IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received October 25, 2019, accepted November 22, 2019, date of publication December 18, 2019, date of current version December 31, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2960580

Improved Sensor Control Method for BLDC Motors

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ABSTRACT The article proposes the replacement of the classic control method of systems with BLDC motor sensors to a system where the inverter switching points are determined by means of a switching estimation algorithm. The switching points are calculated by a microcontroller in accordance with the Hall sensors' switching signals, but can be tuned using an external optimization algorithm. This method of controlling a BLDC motor allows us to use a correction algorithm that significantly improves the commutation of BLDC drives with unbalanced Hall sensors. Both the computation of the sensor's misalignment and the proposed method of correction were developed by the author to improve the functionality of drive systems with BLDC motors with closed-loop speed control. The use of this technique yielded very good results in both static and dynamic states. In addition, it made it possible to precisely influence the motor's commutation angle, which can minimise the production costs of such machines by foregoing the need to provide mechanical elements to move the sensors relative to the rotor axis. The article presents the results of work carried out on a laboratory bench built for this purpose.

INDEX TERMS BLDC motor, sensor misalignment, torque ripple.

I. INTRODUCTION

Compared to conventional DC brush motors, sensor-based brushless DC motors (BLDC) are becoming very popular for many purposes due to low cost, high efficiency and reliable operation. Their operational issues have been widely studied, but they assume that the Hall sensor system is operating correctly and maintaining the symmetry of the signals generated by the motor. Such systems clearly indicate the optimal moment to switch the valves of the BLDC motor controller.

These assumptions do not necessarily have to be met, especially when using cheap, mass-produced motors. Signals from inaccurately placed sensors cause the inverter to operate asymmetrically, which in turn leads to pulsation at the electromagnetic moment, increases the amplitude of the motor current and acoustic noise [1], [2], [7], [9]. Higher current amplitude increases electrical losses as well as EMC interference, in addition to forcing producers to use inverter transistors with a higher-rated current in order to prevent damage during long-term operation.

The associate editor coordinating the review of this manuscript and approving it for publication was Ton Do.

Sensor placement errors can be compensated for in two basic ways. The first focuses on observing the BEMF (back electromotive force) voltage signal in an unpowered motor phase to determine the sensor placement error. The course of the electromotive force is independent of the sensor placement error and, at higher speeds, can be measured by the control system. This information is confronted with the signals generated by the Hall sensors, and the sensor placement error is determined as a result of this confrontation [12].

The second way is a gradual averaging of subsequent values of the commutation time, which yields good results in solid states, while in dynamic states the averaging procedure may be insufficient for the correct operation of such a controlled drive. It is also worth mentioning that this method can be implemented as an independent electronic system connected to a drive that is already in operation [2], [5], [9].

The aim of this research was to develop a method for controlling a BLDC motor with suboptimally placed Hall sensors that would reduce the phase current amplitude of the motor. Correction of transistor switching points is possible after determining the sensor placement errors, which are calculated by comparing the measured instantaneous rotational speed value with its average value for the steady-state drive operation.

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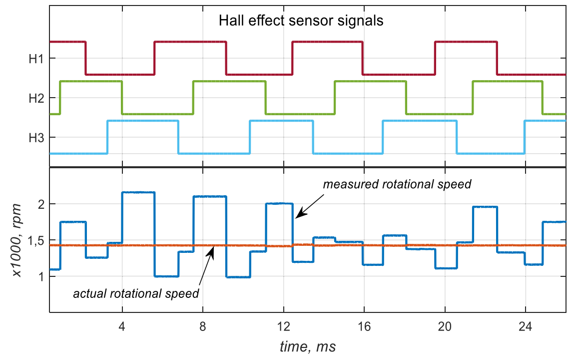

FIGURE 1. Real and measured BLDC motor speed with asymmetrical Hall effect sensors.

The control algorithm developed for this study significantly reduced the phase current amplitude of the BLDC motor, which contributed to the possibility of reducing the use of the power inverter and improved the operational value of the BLDC motor drive system.

II. ERRORS IN THE LOCATION OF THE HALL EFFECT MOTOR SENSORS

To determine the misalignment of Hall sensors in the motor shaft position, an experiment was carried out on the dSPACE MicroLabBox platform whose aim was to compare the actual speed measured by the incremental encoder ω_r with the speed measured using the signal generated by the Hall sensors. In addition, the DC-link values of the inverter were measuredduring the tests. The measure of the positioning error of the sensors for individual motors is the difference between the value of the rotational speed calculated between consecutive Hall sensors signals and the actual value measured with the reference sensor - the incremental encoder.

Figure 1 shows the plot of the actual rotational speed of the drive and the speed measured by using the Hall sensors' signals for a BLDC motor with 4 pole pairs.

The same procedure has been performed for different types of BLDC drives. Every time, a significant difference between the actual and computed rotational speed was observed (Fig. 2a). For a motor with more than one pole pair ($2p > 1$), $2p \cdot 6$ separate speed measurement sectors per mechanical revolution can be defined. Each of them corresponds to a mechanical rotation angle equal to $\pi/(3 \cdot 2p)$, which for a motor with $2p = 4$ pole pairs yields a sector size of 15 mechanical degrees and 24 rotational speed computing sectors per mechanical revolution (Fig. 2b).

A large inaccuracy in the performance of the electronic commutator's components affects the noise generated by the drive, its operating parameters, as well as the ability to work in the feedback loop. It is notable that all tested motors were characterised by a significant error in the location of the sensors, which ranged from around 12 to over 40% of the value of the electrical angle in comparison with the desired Hall sensors signal (Fig. 2a).

