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Department of Electrical and Electronics Engineering

A synopsis on the major project entitled

"Wide Bandgap Gallium Nitride (GaN) Based DC-DC Converter model for Electric Vehicle Application"

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1.Introduction

The global push towards sustainability and reduced carbon emissions has significantly accelerated the transition from conventional internal combustion engine (ICE) vehicles to electric vehicles (EVs). As the demand for EVs continues to rise, driven by environmental concerns and advances in renewable energy technologies, the automotive industry is faced with the challenge of making these vehicles more efficient, affordable, and reliable.

Gallium Nitride (GaN) is a wide-bandgap semiconductor known for its high efficiency and thermal stability, making it ideal for power electronics applications. GaN-based devices, such as High Electron Mobility Transistors (HEMTs), offer advantages over traditional silicon-based devices, including higher switching speeds, reduced conduction losses, and improved thermal performance. However, as EV adoption grows, so does the need for enhanced performance in areas like energy efficiency, power density, and the longevity of the various components that make up an EV's drivetrain and charging systems. Central to the performance of any EV are the powertrains and charging systems, which must work seamlessly together to ensure an efficient and reliable energy transfer.

The powertrain in an electric vehicle, responsible for converting electrical energy into mechanical energy to drive the vehicle, relies heavily on power electronics such as inverters, motor controllers, and DC-DC converters. Similarly, the charging system, which is responsible for transferring energy from the grid to the vehicle's battery, also relies on power conversion systems. Therefore, power electronics play a crucial role in the overall performance, efficiency, and reliability of both the EV powertrain and charging systems. Power efficiency is a critical consideration in electric vehicles for several reasons. First and foremost, it directly impacts the range and performance of the vehicle. Higher efficiency means that more of the energy from the battery is converted into useful mechanical work, minimizing losses and enhancing the driving range on a single charge.

In the context of the EV powertrain, the key power electronics components such as inverters, converters, and motor drives must operate with minimal energy loss to ensure optimal performance. The efficiency of the charging system also plays an essential role in both the user experience and the overall sustainability of the EV. Fast charging technology, which allows drivers to recharge their vehicles more quickly, is a crucial feature for the widespread adoption of EVs. However, fast charging comes with its own set of challenges, including higher power losses and thermal management issues.

An efficient charging system can reduce these losses, enhance the charging speed, and minimize heat generation, all of which are important for improving the user experience and the lifespan of the vehicle’s battery. Improving power efficiency also has economic implications. Reducing energy losses in both the powertrain and charging systems can lead to lower operational costs for EV owners, making electric vehicles even more attractive. Additionally, more efficient systems can extend the overall lifespan of the vehicle’s components, including the battery, which is one of the most expensive parts of an EV

1.1 Problem statement

Problem statement: Design and develop a high-efficiency, compact, and reliable Wide Bandgap Gallium Nitride (GaN) based converter model for electric vehicle (EV) applications, addressing the challenges of high power density, fast switching speeds, and thermal management, while ensuring efficient and reliable operation, and meeting the stringent requirements of the automotive industry.

1.2 Objectives:

- To study about GaN Based transistor and LTSpice software.
- To Design the GaN-based converter topology, including the selection of GaN devices, DC-link capacitor, and output filter.
- To Develop a detailed model of the GaN device, including its electrical characteristics.
- To Simulate the GaN-based converter model under various operating conditions, including different temperatures, loads, and input voltages.
- To Compare the performance of the GaN-based converter with traditional silicon-based inverters.

2 Literature Review:

- Electric Vehicle Adoption and Eco-Friendly Technologies
  Nieuwenhuis, Cipcigan, and Sonder (2024) highlight the growing adoption of electric vehicles as a key means to reduce greenhouse gas emissions and fossil fuel dependency. Their work, published in Future Energy: Improved, Sustainable and Clean Options for Our Planet (Elsevier), emphasizes the environmental benefits and the demand for efficient power electronics to support sustainable automotive technologies .

- Inverter's Role in Electric Vehicles
  Sneha Angeline and Newlin Rajkumar (2023) discuss the critical role of inverters in EVs for converting battery DC voltage to AC to drive motors. Their analysis in Materials Today: Proceedings stresses the necessity of minimizing inverter losses to improve efficiency and overall vehicle performance (see the generated image above).

- Wide Bandgap Semiconductor Technologies
  Millán et al. (2024), in their influential survey published in IEEE Transactions on Power Electronics, examine wide bandgap semiconductors such as Gallium Nitride (GaN) and Silicon Carbide (SiC). They describe the superior electrical and thermal properties of WBG materials that enable higher voltage, frequency, and efficiency in power devices, making them ideal for EV applications (see the generated image above).

