Design Strategy and Implementation of Control Parameters for BLDC Motor Application in an Electric Vehicle

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Abstract: - The brushless dc motor (BLDC) motor is an electric motor that is widely utilized in numerous applications, especially in automotive systems. It is significant to maximize the force of the electric vehicle; however, due to the rapid growth of electric vehicles, motors and power electronics are determined with huge concern. Meanwhile, the Proportional Integral Derivative (PID) cannot balance the load in a stable condition, and this variation generates a change in load and track conditions. In mobile robot the BLDC motor diminished the current and it increased the torque voltage and current by 48V and 50A, respectively. So to overcome these issues, the control algorithm is implemented in this paper to regulate the speed of the motor in 1KW BLDC in an Electric Vehicle (EV). A 1500rpm BLDC motor is designed by Dymola software which is evaluated with MATLAB. The BLDC increases the torque speed characteristics of the motor based on the pole configuration of an electric vehicle. Evaluation of the method is determined with a set of STM 31 ARM processors and a 750 watt driver. The experimentation is simulated using Arduino IDE software and the results revealed that it is applicable for STM 32 or teensy 3.2 development board or Arduino Mega development board.

Key-Words: - Pulse Width Modulated, Electronic Control Unit; Power Train; FPGA, Brushless Dc Motor; Proportional Integral Derivative; Electric Vehicle; Wheeled robot.

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1 Introduction

Electric vehicles are one of the solutions to sustain transportation to reduce emissions around the world. So far, many types of motor have been used to drive electric vehicles. Along with the transmission system, the power electronics and battery, the electric motor is an integral part of its actuation system [1]. High torque and power density, high efficiency over wide torque and speed ranges, variable speed range, high intermediate load capacity, and high reliability and robustness are some requirements of an electric motor for EV applications. BLDC is well suited for electric vehicle trains due to its small size and low maintenance cost [2]. The BLDC motor provides high power, high efficiency, and torque density. However, the conventional BLDC motor topology does not meet all requirements for EV application [3].

1.1 Motivation and Incitement

Nowadays the EV is considered significant for transportation and the selection of motor is obtained as a challenging role. The choice of EV is due to zero carbon emission, cost-effectiveness, and high efficiency [4]. The essential elements determined in EV are the motor, battery, speed controller, and electronic power controller [5]. The BLDC motor is used in various fields such as industries, electric vehicles, and commercial applications due to its noise-free characteristics, good speed regulation, and improved control flexibility [6]. The power supply for the motor is generated from the stator winding and will run more than synchronous speed [7]. Motor speed is estimated based on rpm which calculates time measurement in seconds [8]. The DC-DC converters are used to control the speed and the input DC voltage is maximized at the predicted level. But, while simulating with DC-DC converters, the design for each motor speed varies and it works based on switching components [9]. However, the speed of the motor and converters are minimized, as well as the input power is analyzed based on the arrangement [10]. Error signals are estimated with limited efficiency. The selection of hardware components is based on the type of motor to control speed [6]. The frequency of the PWM signal generates a better result, and it is applied to the duty cycle to control the motor [8]. It takes very low power and is ideal for power train and battery management systems [11]. So to overcome the problem the control parameters for 1 KW BLDC motor are designed and implemented to validate the speed and control unit of the electric vehicle. However, PID is the element determined in control parameters that cannot handle the load in a stable condition. Here, the speed and control unit are measured with 1500 rpm.

1.2 Literature review

Chen et al. [12] proposed the coreless method based on the ferrites structure optimization for the wireless power transfer system. In this paper, the coupling coefficients and the core losses were balanced and the system efficiency and the overall weights were optimized using the core-less method. In this paper, the parameters coupling coefficient, power output, efficiency, voltage, and ferrite thickness were used. The results showed that the efficiency of the system based on the optimal ferrite design was enhanced to 5.5%. However, fixing tiny increments does not improve the optimal ferrite design.

Ivanov et al. [13] introduced shared and connected X-in-the –loop (XIL) technology for the electric vehicle (EV) system. XIL for the design of electric vehicles allowed exploration of interdependencies among different physical processes, which were evaluated and detected in the development of electric vehicles. The experimental results showed that the EV systems, time, and cost were efficient.

Dietrich et al. [7] presented the evaluation and design to develop Plug-in Hybrid Electric Vehicle (PHEV) working methods with the test bench. Noise, harshness, drivability, and vibration are some of the challenges in test vehicles. The consistent loop method was used to overcome these issues, and it also combined the multiple software and real engine hardware elements to represent the behavior of PHEV. The results showed that the on-road behavior of the vehicle was replicated by using the testing environment.