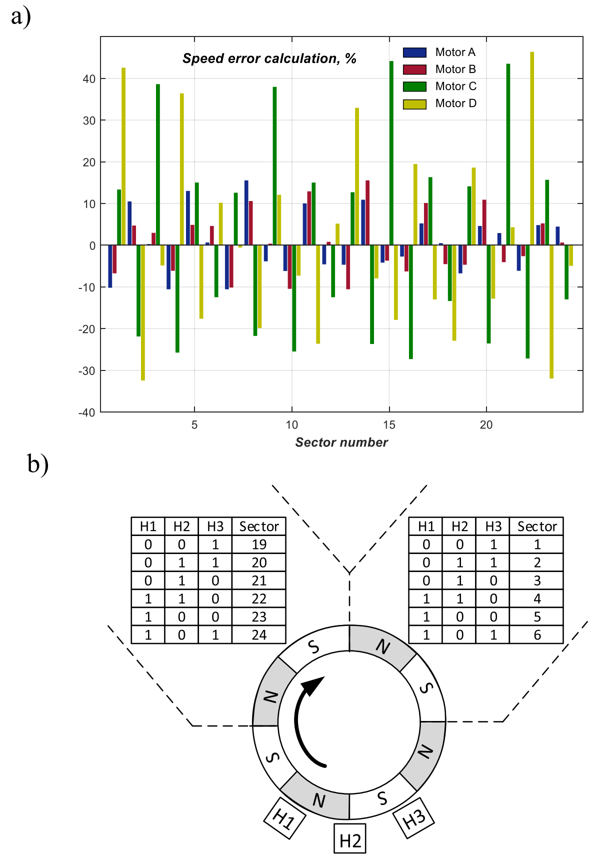

FIGURE 2. The dependence of the speed calculation error for individual motor sectors with 4 pole pairs "a" and 24 speed computing sectors"b".

III. COMPUTATION OF COMMUTATION POINTS OF TRANSISTORS BASED ON MOTOR SHAFT SPEED

In the classic control system of the BLDC motor, the speed value can be averaged and corrected by special algorithms [2], [4], [12], but the switching of the inverter transistors depends only on the signals generated by the Hall sensors. When this element is made with insufficient precision, it often turns out that the only method to ensure the correct operation of this system is to control the BLDC drive without the use of sensors, or to use an additional element determining the position of the motor shaft (for example, position encoders). This entails carrying out significant modifications of the control system and increasing investment costs.

The proposed solution allows for software correction of the BLDC motor sensor's misalignment without the need to modify the control system at the hardware level. Thanks to this method, it is only necessary to use the developed control algorithms.

The basic premise adopted in the course of the tests is to alter the function of the signal generated by Hall sensors in the control system. In a classic system, this signal is critical for switching the power supply of the motor windings, and can additionally be used to calculate the rotational speed of its shaft (Fig. 3).

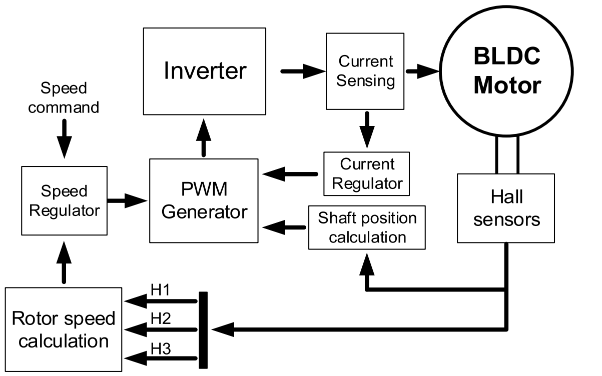

FIGURE 3. Typical block diagram of the BLDC motor control system with shaft position sensors.

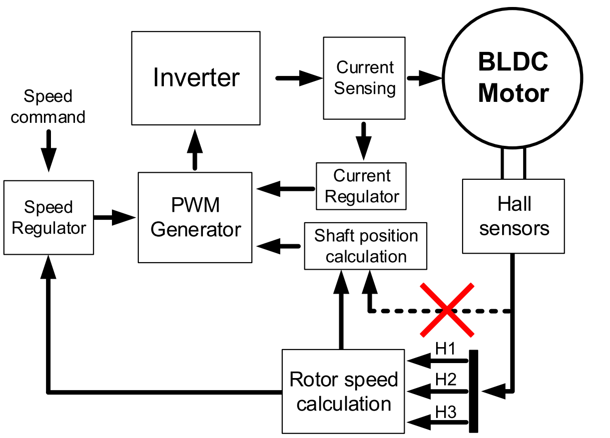

FIGURE 4. The proposed BLDC motor control system.

In the proposed solution, the signal from the shaft position sensors is used directly only to calculate the rotational speed of the motor shaft and indirectly through the algorithm calculating the switching points (Fig. 4.) to determine the switching period T_s of the transistors, depending on the rotational speed of the motor shaft ω_s according to the following equation:

$$T_s = 1/(2p \cdot 6 \cdot \omega_s) \tag{1}$$

At first glance, such a modification should not bring about any significant changes in the motor's operation in static states and significant changes in dynamic states. Indeed, assuming the correct measurement of the motor speed, these systems do not differ in performance and would fulfill their role equally well. Unfortunately, the accuracy of the elements of the system that determine the position of the shaft and the fact that the velocity measured in the previous control step is used to determine the transistor switching time causes the proposed control method to produce worse results compared to the classic control method, in which the change of Hall sensors is a signal for switching the motor windings. It should be remembered that the time, as calculated by Tim_2 for the sector "n", depends on the speed, which is measured using Tim_1 for the sector "n-1". This means that, in dynamic states, we always make a mistake that results from the change of rotation speed between particular sectors. Figure 5 shows the waveforms as a function of time, the signals that are responsible for switching the elements of the electronic commutator in the classic control method and the proposed method of determining the calculated commutation points.

