

RESEARCH ON DIRECT TORQUE CONTROL FOR INDUCTION MOTOR BASED ON MINIMUM VOLTAGE VECTOR ERROR

Abhay Halmare, Neha Prajapati, Gayatri Meshram, Divya Dharpawar,

Kalyani Watmode, Saurabh Sharma

B. Tech, Electrical, K. D. K. College Of Engineering, Negpur

Abstract - Traditional Direct Torque Control (DTC) has gained popularity due to its simplicity, robustness, and rapid torque response. However, it is not without its drawbacks, including high Total Harmonic Distortion (THD), significant torque fluctuations, and varying switching frequencies. These limitations have paved the way for further research in the field of traditional DTC drive systems. In order to enhance performance, this dissertation introduces a novel approach based on minimising voltage vector errors. The primary objective is to reduce the disparity between the voltage vector applied to the machine terminal and the reference voltage vector. This is achieved by optimising the duty ratio through the proposed method. Importantly, this optimization process does not introduce additional complexity to the existing method. The proposed methodology is rigorously simulated using the MATLAB environment to validate its effectiveness and potential improvements in traditional DTC drive systems.

decoupled control of induction motors without the need for complex coordinate transformations, PWM pulse

modulation, or current regulation. Nonetheless, ripples in performance arise due to the use of hysteresis band controllers for stator flux and torque, and these issues become more pronounced under heavy loads. To address these challenges and provide a superior solution characterised by low torque ripple, fast dynamic response, and reduced current THD, a novel approach based on minimum voltage vector error is proposed. This method incorporates a PI-type torque regulator while eliminating the need for a hysteresis comparator. The comprehensive performance of this approach is effectively demonstrated within the MATLAB environment.

Key Words: DTC, Matlab, Speed Regulation, Induction motor

1. INTRODUCTION

Induction machines are widely employed in various industrial applications, primarily due to their advantageous features, including low maintenance requirements, robustness, compact size, and ease of manufacturing. Typically, Direct Torque Control (DTC) is chosen for high-performance control applications. The pioneering work of Noguchi and Takashi in 1985 introduced the DTC method, which gained widespread acceptance due to its numerous merits. These include a low switching frequency, strong robustness, straightforward implementation, and the absence of rotational coordinate transformations. However, its utility is constrained by certain drawbacks, such as variable switching frequency, substantial torque fluctuations, and high current Total Harmonic Distortion (THD). In the DTC method, one out of the six active voltage vectors is selected, and two voltage vectors are generated by the voltage source inverter. This selection is carefully made to ensure that the stator flux and torque remain within their predefined limits for both hysteresis bands. The systematic application of this Two-Level Direct Torque Control (TDTC) method results in the

2. LITERATURE REVIEW

[1] John R G Schoeld et al. In this paper, the author introduces the Direct Torque Control system comprising three basic functions, namely A motor model which estimates the actual torque, stator flux and shaft speed by means of measurements of two motor phase currents, the intermediate circuit dc voltage and information on the state of the power switches. Calculations are performed every 25 micro-seconds and these include corrections for temperature and saturation effects. The parameters of the motor model are established by an identification run, which is made during commissioning.

[2] I Liidtke, Dr. M G Jayne et al. In this paper, the author introduces A direct torque control system for a variable speed induction motor drive consisting of two hysteresis comparators, a selection table, a flux and torque estimator, and a PID speed controller. With this control structure, the drive performance can be significantly improved when compared to field oriented control. In the paper, the principles and characteristics of a direct torque control system are considered.

[3] Yesma Bendaha, et al. In this paper, the author presents an improved direct torque control based on fuzzy logic technique, where the torque and flux hysteresis controllers are replaced by fuzzy controllers and we also used a fuzzy stator resistance estimation. The fuzzy proposed controller is shown to be able to reducing the torque and flux ripples and to improve performance DTC especially at low speed.

[4] Tang, Y. et al. In this paper, the author proposed an on-line self tuning scheme using fuzzy logic controllers (FLC) in this paper. The performance of the developed proposed controller is tested through a wide range of speeds as well as with load and parameters variations through simulation using MATLAB/SIMULINK.

[5] Narongrit Pimkumwong and Ming-Shyan Wang, et al. In this paper, the author introduces a simple to substitute the original PI controller for speed, torque and stator flux magnitude control. The simulation results have confirmed the validity of the proposed controller as well as shown good dynamic and steady-state responses of this control system.

