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Control Techniques for BLDC Motor: A Review

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ABSTRACT

Engineering material technical advances, as well as significant advances in solid phase devices and circuits, have resulted in the development of new kinds of electric motors, such like stepper, switching reluctance and PMBLDC motors. Direct current motors are machines that transform direct current mechanical energy into electrical energy. It is dependent on the magnetic force produced by the permanent magnets in the motor when current is applied to the coils inside the motor. Brushless direct current (Brushless dc) motor is the latest option of motor driving applications to their reliability, highly efficient values, compact size, increased dynamic characteristics, silent operation, and low maintenance requirements. These motors outperform traditional electric motor including such brushed DC motors and inductive motors due to their enhanced speed-torque characteristics, higher speed, and lack of arcing. The BLDC motor's output torque to size is also higher. It is useful in circumstances when space and mass are key factors. BLDC motors are widely utilized in the automobile, appliances, aeronautical, retail, healthcare, instrumentation, and automation industries due to their advantages. These motors can be controlled with or without sensors; however, sensor-less control techniques are more commonly utilized when they resulted in smaller and less expensive motor assemblies. The control strategies utilized for Bldc motors are described in this work.

Keywords: Back EMF, Brush Less Direct Current motor, Hall-effect sensors, PWM, Neural Network, Fuzzy Logic.

1. INTRODUCTION

The number of high-performing things that make human life easier expands by the day as technology advances. Integrated items from the automotive and electronics industries are becoming increasingly evident as smart technology advances. One of them is a BLDC motor. BLDC engines are now widely used in the majority of industrial applications, notably in the car industry, aerospace technology, computer networking, medical instruments, defense applications, robot implementations, and consumer products [2].

Brushed Direct Current (BLDC) motors were launched prior to BLDC motors to replace certain less efficient AC induction motors that had previously existed. Ernst Werner Von Siemens, a very well German inventor and manufacturer, designed the brush DC motor in 1856. Von Siemens' name is now emblazoned on the worldwide grade unit of conductivity. After leaving the service, Von Siemens studied electrical engineering and made important advances in the discipline, notably the first electrically lift in 1880.Von Siemens' brush Electric motor was rudimentary, but it was expanded on by the Harry Ward Leonard, who almost finished the first functioning motor control system at the end of the 19th century. In 1873, Zenobe Gramme invented the modern DC motor. A rheostat regulated the energy in the field winding, which in turn controlled the output voltage from the DC generation, which in turn controlled the motor speed. The Ward Leonard approach was in use till 1960, when the Electronics Regulation Company's thyristor circuits provided solid phase controllers that could more directly convert AC to corrected direct current. It replaced the Ward Leonard technique because to its simplicity and efficacy [5].

Faraday discovered that a conductor carrying current is repellent to a magnetism, which was the initial step towards direct current devices. There is no variation in shape or functioning principle between the initial Electrical machines and the devices utilized today, and their working logic is the same. Collector are used in direct current motors to communicate volts to the armature, whereas brushes are used in the outer circuit to transport current to a armature. Because they lack collector and brushes, BLDC employ electronic commutation. The brushless dc motor is powered by having to engage the stator in the correct order based on the angle position data supplied by the sensors. Because direct current motors lack collectors and brushes, BLDC motors are less costly to maintain and repair. They have a longer lifespan than d.c. motors, produce less heat, operate quietly, have no friction, and produce no arc. Permanent magnets are used for the Bldc rotor [2].

PMLDC motors are an excellent choice for moderate drive systems and position control due to their high torque/mass ratio, remarkable dynamic capabilities, and minimal losses. These motors are generally used in a wide range of applications, from microwatts to megawatt, including aviation equipment, devices, entertainment, power drills, vision and audio equipment, automobiles, and healthcare equipment. BLDC motors are now more appropriate for controller design in machining operations, robotic, and high accuracy servos, as well as torque and speed control throughout variety of industrial drives and control systems applications, due to the creation of advanced motor coordination methodologies and ultra-fast micro controllers [3].

