International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 02 | Feb - 2025 SJIF Rating: 8.448 ISSN: 2582-3930

Advanced Electric Vehicle Battery System Powered by High-Frequency Inverter with Isolation Transformer Technology

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ABSTRACT

The rapid growth of electric vehicles (EVs) necessitates advancements in charging technologies to enhance efficiency, reliability, and speed. Therefore, this project proposes an advanced high-frequency inverter with isolation transformer based EV battery system. The high-frequency inverter configuration designed for efficient energy conversion and storage. Starting with a DC supply, the inverter utilizes a sinusoidal Pulse Width Modulation (PWM) generator to produce high-frequency AC signals. This output is then directed into an LC tank circuit, which optimizes resonance for improved performance. An isolation transformer ensures electrical safety and stabilizes the system by decoupling the load. The parallel synchronous rectifier facilitates efficient power conversion, minimizing losses during the rectification process. PWM pulses are generated to regulate the output, ensuring that the energy delivered to the battery is both stable and efficient. A proportional-integral (PI) generator monitors and adjusts the system's performance, maintaining the desired voltage levels. This system is particularly beneficial for renewable energy applications, enhancing the system's reliability and efficiency. Overall, this project emphasizes advanced control techniques and component integration to achieve optimal energy management. The system's versatility makes it suitable for various applications, promoting sustainable energy practices. Finally this project is implemented by DSPIC30F4011 Controller.

I. INTRODUCTION

Around the world, the ecological and energy crises are getting more and more attention. Electric vehicles (EVs), as opposed to conventional fuel vehicles, offer substantial benefits in terms of conserving oil resources and lowering carbon emissions. Globally, governments and automakers have taken notice of them, and the number of EVs on the road has kept rising. However, the frequent occurrences of EV fires and spontaneous combustion have resulted in significant financial losses for both car owners and operators of charging facilities, and concerns about charging safety have impeded the growth of EVs and associated industries. The automotive industry's trend toward digitalization and intelligence is becoming increasingly apparent as the national big data strategy is fully implemented. Using big data analysis to address the safety of EV problems have grown to be a significant avenue. Undoubtedly, the close integration of EVs and big data will hasten the evolution of automotive safety regulatory technology, which will further support the superior growth of China's EV sector. Research on EV charging process safety warnings and fault diagnosis is currently in its early stages.

Conventional research for diagnosing and warning EV faults typically involves building an electrochemical model of the battery. Utilizing an equivalent circuit model with the battery's open-circuit voltage and state of charge (SOC) as inputs, Seo et al. employed a recursive least squares technique to identify internal short-circuit faults in batteries. For charging fault monitoring and early warning, Zhang et al. built an electrochemical model of the power battery. The battery status is assessed by contrasting the charge response data that the battery model simulates with the battery charge status data. An equivalent circuit model for lithium-ion batteries is established by Tran et al. with careful consideration of SOC, temperature, and state of health (SOH). This model can estimate the battery state can efficiently monitor charge, temperature, and health status with high accuracy.

Fig.1 Electric Vehicle

II. RELATED WORK

In this paper [1], the author says that the high-frequency inverter and isolation transformer-based EV battery system for efficient energy conversion and storage, promoting sustainable practices and enhanced efficiency through the DSPIC30F4011

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Controller. In this paper [2], the author says that the utilizing big data and digitalization to address environmental and energy concerns affecting electric vehicles. In this paper [3], the author proposes an advanced EV battery system featuring a high-frequency inverter, isolation transformer, AC supply, Bridgeless Canonical Switching Cell converter, hysteresis current-controlled generator, parallel synchronous rectifiers, and ultra-wide output voltage reconfigurable LLC resonant converter. In this paper [4], the author says that the BLCSC converters regulate energy flow in renewable systems, storage, and electric vehicle charging using switched capacitors, high-frequency inverters, isolation transformers, PI controllers, PWM generators, and batteries. In this paper [5], the author says that the Math Works' MATLAB/SIMULINK is a robust software that combines computation, visualization, and programming, enabling users to program dynamic systems and analyze results. In this paper [5], the author says that the introduces a high-frequency inverter-based EV battery charging system, developed using MATLAB 2021a Simulink software, with potential for real-world applications and renewable energy integration.