[6] Areed, Fayez G., et al. In this paper the author introduced a direct torque of the induction motor drive controlled by a neuro-fuzzy system. The proposed control scheme uses the stator flux amplitude and the electromagnetic torque errors through an adaptive neuro-fuzzy inference system (ANFIS) to act on both the amplitude and the angle of the desired reference voltage.

[7] D. Casadei, et al. In this paper, the author introduced the basic concept of direct torque control of induction machines is investigated in order to emphasise the effects produced by a given voltage vector on stator flux and torque variations. Numerical simulations and experimental tests have been carried out to validate the proposed method.

[8] G. S. Buja and M. P. Kazmierkowski, In this paper, the author presents a review of recently used direct torque and flux control (DTC) techniques for voltage inverter-fed induction and permanent-magnet synchronous motors. A variety of techniques, different in concept, are described.

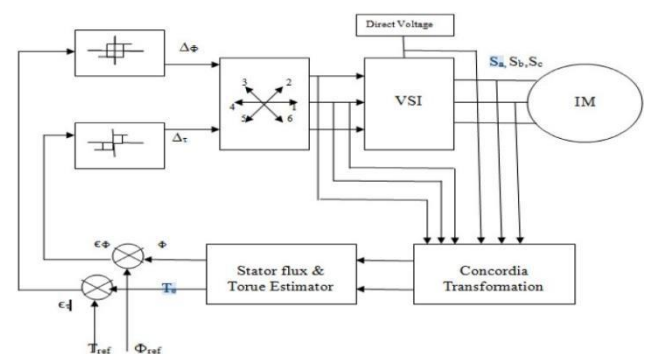
[9] Z. Wang, J. Chen, et al. In this paper, the author presents three control schemes with variable switching frequencies that are proposed and analysed for the paralleled voltage-source inverters (VSIs) fed permanent magnet synchronous motor (PMSM) drive. The proposed schemes could be applied in the low-speed operation region of high-power drive systems, where the frequency modulation index is high.

[10] R. Ortega, N. Barabanov, et al. In this paper, the author Practitioners in the electric drives community have recently introduced a novel torque control strategy for high power induction motor applications called direct torque control (DTC), which has three distinctive features: 1) it focuses on stator (instead of rotor) flux regulation; 2) in contrast to classical field-oriented control, it does not aim at an asymptotic system inversion (hence it does not require additional current loops); and 3) it explicitly takes into account the discrete nature of the control actions, which are simply points of a finite set obtained from a switching logic. Besides its simplicity, it is claimed that the achieved performance is (in some instances) superior to field oriented strategies because of the digital form of the control structure and the reduced dependence on parameter variations of the stator flux calculations.

3. METHODOLOGY

The proposed system is designed to revolutionise the field of motor control by implementing a cutting-edge Direct Torque Control (DTC) method that minimises voltage vector errors with unprecedented accuracy and efficiency. Built using Simulink, it will provide a robust platform for optimising the control of induction motors, particularly in scenarios where they function as loads. The proposed system will seamlessly integrate components to work in harmony; the Simulink-based model will provide a real-time interface for the advanced DTC control technique. This technique will intelligently calculate and apply voltage vectors with minimal error, resulting in precise and rapid adjustments of torque and speed in the induction motor. Through this synergy of components, the system will empower the motor to operate at peak efficiency, adapting swiftly to varying loads and enhancing overall performance.

FLOW CHART



4. SYSTEM REQUIREMENT

SOFTWARE REQUIREMENT

1. MATLAB Software

5. WORKING

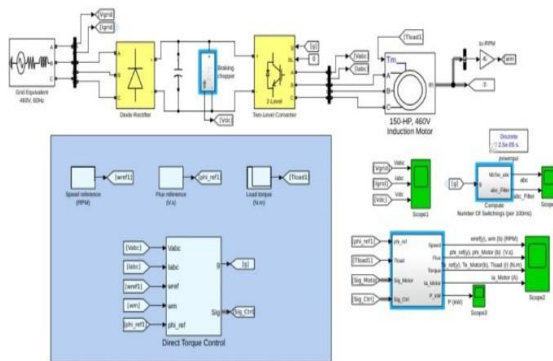
The system operates by utilizing a sophisticated Direct Torque Control (DTC) method implemented through Simulink, which minimizes voltage vector errors with exceptional precision. This system integrates a real-time interface with the DTC control technique, enabling intelligent computation and application of voltage vectors to induce rapid and accurate adjustments in torque and speed for induction motors. By continuously monitoring the motor's operating conditions and calculating required voltage vectors in real-time using the DTC algorithm, precise control of torque and speed is achieved. Minimization of voltage vector errors ensures

accurate and efficient motor operation, allowing swift adaptation to changing load conditions and optimizing overall performance.