- Gallium Nitride MOSFET Properties
  Nexperia Semiconductor (2024) provides datasheet specifications for GaN MOSFETs illustrating lower on-state resistance, higher gate voltage ratings, and reduced switching losses compared to traditional devices. These parameters support GaN’s suitability for high-efficiency inverters .

- Power Loss Modeling in MOSFET-Based Inverters
  Kumar et al. (2023), in Advances in Power Electronics, quantitatively analyze conduction and switching losses in power devices, emphasizing the importance of accurate loss modeling for optimizing propulsion drives. Proper loss calculation is critical for inverter design and energy-efficient operation .

- GaN Versus SiC Inverter Performance
  Xiong et al. (2024) compare switching performances of GaN and SiC MOSFETs using a high-frequency half-bridge inverter, published in the proceedings of the IEEE International Symposium on Industrial Electronics. Their findings confirm GaN’s superior switching capabilities, leading to lower power losses and improved inverter efficiency .

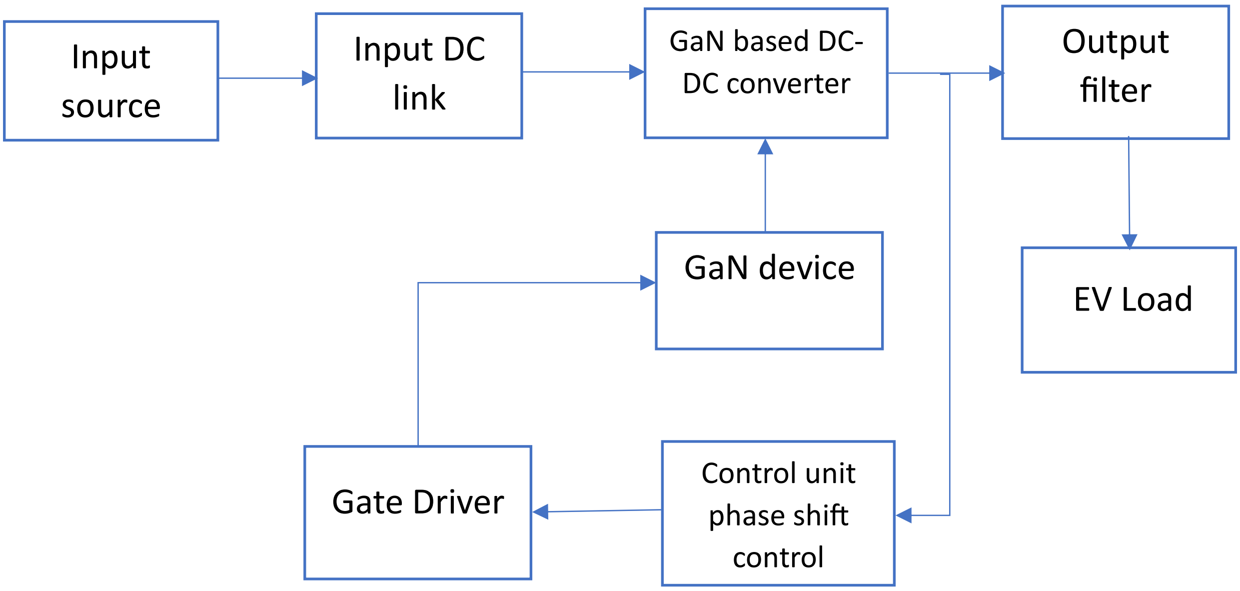
3. Methodology

1. Model three-phase converter circuit in LTspice simulation with GaN MOSFET parameters.
2. Generate phased gate pulses to simulate 3-phase AC output from DC source.
3. Analyze output waveforms and gate signals for performance validation.
4. Compute and compare inverter losses using LTspice integrated calculations.
5. Evaluate simulation results to assess efficiency and energy loss reduction.
6. Recommend future work on thermal effects and dynamic motor load testing.

4. Software required for the development of the project.

- LTspice Software : For modeling, simulation, and analysis of the three-phase GaN-based inverter, including gate pulse generation, power loss calculation, and waveform visualization.
- LTspice Add-ons: Signal processing and SimPowerSystems toolboxes for advanced power electronics simulation and motor load modeling.
- MATLAB IDE (optional): For additional scripting and data analysis related to power loss calculations.
- Datasheet and component parameter databases: To obtain accurate electrical parameters of GaN MOSFET devices for modeling

5. Block Diagram:



6. Expected outcomes:

- Output Waveforms :Three-phase sinusoidal output voltage and current.Motor speed tracking the reference input.
- Performance Analysis Efficiency :Higher due to reduced switching losses (up to 98–99%).Lower harmonic distortion because of higher switching frequency. Lower device heating and reduced cooling requirements.
- Comparision with Si based Inverter : Higher losses, larger cooling system, limited switching frequency (~10–20 kHz).

- GaN based Inverter: Compact, high frequency (50–100 kHz), lightweight, higher efficiency.

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