Kang et al. [14] explained the hybrid electric vehicle (HEV) by integrating two different techniques that support vector regression and rough set theory. Analyzing the mapping between the HEV shape model and the customer's visual sensibility was the main objective of this paper. The rough set theory was used to identify the HEV patterns that had a significant impact on customer satisfaction. However this paper did not consider the comprehensive deconstruction.

Mademlis et al. [15] developed a concept based on a multidisciplinary cooling model for electric vehicles employing 3D- computational-fluid-dynamic components. Here, a cooling plate was designed using a CFD component. Various simulation parameters, namely power module temperature, flow speed, car speed, power, temperature, and turbulence kinetic energy, are evaluated and plotted in graphical form. In addition to this, the inverter losses are computed and from the results, it was observed that this technique achieved a minimum loss rate. Meanwhile, the computation of the inner temperature was difficult.

Li et al. [16] designed a lightweight and crashworthiness of an electrical vehicle by employing six sigma optimization techniques. A multi-objective optimization was carried out to attain minimum mass as well as peak acceleration. The reliability, as well as the Sigma level, was enhanced using the six-sigma robust optimization technique. The safety-based performance of an electric vehicle was improved by evaluating the engineering practicability.

Research Gap

Despite the presence of different speed control units in BLDC motors, the speed control units are determined for estimating and controlling the speed. However there are still several gaps in the literature review.

• Power transfer through the wireless system: While transferring power, the tiny increments utilized to control the electric vehicle diminished the performance of the ferrite structure optimization. The proposed method addresses this gap by presenting the STM 31 ARM processor and 750 watt driver that enhanced the torque speed characteristics.

• Designing an EV with XIL: This allows the interdependencies of the exploration phase of EV but the identification of motor parameters is not predicted exactly. The proposed model addressed this gap by introducing a PI controller unit in the electric vehicle that evaluates the sensing position of the motor.

• Evaluating cooling capacity: Existing methods are used to evaluate multiple cooling models but it is not able to determine the temperature determined within the EV motor. The proposed method addresses this gap by using the BLDC motor that estimates the speed characteristics and the temperature of the vehicle.

1.3. Contribution and paper organization

The main contribution of the paper is as follows.

• Propose the control parameters for evaluating the speed and control unit of an electric vehicle using a 1KW BLDC motor.

• The motor speed characteristics are determined in both the loaded and unloaded conditions at different frequencies.

• The evaluation is performed with a 1500 rpm BLDC motor by designing Dymola software.

• A set of functions, such as STM 31 ARM processor and the 750 watt driver, is determined for validation.

The rest of the paper is as follows. The proposed methodology is presented in Section 2. Results and simulations are discussed in Section 3. Section 4 concludes the article.

2 PROPOSED APPROACH

The BLDC motor is an indefinite synchronous machine with rotor position feedback. A 3-phase bridge network, as shown in Figure 1, is directed by it. A hall sensor is available near the rotor to identify the position and will give a signal to the inverter power module. The rotor commutates these modules electronically according to the position of the rotor. Commutation will occur at every 60 degrees sequentially. As there is no brush present in the BLDC motor, there will be no chance of sparking or problem of wear [17]
BLDC motors are of two major categories depending on the source. One depends on the current source, and the other is the voltage source. Both categories use a permanent magnet. The back emf is trapezoidal, as shown in Figure 2. This type of back emf helps to reach a constant torque.