6. SIMULATION & RESULT

Within this chapter, we delve into the comprehensive exploration of the simulation and outcomes stemming from the project titled "Direct Torque Control for Induction Motors Based on Minimum Voltage Vector Error." In the subsequent sections, we provide a detailed discussion of the methodologies employed, the simulation procedures conducted, and the noteworthy results obtained throughout the course of this project.

DIRECT TORQUE CONTROL FOR INDUCTION MOTORS BASED ON MINIMUM VOLTAGE VECTOR ERROR



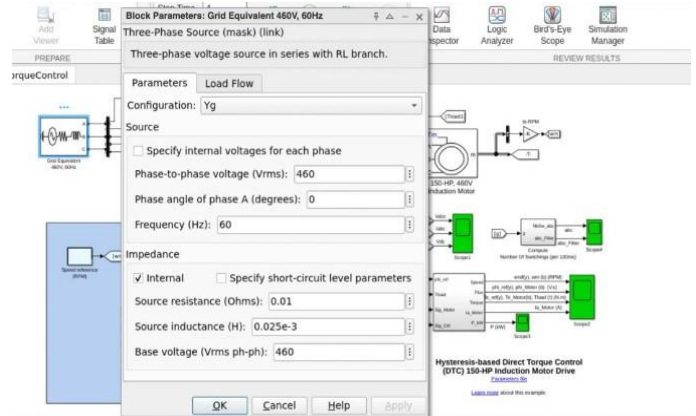
The electrical model described involves the supply of electrical energy from a three-phase AC/DC diode rectifier connected to a grid with specifications of 460 volts and a frequency of 60 hertz, simulating a typical power grid. The rectifier is responsible for converting the alternating current (AC) from the grid into direct current (DC). The DC bus, or direct current bus, is connected to a three-phase, two-level converter. This converter plays a crucial role in generating a variable voltage and frequency that are essential for achieving variable-speed operation of the 150 horsepower (HP) induction motor. The variable voltage and frequency output from the converter allow for fine control over the speed of the motor, enabling it to operate at different speeds based on the application's requirements.

Furthermore, a braking chopper is incorporated into the system, and it is connected to the DC bus. The braking chopper serves the purpose of dissipating the kinetic energy generated by the motor during deceleration or braking. When the motor is slowing down, excess energy is generated, and the braking chopper helps to absorb and dissipate this energy, preventing overvoltage conditions in the DC bus and ensuring a controlled deceleration process.

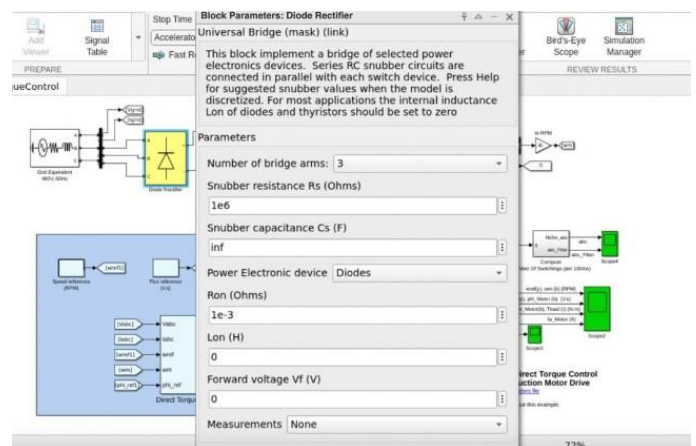
This electrical model integrates a rectifier for converting AC to DC, a converter for generating variable voltage and frequency to control the induction motor's speed, and a braking chopper for managing the dissipation of excess

energy during deceleration, contributing to the overall efficiency and control of the system.

