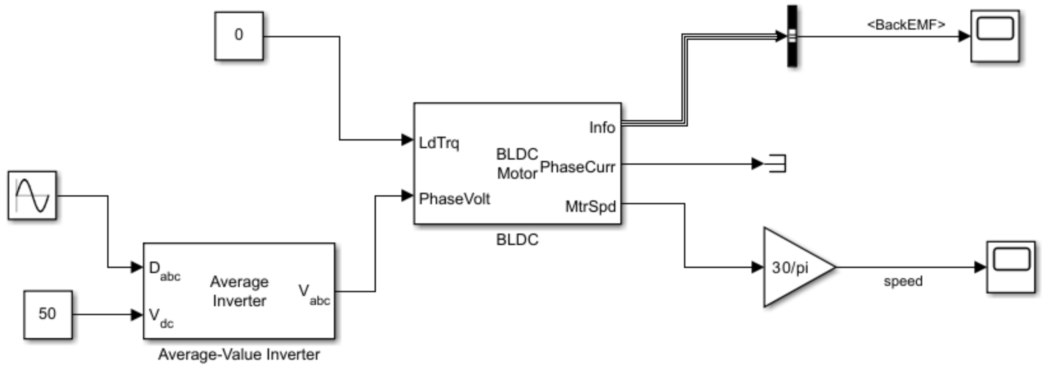

Figure 8 The BLDC motor fed by battery thorough average-value inverter

The Average-Value Inverter models an average-value and full-wave inverter. It computes the three-phase AC voltage output from inverter DC voltage by using the duty cycle information. The input D_{abc} of inverter needed a three-phase signal for its duty cycle, so a *Sine Wave block* is used for this reason. The duty signal needs to be between 0 and 1, similar to a Pulse Width Modulation (PWM) signal and the data for Sine Wave block are: Amplitude = 1, Bias = 0.5, frequency= 120 rad/sec and phase [0, -2*pi/3, -4*pi/3]. The value of voltage DC input Vdc is the same like in the previous case. The BLDC motor shape of Back-EMF and speed response is presented in fig. 9, 10.

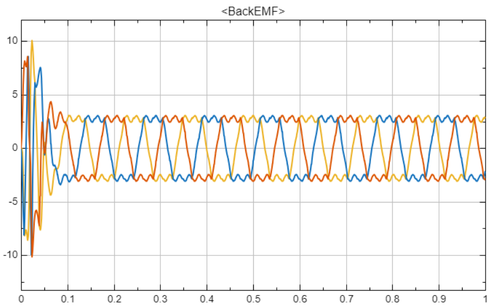

Figure 9. Output of BLDC motor Back_EMF of phases (A, B, C) with inverter

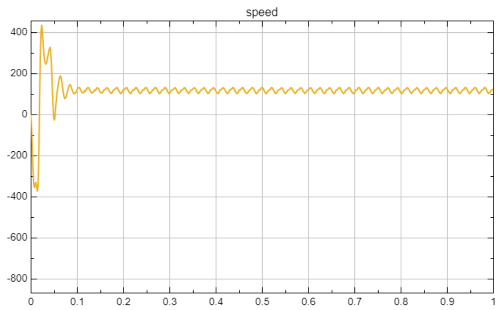

Figure 10. The BLDC motor speed with inverter

The values of the start-up procedure and the ripple of Back_EMF and motor speed are reduced compare with the previous case. The inverter plays a positive role in order to have a system more stable.

2.4 Open loop control for BLDC motor

2.4.1 Voltage by Frequency Control

When the motors are stopped suddenly having the entire supply voltage could create negative behaviours. The motors would be difficult to control, and it would not have smooth movement. A slow, gradual acceleration would be much safer and more comfortable. Control voltage by frequency (V/F) is an open loop control strategy for steadily increasing the applied voltage and signal frequency to an AC motor [15].

In this type of control, the phase voltage and frequency of the signal sent to the motor are increased proportionally. Both parameters are increased till the desired voltage is reached even the frequency continue to increase. The procedure helps the motor to start smooth.

2.4.2 VbyF Controller block in BLDC simulation.

In Motion Control Blokset is used a *VbyF Controller block* to simplify the implementation process and to get quickly a working controller desired motor. The input block contains information about desired rotational speed (Ref_RPM), the rated rotational speed (Rated_RPM), the number of pole pairs in the rotor (No_poles), the rated peak voltage of the motor (Rated_Voltage), the minimum operating voltage of the motor (Minimum_Voltage), considered to be 15% of the motor's rated voltage is often a good place to start, the number of simulation time steps(N-ramp) the controller takes to get the motor up to the reference speed. The input Enable acts as a switch. A value of 0 will turn the controller off, while a value of 1 will turn it on.
The paper presents an open-loop control for a BLDC type using a VbyF controller, a block who permit to implement the value of the speed desired for the considered model. The input values used are presented in the Table 1. In fig. 11 the simulation diagram is presented.

