NOVEL SYSTEM OF WIRELESS POWER TRANSFER FOR BATTERY CHARGING OF EV APPLICATIONS USING QUASI ZSI

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ABSTRACT

This research describes a 60-kW quasi-impedance source-based inductive type wireless power transfer quick charging system. The suggested system comprises of a quasi-Z-source converter (needed to raise the input voltage), a high-frequency inverter, and an inductive coil with capacitive compensation. At the receiver end, a buck converter is installed, which is operated in Constant Current (CC) or Constant Voltage (CV) charging modes based on the State of Charge. Two different PI controllers are used to achieve both CC and CV. The suggested system generates 60 kW of power at 135A, charging the battery from 0 to 80% SOC in less than 30 minutes. The simulation results achieved using MATLAB are consistent with the commercial guidelines for the battery charging process. Detailed simulation outcomes are provided, helping us to take use of many characteristics of the intended charger.

Keywords:- *Quasi Z Source Converter, Wireless Power Transfer (WPT), Design Of Converter, Battery Charging.*

1. INTRODUCTION

Because of the depletion of fossil fuels and the corresponding environmental concerns regarding internal combustion engines, research into electric vehicles has accelerated. The surge in research is due to the cleanness and superior performance of the EV compared to the ICE because it uses ahigh-performance electric motor; nonetheless, the charging process of the energy storage system has been its primary issue. The EV's battery may be charged using two methods: conductive/wired charging and inductive/wireless charging. The issues with conductive charging include safety, charging time, the position of the charging station relative to the EV's range, and so on. In contrast, wireless charging transfers energy using inductive coils.

Wireless Power Transfer (WPT) has been used as a substitute for cable charging because of its safety, load convenience, and reliability. In addition, high-power converters can reduce charge time. WPT supports two types of power transfer: capacitive (CPT) and inductive (IPT). CPT transfers electricity via an electric field. In contrast, the IPT transfers power through a magnetic field. However, due to poor capacitance.

However, due to the low capacitance between the two ends of the WPT, the design for CPT is difficult. In contrast, the greater coupling coefficient has shown to be the most difficult aspect of IPT . Today, IPT has been swiftly developed and successfully commercialized. In IPT, two coils are utilized to charge the battery: the transmitting coil, which is stationary at the charging station, and the receiving coil, which is installed on the EV. The connection between the two coils is weakerdue to the bigger air gap. To transfer the required amount of power, the system must run at high frequencies (in the hundreds of kHz range). However, the frequency is limited by the switching power lossesof power semiconductor devices.

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Lithium-ion (Li-ion) batteries have found use in electric vehicles due to their high energy density and low maintenance requirements. The Li-ion battery can be charged in four different modes: CC, CV, trickle charging, and charge termination mode. The CV charging mode is used after the CC charging mode to ensure the battery's efficiency and longevity.

Several IPT setups have been documented in the literature, including the usage of a quasi Z-source inverter (QZSI). In typical configurations, a boost DC-DC converter is utilized to enhance the input power supply; however, the voltage gain of such boost converters is restricted for practical applications. As a result, the usage of QZSI provides an alternative to greater input voltage boosting.

In this study, a novel converter setup is suggested. A buck converter was added to the receiver end to regulate the various charging modes, and QZSI was used to enhance the input voltage of the WPT. This paper has been divided into five sections. Section II gives the insight details of the proposed configuration and Section III illustrates the control of the proposed configuration. Simulation results and summarization have been provided in Section IV and V resp.

2. QUASI Z SOURCE INVERTER

Power electronics inverters that include a distinct impedance network into their design are known as quasi-Z-Source Inverters, or quasi ZSIs. Passive parts, such as capacitors and inductors, are organized in a certain arrangement to form this impedance network. Being able to generate controlled output voltages and effectively manage a broad variety of input voltages is the primary characteristic of a quasi ZSI. This is achieved by the provision of intrinsic buck-boost capabilities.

With the added capability of intrinsic buck-boost voltage conversion, a quasi-Z-Source Inverter (QZSI) operates via a special power conversion method that combines the conventional features of inverters.

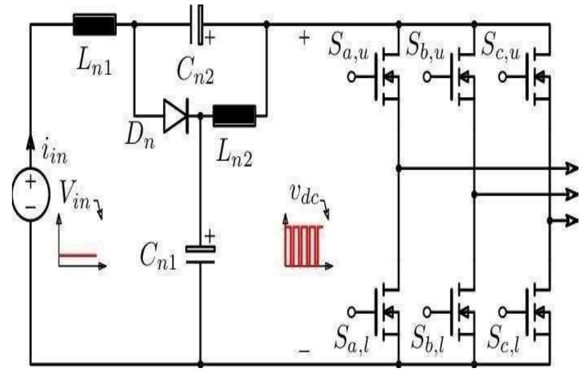

Figure 1 : Quasi Z Source Inverter

A battery, a renewable energy system (such as solar or wind turbines), or the grid can supply the input DC voltage that the quasi ZSI needs to function.

Composed of passive components, usually inductors (L) and capacitors (C), arranged in a certain configuration, the impedance network is the fundamental component of the quasi ZSI. Between the switches of the inverter and the source of the DC voltage input, this network is positioned in the circuit. The QZSI modulates the pulse width of transistors or IGBTs, for example, to regulate the current flowing through the impedance network. The output AC waveform's frequency, amplitude, and voltageregulation are set by the switching control method.

