***CP303***

*CapstoneProject-2*

**A Major Project on**

# TORQUE CONTROL OF BLDC MOTOR

**Submittedtothe**


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*In fulfillments of requirement for the award of degree*

**Bachelor of Technology in Electrical Engineering**

by


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# Certificate

This is a certification that the report titled **TORQUE CONTROL OF BLDC MOTOR** submitted by them,to Department of Electrical Engineering in partial fulfillment of the B.Tech. degree in Electrical Engineering is an accurate record of the seminar work that was completed by them under my direction and supervision. No form of this study has ever been given to another university or institute for any reason.

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# ACKNOWLEDGMENT

We would like to use this occasion to offer our profound gratitude and appreciation to everyone who assisted me in successfully completing this assignment. We would like to extend our sincere gratitude to, Head of Department, Electrical Engineering ,Indian Institute of technology Ropar for providing us with all the facilities and assistance we required .We want to sincerely thank ,Department of Electrical Engineering, Indian Institute of technology, Ropar for their assistance and cooperation. Additionally, we would like to express our profound appreciation to our project guide Dr. K. Ramachandra Sekhar, Assistant Professor, Electrical Engineering, Indian Institute of technology for their advice and mentorship throughout the course.

# Declaration

We hereby declare that the major project report **TORQUE CONTROL OF BLDC MOTOR**, submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology of the Indian institute of technology Ropar is a genuine piece of work that we produced under the guidance of **Dr.K. Ramachandra Sekhar**.Where the thoughts or words of others have been used,we have properly and accurately cited and referenced the original sources. This submission expresses our opinions in our own words. We further affirm that we have followed the rules of academic honesty and integrity and have not falsified or distorted any information,opinion,or fact in our work.We are aware that any infringement of the aforementioned rules will result in disciplinary action being taken by the university or the institute, as well as legal action being taken against the sources who were not properly referenced from whose sufficient permission was not acquired. This report has never before been used as the foundation for the award of a degree, diploma, or other comparable title by another university.

Date
09-05-2024

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# 1. INTRODUCTION

Consider a BLDC motor to be a sort of electric motor that is utilized in a variety of applications, including fans, electric cars, and even household appliances like washing machines. BLDC motors are unique in that they do not require brushes to function, like regular motors do. Instead, they employ magnets and electronic circuitry to spin them. The structure of the stator and rotor is given below –

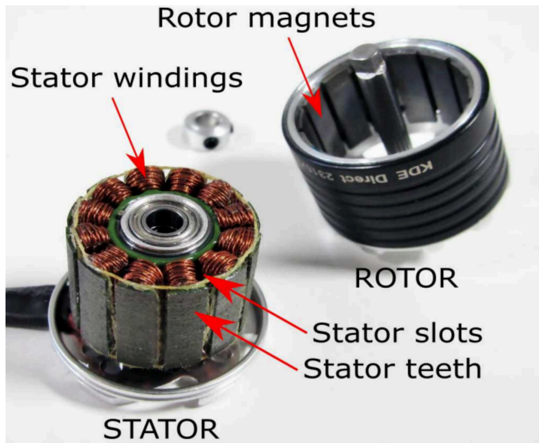


Figure 1: Basic Structure of BLDC Motor

Now let us talk about torque. Torque is the strength or power that causes something to rotate or turn. Torque is what allows a BLDC motor to perform activities such as spinning a fan or moving a vehicle. Torque control in BLDC motors is critical since it influences how much power is delivered and how smoothly it functions.

Consider it like driving a car: you want to manage how fast you drive and how smoothly you accelerate or brake. Similarly, torque control allows a BLDC motor to modify its speed and output as needed.

By adjusting the torque, we may make the motor run more efficiently, consume less energy, and even operate quietly.

This is especially useful in electric vehicles, where we want to maximize their range on a single charge.

Torque management of a BLDC motor is simply controlling its power output so that it accomplishes duties effectively and efficiently, similar to how we adjust the speed of a car to provide a pleasant ride. It is a vital component in making machines function intelligently and seamlessly in our daily lives.

# 1. THEORY

A BLDC motor is a type of electric motor that does not use brushes. Instead, electronic switches govern the flow of power to various areas of the motor, making it more efficient and reliable than typical brushed motors.

Torque control in a BLDC motor entails adjusting the rotational force to meet specified performance objectives. There are other ways to manage torque, but one typical one is to change the amount of current provided to the motor windings.

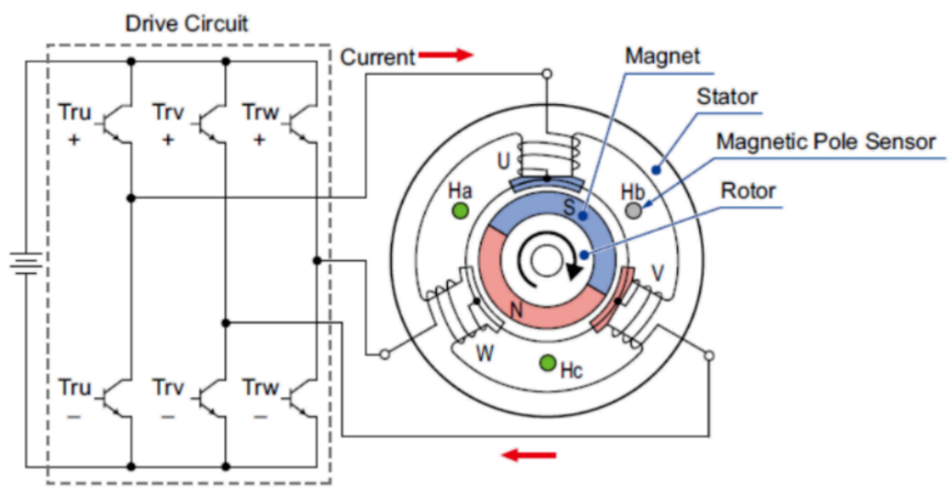



Figure 2: Structure of BLDC Motor

This is how it works. Windings are wire coils that exist within a BLDC motor. When electricity passes through these windings, it generates magnetic fields. Controlling the quantity and direction of current in these windings allows us to adjust the strength and direction of the magnetic fields they generate.