Furthermore, BLDC motors offer benefits over brushed Dc/ induction motors, such as superior torque-to-speed characteristics, noiseless operation, and larger speed ranges. Furthermore, the torque provided is greater than the motor size, making it a great choice for purposes such as washers and electric vehicle where high power is necessary yet compactness and lightweight are crucial. While many recent advances in control theory, like pole positioning and optimization approaches linear regulators based on exact feedback control, are employed of BLDC motors [1].

2. STRUCTURE OF BLDC MOTORS

BLDC are a relatively new kind of motor that is being used increasingly often in industries such as electronic devices, transportation, and aviation due to its lower pricing and improved functionality. Section images of the magnets, which acts as that of the inside rotor, the armature winding, as well as the hall sensor installed on the shaft are shown in Figure 1. Commutation is the process of changing the direction of current passing through such a coil in the armature of a DC motor utilizing collectors slices and brushes.

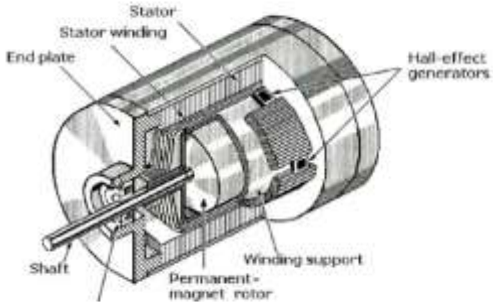

Figure 1: Brushless type DC motor section view

BLDC motors use electronic commutation since they lack collectors and brushes. the brushless DC motor configuration where the electronic driver energizes the stator windings in the proper sequence using information about the rotor's location obtained from sensors

2.1 Stator

The stator, or stationary component, of an electric motor is made of a sheets core which the coils are coiled, and it contains silicon to help reduce magnetic conductor losses. Sheets core are cut and compressed after determining on the number of holes for the moulds. Slurry coating or plastics insulators are used to prevent the coils from coming into contact with stator and short-circuiting. Windings are prepared by employing connector to connect, varnish, and pull out the end wires. Figure 2 depicts various stator outer and inner diameter, Mould kinds, slot counts, and other parameters used in BLDC motors.

Figure 2: BLDC motor stator

2.2 Rotor

The rotor of a BLDC motor is made up of magnets. Both the inside rotor (In runner) and the outer rotor may be utilised to build BLDC motors (Outrunner). The stator are the electromagnets inside the inner rotor structure, as opposed to the stator windings being wrapped around the permanent magnets in the outer rotor design. Permanent magnets may generate magnetic fields without the need of magnetomotive force. Neodymium-Iron-Boron (NdFeB) magnets, sometimes referred as Neodymium magnet, have largely replaced ceramics magnets, which were widely used until around 30 years ago. The amount of magnet in the rotor has a direct impact on the motor's torque and speed value, with more poles leading in a lower motor speed. Figures 3&4 depict Fourteen pole outer rotor & eight pole inner rotor Motor [2].

Figure 3: Brushless type Direct Current motor (stator and outer rotor)

Figure 4: Brushless type DC motor (stator and inner rotor).

3. OPERATION AND WORKING PRINCIPLE OF BRUSH LESS DC MOTOR

3.1 What is a BLDC Motor?

A BLDC is a synchronous permanent magnet electric engine that is driven by DC energy and has an electronic control commutation mechanism rather than a mechanically regulated one. Commutation is the method of generating rotational torque in a motor by varying phase currents via it at the appropriate moments. BLDC motors are also referred to as "trapezoidal permanent magnet motors."

BLDC motors use electronic commutation rather than mechanical commutation, as opposed to traditional brushed type DC motor, which employ a magnet rotor as well as a stator with a series of winding to generate a mechanic commutator on the rotor which produce an electricity path between such a DC power generator and the rotor armature. In this engine, current-carrying cables are static whereas the magnetic force (or field poles) rotates.

Transistors or silicon-controlled rectifiers electronically switch the armature coils at the correct rotor position, ensuring that the stator field is in spatial quadrature with the rotor field poles. The rotor revolves simply as a result of the load exerted to it. The most popular instruments for sensing the position of the rotor are rotating encoders or hall sensors, which are placed all around the stator. The sensor's response to rotor position helps determine when the armature current is switched.