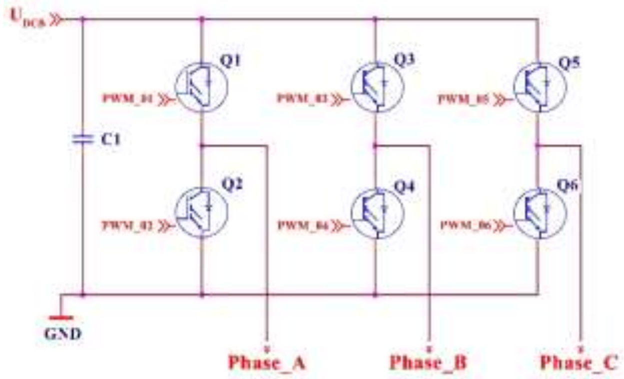

Figure 1: 3-phase inverter for BLDC motor drive

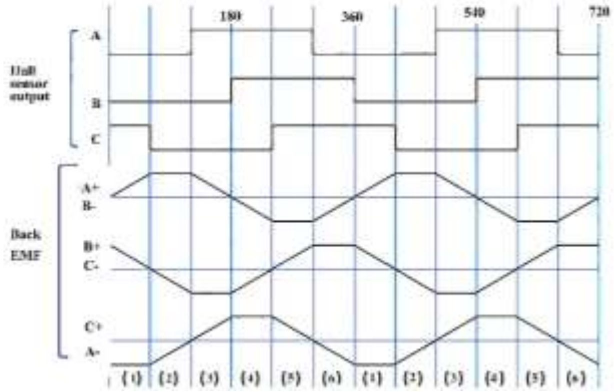

Figure 2: Hall sensor and Back emf waveform of BLDC motor

Figure 3 explains the BLDC drive system with the help of a block diagram. Primarily the motto is electronic type and a 3-phase inverter circuit is required to drive it as shown in Fig.-1. This 3-phase inverter acts like an electronic commutator in auto mode. These commutators get a switching signal from the hall sensor output.

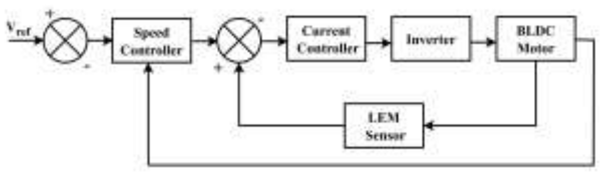

Figure 3: BLDC drive block diagram

2.1 PI control

Proportional and integral control have a role here. Figure 4 describes the current controller here with the current-controlled inverter. There is a PI speed controller with a hall sensor for position sensing. There is also a reference current generator. However, the comparison of reference speed and measured speed paved the way for generating an error signal and determining it in the PI controller for further processing. Although PI is a basic controller, the main novelty lines in implementing the PI controller in BLDC motors for autonomous vehicle applications. [18].

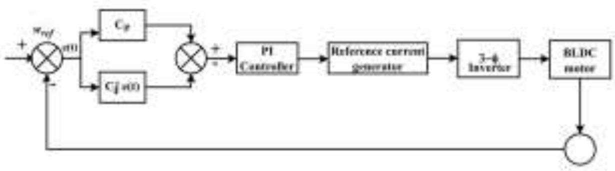

Figure 4: PI control block diagram

The error signal is derived as follows.

$$\mathrm{ERR}(t) = \omega_{ref} - \omega_m(T) \quad (1)$$

Where the proportionality and error signal are denoted by $C_i \int_o^n e(t)dt$ and $C_p e(t)$.

$$S_{ref}(t) = S_{REF}(t-1) + H_r[ERR(t) - ERR(t-1)] + H_L ERR(t) \quad (2)$$

is a proportional constant and the integral constant of the PI controller is denoted by. The output of the controller serves as reference torque. A limit is settled at the speed controller according to the maximum allowed current for the windings. Three reference currents, namely iaref, ibref, and icref, are generated by the reference current generator by getting feedback from the position sensor. The winding currents ia, ib, and ic are regulated by the PWM current controller.

3 EXPERIMENTAL RESULTS

The proportional and integral control blocks have been simulated in MATLAB as well as Dymola. Simulation of electromechanical structures like electric vehicles gives better coordination in Dymola and PI control gives good results in MATLAB, so both are employed here to get a better idea.
3.1 Simulation using Dymola
Dymola has allowed us to use mechanical torque and damping as real-time electromechanical systems. The simulation structure is shown in Figure 5. The output of the half-bridge is shown in Figure 6. The output of the three-phase hall sensor is shown in Figure 7 and, depending on that, the inverter current is shown in Figure 8. In Dymola reference rpm need to be fixed by fixing a voltage from the voltage source. Here, 24 V is used to set the reference. The resulting steady-

state response is shown in Figure 9. It is observed that the system is stabilizing in just 0.3 seconds.