When you install permanent magnets near these windings, the interaction of the windings' magnetic fields with the permanent magnets causes the motor to spin. The strength of this interaction dictates how much torque the motor produces.

$$\varphi_{s\alpha} = \int \left( V_{s\alpha} - R_s i_{s\alpha} \right)$$
$$\varphi_{s\beta} = \int \left( V_{s\beta} - R_s i_{s\beta} \right)$$

$$T_{em} = \frac{3}{2}\frac{P}{2}\left( \frac{e_\alpha}{\omega_e} i_{s\alpha} + \frac{e_\beta}{\omega_e} i_{s\beta} \right)$$

We can control the motor's torque output by adjusting the timing and duration of the current pulses sent to its windings. This is frequently performed via a technique known as pulse-width modulation (PWM), which alters the width of electrical pulses to adjust the average amount of current flowing through windings.

## Why do we need torque control?

1.1 **Precision and Stability:** BLDC automobiles are typically employed in applications such as robotics, electric-powered vehicles, and commercial automation where precise control over torque output is essential. The stability and functionality of those structures depend on the motor's ability to precisely and consistently deliver the required amount of torque, which is ensured by torque manipulation.

1.2 **Speed Regulation:** In BLDC automobiles, torque management and pace law are tightly related. You can successfully change the motor's speed by adjusting the torque. This is crucial for applications like conveyor belts, pumps, and enthusiasts where maintaining a steady speed or reaching specific speed profiles is necessary.

1.3 **Efficiency Optimization:** A BLDC motor can operate sustainably under a range of load circumstances by managing its torque. You may maximize the motor's performance and optimize strength consumption by regulating the torque in accordance with the desired load. This is especially crucial for battery-operated programs since the device's runtime is directly impacted by the strength of the performance.

1.4 **Dynamic Performance:** BLDC cars are known for having exceptionally high dynamic performance, which enables them to react quickly to changes in load or speed commands. Specific dynamic response is made possible by torque management, which enables the motor to quickly adjust its torque production in response to shifting demands. This is crucial for packages that include CNC machines and servo systems that need to accelerate, decelerate, or adapt while in motion quickly.

1.5 **Regenerative Braking:** Torque manipulation allows for the efficient management of regenerative braking in positive applications, such as electric powered motors and regenerative braking systems. You can modify the amount of braking force applied by the motor by adjusting the torque.

# 2. LITERATURE REVIEW

Direct torque control is a better method to manage BLDC motors because of the precision it provides while torque and speed control . Research and development is going on making DTC even more better in regard to efficiency for BLDC motors.
Fuzzy logic control , neural network and model predictive control are popular methods nowadays.these methods ensure that the motor switches smoothly , reduces changes in torque and uses less energy . All the practice is to make the BLDC motor versatile in applications.
There are also other methods for controlling motors like field oriented control and predictive control . main key points to observe are how it behaves in sudden situations and how much energy it needs .
In the future, engineers are planning to put together various motor controlling technologies in order to bring about the ultimate output. Plus, the team intends to take ML on and use it to assist motors in adjusting and finding issues on time. Thus, DTC is evolving with people being dedicated to develop motors which. Ensure that they are more efficient and reliable.

# 3. WORKING PRINCIPLE

Torque control in a BLDC (Brushless DC) motor works by controlling the flow of energy to its coils, or windings, in order to manage the strength of its rotational force. We know that if we want to control torque then first we control the current while constant the flux. We have flux as a constant because our core in the motor is not saturated. If the core is saturated then core material does not work properly and suddenly increases the high current. If high current is produced then our windings burn out and the system does not work. That is why we have constant flux. Magnetic fields are generated inside the motor when electric current travels through these windings. The strength of these magnetic fields can be adjusted by adjusting the timing and intensity of this current. permanent magnets on the motor interact with the magnetic fields, forcing it to spin. We may fine-tune the torque output of the motor by accurately regulating the current to its windings. This level of control enables personalized performance in a variety of applications, ranging from altering the speed of an electric car to precisely positioning robotic arms in manufacturing. Torque management in a BLDC motor guarantees that it produces just the proper amount of rotating force for the task at hand. And we have controlled the current by limiting the current upper and lower values in simulation.

•We are controlling the direct torque using the below given diagram

•First we calculate the actual torque by using the alpha beta emf formula .

•After that give the input on adding junction is actual torque and reference torque and find the difference between them

•If the difference is greater than zero and less than zero accordingly follow the phase sequence in the hysteresis controller .

•Torque control in a BLDC (Brushless DC) motor works by controlling the flow of energy to its coils, or windings, in order to manage the strength of its rotational force.

•We control the current flow to control torque keeping the flux constant .

•Flux is kept constant in order to prevent the core from saturation.

•If the core is saturated then core material does not work properly and suddenly increases the high current.