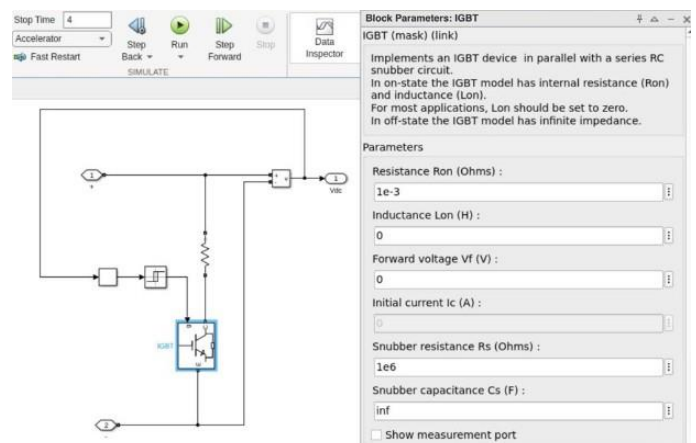
BLOCK PARAMETER: GRID EQUIVALENT 460V,60Hz



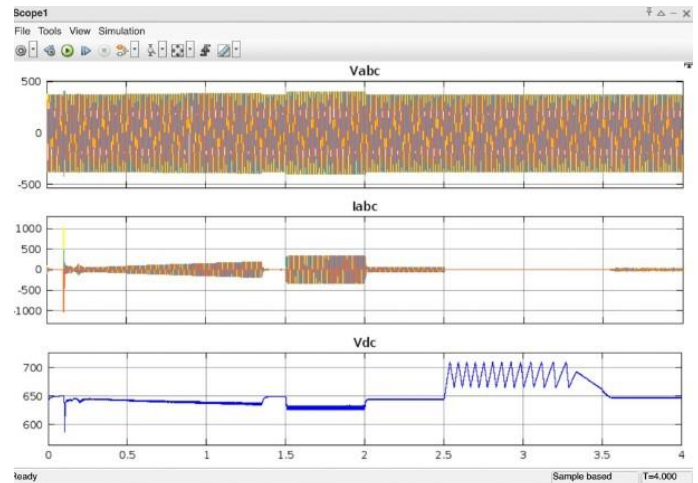
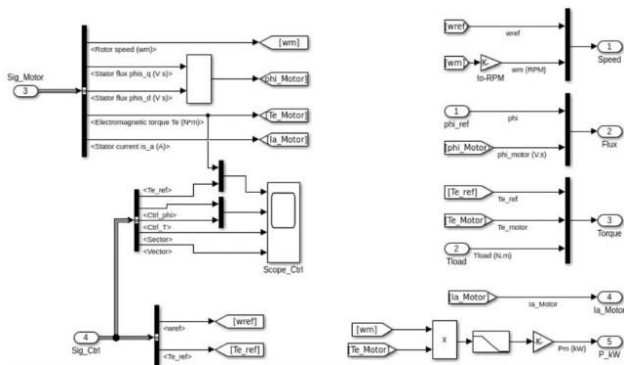
BLOCK PARAMETER: DIODE RECTIFIER



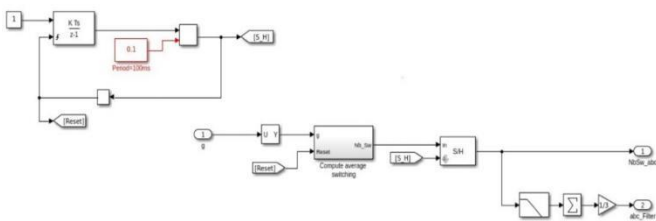
BLOCK PARAMETER :IGBT



SUBSYSTEM



COMPUTER NUMBER OF SWITCHING



I_{abc}: This signifies the current in the abc coordinate system, indicating the flow of electrical current through the motor windings

Monitoring I_{abc} provides insights into how the motor responds to the applied voltage and load conditions. By analysing I_{abc} , the project can assess factors such as motor loading, efficiency, and potential issues such as overcurrent or unbalanced loading.

Vdc: This refers to the direct current (DC) voltage, which is typically used in the control circuitry of the DTC system. Vdc is crucial for generating the voltage vectors that control the motor's torque and flux. Monitoring Vdc helps ensure stable operation of the control system and proper generation of voltage vectors to achieve the desired torque and flux levels.

7. RESULT

SCOPE 1

Direct Torque Control (DTC) for induction motors based on minimum voltage vector error, Scope 1 pertains to monitoring and analyzing various electrical parameters involved in the control scheme. Specifically, it involves observing and understanding the behavior of three-phase quantities such as V_{abc} (voltage in the abc coordinate system) and I_{abc} (current in the abc coordinate system), as well as V_{dc} (direct current voltage).