III. SYSTEM ANALYSIS AND DESIGN

A. Existing System

Green transportation trends have led to advancements in electric vehicle (EV) fast-charging technology. First-generation (G1) EVs have nominal voltages around 400 V, while second-generation (G2) EVs have voltages around 800 V. The state of the EV battery also determines the charging voltage level requirement. A common charger for pre-charging and CC-charging of all G1 and G2 models must provide an ultra-wide range of 100 to 1000 V. Many high-power chargers, such as ABB Terra HP, Turbo EVC, and Wall box supernova, are designed by paralleling multiple identical dc–dc converter modules. Reconfigurable dc–dc converters are increasingly being studied for efficient solutions for high-power EV chargers with ultra-wide voltage range. The existing system presents an ultra-wide output voltage reconfigurable LLC resonant dc–dc converter for fast charging applications. The converter uses six operating modes for a wide output voltage from 100 to 1100 V with a constant current output. The proposed design meets all desired LLC design considerations to attain an ultra-wide output voltage range from the converter.

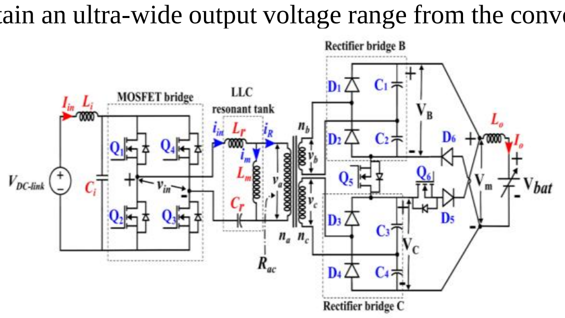

Fig.2 Existing System Circuit Diagram

B. Proposed System

Renewable energy is gaining popularity as a sustainable transportation solution. However, the increased adoption of electric vehicles (EVs) presents challenges, such as uncoordinated charging that exceeds the rating of distribution substation power transformers. This can lead to higher hotspot temperatures, affecting transformer wear-and-tear and aging. To manage this, EV charging rates must be managed considering the transformer's hot-spot temperature limit and EV-specific objectives. This can be a computationally intensive and data privacy-sensitive task. Techniques like primal or dual decomposition can help break down large scheduling problems into smaller ones.

This project proposes an advanced EV battery system using a high-frequency inverter and isolation transformer. The system ensures efficient energy conversion and regulation for various applications, including battery charging and renewable energy integration. The AC supply is processed using a Bridgeless Canonical Switching Cell converter, controlled by a hysteresis current-controlled PWM generator. The system uses parallel synchronous rectifiers for reduced losses and improved efficiency.

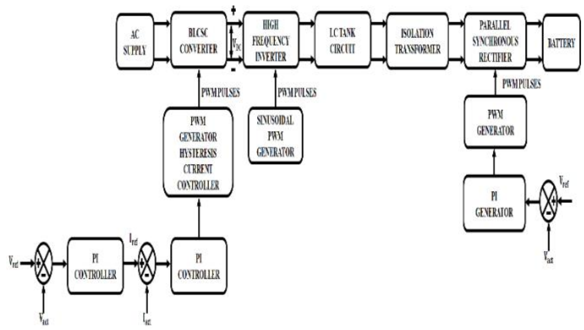

Fig.3 Proposed System Block Diagram

IV. MODULES

A. BLDC Converter

A BLCSC converter is a power electronic converter designed to handle energy flow between two systems, such as renewable energy systems, energy storage, and electric vehicle charging. It uses switched capacitors to regulate power flow, synchronizing the switching of the capacitors to store and release energy to the load. In the reverse direction, the converter stores and releases energy back into the grid or battery, maintaining system stability and preventing energy losses. The converter offers high efficiency, reduced size, and lower losses, making it versatile in various power conversion scenarios.