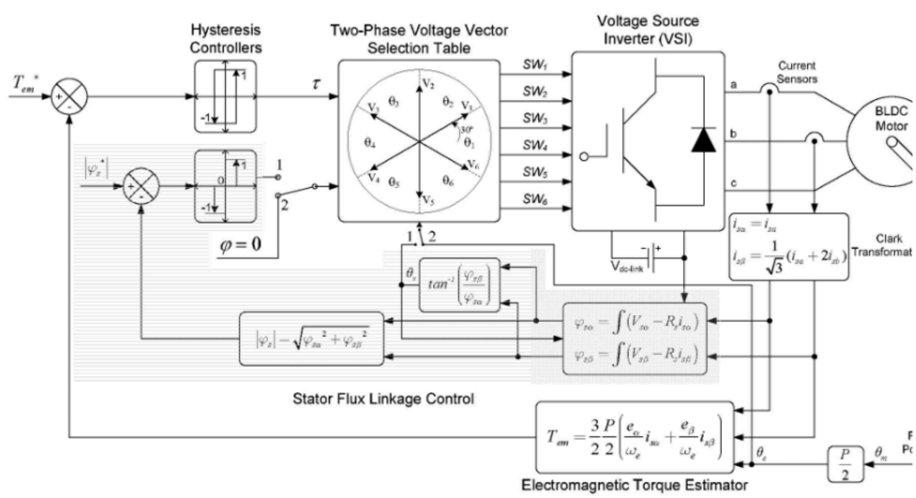
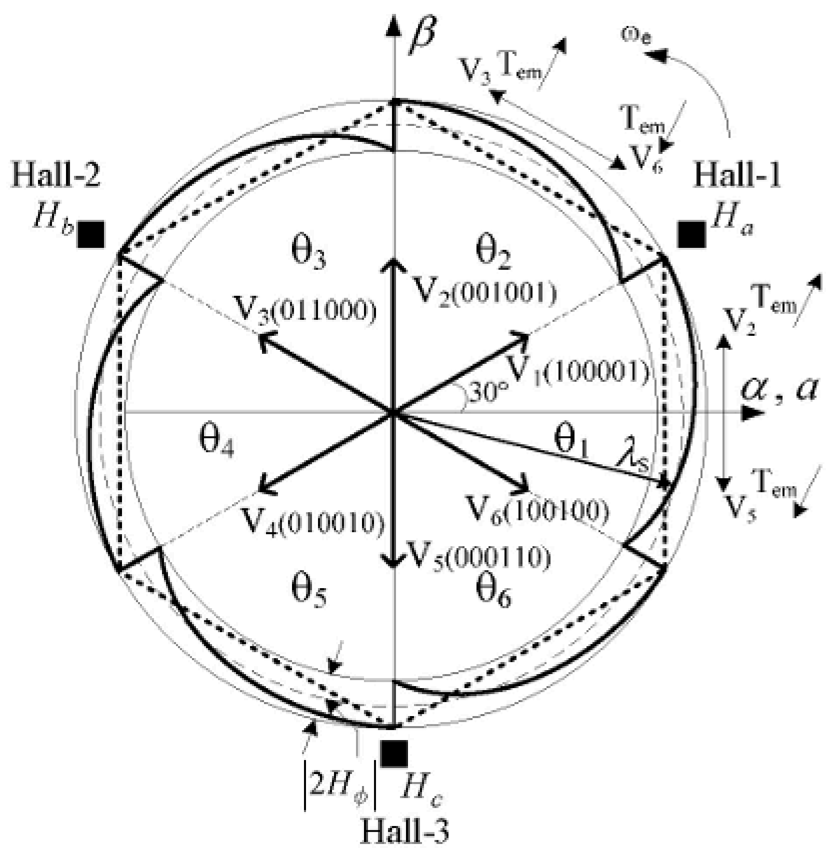



Figure3 - Overall block diagram of two-phase conduction DTC of BLDC motor drive in constant torque region

where 9sa and 9s are the a- and b-axis stator flux connections, respectively. A BLDC motor performs best when the phase current is injected at the flat top of the phase-to-neutral back-EMF. During each half-cycle, the back-EMF is typically flat for 120 electrical degrees and transitional for

60 electrical degrees. In the constant torque region (below base speed), when the phase-to-phase back-EMF voltage is less than the dc bus voltage, there is no necessity to adjust the amplitude of the stator flux link. Above base speed, however, the motor performance will dramatically decline because the back-EMF exceeds the dc bus voltage, and the stator inductance X will not allow the phase current to grow rapidly enough to catch up to theFlat top of trapezoidal back-EMF. Beyond the base speed, the appropriate torque cannot be achieved without additional techniques such as phase advancing and 180-degree conduction. This document does not address the operation of a BLDC motor's DTC over its base speed.
When the unexcited open-phase back-EMF effect and free-wheeling diodes are ignored, conventional two-phase conduction quasi-square wave current regulation allows the locus of the stator flux linkage to be accidentally preserved in hexagonal shape, as shown in with dotted lines. If the commutation-induced free-wheeling diode effect is neglected, a more circular flux trajectory is obtained, similar to a PMSM drive. The elimination of the free-wheeling diode influence on flux locus can be represented.



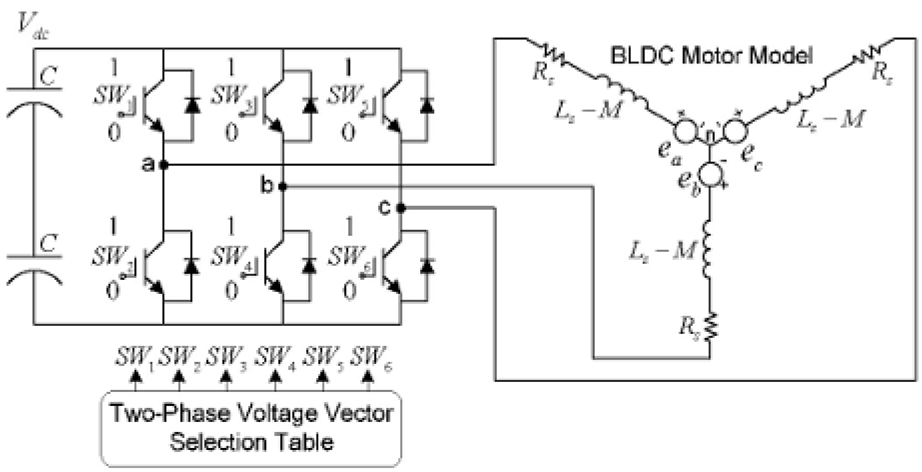
The stator flux linkage trajectory shows that when standard two-phase PWM current regulation is utilized, abrupt dips occur every 60 electrical degrees. This is caused by the action of the freewheeling diodes. The similar phenomena has been observed when using the DTC system for a BLDC motor, as illustrated with straight lines. There is no easy way to adjust the stator flux linkage amplitude because of the severe dips in the stator flux linkage space vector at each commutation and the currents' inclination to match the flat top section of the phase back-EMF for smooth torque generation. On the other hand, the rotating speed of the stator flux linkage is readily regulated, therefore .A quick torque response is obtained.