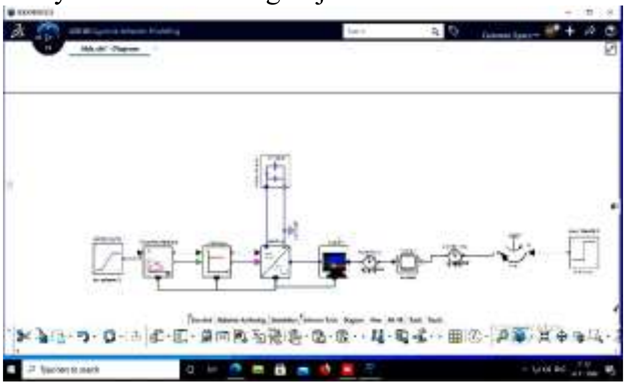

Figure 5: Implementation of the PI controller in Dymola

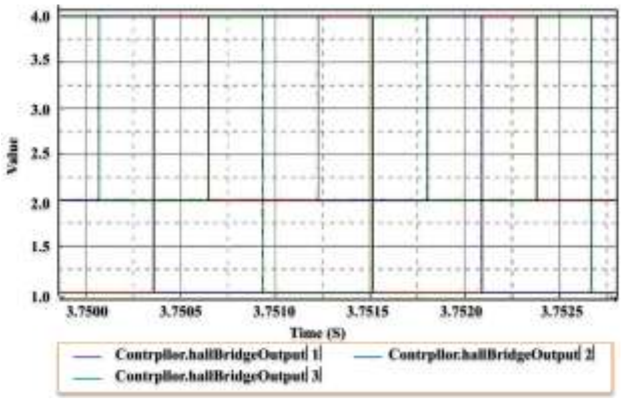

Figure 6: Output of Half-Bridge

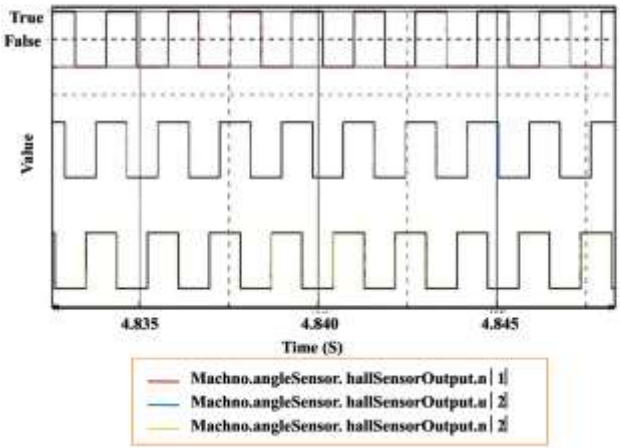

Figure 7: Output of Hall Sensor

3.2 Simulation with MATLAB

The proportional and integral control strategy, as per Figure 4, is executed in MATLAB. Figure 10 shows the execution. The 1500-rpm reference speed is selected and the speed reaches a steady state at 0.05 s. We applied a torque at 0.1s. Figure 11 shows the steady-state response.

