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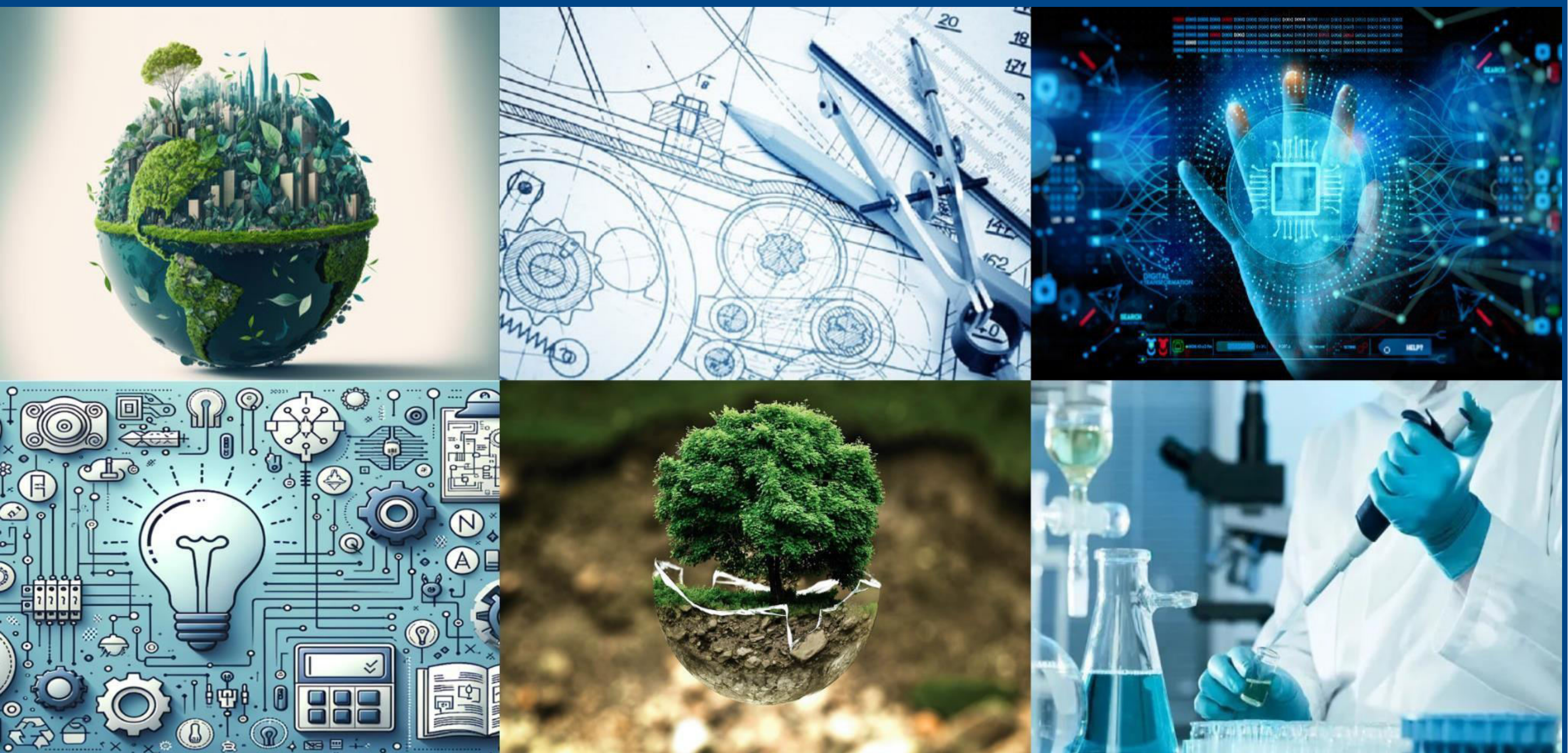

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Advanced Hybrid Control Schemes for Z-Source Invertors Fed Induction Motor Drive in Electric Vehicle

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ABSTACT: The integration of advanced control strategies with Z-source inverters (ZSI) has opened new possibilities in achieving efficient and reliable motor drive systems. This project focuses on the development of an advanced hybrid control scheme that combines vector control and fuzzy logic algorithms to enhance the performance of an induction motor drive fed by a Z-source inverter. The ZSI topology offers both voltage buck–boost capability and improved immunity to shoot-through faults, making it ideal for electric drive applications. The proposed hybrid control system ensures better torque control, dynamic response, and harmonic reduction compared to conventional control methods. Additionally, the integration of IoT-based monitoring enables real-time data acquisition, performance analysis, and fault detection through a cloud platform. The developed system demonstrates enhanced efficiency, reliability, and adaptability, making it suitable for applications such as electric vehicles (EVs) and industrial motor drives.