TWO-PHASE VOLTAGE VECTOR SELECTION FOR BLDC MOTOR

| $\varphi$ | $\tau$ | $\theta$ | | | | | |
|---|---|---|---|---|---|---|---|
| | | $\theta_1$ | $\theta_2$ | $\theta_3$ | $\theta_4$ | $\theta_5$ | $\theta_6$ |
| *1* | *1* | *$V_1$(100001)* | *$V_2$(001001)* | *$V_3$(011000)* | *$V_4$(010010)* | *$V_5$(000110)* | *$V_6$(100100)* |
| | *-1* | *$V_6$(100100)* | *$V_1$(100001)* | *$V_2$(001001)* | *$V_3$(011000)* | *$V_4$(010010)* | *$V_5$(000110)* |
| **0** | **1** | **$V_2$(001001)** | **$V_3$(011000)** | **$V_4$(010010)** | **$V_5$(000110)** | **$V_6$(100100)** | **$V_1$(100001)** |
| | **-1** | **$V_5$(000110)** | **$V_6$(100100)** | **$V_1$(100001)** | **$V_2$(001001)** | **$V_3$(011000)** | **$V_4$(010010)** |
| *-1* | *1* | *$V_3$(011000)* | *$V_4$(010010)* | *$V_5$(000110)* | *$V_6$(100100)* | *$V_1$(100001)* | *$V_2$(001001)* |
| | *-1* | *$V_4$(010010)* | *$V_5$(000110)* | *$V_6$(100100)* | *$V_1$(100001)* | *$V_2$(001001)* | *$V_3$(011000)* |

Note: The italic grey area is not used in the proposed DTC of a BLDC motor drive.

The size of the sharp dips is highly unpredictable and depends on a number of factors, which will be discussed further in this section, with simulations supplied in Section III. The easiest approach to manage the stator flux linkage amplitude is to know its exact shape, but this is deemed too onerous in the constant torque range. As a result, in the DTC of a BLDC motor drive with a two-phase conduction scheme, the flux error in the voltage vector selection look-up table is always set to zero, and only the torque error t is employed, depending on the error level between the actual torque and the reference torque. If the reference torque is greater thanAs indicated in Table I, the torque error t is specified as "1," if the actual torque is within the hysteresis bandwidth, and "-1" otherwise.




# 4. TORQUE CONTROL METHODS OF BLDC MOTOR

There are many methods for torque control of a BLDC motor with advantages and applications:

4.1 **Voltage Control Method: Open-Loop Voltage Control**: This technique involves instantly adjusting the voltage applied to the motor phases, mostly in accordance with the desired torque. It's quite simple, yet it's not precise or effective. Closed-Loop Voltage Control: To ensure greater manipulation accuracy, the voltage applied to the motor stages is adjusted based on feedback from the motor's contemporary or pace sensors.

4.2 **Current Control Method**: Open-Loop Current Control: This method completely regulates the current passing through the motor stages in accordance with the targeted torque. Without comments, though, this method might not work as intended to produce the required torque. Closed-Loop Current Control: The torque output is directly impacted by the current that is adjusted inside the motor stages based on feedback from current sensors. This approach gives better accuracy.

4.3 **Field-Oriented Control (FOC):** Also known as Vector Control, FOC is a complex control strategy that separates the manipulation of torque and flux in a BLDC motor. It involves converting the motor currents from the three segments directly into a -axis reference body (d-q reference body) that is in line with the rotor flux. High performance and accurate torque control are made possible by FOC under a variety of operating circumstances by independently managing the torque and flux components.

4.4 **Direct Torque Control (DTC):** DTC is a method of controlling a motor's torque and flux without the need for a separate function or velocity sensor. By selecting the best voltage vectors to apply to the motor stages mostly depending on the desired torque, DTC achieves rapid torque reaction. It is suitable for programs requiring fast torque changes.

4.5 **Sensorless Control:** Without the need of physical sensors, sensorless torque control techniques estimate the motor's function, speed, and torque using estimation algorithms. The motor kingdom is estimated using methods including observer-based torque control, adaptive algorithms, and again-EMF estimation. This enables torque manipulation without the need for more sensors.

4.6 **Model Predictive Control (MPC):** Based entirely on a dynamic model of the motor and system limitations, MPC is an advanced manipulative technique that forecasts future motor behavior. MPC can obtain unique torque management while satisfying a variety of limitations, including current limits and voltage constraints, by optimizing control actions across a constrained prediction horizon. These methods vary in complexity, accuracy, and suitability for one-of-a-kind applications. We are using DTC because it can control torque without using sensors and also better control.

## DTC method:

A brushless DC (BLDC) motor's Direct Torque Control (DTC) system instantly controls the motor's torque and flux without the need for an additional function or velocity sensor. Compared to standard managed strategies, DTC delivers faster torque response, robustness to parameter fluctuations, and a simpler managed shape.

a. **Motor Model and Flux Estimation:** DTC depends on a precise electromagnetic behavior model for the motor. This version includes parameters like resistance, motor inductances, and EMF constants once more. With DTC, information from the measured motor voltages and currents is used to predict the stator flux. With the help of this flux calculation, DTC can instantly control both flux and torque.

b. **Torque and Flux Control:** DTC separates the manipulating process into discrete time intervals that are commonly referred to as "manage" or "sampling" periods. The preferred torque and flux references are specified for each period. DTC chooses the proper voltage vector to apply to the motor stages based on the selected torque and flux references. The comparison of the intended and actual torque and flux values serves as the basis for choosing the voltage vector.

c. **Voltage Vector Selection**: DTC utilizes a lookup table, often referred to as the "torque hysteresis band," to identify the optimal voltage vector for each manipulation interval.Based on the discrepancy between the intended and actual torque and flux values, the voltage vector is selected.

d. **Switching control:**Switching control involves applying the selected voltage vector to the motor stages by using DTC to ascertain the switching states of the inverter's electricity switches (transistors) after the best voltage vector has been decided. The goal of the switching control is to minimize switching losses while preserving motor performance and achieving the desired voltage vector.

e. **Feedback and Iteration**: The manipulate system continuously adjusts the manipulate moves to ensure proper torque and flux law by using feedback from motor sensors, including contemporary sensors. In order to hold specific control over torque and flux and dynamically regulate the voltage vector, DTC iterates over these stages in each manipulation length.

Ultimately, DTC torque management provides BLDC vehicle management in a robust and environmentally friendly manner, offering quick torque response and excellent dynamic performance without requiring complex mathematical adjustments or velocity sensors. Nonetheless, it's crucial to carefully tune the control settings and hysteresis bands in order to achieve the best possible performance in unique operating scenarios.