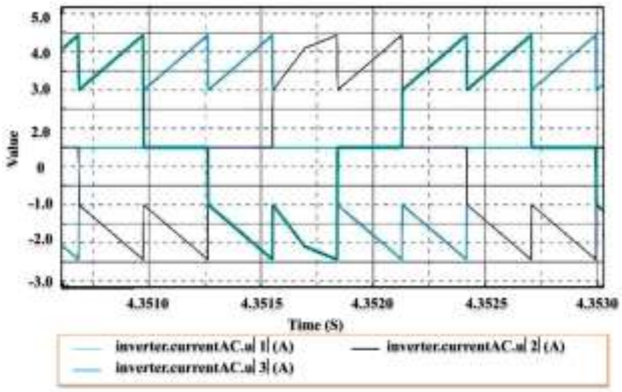

Figure 8: Inverter current

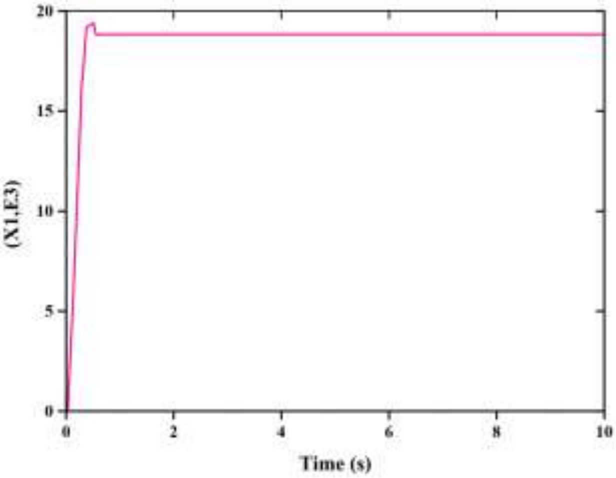

Figure 9: Steady-state response of motor rpm

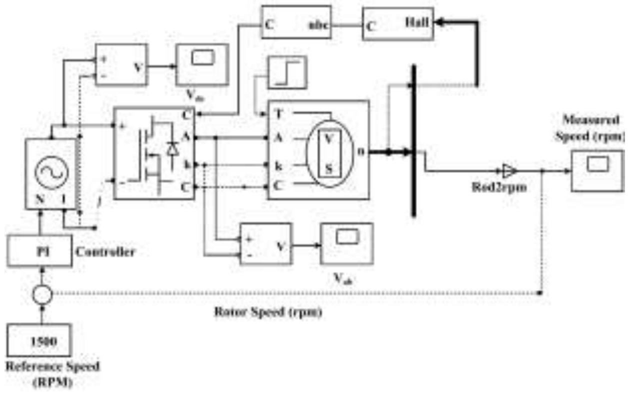

Figure 10: PI controller design in MATLAB

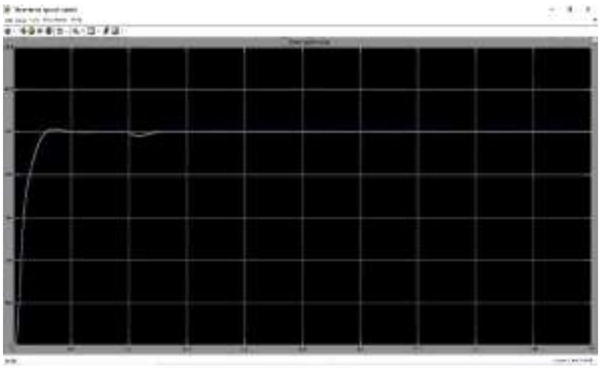

Figure 11: Stabilization of Speed in PI control

3.3. Experimental Setup

A new setup is made to experiment with the ARM processor STM 32 unit. A diagram of the power train design is shown in Figure 12

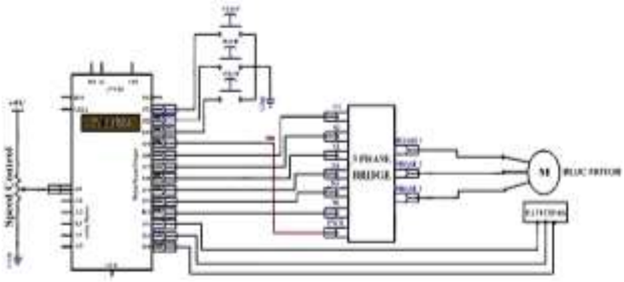

Figure 12: Powertrain design using STM32

The ARM processor STM 32 is connected to a 3 phase bridge, which is a driver unit, which is connected to the motor unit.

Figure 13 shows the connection of the Arduino controller to the driver unit, motor, and powertrain. Figure 14 shows the prototype of the total setup, and the experimental setup is delineated in Fig.-15.

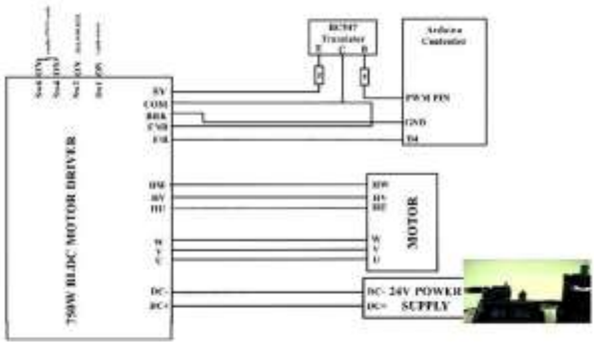

Fig.-13:- Connection with Arduino Controller

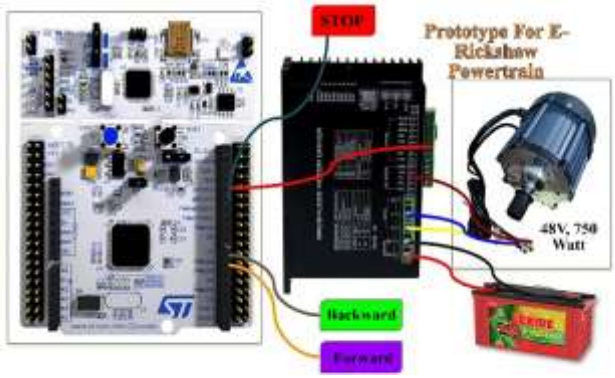

Figure 14: Prototype of the setup

Figure 15: Experimental setup

Figure 16 shows the PCB design for the proposed driver circuit, and Figure 17 shows the controller after assembling all components. The experiment was performed in different loading and no load conditions with different PWM frequencies.