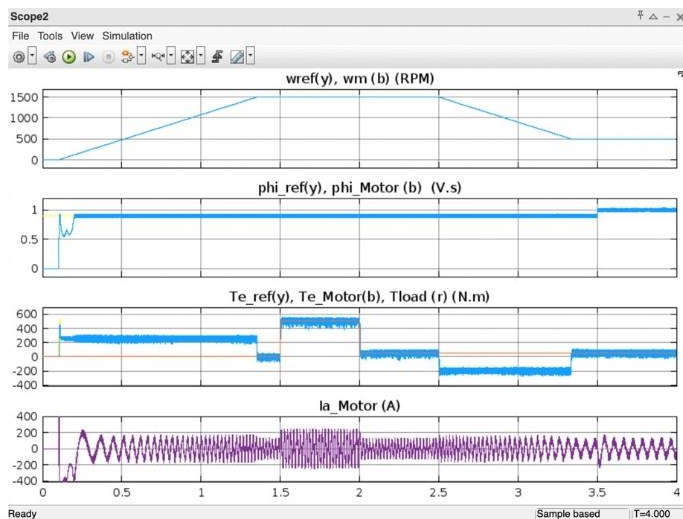
Vabc: This represents the voltage in the abc coordinate system, which typically refers to the three-phase voltages supplied to the induction motor. This represents the voltage in the abc coordinate system, which typically refers to the three-phase voltages supplied to the induction motor.

SCOPE 2

Graph of wref (y) and wm (b) (RPM):

Wref (y) represents the reference speed profile, indicating the desired rotational speed setpoint for the motor. This profile is typically set by the control system based on the requirements of the application.

ω_m (b) represents the actual motor speed, expressed in revolutions per minute (RPM). This graph depicts how closely the motor speed tracks the reference speed over time. Any deviations between ω_{ref} (y) and ω_m (b) indicate the performance of the speed control loop and the effectiveness of the DTC strategy in regulating the motor's rotational speed.



Graph of $\phi_{ref}(y)$ and $\phi_{motor}(b)$ (V.s):

$\Phi_{ref}(y)$ represents the reference flux linkage, which signifies the desired magnetic flux level within the motor. This parameter is crucial for controlling the motor's torque production and efficiency.

$\Phi_{motor}(b)$ represents the actual flux linkage observed within the motor. This graph shows how well the DTC system maintains the flux at the desired level set by $\Phi_{ref}(y)$. Discrepancies between $\phi_{ref}(y)$ and $\phi_{motor}(b)$ indicate the performance of the flux control loop and the ability of the DTC system to regulate magnetic flux within the motor.

Graph of T_{eref} , $T_{emotor}(b)$, $T_{load}(r)$ (N.m):

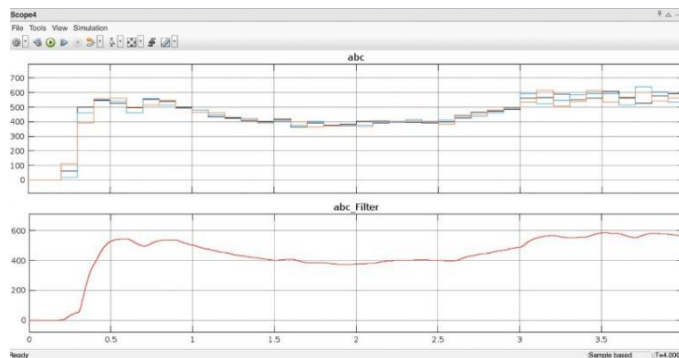
T_{eref} represents the reference electromagnetic torque, indicating the desired torque output from the motor as set by the control system.

$T_{emotor}(b)$ represents the actual electromagnetic torque developed by the motor, expressed in Newton-metres (N.m). This graph illustrates how closely the motor torque tracks the reference torque T_{eref} . Any disparities between the reference and actual torque highlight the performance of the torque control loop and the effectiveness of the DTC strategy in regulating motor torque.

$T_{load}(r)$ represents the applied load torque on the motor. Monitoring this parameter allows the system to understand the external forces acting on the motor shaft, which can influence the motor's performance and behaviour.

SCOPE 4

In the Scope 4 abc graph shows the three-phase currents (I_A , I_B , I_C) of the motor. And abc_filter: This indicates the filtered version of the three-phase currents. Filtering is typically done to remove noise or harmonics from the current signals, providing smoother and more accurate representations of the motor currents.