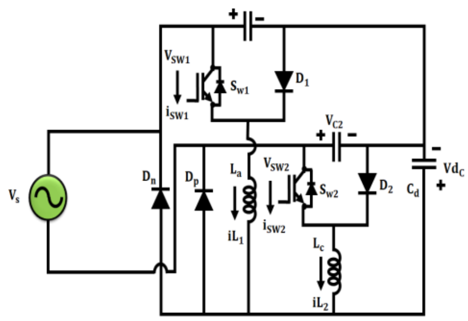

Fig.4 BLDC Converter

B. High Frequency Inverter

High-frequency inverters convert direct current (DC) to alternating current (AC) at higher frequencies. They use high-speed transistors or MOSFETs to create a series of pulses mimicking an AC waveform. The output is a high-frequency square wave, which is refined using a transformer or filter circuit. High-frequency inverters are efficient due to their smaller transformer sizes and lighter components, minimizing energy losses. Control mechanisms regulate the inverter's operation, and protection features like overcurrent and thermal management prevent damage. These inverters are ideal for renewable energy systems and portable power supplies.

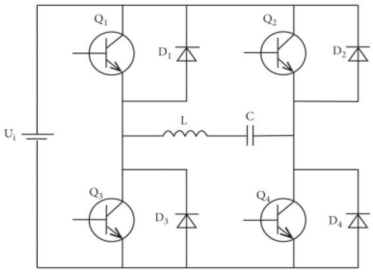

Fig.5 High Frequency Inverter

C. LC Tank Circuit

An LC tank circuit is a resonant circuit consisting of an inductor (L) and a capacitor (C) connected in parallel or series. It oscillates at a specific resonant frequency, based on resonance and energy storage principles. When energized, energy is stored in the capacitor, which then flows into the inductor, generating a magnetic field. This energy transfer causes oscillations at the circuit's natural resonant frequency, allowing it to filter or amplify signals. LC tank circuits are commonly used in oscillators, radio transmitters, and receivers for precise frequency selection. They also have protection features like overcurrent and thermal management.

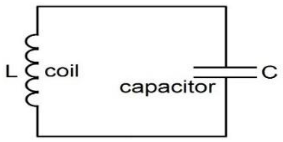

Fig.6 LC Tank Circuit

D. Isolation Transformer

An isolation transformer is a device that transfers electrical energy between two circuits while providing electrical isolation. It separates the input and output circuits, enhancing safety and reducing the risk of electrical shock. The primary winding, a magnetic core, generates a magnetic field that induces a voltage in the secondary winding. This isolation is crucial for applications like medical equipment and sensitive electronic devices. The transformer's transformation ratio is determined by the number of turns in the windings. It also protects against ground faults and electromagnetic interference.

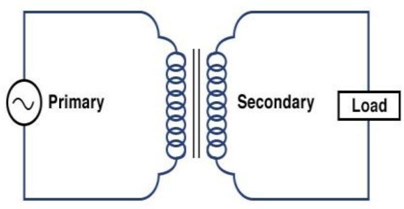

Fig.7 Isolation Transformer

E. PI Controller

A Proportional-Integral (PI) controller is a crucial control strategy in automation and process control systems that minimizes error between set points and actual process variables. It measures system output and compares it to the desired set point, generating an error signal. The PI controller adjusts input based on this error to achieve desired output. It uses proportional and integral control components, with proportional control producing an output directly proportional to the current error. Integral control accumulates the error over time, allowing for adjustments until the error is fully corrected. PI controllers are commonly used in applications like temperature control, speed regulation, and flow control.

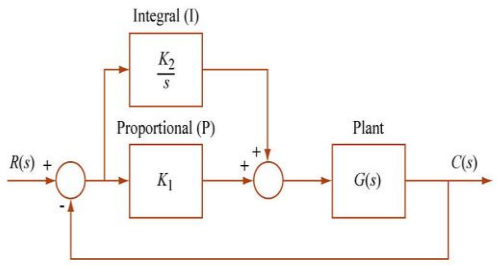

Fig. 8 PI Controller

F. PWM Generator

A Pulse Width Modulation (PWM) generator is a crucial electronic circuit used to control power delivered to devices like motors, LEDs, and heating elements. It creates voltage pulses with varying widths while maintaining a constant frequency, allowing for efficient power and energy delivery. The generator starts with a stable clock signal, which establishes the frequency of the output. A reference voltage represents the desired duty cycle, which determines the average voltage delivered to the load. A comparator circuit compares the reference signal with a triangular waveform, determining the desired duty cycle.