KEYWORDS: *Z-Source Inverter, Hybrid Control Scheme, Vector Control, Induction Motor Drive, IoT Monitoring, Electric Vehicle, Power Electronics, Real-Time Control, Efficiency Enhancement.*

I. INTRODUCTION

The Z-Source Inverter (ZSI) has emerged as a significant innovation in the field of electric drive systems by providing a unified power conversion stage capable of both voltage buck and boost operations. Unlike traditional Voltage Source Inverters (VSI) or Current Source Inverters (CSI), which require separate DC–DC converters for voltage regulation, the ZSI employs a unique impedance network that enables single-stage power conversion, thereby improving system efficiency and reducing complexity [1]. The topology proposed by Peng (2003) introduced the concept of the ZSI, which has since gained considerable attention for its enhanced fault tolerance, shoot-through capability, and voltage boosting characteristics [1].

Building on this foundation, Liu and Xu (2007) investigated the application of ZSIs in electric drive systems, demonstrating superior performance in terms of voltage regulation, harmonic reduction, and overall system reliability [2]. The ability of the ZSI to perform both buck and boost operations makes it particularly suitable for applications with fluctuating input voltage sources, such as those found in induction motor (IM) drives used in industrial and automotive systems. The combination of Z-Source Inverters and Induction Motors provides improved robustness, efficiency, and controllability under dynamic load conditions.

To enhance the performance of ZSI-fed induction motor drives, researchers have focused on implementing advanced and hybrid control techniques. These include model predictive control (MPC) [3], fuzzy logic-based hybrid control [4], and neuro-fuzzy adaptive schemes [6], each aiming to improve torque response, reduce total harmonic distortion (THD), and enhance the dynamic behaviour of the motor under variable load and speed conditions. Rahim and Chandra (2020) [4] proposed a fuzzy logic-based hybrid control system that demonstrated significant improvements in stability and efficiency when compared to traditional control methods.

Recent developments have also emphasized real-time monitoring and adaptive optimization of inverter-fed drives. Studies such as Khan et al. (2019) [5] and Balamurugan and Subramani (2020) [10] have introduced modified space vector PWM and hybrid control algorithms, leading to smoother torque characteristics and reduced switching losses. Similarly, Kumar and Babu (2021) [7] designed a hybrid control framework integrating artificial intelligence and classical control techniques to optimize motor speed regulation and minimize ripple effects.

Therefore, the Advanced Hybrid Control Schemes for Z-Source Inverter Fed Induction Motor Drives present a comprehensive and forward-looking approach to achieving high-performance, energy-efficient, and reliable motor control. By integrating intelligent hybrid control algorithms with the inherent advantages of the ZSI topology, this research contributes to the advancement of next-generation power electronic drives suitable for both industrial and electric vehicle applications.

II. BLOCK DIAGRAM

The block diagram depicts Z-Source Inverter Fed Induction Motor Drive.The Z-Source Inverter Fed Induction Motor Drive system consists of a power supply and rectifier, Z-source network, inverter, filter, driver circuit, triggering circuit, controller, and an induction motor.