8. CONCLUSIONS

In conclusion, the development of a Simulink-based model for Direct Torque Control (DTC) in induction motors with a focus on minimising voltage vector errors offers a promising solution to enhance the efficiency, precision, and reliability of these motors in industrial settings. By optimising DTC techniques and incorporating a minimum voltage vector error strategy, this research project contributes to the ongoing efforts to address the challenges associated with motor control in industrial applications, ultimately leading to more efficient and dependable manufacturing processes.

9. REFERENCES

- [1] John R G Schoeld\Direct Torque Control (DTC) of an AC motor system " IEEE, 2020
- [2] I Liidtkke, Dr. M G Jayne, "Direct Torque Control of Induction Motors" IEEE, Savoy Place, London WCPR OBL, 2021.
- [3] Yesma Bendaha, Mazari Benyounes, "Fuzzy Direct Torque Control of Induction Motor with Sensorless Speed Control Using Parameters Machine Estimation" IEEE Trans. Power Electron., 2021.
- [4] Tang, Y., & Lin, G., Direct torque control of induction motor based on self-adaptive PI controller. 2020 5th International Conference on Computer Science & Education
doi:10.1109/iccse.2010.5593448

[4] Narongrit Pimkumwong and Ming-Shyan Wang, "Direct Torque Control of Three-Phase Induction Motor based on Constant Voltage per Frequency Control with [5] Simple Controller," 15th International Conference on Electrical Engineering/Computer, Telecommunications and Information Technology, 2019.

[6] Areed, Fayez G., Haikal, Amira Y., Mohammed, Reham H., Adaptive neuro-fuzzy control of an induction motor. Ain Shams Eng. J. 1 (1), 71–78, 2019.

[7] D. Casadei, G. Serra and K. Tani, "Implementation of a direct control algorithm for induction motors based on discrete space vector modulation," in IEEE Transactions on Power Electronics, vol. 15, no. 4, pp. 769-777, July 2020, doi: 10.1109/63.849048.

[8] G. S. Buja and M. P. Kazmierkowski, "Direct torque control of PWM inverter-fed AC motors—A survey," IEEE Trans. Ind. Electron., vol. 51, no. 4, pp. 744–757, Aug. 2021.

[9] Z. Wang, J. Chen, M. Cheng and K. T. Chau, "Field-Oriented Control and Direct Torque Control for Paralleled VSIs Fed PMSM Drives With Variable Switching Frequencies," in IEEE Transactions on Power Electronics, vol. 31, no. 3, pp. 2417-2428, March 2020, doi: 10.1109/TPEL.2015.2437893.

[10] R. Ortega, N. Barabanov, G. Escobar and E. Valderrama, "Direct torque control of induction motors: stability analysis and performance improvement," in IEEE Transactions on Automatic Control, vol. 46, no. 8, pp. 1209-1222, Aug. 2021, doi: 10.1109/9.940925.



Neha Prajapati was born in Dudhala, Nagpur, India in 2002. she currently pursuing the B. tech degree in Electrical Engineering from Rashtrasanta Tukdoji Maharaj Nagpur University (RTMNU), Nagpur, India in 2024



Gaytri Meshram was born in Wardha, India in 2002. she currently pursuing the B. tech degree in Electrical Engineering from Rashtrasanta Tukdoji Maharaj Nagpur University (RTMNU), Nagpur, India in 2024.



Abhay Halmare was born in Nagpur, India in 1980. He Recieved M. Tech degree in Rashtrasant Tukdoji Maharaj Nagpur University (RTMNU) Nagpur, India in 2006. In 2007 he join the Faculty of Karamveer Dadasaheb Kannamvar College of Engineering (KDKCE). Where he is currently a professor.



Saurabh Sharma was born in Nagpur, India in 2003. He currently pursuing the B. tech degree in Electrical Engineering from Rashtrasanta Tukdoji Maharaj Nagpur University (RTMNU), Nagpur, India in 2024



Kalyani Watmode was born in Wardha, India in 2002. she currently pursuing the B. tech degree in Electrical Engineering from Rashtrasanta Tukdoji Maharaj Nagpur University (RTMNU), Nagpur, India in 2024



Divya Dharpawar was born in Nagpur, India in 2002. she currently pursuing the B. tech degree in Electrical Engineering from Rashtrasanta Tukdoji Maharaj Nagpur University (RTMNU), Nagpur, India in 2024

