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Design and implementation of digital logic for brushless DC motor control in electric vehicles

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ABSTRACT

In today's world, the rise in global warming is driving a shift towards electric mobility. The progress in battery technology and power electronic devices has facilitated the transition of vehicles from being powered by traditional internal combustion engines to electric motors. The types of motors utilized for propulsion include DC motors, three-phase induction motors, permanent magnet synchronous motors (PMSM), and brushless DC motors (BLDC). Among them, the BLDC motor, when paired with a suitable control algorithm, proves to be the most suitable option for electric vehicle applications. The existing control algorithms for BLD motors are quite complex. Therefore, this study presents the development of an innovative and simple digital control algorithm based on a combinational logic circuit to drive the BLDC motor under motoring and regenerative braking mode. The proposed control algorithm and its effectiveness are validated by simulating it using Xilinx & Proteus software and experimenting with the concept in hardware by utilizing a PIC microcontroller. The proposed control algorithm forms a cost-effective alternative for BLDC motor speed control.

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1. INTRODUCTION

The history of electric vehicles (EVs) is a story of more than two centuries, marked by periods of advancement, decline, and recent revitalization. EVs emerged in the 19th century, initially valued for their quietness and lack of emissions. However, the rise of internal combustion engines and infrastructure limitations led to a decrease in their popularity. In recent years, renewed interest in sustainability and technological progress has fueled a resurgence of EVs. Advances in battery technology, the introduction of new EV models, and the expansion of charging networks have all driven their growing adoption. Today, EVs are essential to the shift towards cleaner transportation, shaping the journey of electric mobility and energy storage.

The advancement of electric vehicles is a captivating journey that spans the better part of two centuries. From their humble beginnings as experimental novelties in the 19th century to the contemporary renaissance driven by environmental concerns and technological advancements, the evolution of EVs reflects a dynamic interplay between innovation, practicality, and societal needs. 1900 marked a remarkable milestone in the history of electric vehicles unfolded in the United States as people recognized the benefits of EVs, including their quiet operation and absence of emissions. This introduction provides a glimpse into the fascinating timeline of EV development, exploring its early roots, periods of prominence, and the present-day resurgence that positions EVs at the forefront of the transportation revolution [1]-[3] (Table 1 (see

Appendix)). Examining the early phases of electric propulsion and obstacles provides insightful viewpoints on how innovation and sustainability will influence transportation in the future.

The continuous rise of global warming led the leaders throughout the world to arrive at a global climate change agreement in November 2016. The 21st Conference of the Parties (CoP21), conducted in November 2015 in Paris, paved the path for the global climate change agreement. The goal of the agreement is to attenuate global warming by 1.5 to 2 ℃. The major causes for global warming are increased concentrations of greenhouse gases, which are caused by to burning of fossil fuels and deforestation. According to 2014 statistics, 6.5% of the world's carbon emissions are from India. India had dedicated itself to the Intended Nationally Determined Contribution (NDC) with the target of minimizing the emission intensity of its GDP by 33-35% by 2030, compared to that in 2005 [4]. In India, 97% of the vehicles are powered using diesel and petrol, which has an adverse impact. To meet its greenhouse gas emission targets outlined in India’s Intended Nationally Determined Contribution, India is directing its efforts towards mobility technologies based on renewable sources. [4].

In the proposed work, a combinational logic-based control algorithm is developed to control the speed of the BLDC motor. The contributions made in this paper are: i) A combinational logic-based control algorithm is developed to control the BLDC motor; ii) The developed control algorithm is simulated using Xilinx and Proteus software; and iii) The proposed combinational logic-based control algorithm is tested in a real-time prototype model using a PIC microcontroller.

2. OVERVIEW OF ELECTRIC VEHICLE

The traditional automobiles release a lot of emissions. To reduce emissions, the automobile industry in the entire world is moving towards electric vehicle. Electric vehicle has added advantages such as being highly reliable, more comfortable, and improved efficiency in the vehicles. Hence, research and development are focused on including enhanced technological features such as auto driving, passenger safety, and regenerative braking. An electric vehicle is also utilized as a controllable load for the standardization of the grid and to compensate for the fluctuations caused due to the sporadic nature of renewable-based generation [5].

The fundamental idea of an electric vehicle is to supplant the conventional internal combustion engine with a combination of battery, motor, and power electronic controller (Figure 1). Thus, the major parts of an electric vehicle are the battery, charger, charging port, power electronic controller (DC-DC converter, inverter), and drive train [6], [7]. The key component of an electric vehicle is the power electronic controller. It forms the adaptive interface between the battery and motor by making the output from the battery compatible with the motor input. It also makes the speed and torque of the traction motor adaptive based on the scenario. The battery forms the power source for the electric motor. The motor transforms the electrical energy into mechanical energy, which is utilized to power the electric vehicle.

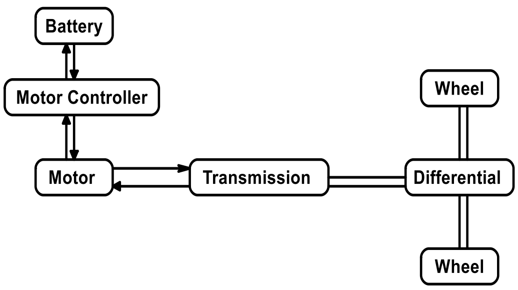

Figure 1. Block diagram of an electric vehicle

For electric vehicle applications, the motors are controlled to be operated in four quadrants, namely forward motoring, reverse motoring, forward braking, and reverse braking. The speed is controlled by controlling the pulse-width modulation signal given to the converter [8]. The drive train is a device that delivers mechanical power from the primary engine to drive the wheels. The charger and charging port are used to charge the battery from an external supply. Different varieties of motors applied in electric vehicles encompass DC motors, brushless DC motors, three-phase induction motors, switched reluctance motors (SRM), and permanent magnet synchronous motors (PMSM). The selection of a suitable motor for an electric vehicle is a key factor. The basic requirements for traction motors are a high power-to-size ratio, more torque at low speed, fixed power for a wide variation of speed, more efficiency, and electronic controllability. In a three-phase induction motor, the speed of the rotor lags behind the stator flux speed by the slip speed. The slip varies in direct proportion to the load torque. Also, it draws high initial current, and the slip diminishes when the motor speed reaches the rated speed. In a DC brushed motor, the torque of the motor is inversely proportional to its rotor speed. Thus, the DC motor produces high torque at reduced speed, which makes it one of the better choices for traction applications [7].