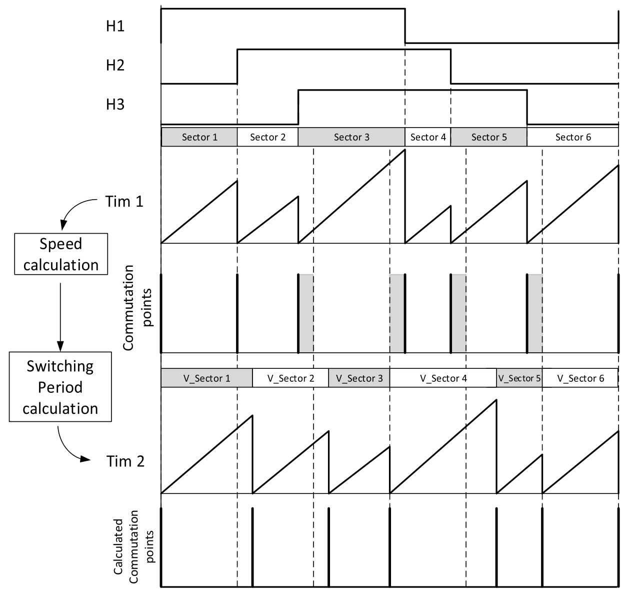

FIGURE 5. Calculation of the BLDC motor commutation points using the speed measured from the signal of the unbalanced Hall sensor.

It is clearly visible that the errors in determining the speed by "Tim_1", which result from the erroneous arrangement of sensors, negatively affect the accuracy of commutation with both the standard algorithm and the proposed one based on the use of the calculated rotational speed (used by "Tim_2").

Fortunately, due to the logical separation of sensors from the block that performs transistor switching, it is possible to introduce an additional block into the path of the control system whose task will be to correct the error in calculating the rotational speed (Fig. 6a).

Using the correctly calculated BLDC motor speed in the proposed control method allows for the electronic commutator to achieve optimal operation(switching takes place at the optimum position of the motor rotor, Fig. 6 b). In this case, it is necessary to obtain the actual shaft speed despite the inaccuracy of the sensor arrangement ("Correction" Block, Fig. 6 a).

IV. CORRECT DETERMINATION OF THE ROTATIONAL SPEED

The misalignment of the Hall sensors leads to errors when trying to determine the speed of the shaft based on the time elapsed between successive states. The simplest solution to this problem would be to average the rotational speed measurements to measure the actual value. There are also correction algorithms based on successive averaging of time intervals between successive Hall sensor switches, which work very well in steady states [1], [2], [4], [7]. Unfortunately,

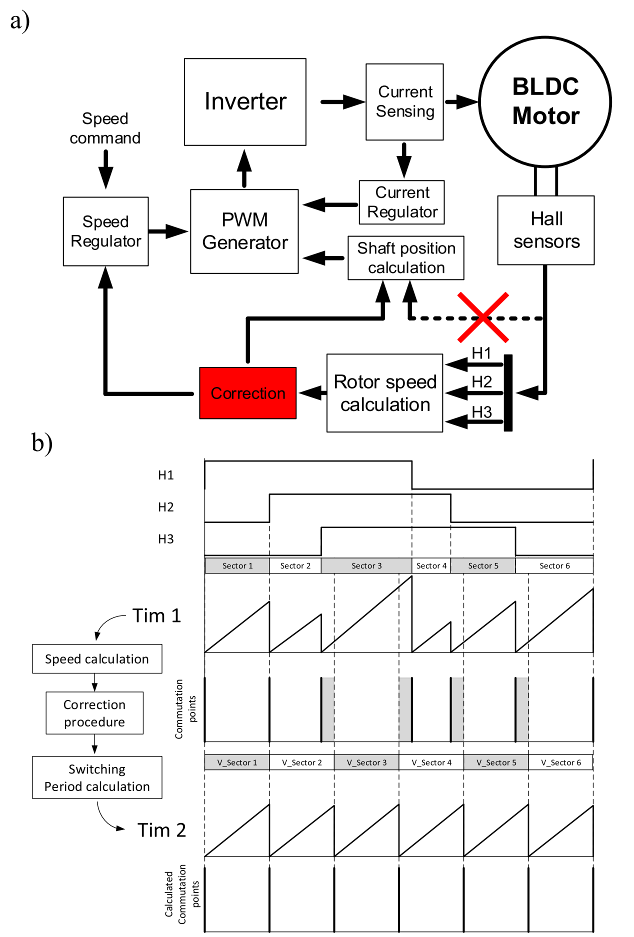

FIGURE 6. Control structure with correction block "a" and calculated motor commutation points "b".

the averaging algorithms introduce a delay, which in the control method proposed is unacceptable. The commutation error would gradually increase in dynamic states, which could lead to system disruptions.