This digital commutation technology eliminates the commutator mechanism and brushes in a DC motor, resulting in a more dependable and calmer operation. Due to the lack of brushes in BLDC motors, they may work at high speeds. BLDC motors typically have a performance of 85 to 90 %, whereas brush type DC motors have a performance of 75 to 80 percent. BLDC motors are available in a wide range of power ranges, including minuscule power ranges, fractional, integral horsepower, and massive power ranges.

The Lorentz force law, that says that when a current-carrying conductor is placed in a magnetic field, it experiences a force, is the same notion that underpins the functioning of a BLDC motor. As just a function of the reaction force, the magnet will experience an equal and opposing force. The permanent magnet of a BLDC motor travels whereas the current-carrying wire stays stationary.

When a supply source electrically changes the stator coils, they reshape in to the electromagnetic force and begin to generate a constant field within the air gap.Regardless of the fact that the supply is Direct Current, switch produces an AC reference voltage with a trapezoidal shape. The connection between both the magnet stator and the electromagnet stator keeps the rotor rotating [4].

4. ADVANTAGES OF BLDC MOTOR OVER OTHER MOTORS AND DISADVANTAGES

We will compare several characteristics of brushless DC motors, induction motors, and brushed DC motors in this part. Due to the benefits listed below, brushless DC motors are preferred over other motor types with comparable ratings for industrial and commercial applications. Based on the features listed above, the Motor has the capability to replace other kinds of motors due because of its wide variety of applications [1].

ADVANTAGES	BLDC MOTOR	BRUSHED DIRECT CURRENT MOTOR	INDUCTION MOTOR
Mechanical structure	Permanent magnets on rotor and field winding on stator.	Stator is made of permanent magnets or electro magnet and field Winding on the rotor.	Both the stator and rotor having coils but the alternating current lines are connected to the stator.

Maintenance	No maintenances	Periodic maintenance charge because of brushes present	Less maintenance charge
Speed-Torque characteristic	operation at all speeds with rated load they are flat	Loss in torque at higher speeds because of losses in brushes are moderate	They are Non-linear
Commutation method	Using solid state switches	Mechanical contacts between brushes and commutator	Special starting circuit is required
Speed Ranges	Because of no losses present in brushes there are high	Losses in brushes are moderate	They determined by the AC line frequency; increases in load further reduces speed. So it is low range
Detecting method for rotors position	Hall sensor, optical encoder, etc.	Automatically detected by the commutator and brushes	Not available
Direction reversal	Reversing the switch sequence	Reversing the applied voltage	By changing the 2 phases of the motor input
Electrical noise	Low	High – as brushes used	High – as brushes used
System cost	Because Of external Controller requirement cost is high	Low cost	Low cost

Table I: Comparison of BLDC Motor with Brushed DC Motor and Induction Motor

DISADVANTAGES OF BLDC

1. These motors are expensive.
2. Controlling an electronic controller was necessary. This motor is pricey.
3. Many combined electronic control solutions are not widely available, particularly for small BLDC motors.
4. Complex driving circuitry is needed.
5. Additional sensors are required.

5. BRUSHLESS DC MOTOR CONTROL

BLDC motor with high power densities and speeds are increasingly being employed in industrial application including such industrial machinery spindle drive, compressor, and electric car traction systems. However, high electrical frequency, massive phases inductor, and limited inverting voltage always are unavoidable in these Brushless dc motor drive systems in order to attain high speed and high-power density, resulting in protracted commutation throughout normal operation. Long commutation is often undesirable since it is a key source of torque fluctuation and power factor deterioration [15].

Both in sensor and sensor-less modes, BLDC motor speed control is possible. Sensor-based approaches make use of low-price sensors such as hall-effect sensors. Inertial sensors were also used to determine the location and speed of motors. Sensor-less control methods are frequently used to lower the overall cost of actuation devices.

Because the commutation process is only activated after identifying the position of the rotor, the BLDC motor contains rotor position knowledge for proper electric charge commutation to its stator armature conductors. Brushless DC motor control relies heavily on rotor position detection, PWM generation, and three-phase inverters. Only two of the phases are engaged at one time in these motors, with the third phase turned off. Each phase is turned on until the voltage reaches 120 volts. The brushless DC motor's speed is dependent on the applied voltage. The PWM logic specifies when the switches ought to be ON and OFF in addition to average the supplied dc bus voltages and so control the speed. Figure.5 shows the 3-phase inverter circuit.