The SRM belongs to the category of synchronous motors. But it does not have a slip ring, field winding, or brushes. A switched reluctance motor (SRM) has a ferromagnetic rotor. The SRM motor is controlled by an electronic commutation technique. The direction of the torque produced by the SRM depends on the rotor's position and the sequence in which the phases are energized. The SRM motor is simple, operates in a wide speed range under fixed power, is highly reliable, and has low cost, making it applicable for traction applications.

The permanent magnet synchronous motor is categorized as either a sinusoidal or trapezoidal wave back electromotive force motor. The permanent magnet synchronous AC motor, known for its sinusoidal back emf, is termed the permanent magnet synchronous AC motor, while the permanent magnet brushless DC motor, with trapezoidal back EMF, is called the permanent magnet brushless DC motor. In a BLDC motor, commutation is done electronically. Hence, it needs less maintenance and also dissipates minimal power in the air gap. There are two methods of control of the BLDC motor. They are sensor modes of control and sensorless control. In the sensor control mode, the BLDC motor incorporates three Hall sensors, each placed at a 120° phase shift, enabling precise monitoring of the position of the rotor. The exciting sequence of the BLDC motor is done in accordance with the position of the rotor. In sensorless control, the position of the rotor is detected based on the motor parameters such as voltage, back emf flux linkage position function, and current [9]-[11]. However, the sensorless control mode is more complicated.

The battery pack plays a pivotal role in electric vehicles, acting as the main energy storage that powers their operation. Advances in battery technology are driving the adoption of EVs. The advancements of batteries are done by focusing on the improvement of energy density of the battery, charging speed, and its overall performance. Several batteries used in EVs are lead-acid batteries, lithium-ion batteries, sodium-ion batteries, and nickel-metal-hydride batteries. However, an appropriate control strategy has to be designed to achieve better robustness and efficiency [12].

Charging equipment plays a pivotal role in the electric vehicle ecosystem, facilitating the replenishment of energy in EV battery packs. Electric vehicle charging infrastructure encompasses multiple solutions, including public charging stations, residential charging setups, and fast-charging options. Home charging stations offer the convenience of overnight or low-demand charging, catering to daily charging needs. Although they typically provide slower charging speeds, they are ideal for residential charging requirements. Public charging stations are very much essential for EV owners who require charging options while away. These stations are optimally located in public areas, parking lots, and commercial spaces, providing EV owners with the convenience of charging their vehicles during their daily activities. Public charging stations offer varying charging speeds, ranging from slower level 2 chargers to faster level 3 DC fast chargers. Fast-charging stations, also known as rapid chargers, are designed to supply a substantial charge to an EV in a short period. These stations utilize high-power charging infrastructure, enabling EV owners to quickly replenish their battery levels during long-distance travel or when time is limited. Fast-charging stations are typically found along major highways, facilitating extended EV travel with minimal charging time. The power electronics components of an electric vehicle are essential for efficient power conversion, motor control, and charging capabilities. These components include the inverter, converter, motor controller, DC-DC converter, and on-board charger [13].

3. CONTROLLERS FOR BLDC MOTOR

A BLDC motor transforms electrical energy into mechanical energy through electromagnetism. Unlike regular brushed motors, BLDC motors don't need brushes & commutator to alter the current direction. They use electronic communication instead. [14]. An electronic controller adjusts the current in the stator coils based on the feedback obtained from the position sensors located in the rotor. The stator field interacts with the rotor magnets, allowing precise control of speed and direction. In a BLDC motor, the rotor’s position is identified using sensors like hall effect sensors and encoders. By precisely controlling the current in the stator coils based on feedback, BLDC motors work efficiently and accurately in various applications like electric vehicles, industrial machines, and electronics. The control techniques for BLDC motors are classified mainly into two types, namely sensored and sensorless control techniques [15].

In sensored control techniques, sensors such as back-EMF detection, hall effect sensors, and encoders are utilized to track the information regarding the rotor’s position. In the hall effect sensor-based control technique, three sensors are utilized to track the rotor's position in reference to the stator windings. Based on the signals from these sensors, the controller can determine the optimal timing for commutating the motor windings [16].

In the back electromotive force (EMF) detection-based method, the EMF produced by the motor windings is measured when the motor rotates. By analyzing the angular displacement of the back EMF waveform, the controller can deduce the rotor's position and adjust the commutation accordingly. This method offers precise control but may be more complex and expensive compared to hall effect sensors [14], [17].

In sensorless control of BLDC motors, several methods such as back EMF zero crossing detection, model-based estimation, high-frequency injection, observer-based techniques, and third harmonic injection are utilized for estimating rotor position and controlling motor operation. In the back EMF zero-crossing detection method, the zero-crossing points of the back EMF waveform are generated by the unexcited phase winding. These points are utilized to estimate rotor position for sensorless commutation [18], [19]. However, detecting back EMF zero crossings is crucial for controlling BLDC motors accurately [20]. Sensor-based methods offer high accuracy but can be costly. Sensorless methods are cheaper and simpler but may not always be as accurate. More research is required to enhance the accuracy of sensorless methods, especially at low speeds and under various conditions.

Scalar and vector control are two common methods used for controlling the torque and speed of BLDC motors. Both methods have their advantages and are suitable for different applications. Scalar control is a straightforward method used to control the speed of BLDC motors [21], [22]. In scalar control, the voltage and frequency applied to the motor are changed in proportion to control the speed. Hence, it's called scalar control because only the magnitude (or scalar) of the voltage signal is adjusted. This method is relatively simple to implement and is commonly used in applications where accurate control of torque and speed is not required. However, scalar control lacks the ability to individually control the flux and torque of the motor, which limits its performance in dynamic applications.

Vector control, alternatively termed field-oriented control (FOC), represents an advanced method employed to achieve precise control over BLDC motors. In vector control, the stator currents are controlled in both magnitude and phase angle with respect to the rotor flux, thereby enabling the independent control of flux and torque [23]-[26]. By controlling the stator currents within a rotating reference frame synchronized with the rotor flux, the vector control effectively decouples the flux and torque control loops, enabling high-performance control of both speed and torque. Vector control provides superior dynamic performance and efficiency compared to scalar control, making it suitable for applications where exact control of speed, torque, and flux is required, such as in industrial automation systems and electric vehicles. However, vector control algorithms are more complex and require more computational resources compared to scalar control.