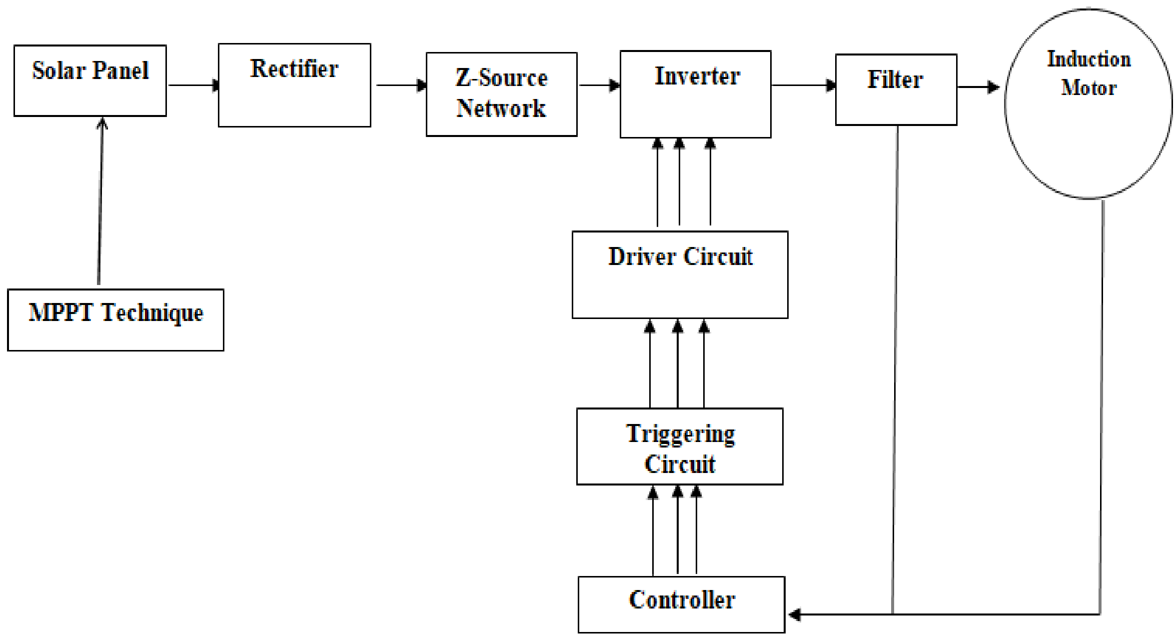

Figure 1: Block Diagram of Proposed System

The power supply and rectifier block provides the required DC input voltage to the system by converting the AC supply into DC. This DC voltage is then fed to the Z-source network, which is the key element of the system. The Z-source network is made up of two inductors and two capacitors arranged in an X-shaped configuration that allows both voltage boosting and bucking. It enhances the voltage level and enables shoot-through operation of the inverter without damaging the switches.

The inverter receives the boosted DC voltage from the Z-source network and converts it into three-phase AC to drive the induction motor. The filter connected at the inverter output smoothness the PWM waveform by removing unwanted harmonics, ensuring that a clean sinusoidal voltage is supplied to the induction motor. The motor converts this

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electrical energy into mechanical energy, and its speed and torque are controlled by regulating the inverter output voltage and frequency.

The driver circuit amplifies and isolates the control signals generated by the triggering circuit, which in turn is governed by the controller. The controller, which may be a micro controller or DSP, generates the required PWM pulses based on feedback signals received from the induction motor such as speed or current. These feedback signals ensure closed-loop operation, allowing the controller to adjust inverter parameters in real-time for stable and efficient motor performance. Overall, the system integrates power conversion and intelligent control to provide smooth, efficient, and reliable operation of the induction motor under varying load conditions.

Figure 2 represent the Z-source inverter connection.

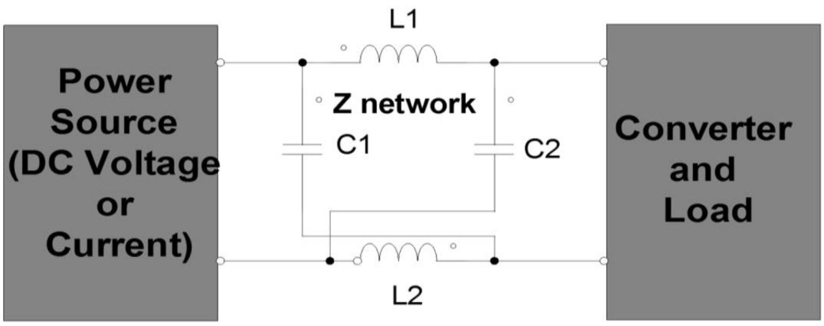

Figure 2: Z- source inverter connection

III. COMPONENTS

1. Power Supply & Rectifier
The system starts with an AC power supply or a DC source. If the input is AC, it passes through a rectifier that converts AC to DC. This DC voltage serves as the input for the Z-source network. The rectifier ensures a stable and ripple-free DC supply to the inverter stage.

2. Z-Source Network
The Z-source network is the heart of this drive system. It consists of two inductors (L1, L2) and two capacitors (C1, C2) connected in an X-shaped configuration. Allows shoot-through operation (both inverter switches ON in a leg) without damaging the inverter. This eliminates the need for a separate DC–DC boost converter.