Since the sensor location error is constant, it could be calculated for each of the $6{\cdot}2p$ unique BLDC motor rotor positions (speed measuring sectors). These values are calculated for each speed measuring sector in the classic control system for steady state conditions by comparing the calculated value ω_{sec} with the speed value ω_a calculated for a full mechanicalshaft revolution.Since in steady state conditions actual rotational speed is equal in all speed measuring sectors, it is possible to compute the sector misalignment error,δ_{sec}.

$$\delta_{sec} = \frac{\omega_{sec} - \omega_a}{\omega_a} = \frac{\omega_{sec}}{\omega_a} - 1 \tag{2}$$

The correction factors δ_{sec} determined in this way are used each time to calculate the rotational speed of the motor shaft for each sector [7].

These coefficients can only be calculated with finite accuracy. This is closely related both to the quantisation errors that are unavoidably encountered during the time measurement by the microprocessor system and the quality of the electrical signal generated by the Hall sensors. Since in practice it is impossible to reduce this error to zero, it was decided to determine the accuracy of the measurement results obtained.

Because it can be assumed that the speed reading for the full rotation of the motor shaft is not burdened with an error related to the accuracy of the distribution of electronic commutator elements [4,7], we can assume that, for a constant rotational speed, the sum of errors in individual measurement intervals for a full turnover should be 0.

$$k_s = \sum_{sec=0}^{2p-1} \delta_{sec} \rightarrow 0 \tag{3}$$

where 2p is the number of pole pairs.

This assumption is very difficult to achieve. The lower the k_s indicator, the more efficient a microprocessor system becomes, and the closer the Halls signal gets to the square-shape signal. It is easy to notice that by analysing the value of this index, it is possible to determine the correctness of the obtained coefficients related to the error in their placement. The procedure for their calculation can be performed until the indicator reaches the assumed value and only then will the measurement results be considered reliable (a suitably low k_s index is assumed), and the proposed control method is activated.

The table below presents a tabular summary of the ratio k_s, expressed as a percentage calculated for 4 different BLDC motors.

TABLE 1. Average percentage error in calculating the commutation point.

	k_s[%]	Pole pairs	error/sector [%]
Motor A	12.93	4	0.54
Motor B	14.31	4	0.60
Motor C	31.31	4	1.30
Motor D	22.79	4	0.95

In practice, the index $k_s = 0$ cannot be achieved. This is due to quantisation errors as well as physical phenomena accompanying the work of the sensors (steepness of the rising/falling edges of the signal). During the work it was assumed that a value of k_s lower than 30% is satisfactory. This would mean that commutation error is lower than 1.25% of electrical angle per sector for a BLDC motor with 4 pole pairs ($2p = 4$). After computing correction factors for each sector, it is possible to estimate the interval for switching inverter transistors T_s' as a function of measured sector rotational speed and the sector correction factor $T_s' = f(\delta_{sec}, \omega_{sec})$.

V. SYNCHRONISATION OF THE CONTROL SYSTEM WITH A REFERENCE SIGNAL

The proposed control method is immune to sensor positioning errors, but also needs to precisely determine the mechanical position of the motor shaft so as to trigger the procedure for calculating the transistor commutation points. This trigger can be any single signal from the Hall sensors. The difficulty lies in the fact that this signal should be generated only once per full rotation of the motor, so that the inaccuracy with

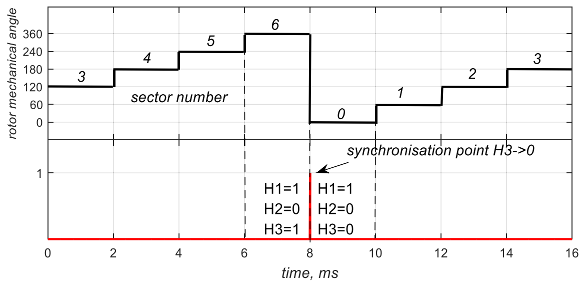

FIGURE 7. Synchronisation point of the algorithm that calculates the commutation points of the transistors.

which it is mounted sensor does not affect the algorithm for calculating commutation points. For motors with a number of pole pairs equal to 1, this is a simple task. The reference signal can be the edge of any signal from the Hall sensors; it clearly defines the mechanical position of the rotor and occurs only once per full revolution (Fig. 7).

Unfortunately, in practice, the vast majority of BLDC motors are constructions with four pairs of poles, which means, that during the full rotation of the shaft of such a motor, we deal with four repeating sequences of Hall sensor states. This makes it impossible to directly determine the triggering signal against which the control algorithm will synchronise the switching points of the control transistors.

The inability to determine the reference signal means that, after each start of the motor, it is necessary to select it again and determine the optimal phase shift of the signals controlling the electronic commutator of the motor. This is similar to a situation in which, after each start of the BLDC motor, the Hall sensor dial would have to be adjusted relative to the position of the stator. This is a situation that disqualifies such a BLDC motor control method.

VI. DETERMINING THE ABSOLUTE POSITION OF THE BLDC MOTOR ROTOR

During the tests, we determined the correction factors for the position of the motor sensors and analyzed the effect of the speed at which these errors were calculated. It has been shown that, for a wide range of rotational speeds, these errors are almost immutable – and, interestingly, unique for each motor used in the study. Figure 8 presents the distribution of speed determination errors for motor D with four pole pairs. Because the standard Hall sensor system only distinguishes 6 unique combinations of their states during full rotation, the sequence of sensor states is repeated depending on the number of pole pairs of the motor (here - 4 times).

The graph shows that it is possible to identify the position of the rotor using the state of the sensors with the support of an algorithm that looks for a specific pattern of error distribution measured while the machine is insteady-state operation.