Sutikno *et al.* suggested an FPGA-based PWM control for BLDC control [26]. Naqvi *et al.* created a multi-objective optimization speed control system for BLDC motors using particle swarm optimized PID controllers and restricted differential evolution. The suggested approach improves EV motor speed control [27]. An artificial neural network controller-based speed control of a BLDC motor was suggested by Megrini *et al.* The system is rapidly stabilized and responds well to the artificial neural network controller [28].

The proposed control algorithm is a sensor-based control algorithm. The authors made an attempt to replace the complex sensor-based algorithm with a simple algorithm. The traditional sensor-based control algorithms continuously track the position of the rotor and verify with the lookup table, and generate the control signal accordingly. This involves several switch cases, which increases the time delay. In the proposed combinational logic-based algorithm, the control signal is generated directly based on the position of the rotor (i.e., it depends only on the present inputs). Hence, the proposed algorithm provides a fast response in the generation of a control signal for the commutation of switches, which suits very much better for real time applications. The sensorless control involves a very complex algorithm. The complexity increases with the number of switches used in the inverter. But the proposed algorithm remains simple and fast enough even with an increased number of hall sensors.

4. COMBINATION-BASED CONTROL ALGORITHM FOR BLDC MOTOR

This article proposes a combinational logic-based control algorithm for BLDC motor. As discussed earlier, a BLDC motor is composed of two major parts: the stator, which remains stationary and contains wire coils wound around iron cores, and the rotor, which is the rotating component made of permanent magnets. The operation of a BLDC motor heavily depends on an electronic speed controller (ESC) to manage its speed and direction by transmitting appropriate electrical signals to the motor windings. Hall effect sensors are incorporated to identify the rotor magnets' position and to provide feedback to the ESC for precise control. The ESC triggers the stator coils in a predetermined order to generate a rotating magnetic field, ensuring its interaction with the permanent magnets on the rotor, thereby initiating rotation. Speed regulation is achieved through the ESC's modulation of the amplitude and duration of electrical pulses sent to the stator coils. This control method, known as pulse-width modulation (PWM), effectively adjusts the average voltage applied to the motor, thus controlling its speed. The proposed work suggests an innovative control algorithm for the BLDC motor, which propels the electric vehicle (Figure 2). The BLDC motor is fed by a battery through the voltage source inverter. Three hall effect sensors are placed at 120° phase shift to track the rotor position.

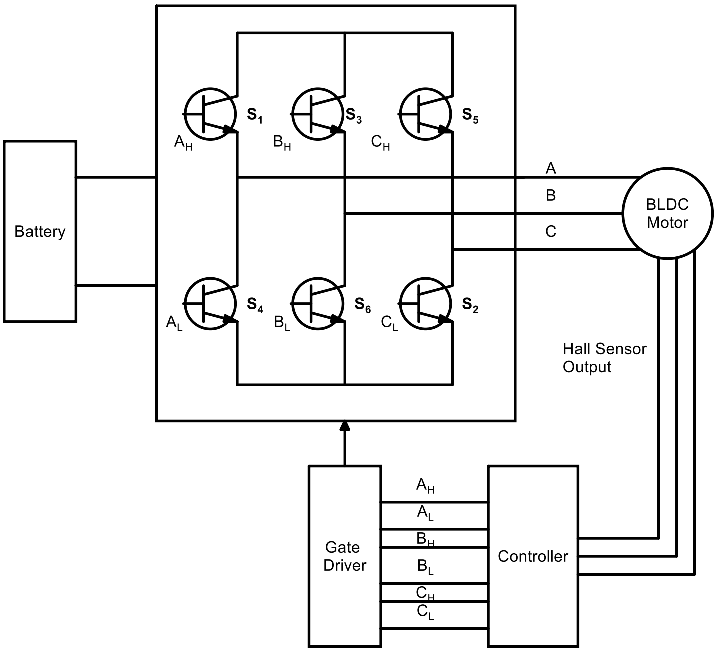

Figure 2. Block diagram of BLDC motor drive system

In this proposed method, the gate signals to trigger the switches are generated based on a combinational circuit. A combinational circuit is a digital electronic circuit in which the output relies on the input variables. The procedure to design the combinational circuit is i) Decide the number of input variables; ii) Decide the number of output variables; and iii) Create a truth table with inputs and outputs. For a circuit with ‘n’ input variables, the possible combinations of inputs are 2^n. For all possible combinations of inputs, fill the required output; iv) Relate the output variables in terms of input variables using the Karnaugh Map in a logical expression; and v) Using the reduced expression, implement the combinational circuit. A half adder is an example of a combinational circuit.

For example, to design and implement a circuit that adds two single-bit numbers (a half adder circuit):

- Step 1: Decide the number of input variables. The objective is to add two single-bit numbers. Hence, the number of inputs is 2. Let it be A and B;
- Step 2: Decide the number of output variables. The function that has to be executed by a half adder circuit is to add A and B. Hence, the expected outputs are 2 (sum and carry);
- Step 3: Create a truth table (Table 2) with inputs and outputs. Since we have 2 inputs, the possible combinations of outputs are 22 = 4. They are 00,01,10,11. For all the possible input combinations, fill in the expected outputs. The function is to add A and B. So, when we add the first set of inputs 0 and 0, the required output is sum = 0 and carry = 0. Likewise, fill in the expected output for all possibilities; and
- Step 4: Now express the inputs in terms of the Output by plotting (Figure 3) in a Karnaugh Map (K-Map). Using the reduced expression, implement the combinational circuit (Figure 4).

In a similar manner, the control signals for the inverter triggering the BLDC motor drive are generated in this proposed algorithm, which is discussed in detail below.