3. Inverter
The inverter converts the DC output from the Z-source network into three-phase AC power. It uses six semiconductor switches (IGBTs or MOSFETs). The modulation technique (e.g., PWM or SVPWM) determines the AC output's voltage and frequency. The inverter output drives the induction motor after filtering.

4. Filter
A LC filter is connected at the inverter output. It smoothness the PWM waveform, removing high-frequency harmonics. Ensures a pure sinusoidal AC voltage is supplied to the induction motor, improving efficiency and torque quality.

5. Induction Motor
The three-phase induction motor is the load of this system. It converts electrical energy into mechanical rotation. The inverter controls its speed and torque by adjusting voltage and frequency.

6. Driver Circuit

The driver circuit provides isolation and amplification for the inverter gate signals. It ensures that the control signals from the micro-controller (low voltage) can safely drive the high-power inverter switches. Often uses opto-couplers or gate drivers for signal protection.

7. Triggering Circuit

The triggering circuit generates precise PWM pulses required to control the inverter switches. It coordinates with the controller to determine the correct timing and duration of ON/OFF states. Plays a key role in maintaining desired speed and torque characteristics.

8. Controller

The controller (such as a DSP, micro controller, or FPGA) forms the brain of the system. Monitors speed, voltage, and current feedback from the induction motor. Generates appropriate control signals for the triggering circuit. Implements control strategies like: V/f (Volts per Hertz) Control

9. Feedback Loop

The feedback from the induction motor (speed or current sensors) is sent to the controller. This enables closed-loop control, improving accuracy, dynamic response, and protection.

IV. HARDWARE SETUP

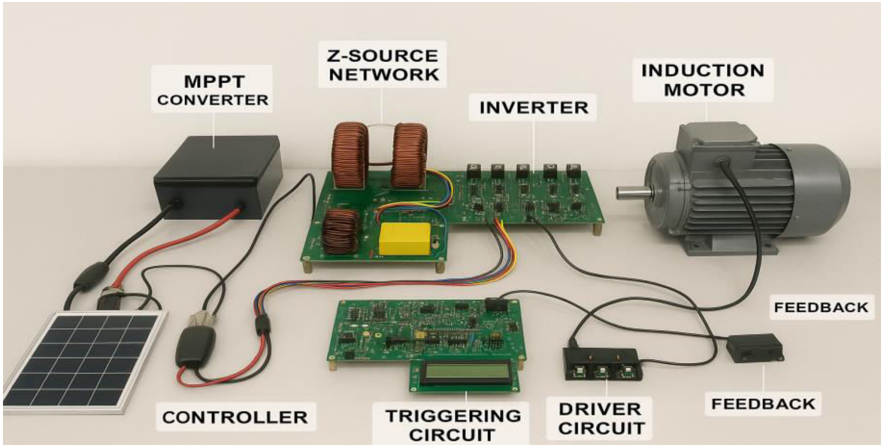

Figure 3: Hardware setup

The hardware setup of the proposed system is depicted in figure 3. The advanced hybrid control scheme for a Z-source inverter (ZSI) fed induction motor drive integrates intelligent control algorithms with the inherent voltage-boosting capability of the ZSI to achieve superior dynamic performance, high efficiency, and robustness against system disturbances. In this configuration, the Z-source network—comprising two inductors and two capacitors connected in an X-shaped topology—is placed between the DC power source and the inverter bridge. This unique arrangement enables the inverter to operate in both buck and boost modes using a controlled shoot-through state, during which both switches of an inverter leg are turned on simultaneously without causing device failure. The energy stored in the inductors during this interval is transferred to the capacitors, effectively increasing the DC-link voltage supplied to the inverter. Consequently, the inverter can produce an AC output voltage greater than the input DC voltage without requiring a separate DC–DC converter.

The hybrid control algorithm combines conventional vector control techniques, such as field-oriented control (FOC) or direct torque control (DTC), with intelligent methods like fuzzy logic, neural networks, or adaptive neuro-fuzzy inference systems (ANFIS). The intelligent controller dynamically adjusts parameters such as the shoot-through duty ratio and modulation index based on real-time feedback of motor speed, current, and Z-network capacitor voltage. This adaptive coordination ensures precise torque control, reduced steady-state error, and improved transient response under

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varying load and supply conditions. Overall, the advanced hybrid-controlled ZSI-fed induction motor drive provides a single-stage, high-performance power conversion system suitable for electric vehicle propulsion and renewable energy applications, offering a compact, efficient, and fault-tolerant alternative to conventional inverter-fed motor drives.