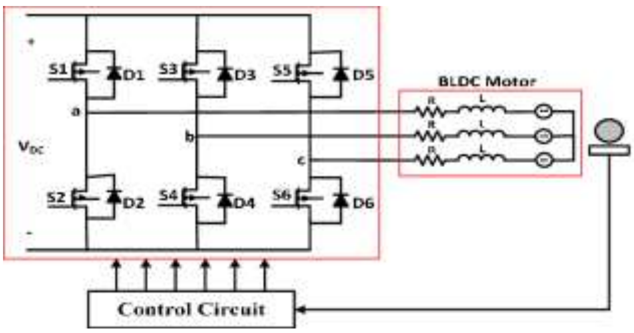

Figure 5: 3-phase inverter circuit powering BLDC motor.

The three-phase MOSFET bridge works as an inverter, transforming the battery's DC input to AC. This output is controlled by the MOSFETs' firing angle. These are made up of 6 MOSFETs that convert the input DC to three-phase AC for the Motor. They are perfect for this duty since they can function as an inverter as well as a converter. They act as an inverter during motor operation, delivering 3-phase AC to the engine. This helps keep the engine running. The firing angle given to the MOSFETs in this procedure is significantly below 90 degrees. This enables them to function as an inverter, producing the necessary output. When braking or regenerative braking, the MOSFET bridge works as a rectifier. It transforms the engine's AC power to Dc power. This is then utilized to recharge the battery. The firing angles of the MOSFETs are given with values greater than 90 degrees in this method. The AC can now pass between the diode and MOSFETs.

The purpose of a Bldc control is to deliver speed and/or torque. A controller will generally give torque or control the motion. The required speed is maintained by detecting the motor's speed and regulating the phase voltage. Motor power is used to regulate torque. Using very basic techniques, the motor current may be managed to maintain a constant level, resulting in constant torque. Computer chips, micro - controllers, DSP-based, FPGA-based, and Adaptive Neuro - fuzzy inference controllers are among the controllers utilized. Those controllers are chosen according to the application and needs [3].

5.1 Speed control

Commutation ensures that the BLDC motor's rotor rotates approximately, while the motor's speed is only impacted by the amount of voltage supplied. The Pulse width modulation method is used to regulate the required speed by varying the magnitude of the supply voltage speed controller, like a PI controller user. The controller receives the speed difference between the real as well as required speeds and changes the duty ratio Pulse width modulation pulses to keep the desired speed [7].

5.2 Torque control

The efficiency of Bldc is regarded quite important due to their varied usage in industry and home applications. Due to manufacturing restrictions and magnetic material selection concerns, the resulting Back-EMF waveform varied from its intended shape. The resulting electromagnetic torque does have a ripple in its waveform due to the commutation of power electronics switches and PWM switching. These torque ripples produce noise, which reduces motor efficiency and has an impact on speed-control characteristics, especially at low speeds. Commutation torque ripple & harmonic distortion induced by device freewheeling in an idle period have become research hotspots in recent years.

After analysing the different PWM ways utilised in commutation torque ripple reduction for BLDC motor drive with appropriate back EMF waveform, the PWM ON method was chosen as the best option for BLDC motors. Unfortunately, the non-linearity in the back EMF wasn't really considered in this way.

The Kuhn-Tucker theorem was used to study the torque control of a multi stage BLDC motor, resulting in lower copper loss and torque ripple. However, feedback sensors including such high-resolution encoders & torque transducer are required, raising the cost of the system, & Clarke and Park transforms are used for flux and torque calculations in direct torque & indirectly flux control mechanisms. These improvements, however, reduced the accuracy of parameter estimation, making them extra time consuming.

To achieve efficient control of torque, a mixture of uni and bipolar drives was explored, taking advantage of the bipolar drive's high beginning torque and the unipolar drive's higher running speed. FPGA/DSP based controllers are also used to drives BLDC motor with bi or unipolar driving &transition between the two at any speed [8].