This procedure, in its simplest implementation, consists in searching for the greatest error in the location of Hall sensors for the same sequence of their state. For example, sequence (H3 = 0; H2 = 0; H1 = 1) corresponds to sectors

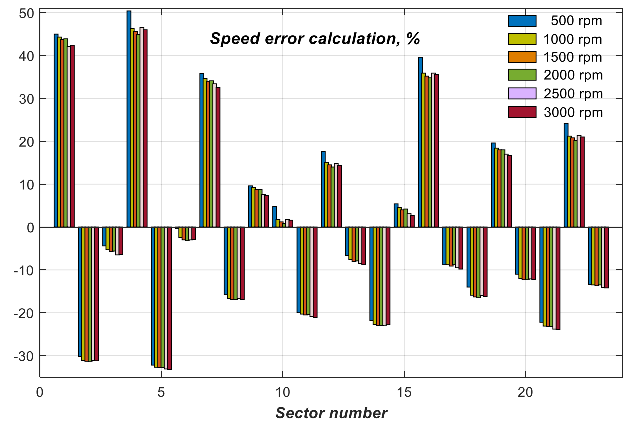

FIGURE 8. Distribution of BLDC motorspeed calculation errors for different speed rotations for motor D.

TABLE 2. Motors parameters.

Rated Voltage (V)	Rated Current (A)	Rated Power (Watts)	Rated Torque (N*m)	Back EMF Voltage (V/kRPM)	Rated Speed (rpm)	Line-to-Line Resistance (ohm)	Line-to-Line Inductance (mH)
48	11,5	440	1,4	13.7	3000	0.20	0.48
24	3.2	60	0.14	4.75	4000	0.95	1.5

1; 7; 13; 19 (Fig. 8), and the highest error occurs for sector 1. This is a change in the state of the sensors, which is a signal to go into sector "0" and is correlated with the largest calculated error in determining the speed that will from now on be a signal to trigger the proposed control system. This situation occurs only once per revolution of the motor. This procedure can be used independently to determine the absolute position of the rotor, which is crucial in some industrial applications (positioning of machine tool spindles).

VII. RESEARCH SET-UP

The basic purpose of developing the control method described here is to simply apply it to control systems commonly used in electric drive technology without increasing their cost. Because one of the most commonly used platforms in mass production is a platform based on STM32 microcontrollers, the microcontroller of this family with the designation STM32f302R8 was used for the tests.

The minimum hardware requirements include two additional timer circuits, the first of which implements the procedure for calculating the rotational speed, while the second cyclically counts down the time interval after which the control transistors are switched. A dedicated IHM08M1 board was used as the inverter, as it is optimized to work with platforms that use STM32F302R8 microcontrollers.

The stand consisted of a system of 2 BLDC motors connected by a shaft, one of which worked as a motor and the other as a generator performing the function of the system load.

FIGURE 9. Research set-up.

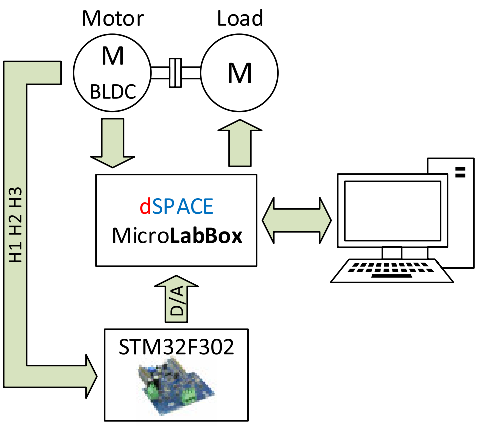

FIGURE 10. Diagram of the test bench system for the acquisition of measurement data.

The measuring functions were executed by the dSpace MicroLabBox system supported by the DPO 5054-B digital oscilloscope. In addition, a 10-bit DAC converter of the inverter's microcontroller was used to generate a signal corresponding to the mechanical angle of the BLDC motor rotor position.

The recorded waveforms were saved and developed using the Matlab-Simulink package.

A. MEASUREMENT RESULTS IN IDLE STATES

During the system's operation in idle state, we registered speed values measured on the basis of the Hall sensor signals as well as the DC-link current of the control inverter. On the basis of changes in sensor states, the mechanical angle of the motor rotor was determined (the motor had 4 pairs of poles). The change in position corresponds to the rotation of the rotor by a mechanical angle equal to$2 \cdot \pi/(3 \cdot 2p)$. The measurements were carried out with the sensors being adjusted, which corresponded to the lowest current drawn from the DC power supply. Such a way of determining their setting is the most commonly implemented method in industrial practice. The measurement results are shown in Figure 11.

The difference between the actual rotational speed and the one measured on the basis of the state of the position sensors is clearly visible. These differences reach several dozen percent and are the highest for sectors 0; 6; 12; 18,

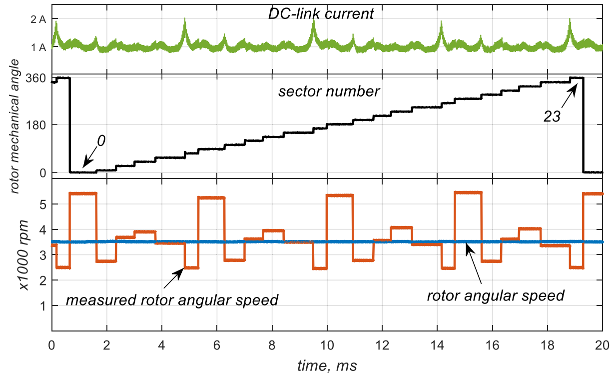

FIGURE 11. Current waveforms of the inverter, measured speed and position of the BLDC motor shaft during idling, using the traditional control method.