Table 2. Truth table of half adder

Input		Output	
A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

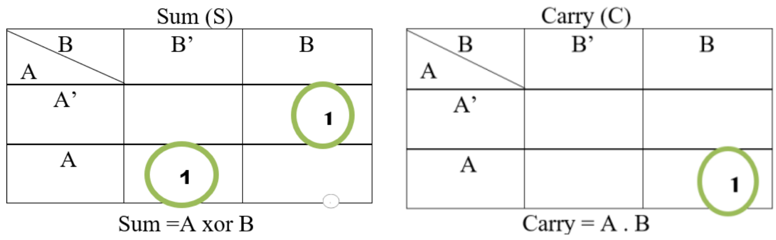

Figure 3. K-map for a half adder

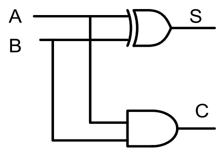

Figure 4. Combinational circuit of a half adder

In a 4-pole BLDC motor, three hall sensors (Ha, Hb, Hc) are attached to determine the position of the rotor. A hall sensor produces the output signal only when the north pole passes through the hall sensor. There will be six possibilities of outputs from hall sensors. When the rotor is in a position similar to Figure 5, the hall sensor outputs are (0,0,1). Then, stator coils A should be excited as the north pole, which will push the rotor in a clockwise direction, and excite the stator coil C as the south pole, which will attract the rotor in a clockwise direction. Similarly, when the hall sensor outputs are 011, the switches connected to the A phase and B phase have to be excited, which is tabulated in Tables 3 and 4 for all possibilities.

The direction of the motor is controlled using the input ‘dir’ and the mode of operation using the input ‘mode’, respectively. The motor is switched ON using the input ‘ctr’. As soon as the ‘ctr’ is enabled, the coils will be excited accordingly to the combinational logic until the hall sensor output changes. The excitation is done based on the current position of the rotor, mode of operation, and direction of the motor.

Thus, the inputs to the controller to generate gate pulses are hall sensor positions (A, B, C), mode of operation (motoring, braking), direction of rotation (forward, reverse), and the outputs are gate pulses for the inverter (A_H, A_L, B_H, B_L, C_H, and C_L). Tables 3 and 4 [26] represent the sequences of gate pulses to be given to the inverter circuit to drive the BLDC motor. Using Tables 3 and 4 as the truth table, the gate pulse outputs (A_H, A_L, B_H, B_L, C_H, and C_L) in terms of inputs are generated by reducing the K-map expression, which is shown in (1)–(6).

$$A_H = ctr(\overline{mod\,e}\,\overline{(dir}\overline{AC} + \overline{B}(\overline{dir \oplus A}))) \tag{1}$$

$$A_L = ctr(dir\overline{AC} + \overline{B}(\overline{dir \oplus A}))) \tag{2}$$

$$B_H = ctr((\overline{mod\,e}\,\overline{(dir}A(B + C))) + (\overline{mod\,e}\,dir\overline{A}B)) \tag{3}$$

$$B_L = ctr((\overline{(dir}\overline{A}B) + (dirA(B + C))) \tag{4}$$

$$C_H = ctr(\overline{mod\,e}\,\overline{(dir(B \oplus C)} + dir(\overline{A \oplus B})) \tag{5}$$

$$C_L = ctr(dir\overline{(B \oplus C)} + \overline{dir}(\overline{A \oplus B})) \tag{6}$$

Initially, the control logic suggested in (1) to (6) is verified in Xilinx software (shown in Figure 6). For all the possibilities and modes of operation, the control algorithm was generated precisely as given in Tables 3 and 4. Then, the same proposed controller for speed control of the BLDC motor is designed with a PIC microcontroller using Proteus software (shown in Figure 7). The output from the controller is fed to the driver circuit to trigger the IGBTs in the voltage source inverter. The voltage source inverter drives the BLDC motor, which is used to propel the vehicle (shown in Figure 8). For different operating modes, the excitation is faster than the state machine logic. By means of the above combinational logic, the desired gate signals will be faster than the sequential logic controller.

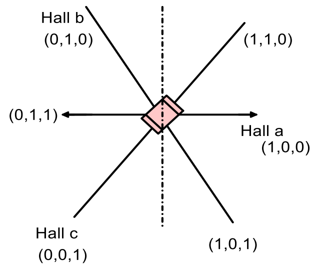

Figure 5. Different possibilities of hall sensor outputs

Table 3. Position of the hall sensor and drive bits in forward and reverse rotations

Hall effect sensor			Phase	Forward rotation						Phase	Reverse rotation					
A	B	C		A_H	A_L	B_H	B_L	C_H	C_L		A_H	A_L	B_H	B_L	C_H	C_L
0	0	1	1	1	0	0	0	0	1	6	0	1	0	0	1	0
0	1	1	2	1	0	0	1	0	0	5	0	1	1	0	0	0
0	1	0	3	0	0	0	1	1	0	4	0	0	1	0	0	1
1	1	0	4	0	1	0	0	1	0	3	1	0	0	0	0	1
1	0	0	5	0	1	1	0	0	0	2	1	0	0	1	0	0
1	0	1	6	0	0	1	0	0	1	1	0	0	0	1	1	0

Table 4. Position of hall sensor and drive bits in forward and reverse regenerative braking

Hall effect sensor			Phase	Forward regenerative braking						Phase	Reverse regenerative braking					
A	B	C		A_H	A_L	B_H	B_L	C_H	C_L		A_H	A_L	B_H	B_L	C_H	C_L
0	0	1	1	0	0	0	0	0	1	6	0	1	0	0	0	0
0	1	1	2	0	0	0	1	0	0	5	0	1	0	0	0	0
0	1	0	3	0	0	0	1	0	0	4	0	0	0	0	0	1
1	1	0	4	0	1	0	0	0	0	3	0	0	0	0	0	1
1	0	0	5	0	1	0	0	0	0	2	0	0	0	1	0	0
1	0	1	6	0	0	0	0	0	1	1	0	0	0	1	0	0