6. CONTROL OF BLDC MOTORS USING SENSORS

An angular position sensor is necessary for the brushless DC motor, which converts information about the rotor shaft position into an appropriate electric signal. This signal is used to turn on and off the electrically operated electronics of the BLPM motor, also known as the electronic commutator. The majority of rotor position sensors use Hall-Effect position, optical position, and electro - magnetic variable reluctance sensors. These are what are known as explicit position sensors. Hall-Effect sensors are widely used among these. They work on the Hall-Effect principle. It claims that when an current carrying conductor is placed in a magnetic field, the field imposes a transverse force on the movable charge carriers, causing them to transfer to either side of the conductor. The concentration of charges at the conductor's side balances the magnetic influence, leading in an observable voltage between the conductor's two sides. Hall sensors require a power supply varying between 4 V - 24 V. The required current ranges from 5 to 15 mA. To spin the BLDC motor, the stator two coils are ignited in sequence. Understanding the rotor position is essential for determining which coils must be energized following the energizing procedure. The rotor's position is detected via Hall-Effect sensors inserted in the stator [10].

A Hall-Effect sensor is a device that monitors the intensity of a magnetic field and Its output voltage is equal to the magnitude of the magnetic field travelling through it. Hall-Effect sensors are frequently used in application such as position, speed recognition, proximity monitoring, and current sensing. They are used to determine the location of the permanent magnet in BLDC motors. The voltage from of the sensor will peak again for every turn. An indium compound semiconductor crystal, including such indium antimonide, is placed on an aluminum backing plate and enclosed in the Hall probe probe head. When the Hall probes is held such that the field lines cross at perpendicularly across the sensor, the meter shows the flux density measurement. When placed in a field, a current flow through the crystal, producing a voltage across it. The Hall Effect is observed when a conductor is transported through a consistent magnetic field. A current is sent via a narrow section of metal in a detector. The separation of particles will come to an end when the forces produced by the electric field match the forces created by the magnetic field. If the current remains constant, the Hall voltage indicates the concentration of magnetic flux. There are two types of hall effect sensors. The first is linear, which implies the output is linearly dependent on magnetization; the other is threshold, which means the voltage decreases abruptly at each the magnetic flux density [9].

Commutation logic is the process of excited the proper phase coil depending on Hall effect sensor inputs. A fresh drive switching pattern is implemented whenever a new signal change is detected. The commutation logic determines which coils must be activated depending on Hall inputs. Hall sensor inputs are switched to obtain the Drive Pattern for clockwise and anticlockwise directions. Figure 6 and Table 2 depict the power circuit diagram and clockwise rotation commutation logic, respectively

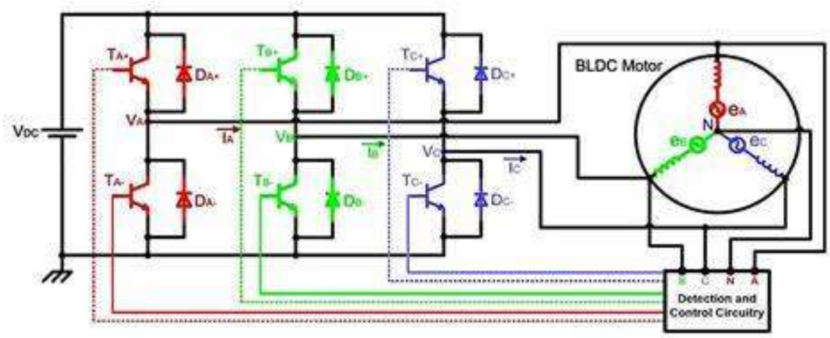

Figure 6: Power Circuit Diagram

HALL SENSOR VALUE (H3 H2 H1)	PHASE	SWITCHES
101	U-V	Q1:Q4
001	U-W	Q1:Q6
011	V-W	Q3:Q6
010	V-U	Q3:Q2
110	W-U	Q5:Q2
100	W-V	Q5:Q4

Table 2: Commutation Logic for clockwise rotation

The control method used in Hall sensor-based commutation is simple and easy to understand. Hall sensor-based commutation can also be used to drive motor at very low speeds. The sensor commutation strategy is a great choice whenever a BLDC motor application needs high torque at low speed or when starting from a standstill.