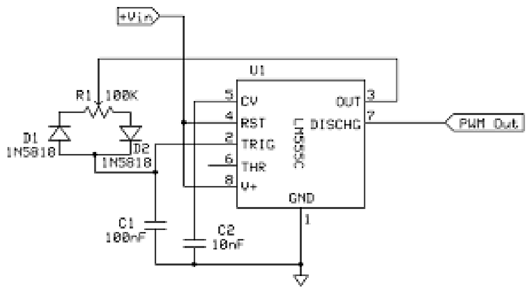

Fig.9 PWN Generator

G. Battery

A battery is a device that stores and converts chemical energy into electrical energy through electrochemical reactions. It consists of two electrodes, an anode and a cathode, in an electrolyte solution. The anode oxidizes, while the cathode reduces. When connected to an external circuit, the anode generates free electrons, providing electricity. The positive ions migrate to the cathode, combining with the incoming electrons to deliver power.

V. RESULTS AND DISCUSSION

The simulation results are examined using MATLAB/SIMULINK, a high-performance software add-on developed by The Math Works. MATLAB is a mathematical tool that integrates computation, visualization, and programming in an easy-to-use environment. Simulink is used to visually program dynamic systems and analyse results. It offers various toolboxes for different techniques, such as Fuzzy

Logic, Neural Networks, DSP, and Statistics. Simulink organizes its blocks into block libraries based on their behaviour, such as Sources, Scope, voltage, and continuous libraries. The scope block displays signals during simulation, while the voltage measurement block measures voltage in a circuit. The bus bar block implements a labelled network node, allowing multiple electrical block outputs and inputs to be connected together. Simulink is a graphical extension to MATLAB for modelling and simulation of systems, drawing systems on screen as block diagrams. It is integrated with MATLAB, allowing data transfer between programs. The main "Simulink" folder contains most necessary blocks for modelling basis systems. There are two major classes of elements in Simulink: blocks and Lines. Blocks are used to generate, modify, combine, output, and display signals, while Lines transmit signals in the direction indicated by the arrow. Lines can be either scalar or vector signals, and for single-input, single-output systems, scalar signals are generally used.

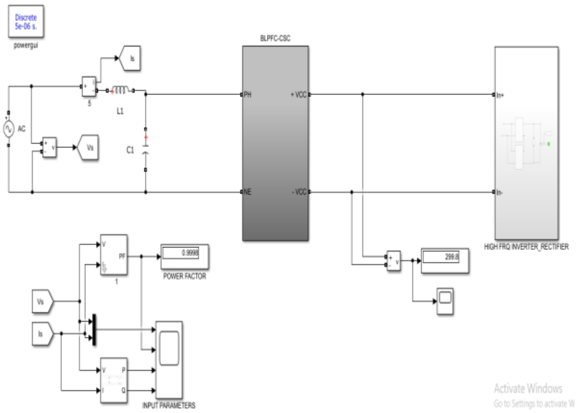

Fig.10 Overall Simulation Diagram

Scope:

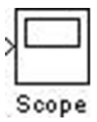

Fig.11 Scope

Purpose: Display signals during simulation.
Description: While the simulation is running, the Scope block displays the output of the block driving it. Opening a scope block produces a scope window. The title of this window matches the name of the block. Display signals generated during a simulation.

Voltage Measurement
Purpose: Measure a voltage in a circuit
Description: The Voltage Measurement block is used to measure the instantaneous voltage between two electric nodes. The output is a Simulink signal that can be used by other Simulink blocks.

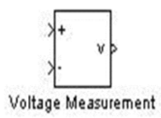

Fig.12 Voltage Measurement

Bus bar

Fig.13 Bus bar

Purpose: Implement a labelled network node.
Description: The Bus Bar block is used to interconnect components. It allows multiple electrical block outputs and inputs to be connected together.