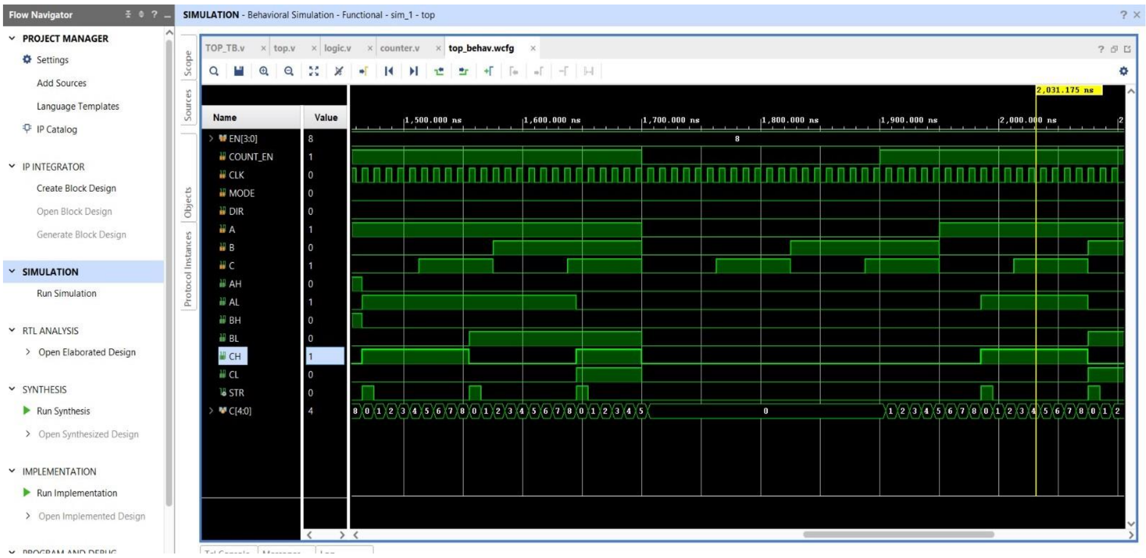

Figure 6. Control logic algorithm for the BLDC motor in Xilinx software

A counter circuit is incorporated to facilitate precise speed control of the BLDC motor (Figure 9). The counter has the input of clock, count, and end value of n+1 bits (E_0, E_1, …, E_n). The counter starts counting from 0 to E (max value). Once the counter reaches the value E, the load pin goes high, which resets the counter and enables the combinational logic algorithm and the register. According to the hall sensors' outputs, mode, and direction, the gate pulse signals are generated for the inverter. The gate pulse input values is stored in the register until the load pin becomes high.

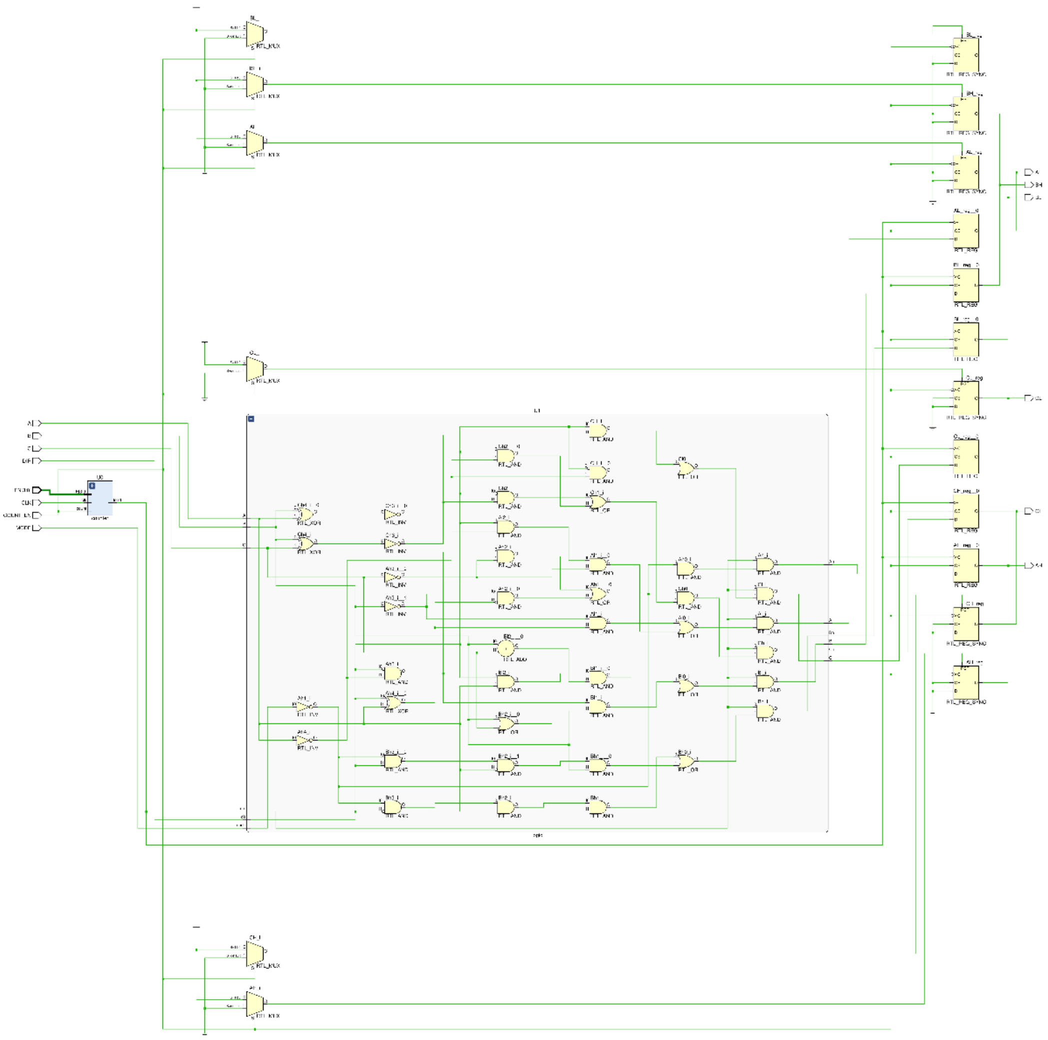

Figure 7. Control logic algorithm for the BLDC motor in Proteus software

The value of ‘E’ is calculated based on the required speed of the BLDC motor. Let us consider ‘f’ to be the clock frequency, ‘m’ be the counter end value in decimal, ‘t_e’ to be the time required for excitation of the combinational logic, and ‘tr’ to be the time required for one complete revolution of the rotor. Then:

$$t_e = \frac{m}{f} \tag{7}$$

Since each coil is positioned exactly 60°, there are 12 different positions for the rotor to complete one revolution, according to the six combinational logics determined from the hall sensors. Time required for one complete revolution (t_r):

$$t_r = 12\ t_e \tag{8}$$

Speed of the BLDC motor in revolutions per second (Nrps):

$$N_{rps} = 1/t_r \tag{9}$$

Speed of the BLDC motor in revolutions per minute (Nrpm):

$$N_{rpm} = 60 / t_r \tag{10}$$

From these equations, the value of m can be obtained by:

$$m = \frac{5f}{N_{rpm}} \tag{11}$$

The value of E is determined by decoding m to a binary format, now it can now be fed to the counter for controlling the speed. The proposed speed control algorithm for the BLDC motor is simulated and verified using Proteus software and is shown in Figure 8.