The downside is that its installation requires independent Hall sensors within the engine block as well as additional sensor interface hardware. These Hall-Effect sensors increase the price & volume of the motor, in addition to need a one-of-a-kind mechanical arrangement for mounting the sensors. They are also temperature sensitive. As a result, the operational range is constrained. The increasing number of parts and connections required reduces system reliability. As a result of the control difficulty and high price of PMBLDC motor with sensors, they are not widely used.

Sensor reduction is critical in low-cost, reduced BLDC motor drives so it affects system cost. Sensors are costly, and their performance is influenced by temperature and electromagnetic interference induced by stator current. Sensor less management of a BLDC motor is used to terminate Hall-effect sensors [3].

7. SENSORLESS CONTROL OF BLDC MOTOR

The emerging interest is to drastically reduce system size and cost, which eliminates some of the challenges that arise when trying to implement sensor-based solutions. The following are the disadvantages of position sensors: The sensor can boost the volume of BLDC motors for starters. Second, the position sensor adds to the wire that connects the motor as well as the control system, growing the system's sensitivity to external forces. Lastly, the sensor's response decreases when having to work conditions are poor, such as high temperature, air intensity, or high humidity.Finally, the position sensor installation precision has certain requirements, and erroneous commutation induced by equipment installation flaws has a direct influence on the BLDC motor's operational performance. As a result, sensor-less approaches are used to create low-cost, low-parts brushless DC motors with good system dependability. Sensor-free methods are utilised to build less-cost, low-parts BLDC motors having high system reliability.

Sensor-less control mechanisms, like the Back-EMF method, magnetic flux linkage method, and inductive method, use motor voltages or currents to sense rotor position. The Back-EMF method is the one most commonly used. When a BLDC motor turns, each winding generates a voltage recognised as back Electromotive force or back EMF, which, as according Lenz's law, opposes the main supply voltage delivered to the windings. The induced back EMF has the same polarity as the power supply. The rotational velocity of the rotor, the magnetic field created by the rotor magnets, and the number of turns in the stator windings all have an effect on the back EMF. As a result, new sensor-less approaches are emerging.. Back-EMF detection, detection of voltage level, Back-EMF integrating, Straight Back-EMF sensing, direct phases current detecting & freewheeling diode conduct techniques are all part of the Back EMF technique. The phase coils of Bldc are arranged sinusoidal or trapezoidal. Back EMF can be sinusoidal or trapezoidal. In trapezoidal commutation, only two stages are conducting at every given time, whereas all 3 phases are trying to conduct at any given time in sinusoidal commutation. Sinusoidal voltage allows for smoother motor rotation with fewer ripples. Trapezoidal commutation, on the other hand, represents the most basic and uncomplicated technique of controlling the BLDC motor. Sensor less commutation has the advantage of simplifying hardware design by eliminating the need for sensors and accompanying interface circuits. The downside is that it necessitates a very sophisticated control algorithm, and it does not support low motor speeds when the quantity of back-EMF produced is small [3].

PMBLDC motors are typically powered by three voltage source inverters (VSI) or current source inverters (CSI), which are controlled by rotor position data from hall sensors, resolvers, or outright position sensors.However, these position sensors have a number of disadvantages, including increased cost, control complexity, and temperature sensitivity that necessitates particular setups. These sensors degrade system dependability and acceptance. As a result, sensor-free solutions have gained popularity in recent years. For PMBLDC motors, a number of sensor-free approaches have been developed [12].

Sensor less DC motor control has recently been achieved by sensing the zero-crossing point in the line voltage and computer technology the virtual hall signal. The flip-flop was used to generate the virtual hall aspects associated with the zero crossings that represent the rotor position and start the commutation. This sensor less control of BLDC motor layout is extremely important in its design and functions. It used the technique of measuring the motor's line voltage to produce virtual hall signals for motor commutation. The Power Factor Correction (PFC) converter has been fed the input AC supply, and its result is fed up to the inverter and delivered to the BLDC motor. The virtual hall signal has been generated using the line voltage differential in this case. This critical method for producing the required span commutation pulses was formed by using a JK flip-flop to detect the zero-crossing point. The peak input current contains a high amount of Total Harmonic Distortion (THD) and a low input power factor. The IEC61000-3-2 standard does not allow for such a high level of THD content. To improve power quality at the input mains, a DCDC boost PFC converter is used. The goal is to keep THD below 5percent while growing the factor of input power to nearly unity [11].