# 5. SIMULATIONS AND RESULTS

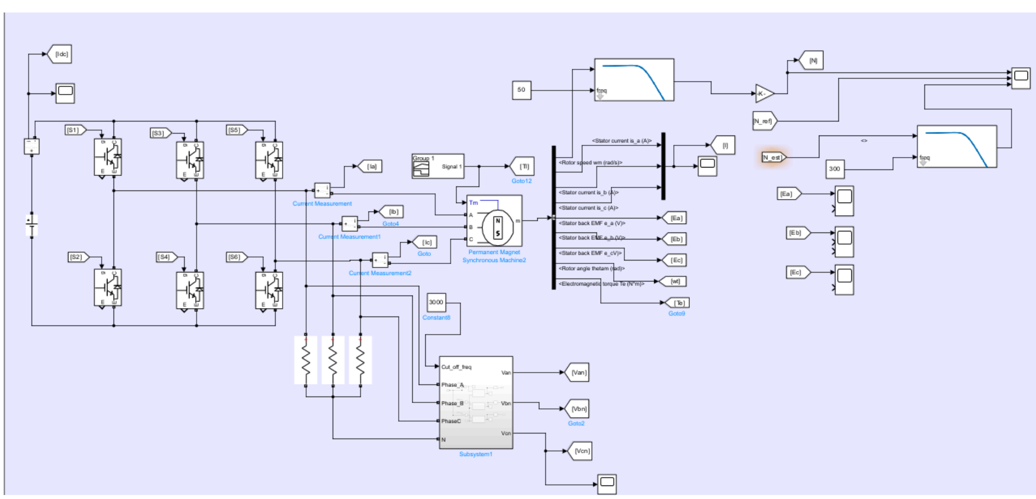


Fig 1:Motor with switching

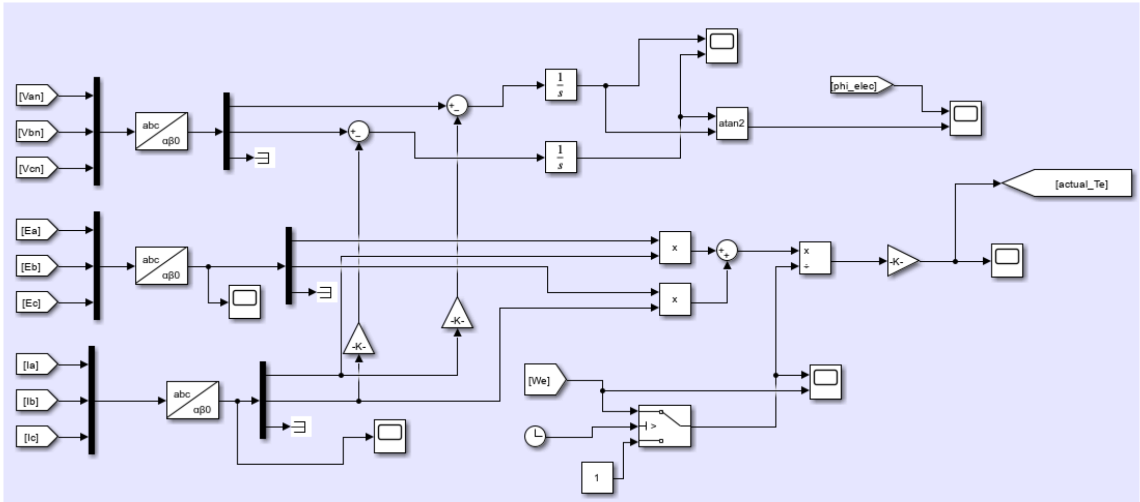



Fig2 :Actual torque and angle(theta e)