Parameters Specifications

<table>
<tr><th>PARAMETER</th><th colspan="2">Specifications</th></tr>
<tr><td>Input AC Supply</td><td colspan="2">230V</td></tr>
<tr><td>Inductance (LF)</td><td colspan="2">$1.5e^{-3}$</td></tr>
<tr><td>Capacitance (CF)</td><td colspan="2">$330e^{-9}$</td></tr>
<tr><td rowspan="3">BLCSC CONVERTER</td><td colspan="2">L1= $330e^{-6}$</td></tr>
<tr><td colspan="2">L2 = $330e^{-6}$</td></tr>
<tr><td colspan="2">C1 = $10000e^{-6}$</td></tr>
<tr><td rowspan="3">RECTIFIER</td><td colspan="2">Capacitance = $650e^{-6}$</td></tr>
<tr><td colspan="2">Resistance = 100 ohm</td></tr>
<tr><td colspan="2">Switching Frequency = 10K Hz</td></tr>
<tr><td rowspan="8">ISOLATION TRANSFORMER</td><td colspan="2">Nominal Power = 250 W
Nominal Frequency = 10000Hz</td></tr>
<tr><td rowspan="3">Winding 1 Parameters</td><td>V1 = 100V</td></tr>
<tr><td>R1 = 0.002 ohm</td></tr>
<tr><td>L1 = 0.080001H</td></tr>
<tr><td rowspan="3">Winding 2 Parameters</td><td>V2 = 100V</td></tr>
<tr><td>R2 = 0.002 ohm</td></tr>
<tr><td>L2 = 0.080001 H</td></tr>
<tr><td colspan="2">Magnetization Resistance = 500 ohm
Magnetization Inductance = 500 H</td></tr>
</table>

Table.1 Parameter Specification

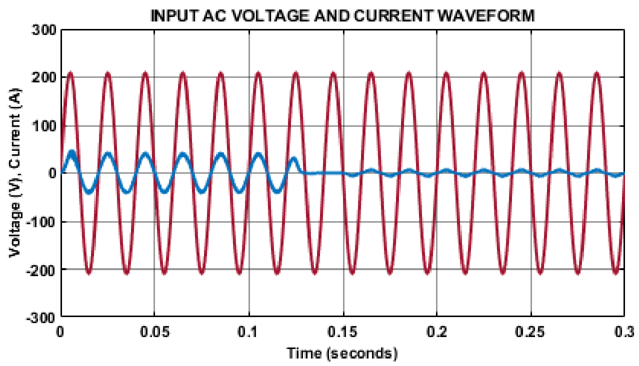

Fig.14 Input AC Voltage And Current Waveform

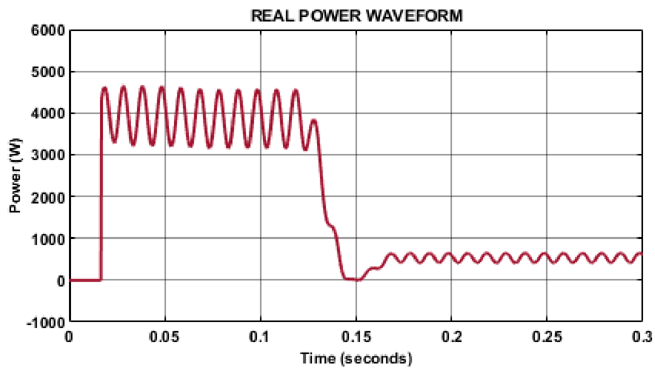

Fig.15 Real Power Waveform

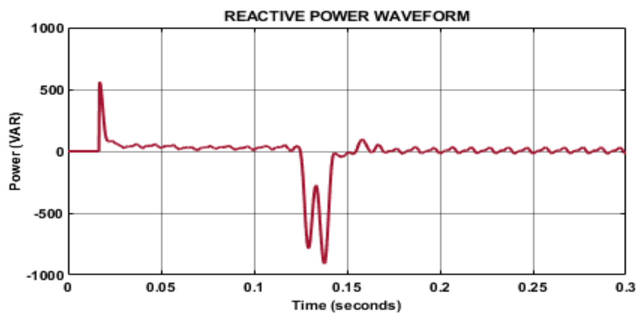

Fig.16 Reactive Power Waveform

VI. CONCLUSION

The project showcases an advanced high-frequency inverter-based electric vehicle (EV) battery charging system. It incorporates a BLCSC converter, high-frequency inverter, LC TANK filter circuit, parallel isolation transformer, synchronous rectifier, PWM generator, and PI controller for efficient power delivery. The system's multi-stage approach ensures high-quality power for demanding EV applications. The project's implementation in MATLAB 2021a Simulink software validates its potential for real-world applications. Future work could integrate renewable energy sources and enhance smart charging and grid integration.

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