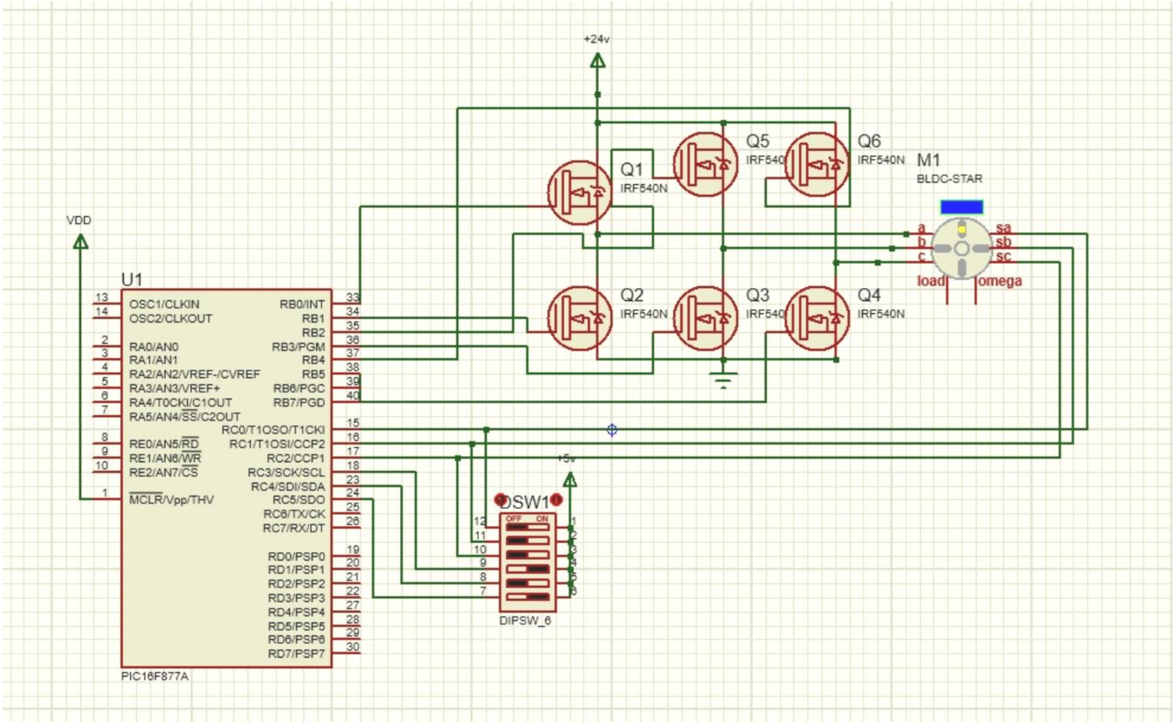

Figure 8. Speed control of the BLDC motor in Proteus software

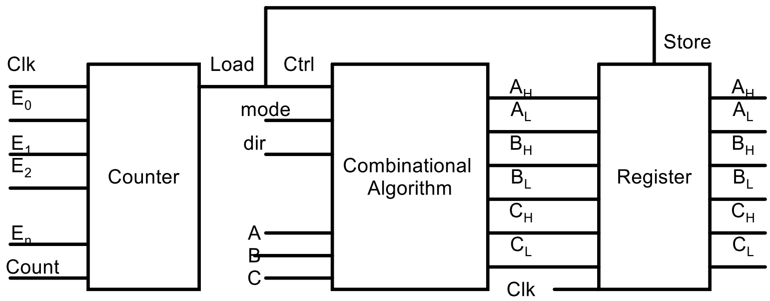

Figure 9. Block diagram of the controller unit

5. HARDWARE RESULTS

The proposed algorithm is implemented using a PIC microcontroller (PIC16F877A) and is shown in Figure 10. The output from the PIC microcontroller is fed to the gate driver circuit (TLP 250), which is being fed to the MOSFETs (IRF840) of the three-phase voltage source inverter. A 60 W, 24 V BLDC motor is connected through the voltage source inverter, and its speed is controlled as per the proposed algorithm. The proposed algorithm is very simple compared to the traditional algorithms. The comparison between the traditional algorithm and the proposed algorithm is given in Table 5.

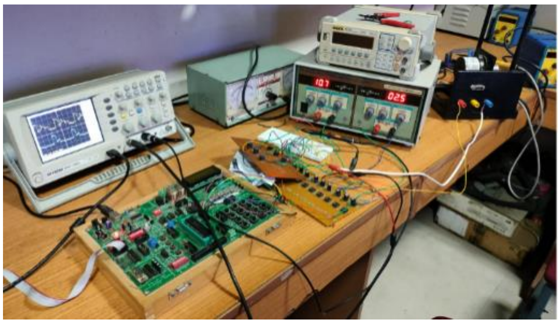

Figure 10. Hardware setup

Table 5. Comparison of the proposed algorithm with traditional algorithms

Features	Lookup table-based algorithm	Sensorless control algorithm	Proposed combinational-basec control algorithm
Flexibility	Low	High	High
Speed of operati	Fast	Slow	Very Fast
Complexity	Low	High	Low
Cost	Low	High	Low

6. CONCLUSION

Global warming keeps rising due to emissions. Initiatives such as green transportation are encouraged by policymakers to reduce emissions. BLDC motor with electronic commutation forms the popular drive train for electric vehicles. This paper proposed a simplified combinational logic-based control algorithm to drive the BLDC motor. The proposed control algorithm is developed and verified using Xilinx and Proteus software initially. Then it is being tested in a real-time environment using a PIC microcontroller. The proposed algorithm is very simple, fast, and efficient, which suits very much better for real-time applications. However, the PIC microcontroller has limited memory; hence, in the future, the PIC microcontroller can be replaced with an FPGA controller.