V. CONTROL STRATEGIES FOR THE INDUCTION MOTOR

- **V/f (Open-loop scalar):** simplest; keep V/f constant; allows basic speed control. Good for low-cost, low-performance systems.
- **Vector Control (Field Oriented Control — FOC):** decouple torque/flux, precise torque/speed control. Requires rotor flux estimation or speed/position sensor.
- **Direct Torque Control (DTC):** fast torque response, no explicit PI loops for flux, but switching frequency varies.
- For ZSI-fed drive, use FOC with inner current loop plus outer speed PI. Include Z-network voltage control loop to regulate capacitor voltage (or boost factor).

VI. MERITS OF THE SYSTEM

- **Boost and Buck Operation in One Stage:** Unlike conventional inverters, the ZSI can both step up (boost) and step down (buck) the voltage without an additional DC–DC converter.
- **Improved Reliability**: The Z-source network protects against shoot-through faults (when both switches in one inverter leg turn ON), preventing inverter damage.
- **Reduced Component Count**: Eliminates the need for a separate DC–DC boost converter, leading to a simpler and more compact system**.**
- **Higher Efficiency**: Fewer conversion stages result in lower switching and conduction losses, improving overall efficiency.
- **Enhanced Voltage Utilization:** The inverter can produce an output voltage greater than the input DC voltage**,** achieving better voltage utilization.
- **Improved Power Quality**: With appropriate control and filtering, ZSI provides low harmonic distortion and smooth AC output for the motor.
- **Wide Speed Control Range**: The embedded control system allows precise speed and torque regulation across a broad operating range.
- **Cost-Effective Solution:** The combination of inverter and boost functions in one circuit reduces cost, size, and weight of the drive.
- **Better Dynamic Response**: Embedded controller integration ensures fast response to load or speed variations.
- **Suitable for Renewable and Distributed Systems:** ZSI-based drives are ideal for solar, wind, and battery-powered systems where DC voltage fluctuates.

VII. RESULTS AND DISCUSSION

The simulation model of the Advanced Hybrid Control Scheme for a Z-Source Inverter (ZSI) fed Induction Motor Drive was developed and analyzed using MATLAB/Simulink. The system integrates a Z-source impedance network between the DC input source and the inverter bridge to achieve both voltage buck and boost functionality through controlled shoot-through states.

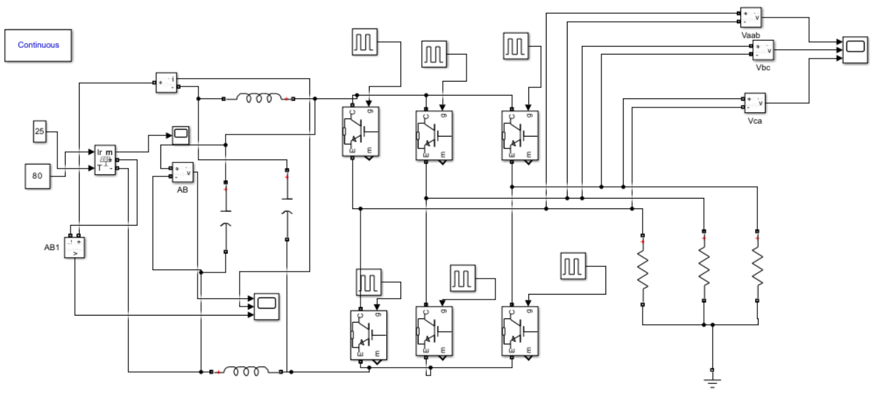

Figure 4: Mat lab Stimulation of Z source Fed Invertors

Figure 4 represent the Mat Lab Stimulation of Z source Fed Invertors with solar panel. Figure5,6,7 represent the output graph for voltage time, current time, rotor speed time respectively