8. AI BASED SPEED CONTROL OF BLDC MOTOR

Due to simplicity and ease of design, PI or PID controllers are commonly utilized for operation of variable speed. However, it has certain drawbacks because its performance is dependent on proportional and integral improvements. As operating circumstances such as load, motor characteristics, and disturbances vary, re-tuning of gain settings is required. To address the shortcomings of PI controllers, several AI -based speed control strategies has been tested on BLDC motors employing Neural Network and Fuzzy controllers. Fuzzy Logic Control includes just approximated information of the overall network, knowledge discovery and inference are basic, and implementation is simple. Non-linear mappings between inputs and outcomes are possible in Neural Network-based control. Customized training is also available for a variety of operational settings. Whereas a Fuzzy controller is an effectual nonlinear controller, its structure cannot adapt to changing conditions. Neural Network designs, on the other hand, adjust their weights in response to such events. Controllers based on neural networks enhance speed responsiveness and decrease torque ripples. Traditional controllers are less sensitive to parameter changes than neural network models [3].

One of the issues that arises in enhancing the performance of the BLDC motor speed is the need for numerous particular BLDC motor characteristics, such as resistance value, mechanical torque, and electric torque, all of which work to create the transfer function. As a result, it was carried out in multiple phases to increase performance. The first step is identifying parameters system to get a mathematical model in the form of a transfer function, the second stage is optimizing utilizing AI such as fuzzy logic control and PSO Algorithm [14].

Fuzzy logic might be utilized to provide braking in an electric vehicle driven by a BLDC motor. The system created is totally nonlinear fuzzy logic with PID. The designed FLC rotates continuously along the d-q frame of reference since it is commonly used in BLDC motors and multilayered H - Bridge inverters. Two distinct controllers with fuzzy logic are designed and built for two distinct axes. The rotor position is critical for trying to regulate the BLDC motor; the rotor position determines BLDC commutation. Bldc employs Hall sensors to detect the location of the rotor. In this case, the motor acts as a generator, so they employ the same driving circuit and an optimal switching arrangement to redirect the current from the source to the battery. The PWM method is used in conjunction with individual switching to achieve exceptional brake control. When the EV is moving slowly, the emf produced cannot reach the battery.As a result, all MOSFETs in the upper arms of a particular H bridge inverter are turned off, and the lower arms are regulated with PWM. Fuzzy and PID algorithms are used in the totally controlled hybrid brake system. FLC is made up of five distinct blocks that work together to acquire a suitable membership function: fuzzi and defuzzication, data and rule base, and interference engine. This method allows for uniform braking force distribution as well as regenerative braking [3].

9. REGENERATIVE BRAKING OF BLDC MOTOR

With the onset of the energy crisis, decreasing air pollution has become a major concern. Automobiles powered by fossil fuels are now the primary mode of mobility. Automakers have made significant efforts to develop green energy-efficient, and vehicles with zero-pollution transportation. As a result, EV's have recently evolved at a rapid pace. Meanwhile, some of the major barriers to EV commercialization, such as driving range, remain. The biggest issues with EVs are the long charging times for battery packs and the low driving range. Battery utilization and improved motor control have become critical issues for EVs [13].