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K. Ganesh Kumar	✓			✓					✓					✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

REFERENCES

[1] V. Iulia and S. Loránd, “A brief history of electric vehicles,” *Journal of Computer Science and Control Systems*, vol. 15, no. 1, pp. 19–26, 2022.
[2] M. Amatucci, “The world that chose the machine: an evolutionary view of the technological race in the history of the automobile,” *International Journal of Automotive Technology and Management*, vol. 15, no. 1, pp. 43–62, 2015.
[3] J. Larminie and J. Lowry, *Electric Vehicle Technology Explained*, Second Edi. Wiley, 2012.
[4] L. Ferry and P. Eckersley, “Debate: Climate change and 21st Conference of the Parties (COP21) Paris—addressing the ‘ultimate’ wicked issue,” *Public Money & Management*, vol. 36, no. 4, pp. 241–242, Jun. 2016, doi: 10.1080/09540962.2016.1163021.
[5] A. Tashakori and M. Ektesabi, “Comparison of different PWM switching modes ofBLDC motor as drive train of electric vehicles,” *World Academy of Science, Engineering and Technology*, vol. 6, pp. 596–602, 2012.
[6] S. Goel, R. Sharma, and A. K. Rathore, “A review on barrier and challenges of electric vehicle in India and vehicle to grid optimisation,” *Transportation Engineering*, vol. 4, p. 100057, Jun. 2021, doi: 10.1016/j.treng.2021.100057.
[7] A. T. Abkenar, “BLDC motor drive controller for electric vehicles,” Swinburne University of Technology, 2014.
[8] M. S. Abdelfatah, P. S. Solanki, and S. Sreedharan, “Design and implementation of 4-quadrant chopper for speed control of EVs and regenerative braking analysis,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 16, no. 1, p. 407, Mar. 2025, doi: 10.11591/ijpeds.v16.i1.pp407-417.
[9] T.-H. Kim and M. Ehsani, “Sensorless control of the BLDC motors from near-zero to high speeds,” *IEEE Transactions on Power Electronics*, vol. 19, no. 6, pp. 1635–1645, Nov. 2004, doi: 10.1109/TPEL.2004.836625.
[10] W.-S. Yan, H. Lin, H. Li, and W. Yan, “Sensorless direct torque controlled drive of brushless DC motor based on fuzzy logic,” in *2009 4th IEEE Conference on Industrial Electronics and Applications*, IEEE, May 2009, pp. 3411–3416. doi: 10.1109/ICIEA.2009.5138835.
[11] A. Gupta, Taehyung Kim, Taesik Park, and Cheol Lee, “Intelligent direct torque control of brushless DC motors for hybrid electric vehicles,” in *2009 IEEE Vehicle Power and Propulsion Conference*, IEEE, Sep. 2009, pp. 116–120. doi: 10.1109/VPPC.2009.5289860.
[12] A. R. Al Tahtawi, A. S. Rohman, P. H. Rusmin, and A. Rizqiawan, “Dynamic model and control strategies of battery-supercapacitor hybrid power sources for electric vehicles: a review,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 16, no. 2, p. 695, Jun. 2025, doi: 10.11591/ijpeds.v16.i2.pp695-709.
[13] G. Rituraj, G. R. C. Mouli, and P. Bauer, “A comprehensive review on off-grid and hybrid charging systems for electric vehicles,” *IEEE Open Journal of the Industrial Electronics Society*, vol. 3, pp. 203–222, 2022, doi: 10.1109/OJIES.2022.3167948.
[14] R. Krishnan, *Electric Motor Drives: Modeling, Analysis, and Control*. Prentice Hall, 2001.
[15] D. Mohanraj *et al.*, “A review of BLDC motor: State of art, advanced control techniques, and applications,” *IEEE Access*, vol. 10, pp. 54833–54869, 2022, doi: 10.1109/ACCESS.2022.3175011.
[16] B. K. Bose, *Power Electronics and Motor Drives*. Elsevier, 2021. doi: 10.1016/C2019-0-02032-8.
[17] H. A. Toliyat and S. Campbel, *DSP-Based Electromechanical Motion Control*. CRC Press, 2004.
[18] K. G. Dhawad, “Sensor less BLDC motor control with Back EMF zero crossing detection using PIC 18F2431 MCU,” no. 5, pp. 6–9, 2016.
[19] X. Zhou, Y. Zhou, C. Peng, F. Zeng, and X. Song, “Sensorless BLDC motor commutation point detection and phase deviation correction method,” *IEEE Transactions on Power Electronics*, vol. 34, no. 6, pp. 5880–5892, Jun. 2019, doi: 10.1109/TPEL.2018.2867615.
[20] A. B. Sankar and R. Seyezha, “Sensorless control of a BLDC motor using Back-EMF detection method,” *2023 International Conference for Advancement in Technology, ICONAT 2023*, pp. 1426–1434, 2023, doi: 10.1109/ICONAT57137.2023.10079963.
[21] P. Krause, O. Wasynczuk, S. Sudhoff, and S. Pekarek, Eds., *Analysis of Electric Machinery and Drive Systems*. Wiley, 2013. doi: 10.1002/9781118524336.
[22] J. M. Miller, *Brushless Permanent-Magnet and Reluctance Motor Drives*, 2nd ed. New York, NY, USA: Oxford University Press, 2012.
[23] I. Boldea and S. A. Nasar, *Electric Drives*, 2nd Edition. CRC Press, USA, 2005.
[24] K. T. Chau, *Electric Vehicle Machines and Drives: Design, Analysis, and Application*. John Wiley & Sons, 2015.
[25] T. Kenjo and S. Nagamori, *Permanent-Magnet and Brushless DC Motors*. New York, USA: Oxford University Press, 1985.
[26] T. Sutikno, N. R. Nik Idris, N. Satya Widodo, and A. Jidin, “FPGA based a PWM technique for permanent magnet AC motor drives,” *International Journal of Reconfigurable and Embedded Systems (IJRES)*, vol. 1, no. 2, p. 43, Jul. 2012, doi: 10.11591/ijres.v1.i2.pp43-48.
[27] S. S. A. Naqvi *et al.*, “Multi-objective optimization of PI controller for BLDC motor speed control and energy saving in Electric Vehicles: A constrained swarm-based approach,” *Energy Reports*, vol. 12, pp. 402–417, Dec. 2024, doi: 10.1016/j.egyr.2024.06.019.
[28] M. Megrini, A. Gaga, and Y. Mehdaoui, “Processor in the loop implementation of artificial neural network controller for BLDC motor speed control,” *Results in Engineering*, vol. 23, p. 102422, Sep. 2024, doi: 10.1016/j.rineng.2024.102422.