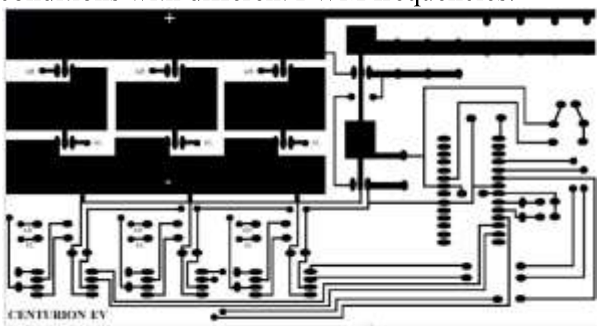

Figure 16: PCB design for the final control unit

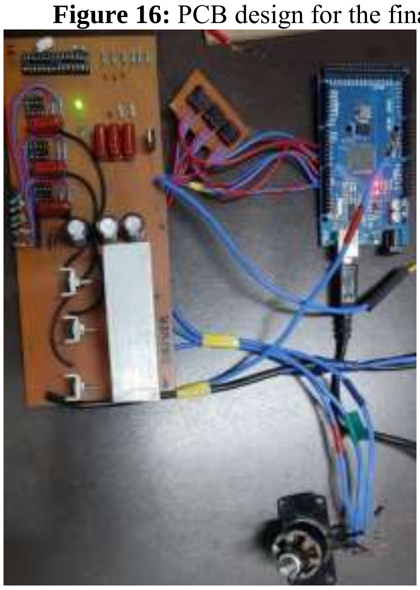

Figure 17: Total control assembly after fabrication with teensy 3.2

3.4. Performance Analysis

In DC motor control, the frequency and duty cycle must be controlled for the PWM signal. The following parameters define the PWM period (1/FPWM): ARR value, the pre-scalar value, and the internal clock itself, which drives the timer module FCLK.

The PWM frequency is set using the following formula.

$$F_{PVM} = \frac{F_{CLK}}{(ARR+1)(PSC+1)} \qquad (3)$$

Four different frequencies are set and tabulated in Table 1.

Table 1: Set and measured frequency of the PWM signal

Clock Frequency(kHz)	CCR	ARR	PSc	ARR+1	PSc+1	PWM Frequency[kHz] = Clock Frequency/(ARR+1)(PSc+1)	Measured PWM frequency [kHz]
84000	875	41999	29	42000	30	0.066666667	0.066
84000	1875	41999	20	42000	21	0.095238095	0.096
84000	11875	41999	9	42000	10	0.2	0.204
84000	12875	41999	3	42000	4	0.5	0.515

The percentage change in duty cycle by changing the value of the CCR register. In addition, the duty cycle equals (CCR/ARR) (percentage). The duty cycle is set from minimum to maximum and is tabulated in Table 2.

Table 2: Set and sss measured duty cycle of the PWM signal

CCR	ARR	Duty Cycle= CCR/ARR	Measured Duty Cycle %
875	41999	2%	2.13
1875	41999	4%	4.5
11875	41999	28%	28.3
12875	41999	31%	30.6
15875	41999	38%	37.7
18875	41999	45%	44.8
20875	41999	50%	49.6
25875	41999	62%	61.6
30875	41999	74%	73.5
35875	41999	85%	85.4
39875	41999	95%	95
40175	41999	96%	95.7
40575	41999	97%	96.5
40875	41999	97%	97.3
41175	41999	98%	98.1
41575	41999	99%	98.9
41875	41999	100%	99.7

The driver circuit got the PWM signal to control the motor speed at different duty cycles and frequencies. Table 3 and Figure 18 describe the response of the motor.