Due to the growing price of gasoline, their low emissions, quiet operation, and increased efficiency, battery-operated electric vehicles (BEVs) are becoming more and more popular. Because they need less effort and time to operate, lightweight EVs like rickshaws are becoming more popular in Bangladesh. Additionally, since there is no dependence on fuel, fares are fairly inexpensive, which is quite convenient for the passenger. The BLDC Motor is becoming into a desirable option for EVs because to its wider speed ranges, improved efficiency, superior speed versus torque characteristics, and noiseless operation. However, a notable disadvantage of BLDC motor-based Electric vehicles is the high electricity consumption required to charge the battery that powers the motor. Most of the time in Bangladesh, EVs are operating in congested areas where drivers must constantly start and stop. By employing a traditional mechanical braking system, a lot of kinetic energy is wasted as heat, which shortens the battery backup duration. Regenerative braking will be an efficient approach to increase the driving range of EVs in the congested conditions of a large metropolis. The regenerative brake is an energy recovery technology that converts kinetic energy into electrical energy to brake an electric vehicle and recharge the battery. Regenerative braking can occasionally be achieved by absorbing the immediate braking energy with an ultra-capacitor pack. This approach needs extra switches and sensors to detect the ultra-capacitor charging state. For the purpose of preventing overcharge prior to the braking, additional discharge circuits are also necessary. Due to the high cost of the ultra-capacitor pack and the high cost of the controller for this method, the entire system becomes complex. A bidirectional DC-DC power converter may occasionally be utilized to increase control during regenerative braking. The back electromotive force, which is substantially lower than the applied voltage of the battery, must be increased to charge the battery pack. All of those traditional methods add to the system's cost and size while resulting in additional power losses. Therefore, those technologies are not appropriate for inexpensive, light electric cars [5].

Brushless, electrically loaded DC motors have begun to be developed as a consequence of technological improvement to overcome these concerns. Brushless direct current motors require electronic circuit components to operate. This document describes the electrical circuit design required for the usage of BLDC motors, as well as the results of test on an electric automobile. A controller with fuzzy logic is used to regulate the speed of the motor. The computer displays the fuzzy logic controller's real-time results.

The entry of simulation parameters includes a user-friendly interface. The widely used modular design makes it easier to maintain and advance the software. Results from simulation and verification have been included. In the construction of a neural network, the defining rules and functions of fuzzy systems are represented in processing nodes. The controller has shown to be reliable, flexible, and teachable. The findings of the incentive research, when compared to the proportional-integral controllers, showed that the fuzzy-neural network controller was more successful. Regenerative braking can extend an electric vehicle's range and improve energy consumption efficiency (EA). It is advised to use the cutting-edge regenerative braking technology from EA with a BLDC engine.

The findings demonstrate that, if the quality of the braking circumstances is confirmed, neuron fuzzy logic and PID control can determine that braking can extend the EA's driving duration. Finally, MATLAB R2014a software has been used to show the suggested technique. For more effective system operation and secure charging status, Fuzzy and PID controllers are combined in regenerative mode. As input parameters for fuzzy controls, three elements are taken into account. These elements are the battery charge level, the braking force, and the immediate speed of the vehicle. The control output decided the degree of regenerative braking. Comparative evaluations of the outcomes were made for both the engine and the regenerative modes of operation. In order to increase power density and minimize torque variation on BLDC engine / generator systems for EV and HEV, advanced control techniques have been developed [6].

10. RESULTS AND DISCUSSION:

BLDC motors are becoming more popular among industrial and home appliances manufacturers due to their high efficiency, longevity, limited inertia & friction, quicker acceleration, large power density, quiet operation, low interference from radio frequencies and noise, low maintenance requirements, compact size, and reliability. Due to rapid advancements in power devices, semi-conductor technology, and manufacturing techniques for high performing magnetic materials, BLDC motors have been used in power application including such air conditioners, freezers, kitchen equipment, and electric cars.

BLDC motors are frequently driven by hall effect sensors, shaft encoders, accelerometers, and electro - magnetic variable reluctance sensors. Hall sensors are commonly used for sensor-less speed control, although back-EMF sensing techniques are used. The higher cost and size of using Hall sensors to run BLDC motors are drawbacks. The motor as well as the controller decide the cost of a magnet BLDC motor drive. Numerous studies have been carried out in order to lower the cost and improve the effectiveness of these motors. Therefore, the price of the controllers as well as the real power of the drives must be taken into account. Despite their expensive cost, they are preferred for a wide range of uses in reduced power and drives with variable speeds due to their ease of control.

This paper gives a good overview of the many control mechanisms available. These motors may be used in a variety of applications. The selection on the vehicle control technique (sensor less or even with detectors) and controller design must be made based on the needs for a given application, but keeping the system's precision, cost, intricacy, and trustworthiness in mind.

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