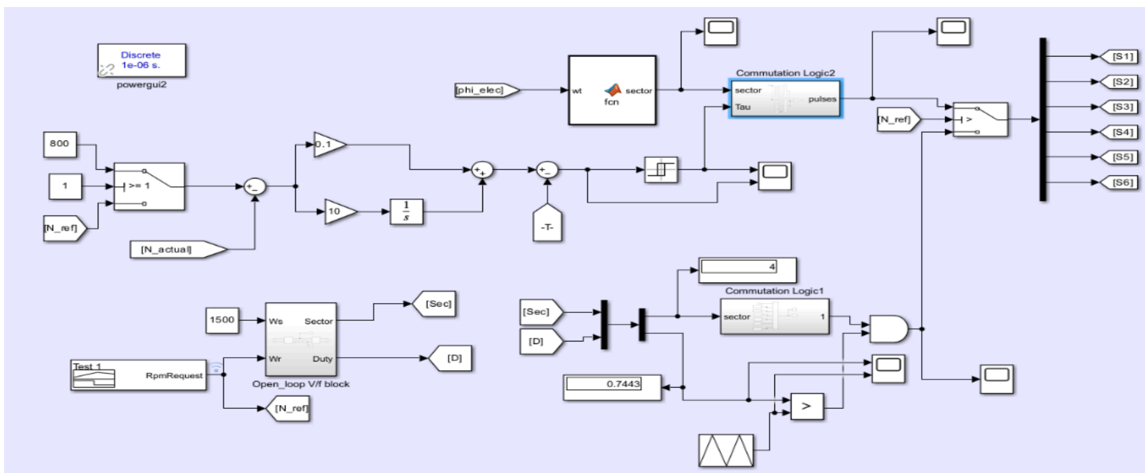



Fig 3 : Torque controller

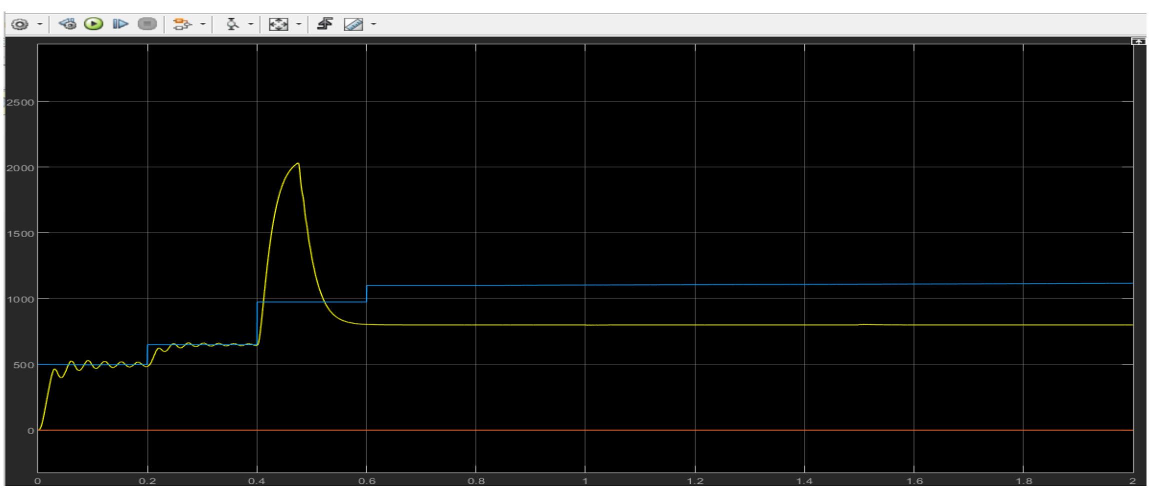


Figure 4: speed of motor

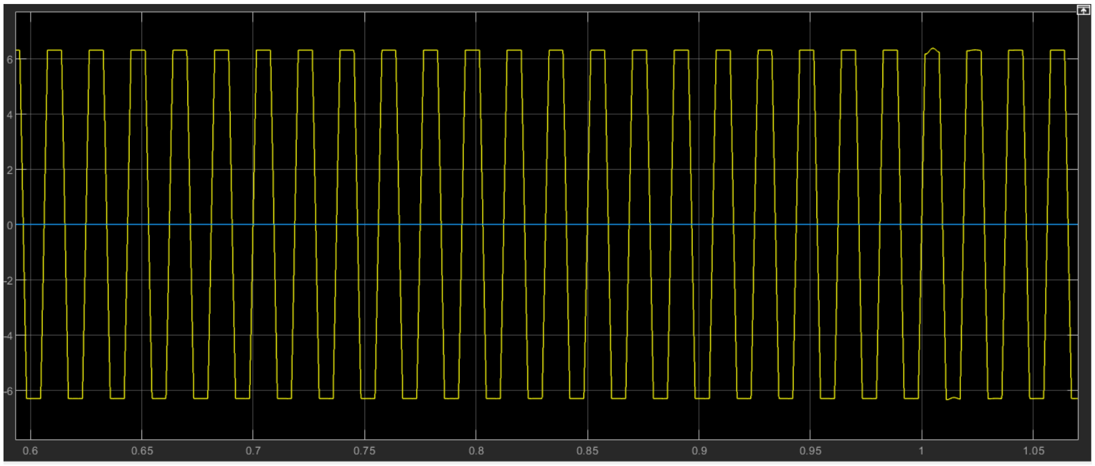



Figure 5: Waveforms of back emf

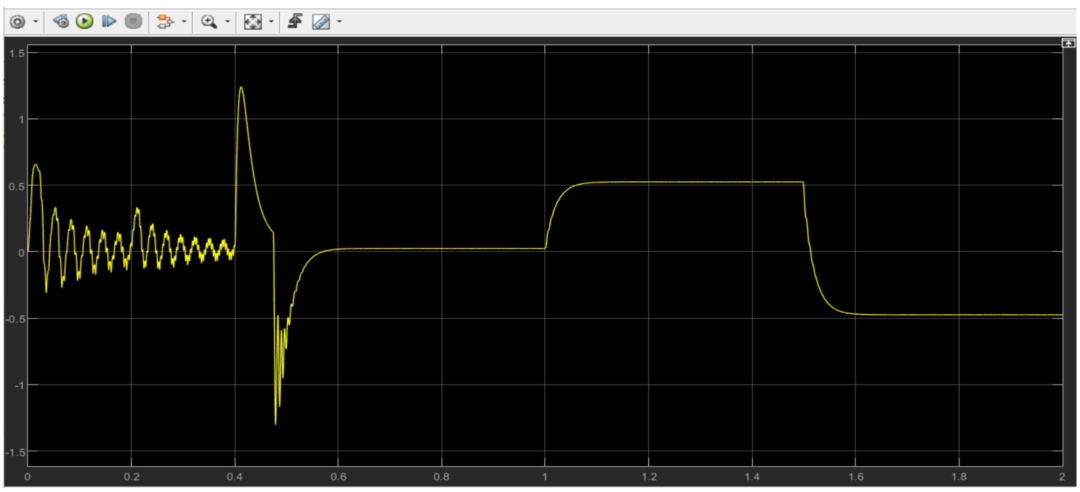



Figure 6: waveform of Torque Te

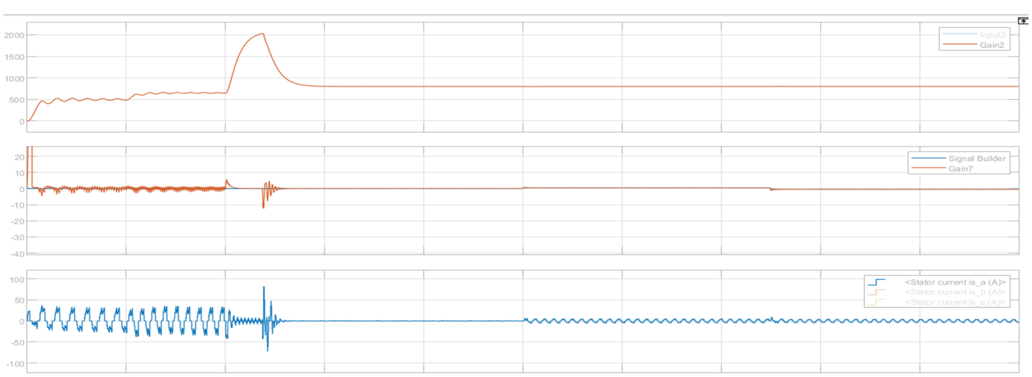


Figure 7: waveform of Idc and Te and speed

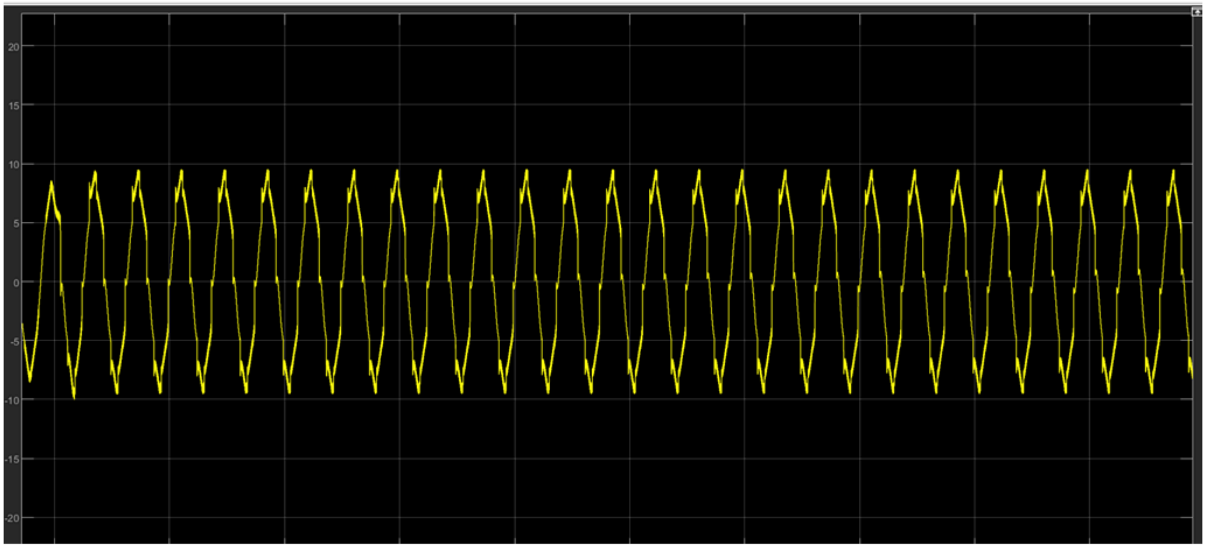



Figure 8: waveform of Vcn

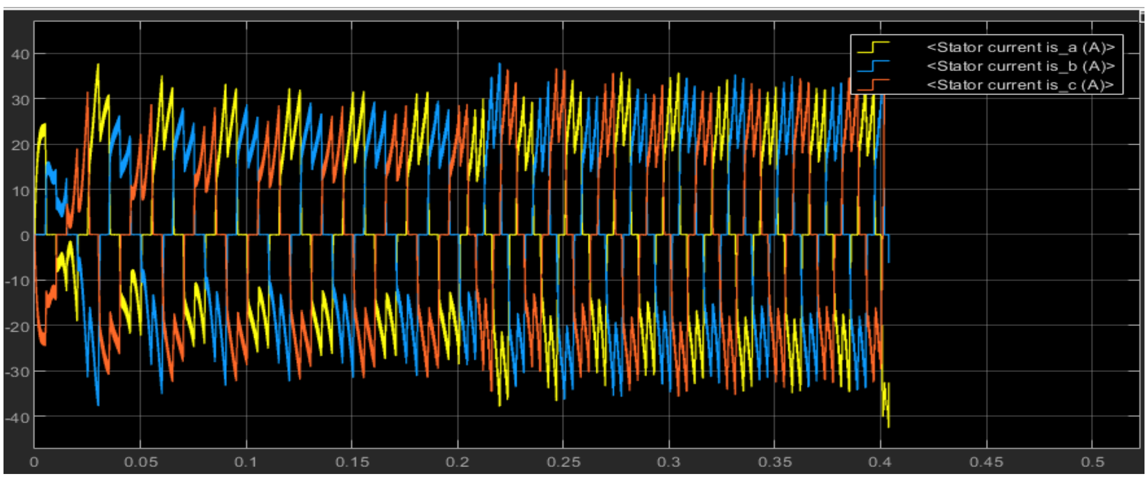



Figure 9: Waveforms of stator current

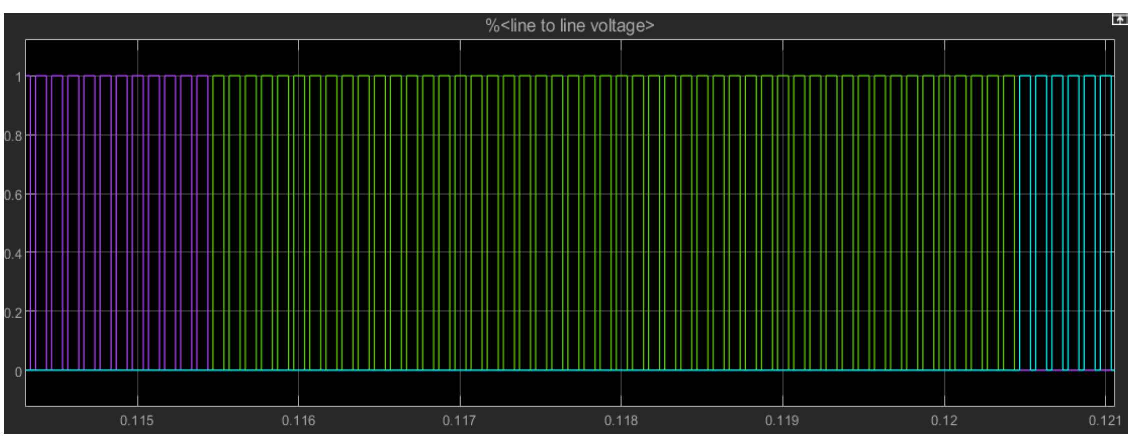



Figure 10: Waveforms Line to line voltage

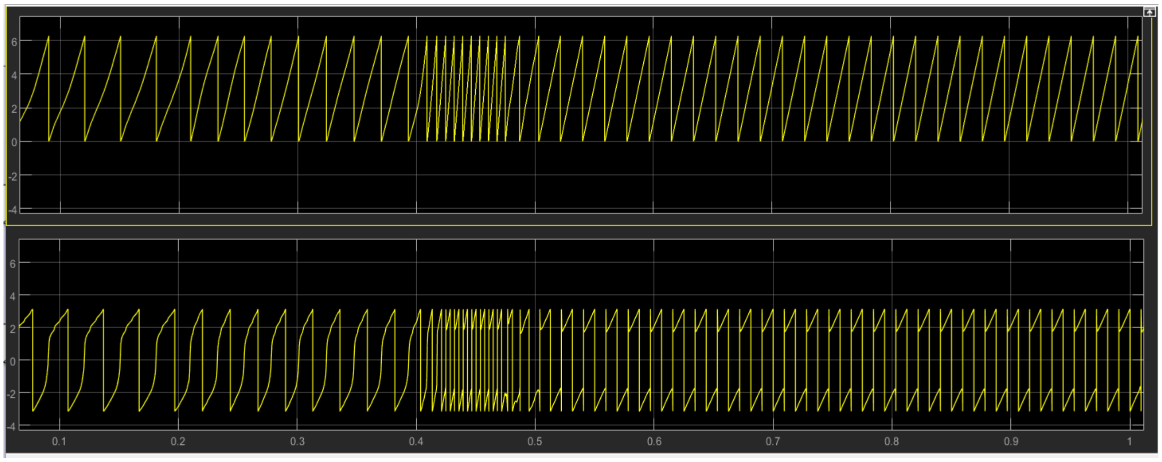


Figure 11: Waveforms of flux

**error= reference - Actual**

- ❖ When error is greater than 0.05 output of the hysteresis controller will give output 1 and +1 sequence phase start conduction and when it is less than 0.05 it will give -1 and so -1 sequence phase start conduction.
- ❖ Torque graph will oscillate between reference points that were set by us +1, -1.

# 6. APPLICATIONS

DTC or Direct Torque Control has become an indispensable tool in the suite of AC motor drive control techniques for high-efficiency torque and speed control. This controlling principle is frequently linked to the Induction Motors, but also can be applied to the Brushless DC (BLDC) motors, in particular in the applications where the management of torque and speed is required to be more accurate. Here are some key applications of DTC in BLDC motors: Here are some key applications of DTC in BLDC motors:

6.1 **Electric Vehicles (EVs):** The reason for a BLDC motor to be favorable for electric vehicles is attributed to their efficiency, compact size and high torque-to-weight ratio. DTC can be used in EVs so that the torque and speed of BLDC motors are controlled not only less abruptly but also efficiently through smooth acceleration, regenerative braking and in the end overall improved vehicle performance.

6.2 **Industrial Automation:** BLDC motors possess a wide range of use in industrial automation applications, namely robotics, CNC machines as well as a kind of conveyor system. The DTC is able to obtain a tight control of the motor which allows for more precise tuning of the torque and speed levels available. Hence the automated systems will work more accurately, faster and more energy efficient.