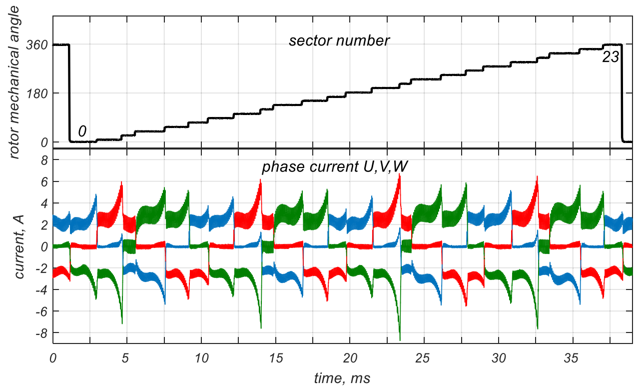

FIGURE 12. Waveforms of the motor's phase currents and the BLDC motor shaft position during operation with 30% load using the traditional control method.

which suggests a large error in the location of the H1 sensor. In addition, there is a significant increase in the inverter DC-link current for these BLDC motor shaft position sectors. In addition, although rotational speed is constant, individual control sectors have different durations, which directly affects the duty of the inverter transistors. Because of this inaccuracy, transistors are not switched at the optimal moment, which increases current amplitude and torque ripple.

The phase currents of the motor were also measured for the machine, loaded with 30% of the nominal torque value. The waveforms shown in Figure 12 indicate clearly the high current amplitude resulting from the inaccurate commutation of the motor. The maximum amplitude of the motor phase current is 8.4 A.

Following the proposed control algorithm, we created a software program that determines the location error of the Hall sensors and performs software correction of the switching point of the motor winding bands. In order to make this procedure possible, the motor should be started using the traditional sensor control method. Then, while operating in the open feedback loop, one should determine the positioning errors of the sensors so as to reach the target accuracy index ($k_s- >0$). After analysing the distribution of sensor location errors for individual sectors (Fig. 2), we synchronised the

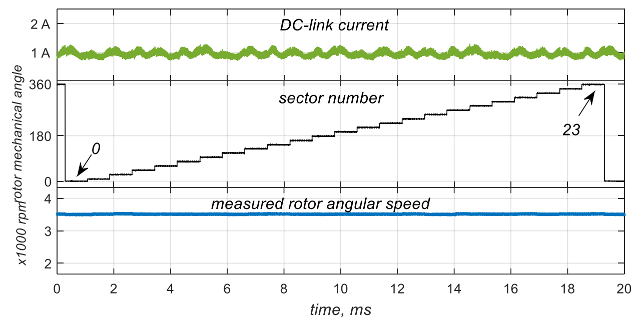

FIGURE 13. Waveforms of the inverter current, measured speed and position of the BLDC motor shaft during idling, using the developed control method.

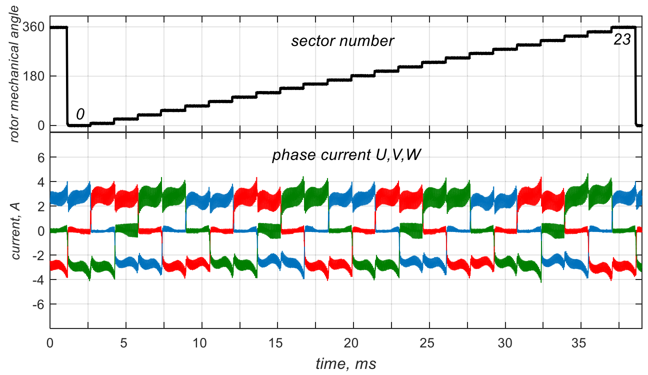

FIGURE 14. Waveforms of the motor phase currents and the BLDC motor shaft position during operation with 30% load using the developed control method.

calculation algorithm with the mechanical position of the BLDC motor rotor and changed the control method to the that used the algorithm to determine the virtual switching points of the motor winding bands. The diagram of the measured speed, the DC-link current of the inverter and the change of the BLDC positioning sector for the proposed control system are shown below.

It is clearly visible that if a correction algorithm is used, the calculated speed coincides with the actual speed, and the error in its measurement is lower than 1%. In addition, the maximum amplitude of the current decreased, which resulted in the reduction of losses in the drive system as well as the reduction of noise emitted by the drive system during operation.

The measurement of motor phase currents for a machine loaded with 30% of the rated torque value shows a clearly lower current amplitude relative to a maximum value of approximately 4.2A.

B. FAST AND DELAYED COMMUTATION

The logical separation of the commutation process of the transistors from the state of the Hall sensors provides additional possibilities of influencing the operation of the BLDC motor. Without interfering with the mechanical part of the drive, we can carry out the process of accelerating and delaying the commutation, which with the standard control method

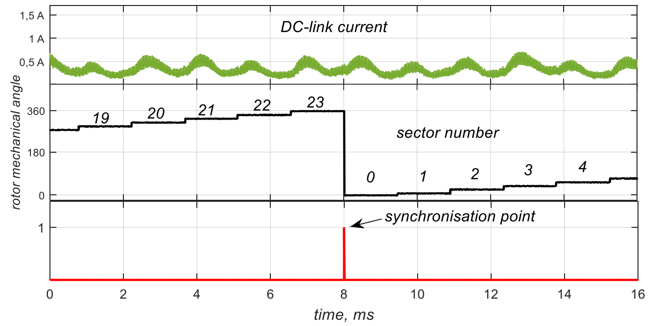

FIGURE 15. Current waveforms, state changes of the rotor position sector and synchronisation signal for the optimal switching case.