Table 3: Response of motor rpm to duty cycle and frequency variation

Duty Cycle %	rpm at frequency 66Hz	rpm at frequency 96Hz	rpm at frequency 200Hz	rpm at frequency 515Hz
2.13	2800	2930	2930	2916
4.5	2740	2930	2930	2912
28.3	2740	2930	2930	2900
30.6	2740	2912	2910	2896
37.7	2720	2916	2910	2858
44.8	2462	2590	2584	2510
49.6	2350	2370	2360	2290
61.6	1788	1792	1790	1720
73.5	1210	1234	1220	922
85.4	670	674	652	570
95	224	222	194	0
95.7	187	188	156	0
96.5	150	140	107	0
97.3	110	104	0	0
98.1	28	0	0	0
98.9	0	0	0	0

From the result, it is clear that the low-frequency range is suitable to control the motor as a good high and low speeds in varying duty cycles are assigned.

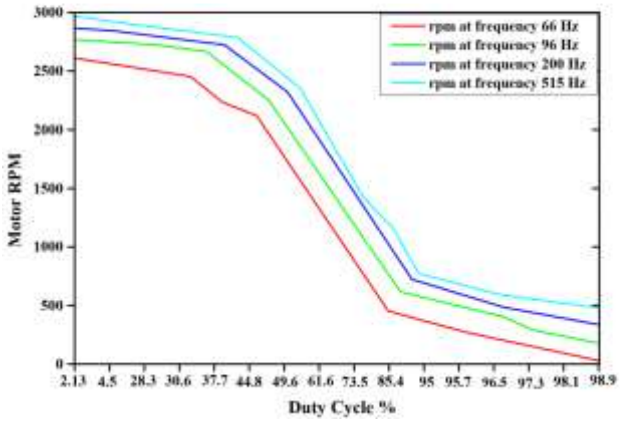

Figure 18: Response of motor rpm to duty cycle and frequency variation

Figure 19 shows the speed control of the BLDC motor based on the input of the staircase. The actual speed of the motor is determined by the better transient and steady-state behavior of the EV. It is determined with a simple component PI controller that evaluates the load condition in the form of a staircase. The speed is determined at 1500 rpm.

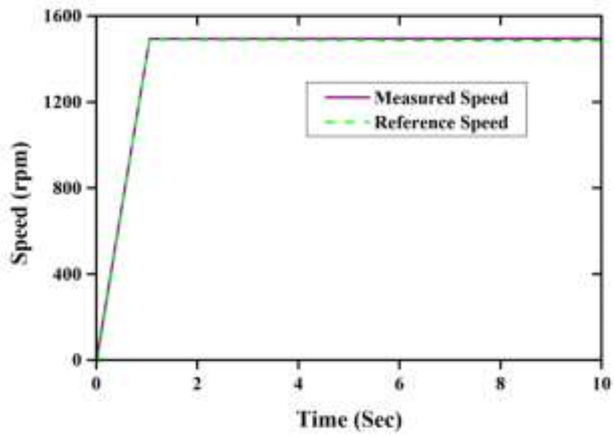

Figure 19: Speed control with a ramp input

Validation of the speed control of the BLDC motor in the ramp input is delineated in Figure 20. Determine the force exerted in the motor of the electric vehicle. The target speed of the engine is determined with high throttle and maximizes the speed characteristics of the engine.

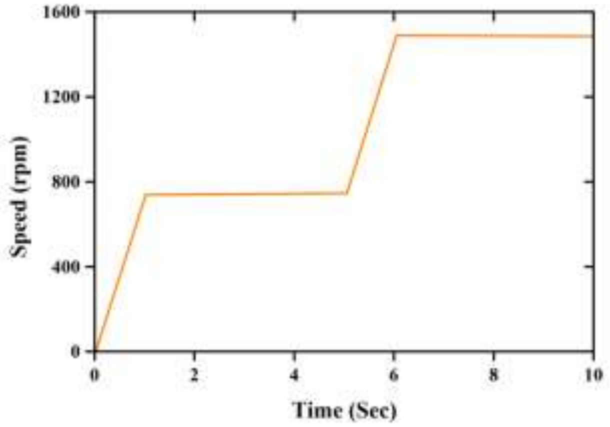

Figure 20: speed control; with staircase input

Figure 21 shows the control of the speed of the electric vehicle based on the triangular form. It evaluates the loaded state of the controller in various test cases. The reference speed as well as the loading condition of the motor determined a stable and good transient capability of the torque speed characteristics.