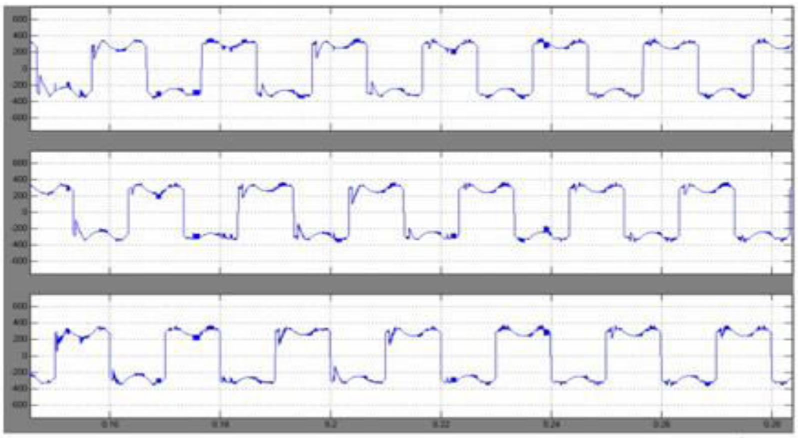

Figure 5: Voltage-Time Waveform

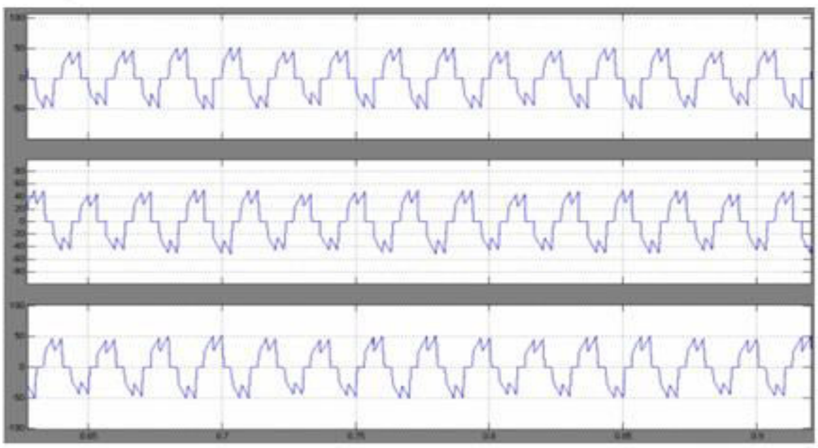

Figure 6: **Curent-Tmewavefom**

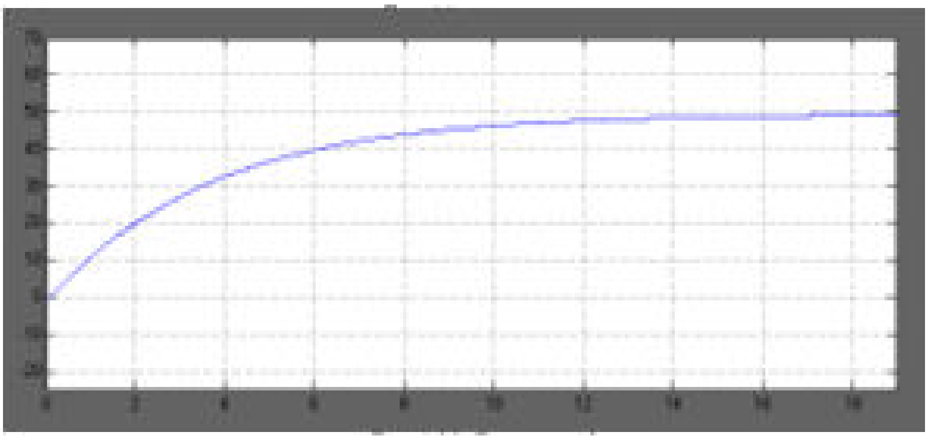

Figure7: Rotor Speed-Time waveform

The output phase voltages (V_{AN},V_{BN},V_{CN}) and corresponding stator currents were balanced and sinusoidal, confirming proper inverter switching and effective harmonic suppression. The Z-source capacitor voltage remained stable throughout operation, indicating efficient energy transfer within the impedance network.

VIII. CONCLUSION

The Embedded Z-Source Inverter (ZSI) Fed Induction Motor Drive provides an efficient, reliable, and flexible solution for modern motor control applications. By integrating the unique Z-source impedance network, the system effectively performs both voltage boost and inversion within a single stage, eliminating the need for additional DC–DC converters. This not only enhances efficiency and voltage utilization but also improves reliability by allowing safe shoot-through operation.

With an embedded control unit**,** the drive achieves precise speed and torque regulation, ensuring smooth dynamic performance under varying load conditions. The simplified structure, reduced cost, and suitability for renewable and distributed energy sources make the ZSI-fed induction motor drive a promising alternative to conventional inverter systems for next-generation power electronics and industrial automation.

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