APPENDIX

Table 1. Revolution in transportation

Invention	Inventor	Year	Significant details
Electric Motor	Hungarian physicist and priest Ányos Jedlik	1828	Powered a small model car, marking a significant step forward in the exploration of electric propulsion for transportation
compact electric car	Scottish inventor William Morrison	1832	Limited range covering approximately 12 miles on a single charge.
Electric Carriage	Robert Anderson's	1832-1839	Laid the groundwork for future advancements in electric transportation
Electric Car	Stratingh and Becker's	1835	A small-scale electric car driven by primary cells. This achievement showcased the potential feasibility of electric power for transportation and paved the way for further innovations.

Table 1. Revolution in transportation (continued)

Invention	Inventor	Year	Significant details
Electric Tram	Invented in city of Berlin	1881	Runs on overhead lines and has a speed range of up to 16 miles per hour.
Flocken Elektrowagen	Andreas Flocken	1889	Its emergence laid the groundwork for subsequent advancements in electric vehicle technology, setting the stage for the transformation of the automotive industry.
First Hybrid Car	Jacob Lohner and Ferdinand Porsche	1900	The car was first showcased in 1900 at the Paris Auto Exhibition
First Hybrid Car Invented	Henry Seth Taylor, a prominent Canadian electric vehicle manufacturer	1901	This innovative creation seamlessly integrated both gasoline and battery power sources to propel the electric car forward.
Ford Model T electric car	Henry Ford	1908	This electric vehicle proved to be a highly popular choice, providing consumers with a feasible alternative to conventional gasoline-fed cars. Moreover, its affordability played a pivotal role in making electric vehicles accessible to a wider range of people
Electric Vehicles - took up to (1/3)rd of US Market Share		1909	After the year 1909, electric vehicles gained significant traction in the USA, capturing up to a 3rd of the share of the market. This rise in popularity led to the increased demand for electric vehicles.
Electric Vehicle Boom Ends		1920	After 1920, the surge in electric vehicle adoption came to an end due to a significant drop in gasoline prices. This shift had severe implications for the electric car sector, leading several manufacturers to face insurmountable challenges and ultimately shut down due to their inability to contend with the burgeoning automobile industry.
Edsel electric car	Edsel Ford, the son of Henry Ford	1947	The Edsel electric car struggled to capture significant attention and ultimately fell short in its competition against the more predominant gasoline-powered vehicles.
NASA’s Electric Lunar Rover		1971	Electric vehicles made a resurgence in 1971 with the deployment of NASA's electric Lunar Rover during its Moon mission. Fueled by solar energy, this innovative rover successfully traversed a remarkable distance of 400 miles on the lunar surface. This pivotal event marked a significant milestone in re-establishing the prominence of electric vehicles. The introduction of NASA's Lunar Rover not only demonstrated the viability of electric propulsion but also played a crucial role in familiarizing the market with this technology.
CitiCar	Sebring Vanguard, an electric car manufacturer	1975	CitiCar itself was a compact, two-passenger electric car that operated using lead-acid batteries, boasting a range of 40 miles per charge. The CitiCar specifically appealed to urban commuters whose regular travel needs didn't encompass long distances. Its design and functionality catered to those seeking an economical electric vehicle option that minimized both maintenance expenses and gasoline outlays. It became a favored choice among individuals looking for an affordable and efficient mode of transportation. However, the initial surge in the growth of electric vehicles experienced a downturn after a few years. By 1979, the fervor surrounding the CitiCar and similar electric vehicles began to wane.
Electric Vehicle Interest Dies Off		1979	After the rise in popularity of electric cars, there was a significant demand for these vehicles in the market. Nonetheless, the momentum of this growth came to a halt in 1979, primarily due to the inability of electric car manufacturers to meet the escalating consumer demands effectively. Furthermore, the decrease in gasoline prices further exacerbated the situation, rendering electric cars less economically viable in comparison to their gasoline powered counter parts.
EV1 Produced		1996	General Motors introduced its groundbreaking EV model, known as the EV-01. The EV-01 stood as a compact electric car propelled by a reluctance motor, which is fed with a lead-acid battery. It is capable of covering distances of up to 40 miles on a solitary charge.
First Mass-Produced Hybrid Car	Honda company	1997	This pioneering hybrid electric vehicle gained significant traction among consumers who aimed to minimize their ecological impact. They found the Insight particularly appealing because it allowed them to decrease their carbon footprint while also accommodating their budget, as gasoline-powered vehicles were more cost-effective when compared to fully electric cars
Prius, a sedan-style car,	Toyota Prius Introduced	1998	The Prius, a sedan-style car, operated on a combination of an electric battery and conventional gasoline. This groundbreaking electric hybrid garnered significant attention from consumers who were environmentally conscious and aimed to minimize emissions.
Tesla’s Luxury Electric Vehicle		2006	Tesla, a notable electric car manufacturer, unveiled its ambitious strategy to manufacture a high-end electric automobile. Unveiling itself as the Tesla Roadster, this remarkable vehicle stood out as the pioneering electric sports car with an impressive ability to cover up to 245 miles on just one charging cycle
Tesla Roadster		2008	Tesla, an innovative electric car manufacturer, introduced the Roadster, a groundbreaking electric sports car model.

Table 1. Revolution in transportation (continued)

Invention	Inventor	Year	Significant details
Nissan LEAF Released		2011	Nissan introduced a groundbreaking addition to their automotive lineup – the LEAF electric car model. This revolutionary vehicle, known as the LEAF, took the form of a five-door electric hatchback and was powered by an advanced electric battery. Remarkably, the LEAF had the capacity to journey up to 100 miles on a solitary charge.
Plug-In Electric Vehicles Skyrocket		2018	In the year 2018, sales of electric cars achieved an unprecedented milestone. The market share of plug-in electric vehicles rationalized for approximately 0.004% of the total global motor vehicle population by the conclusion of 2018.
Tesla Model Y		2020	In 2020, Tesla, the renowned electric car manufacturer, introduced their latest electric SUV model. This remarkable electric vehicle was powered by a cutting-edge battery that enabled it to achieve an impressive travel range of up to 316 miles on a solitary charge.

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