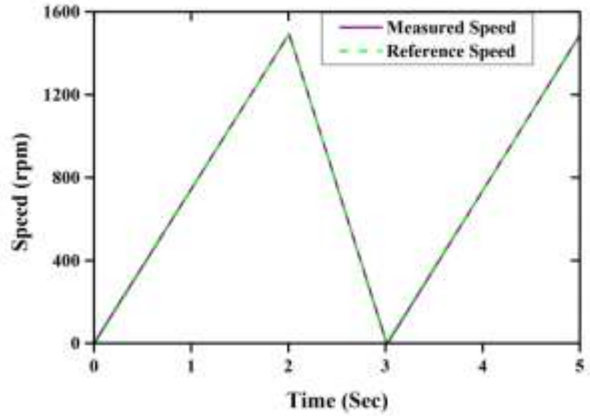

Figure 21: Speed control with triangular input

Figure 22 shows the evaluation of the motor speed based on different time values. The speed of the motor is determined in rpm. Controlling the motor speed is performed based based on DC and voltage. The speed of this proposed control parameter is determined at 1500 rpm.

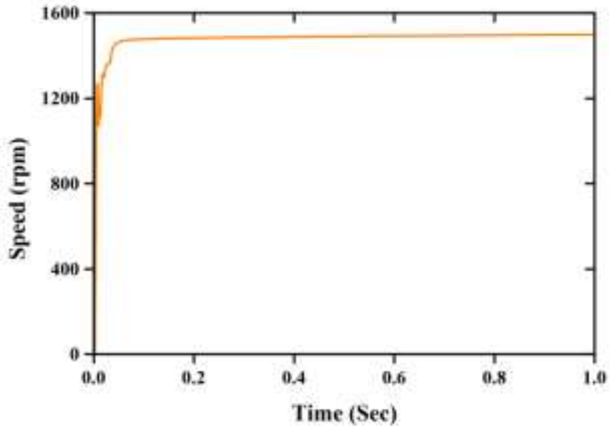

Figure 22: Speed of the BLDC motor

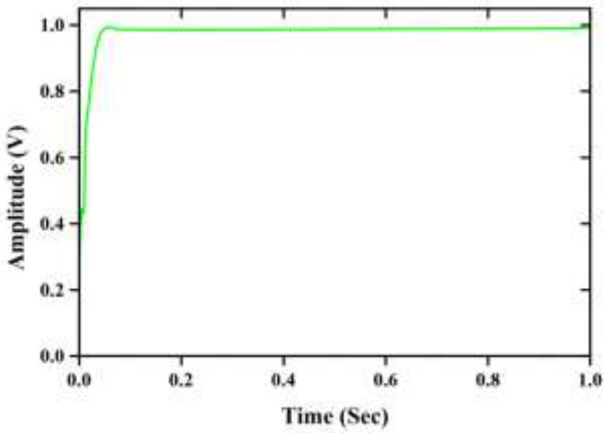

Figure 23: Step Response

3.5 Discussion

The implementation of BLDC motor applications in electric vehicles is widely used to automatically carry out the working strategy. Consuming more power and EV motors are a huge concern all over the world. In some motors, the load cannot be balanced in a stable condition. So, the control parameters in the BLDC motor application are proposed to validate the variations that occurred in both loaded and unloaded conditions. To regulate the speed of the motor, 1KW BLDC is employed in EV with 1500rpm. It generates feedback based on the position of the rotor, and the communication is performed with different power systems. The speed of the motor is increased, and the control unit is minimized. The torque speed characteristics of the motor are maximized, and it is validated based on the current and voltage generated from the motor. The overall power is obtained and evaluated under different load and unloading conditions. In addition, it reduced the cost of the control unit and solved the optimization problems.

4 Conclusion

Proportional and integral control is very helpful to reach a steady state very quickly in the case of BLDC motors. Almost zero response time helps to understand any quick reference change and the system responds accordingly. Both the simulation results showed great responses against error signals. The complete algorithm is physically implemented in the driver and controller loop of an electric vehicle. The entire power and control unit is used under different no-load and loaded conditions for further analysis of the design. The novel target of designing the low-cost control unit, which is suitable for a teensy 3.2 development board or Arduino Mega development board, is achieved, and it is easily programmed with Arduino IDE software. The torque speed characteristics of the BLDC motor enhance the EV regulation and make the load condition stable. The proposed method is analyzed with different parameters, and the evaluation is performed with the comparison based on the speed of the motor. In this analysis, the control unit is minimized, and the torque speed characteristics of the 1KW BLDC motor are increased. Furthermore, the control parameters regulate the speed of the motor under high torque conditions. Evaluation based on scalability and compatibility is performed in more detail. With little modification, this design will be employed in the future for any high-twist motor of further increased load, which in turn makes it easy for further developments.

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