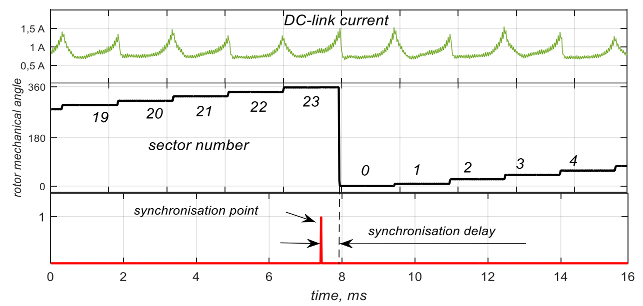

FIGURE 16. Current waveforms, state changes of the rotor position sector and synchronisation signal for the delayed commutation case.

involved the necessity of physical interference in the drive system. The waveforms recorded for the 3 states –optimal (Figure 15), accelerated (Figure 16) and delayed (Figure 17) switching – are shown below.

Optimal commutation is the case in which the change of the sensor's state with which the control system is to synchronise is at the same time a signal to change the control sector. It is a state in which the sensor signal change occurs at the optimal moment for the rotor's position at any given time. In practice, this may be easier than to set the sensor relative to the motor housing, that is to apply a synchronisation correction factor that can affect the acceleration or delay of the process of switching the signals that control the operation of the motor.

The case of using such a technique is shown in Figure 16, where the commutation system is delayed relative to the synchronisation signal, and Figure 17, where the commutation occurs before the synchronisation signal.

In both cases, one can see an increase in the current amplitude associated with the suboptimal commutation point. In the case where the synchronisation point was shifted from the optimal one, introducing a delay in or accelerating commutation could significantly improve the operating parameters of such a machine, while the offset parameter could be saved in the non-volatile EEPROM memory of the controller and entered into the main program every time it is started.

In practice, it was possible to influence the acceleration or delay of commutation on the program path, which is of great importance in the BLDC motor optimisation process.

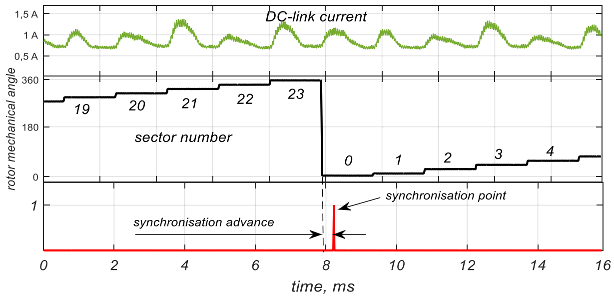

FIGURE 17. Current waveforms, state changes of the rotor position sector and synchronisation signal for the accelerated commutation case.

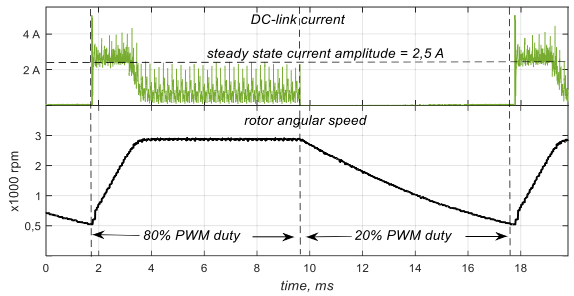

FIGURE 18. Waveform of the motor's rotational speed and the current drawn from the DC power supply for the classic control system.

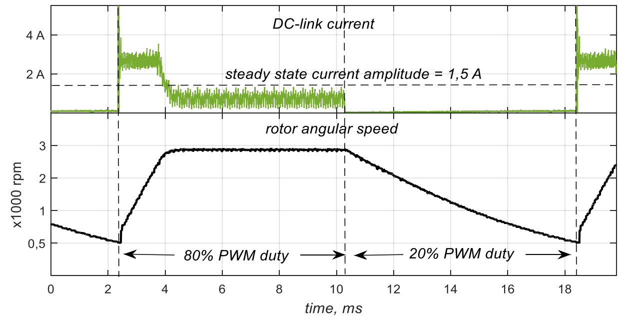

FIGURE 19. Waveform of the motor's rotational speed and the current drawn from the DC power supply for the developed BLDC motor control method.

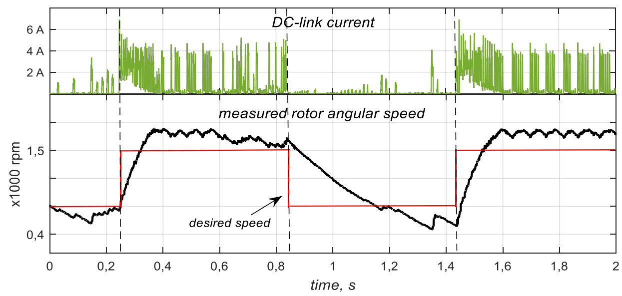

FIGURE 20. The current, setpoint and actual speed flow for the classic BLDC motor control system without optimising the speed measurement and without commutation correction.