6.3 **HVAC Systems:** BLDC motors, applied in HVAC systems for filtering fans and pumps, are a common technology application. DTC has inbuilt functionalities to direct the system regardless of motor rotation and torque so that the energy can be better controlled. Because of that DTC provides quieter operation and longer motor life.

6.4 **Home Appliances:** BLDC motors are being used frequently in the different home appliances like refrigerators, washing machines, and fans that can reduce their energy usage by 8-10%. DTC can be exploited not only for the optimization of fuel consumption but also for a driver's comfort and facilitating vehicular control.

6.5 **Renewable Energy Systems**: BLDC motors are also used in renewable energy systems such as ITO turbines and solar tracking systems. DTC acts as the central gatekeeper of torque and speed of the motor with the purpose of optimizing energy harvesting efficiency, improving system reliability as well as minimizing maintenance costs

# 7. FUTURE SCOPE

The future of Direct Torque Control (DTC) technology for Brushless DC (BLDC) motors can be -

- **Better Efficiency and Performance**: Science and tech community are working at boosting the efficacy of the DTC in BLDC machines. By doing so, the power losses are reduced drastically and the motor runs in its ultimate state at any speeds and loads.

- **Smarter Control Methods**: we are looking at the use of the intelligent algorithms such as AI and ML to enhance motor skills control. These algorithms can be retuning the work of the motor, depending on the realtime, in order to use less energy and make the motor and may be more reliable.

- **No Need for Some Sensors**: if we can design motors without need of physical sensors then it can be cost effective.

- **Using Renewable Energy**:  BLDC motors with DTC should be connected with the wind or solar energy which is considered one of the most environmentally friendly renewable energy types.

# 8. CONCLUSION

In conclusion we had the analysis and the control aspects of BLDC motors in a DTC methodology with it as the main touchpoint. To start with, we did deep research on types of BLDC motors, their makeup and operation.