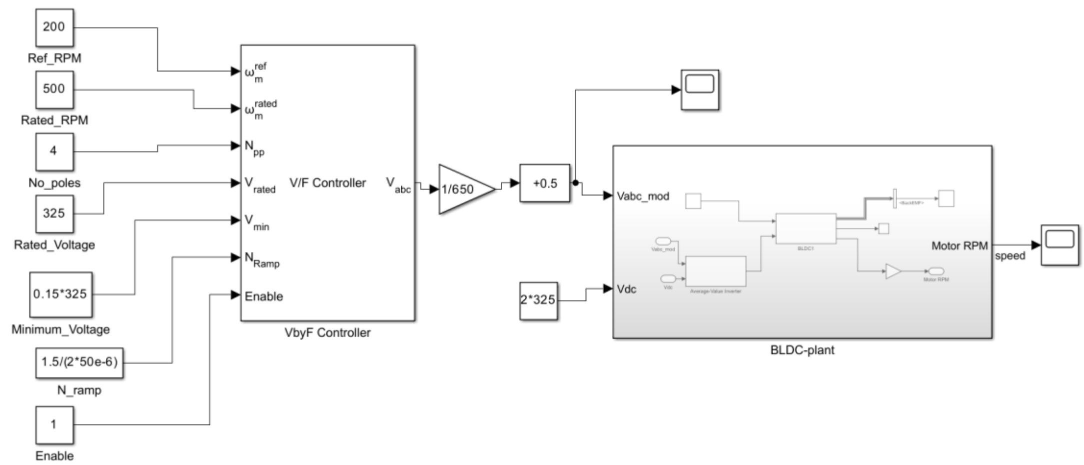

Figure 11 Open-loop BLDC speed control

The subsystem *BLDC-plant* contains the structure created before which contains an inverter. A voltage by frequency (V/F or VbyF) controller was added and the existing system for controlling the speed motor safely from a stop up to the desired speed. This block has an output V_{abc} which is a three-phase voltage signal. The meaning of the block is to simulate the action of accelerating pedal in a safe mode (slowly and gradually). Most of the previous parameters used to set up the motor-inverter plant model still work here for notice the impact of control by VbF controller has on the BLDC's behavior.
The value to the motor's peak-to-peak rated voltage is using like value for the dc input of the inverter.
The output of BLDC motor (Back_EMF and speed motor) when a VbyF controller is used are presented in figures 12 and 13.

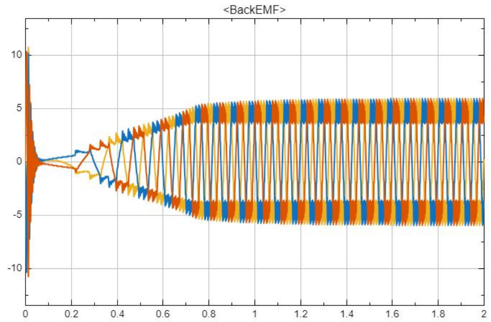

Figure 12. Output of BLDC motor Back_EMF of phases (A, B, C) with Vbf controller

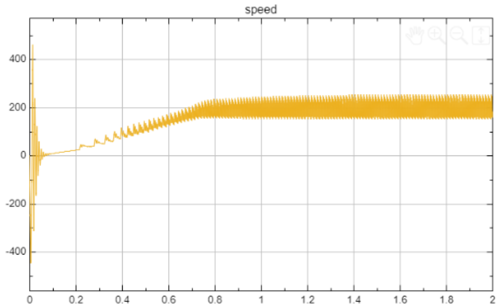

Figure 13. The BLDC motor speed with Vbf controller

The simulation emphasis some ripple in Back_EMF shape and motor speed. Ripple in the speed of a BLDC motor is mainly caused by torque ripple, which arises from the motor's non-ideal commutation, magnetic design, and control methods.
The results obtained emphasis the utility of the procedure in testing motor wiring and inverter operation with reduce cost and complexity, provides insights into performance limitations, and supports applications where simplicity and efficiency outweigh precision. More, motor parameter estimation represents a very important element for implementing motor control algorithms with good results.
Open-loop control eliminates sensors and feedback mechanisms, making systems cheaper and easier to implement. This is especially valuable in low-cost consumer devices or applications where precise speed/torque control is not critical. It also lays the groundwork for improving closed-loop systems by understanding baseline behaviors.

3 Conclusions

This simple control method is suggested to replace conventional induction motors in applications like fans, pumps and ventilation systems where high dynamic performance is not a requirement.
The paper presents a modality to apply the new toolbox implemented by MATLAB, *Motor Control Blockset* who offers strategies to control systems.
Open-loop systems are more vulnerable to disturbances such as sudden load changes, supply voltage fluctuations, or mechanical stress. This can reduce reliability in industrial or automotive contexts.
The results obtained in simulations in motor speed especially are good even the speed ripple is significative. This simulation could a pointing start for developing a closed loop control strategy where precise speed and torque regulation using feedback (Hall sensors, encoders, or sensorless estimation are necessary especially when varying loads existing. Closed-loop control offers precision and robustness but at higher cost and complexity. Future research should focus on sensorless and hybrid strategies to bridge the gap, making BLDC drives both affordable and efficient across diverse applications.

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