C. TRANSIENT STATES

In the proposed control method, in which the switching points of the BLDC motor windings are determined based on the value of the measured rotational speed, there is a danger of the system malfunctioning in transient states. If the motor shaft speed is significantly reduced, the control transistors may prematurely switch over. This is because the switch time of the commutator is determined based on the previously measured motor shaft speed. Interestingly, this effect will not occur in the case of an increase of the rotational speed of the shaft, as in that case an actual recalculation of the actual speed will take place and the value of the calculated switching time will be corrected. To test the correctness of the drive system in dynamic states, two experiments were conducted:

a. System without speed feedback: in this case the command value was changed gradually from 20% to 80% PWM duty, every 0.8 seconds. The results are shown in Figures 18 and 19.

The figures clearly show a much higher current amplitude of the power supply for the classic control method. During the tests, we found that the motor worked much louder than in the method that used the optimised commutation of the BLDC motor inverter transistors. Also, the amplitude of the power supply's current was much lower, which translates directly into a reduction of power losses in this type of drive system. The speed course was not noticeably different, which allows us to conclude that, in the open speed control loop, the differences in operation would be limited mainly to the possibility of using power transistors with a lower rated current and reducing the BLDC motor's noise. At the same time, we recorded no problems with normal operation in dynamic states for the developed control method.

b. System with speed feedback loop for the same settings of the speed PID controller k_p, k_i and k_d. Every second the set speed was changed gradually from a value of 1500 rpm to 500 rpm. The results in terms of system operation are shown in Figures 20, 21 and 22.

This figure clearly shows that the BLDC motor, whose rotational speed is calculated based on the time elapsed between successive Hall sensor states, is not able to work properly in a closed feedback loop. This is due to the inaccuracy of the location of the sensors. It is possible to use averaging algorithms, which, however, introduce a significant delay in the BLDC motor in obtaining the correct speed value and make it impossible to perform efficient regulation – especially for low speed values, where the speed reading frequency is low.

Figure 21 below shows the waveforms for the same motor with a real-time correction algorithm for measuring the rotational speed of the BLDC motor shaft applied [7].

It is clearly visible that a controlled system set up in this way is running correctly and the speed is maintained at the level set by the user.

On the next run, commutation of transistors was added, which in the case of a fast feedback loop may result in deteriorating functionality in the dynamic states of the system.

On the basis of the reported values, it can be stated that the system that used the control method presented here worked correctly in dynamic (transient) states as well. An additional advantage is the reduction of the amplitude of the current

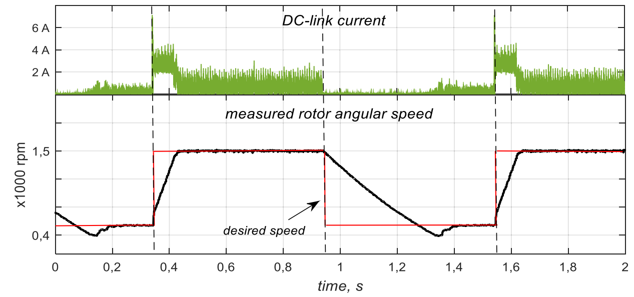

FIGURE 21. The current, setpoint and actual speed flow for the classic BLDC motor control system using the velocity optimisation algorithm and without commutation correction.

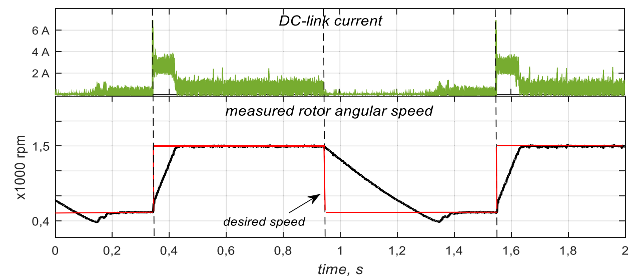

FIGURE 22. The current, setpoint and actual speed course for the developed BLDC motor control method using the speed measurement optimisation algorithm and commutation correction.

drawn from the power supply, which results in a significant reduction in the amplitude of the current running through the motor and contributes to the minimisation of losses and noise reduction of the BLDC powered drive system.

VIII. CONCLUSION

The proposed method of motor control differs quite significantly from the typical control, which uses information from Hall sensors. Usually, the changing signal from one of the sensors is a prompt for the control system to switch the inverter transistors. In the system presented, this signal only provides information that allows for the measurement of rotational speed and the position of the motor rotor. On the basis of this information, the management system synchronises the algorithm controlling the operating cycle of the transistors and calculates their optimal switching time so that, regardless of the accuracy of the placement of the sensors, commutation occurs at the optimal points. An additional advantage is the ability to influence the commutation's acceleration or delay by simply modifying the appropriate variable in the control software, which frees the manufacturer from the need to prepare an adjustable system orientating the sensors to the motor stator. The developed method of identifying the position of the BLDC motor shaft using the analysis of the speed calculation in individual sectors can be used in applications where the positioning of the BLDC motor shaft is necessary, without the need for additional absolute encoders.

Such a method ofcontrol significantly reduces the amplitude of the inverter current, reduces the noise emitted by the running motor and the EMC interference emitted to the environment. At the same time, it does not require any capital expenditure, excluding the need to modify the algorithm controlling the operation of the motor.

The logical separation of the Hall sensors from the switching function of the control transistors enables us to become almost independent of their proper location. It gives us the possibility of preparing an algorithm that detects faults in any or all of the sensors [8] without disturbing the operation of the motor, which in some applications (e.g., electric car drive systems) can significantly affect the safety of the users of such drives.

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