This fundamental knowledge was the essential tool to create a model for simulation in order to comprehend the pull characteristics and the influence of pull on the performance of the motor. During the research, we looked through different torque combing techniques that include voltage control, field-oriented control (FOC) as well as the current-controlled systems. Each of these control methods carries out unique benefits and shortcomings that categorize such techniques as dynamic, efficient and flexible.

Direct Torque Control, therefore, was successfully investigated and implemented as a reliable approach to BLDC motor control. The main advantages comprise the controllable torque and flux, the reduced frequency of operation, and the simplified control algorithms that could be implemented in contrast with the other methods like Vector or SVPWM.

What empowered us to come up with many possible options and uses is the types of industries we help through DTC which include but not are limited to automotive, robotics, renewables to name a few. Apart from being equally significant for the scientific approach to BLDC motors control, our results can be applied in real life for the engineers in a search for efficient and reliable solutions in the area of motor control.

With the development of technology, DTC finds itself among the key objectives as well as the subject matters of research and development, offering constant updates in motor control applications

# 9. INDIVIDUALCONTRIBUTIONS

1)Ankit sulaniya: Simulation and results, Applications

2)Ashish meena: Working principle and DTC method, Literature review

3)Prashant: Introduction, Theory, Conclusion, Future scope

# 10. REFERENCES

1)S. B. Ozturk and H. A. Toliyat, "Direct Torque Control of Brushless DC Motor with Non-sinusoidal Back-EMF," 2007 IEEE International Electric Machines & Drives Conference, Antalya, Turkey, 2007, pp. 165-171, doi: 10.1109/IEMDC.2007.383571. keywords: {Torque control;Brushless DC motors;Pulse width modulation;Stators;Couplings;Pulse width modulation inverters;Current control;Tablelookup;Shape Control;Voltage Control;Direct torque control;brushless dc motor drives;non-sinusoidal back-EMF;two-phase conduction;fast torque response;low-frequency torque ripples},