The quasi-Z source inverter (QZSI) has various advantages, including higher voltage boost capability, a lower passive component count, and increased reliability due to reduced component stress. It has inherent shoot-through immunity and performs efficiently in both buck and boost modes, making it suitable for a variety of applications. However, as compared to standard inverters, they have larger switching losses and require more complicated regulation.

QZSI can be used in renewable energy systems, electric vehicles, uninterruptible power supplies, and grid-tied inverters. It efficiently controls changing input from renewable energy sources such as solar and wind. It helps electric vehicles with bidirectional power flow and regenerative braking. It enables uninterrupted power transmission in UPS systems while minimizing harmonic distortion. It makes it easier to integrate renewable energy sources into grid-tied inverters.

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3. WIRELESS TRANSMISSION

The utilization of wireless power transfer (WPT) for electric vehicle (EV) charging has revolutionized the industry by providing a hassle-free and effective substitute for conventional wired charging. It makes EV charging easier by doing away with physical connections, improving user comfort, and allowing automatic charging. With this method, energy losses and heat generation are reduced and efficiency gains are outstanding. Additionally, by being scalable, it reduces maintenance expenditures and infrastructure costs. EVcharging for a convenient and sustainable future.

Inductive Coupling method uses two coils—one in the transmitter and one in the receiver placed in close proximity. An alternating current travels through the transmitter coil, creating an oscillating magnetic field that generates a voltage in the reception coil. Inductive charging is widely used for devices like smart phones and electric toothbrushes. **Resonant Inductive Coupling is** Similar to inductive coupling, but with a resonant frequency matching between the transmitter and receiver coils. This improves the efficiency of power transfer over slightly longer distances and is used in some wireless charging pads. **Laser Power Transmission:** Laser beams are used to transmit power over relatively long distances with high precision. Laser-based WPT is employed in applications such as charging drones in-flight or transferring power to space-based solar power stations. **Resonant Magnetic Coupling:** This method uses resonant coils tuned to the same frequency to achieve efficient power transfer over slightly longer distances compared to traditional inductive coupling. It's used in some wireless charging systems for electric vehicles.

With the added capability of intrinsic buck-boost voltage conversion, a quasi-Z-Source Inverter (quasi ZSI) operates via a special power conversion method that combines the conventional features of inverters. The functioning of a quasi ZSI will be elucidated in detail below:

1.Input DC Voltage: A battery, a renewable energy system (such as solar or wind turbines), or the grid can supply the input DC voltage that the quasi ZSI needs to function.

2.Impedance Network: Composed of passive components, usually inductors (L) and capacitors (C), arranged in a certain configuration, the impedance network is the fundamental component of the quasi ZSI. Between the switches of the inverter and the source of the DC voltage input, this network is positioned in the circuit.

3.Switching Control: The QZSI modulates the pulse width of transistors or IGBTs, for example, to regulate the current flowing through the impedance network. The output AC waveform's frequency, amplitude, and voltageregulation are set by the switching control method.

4.Buck-Boost Voltage Conversion: Supplying buck-boost voltage conversion is one of a QZSI's main benefits. It can thus be configured so that, depending on the switching arrangement, the output AC voltage is either higher or lower than the input DC voltage. When the input voltage needs to be adjusted to meet the demands of the load or is subject to change, this flexibility becomes extremely important.

5.Output AC Voltage: The Quasi Z Source Inverter (QZSI) transforms input DC voltage into a steady AC output voltage at the specified frequency and voltage level. This regulated AC output provides a flexible power source for a variety of applications, including electric motors and grid-connected equipment. The QZSI facilitates the operation of varied loads by supplying consistent and precisely regulated AC power, assuring optimal performance across various electrical systems. Whether powering industrial machinery, domestic appliances, or feeding energy into the grid, the QZSI's output AC voltage is critical to enable efficient and sustainable energy consumption in a wide range of industries and applications.

6. Bidirectional Power Flow (Optional): Bidirectional Power Flow, an optional feature in many Quasi Z Source Inverters (QZSIs), allows energy to flow in both ways, from DC to AC and vice versa. This functionality is extremely valuable for grid integration and energy management systems. Notably, QZSIs with bidirectional power flow capacity may effectively return surplus energy to the input source, increasing overall system efficiency

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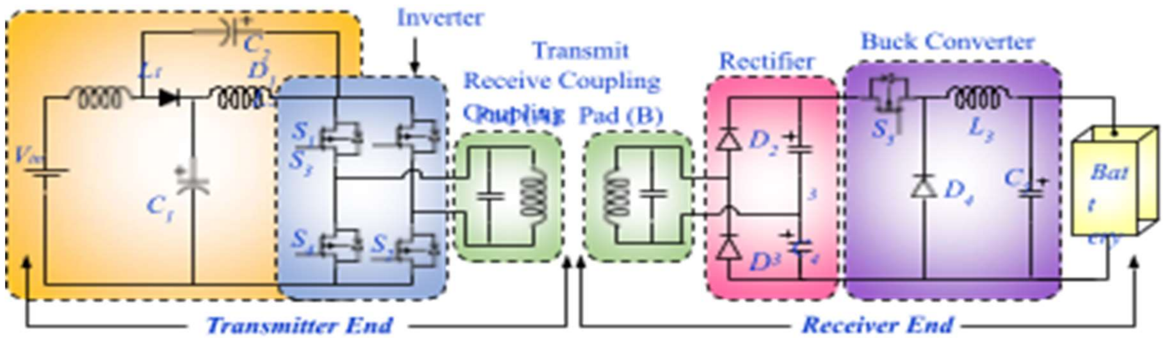

QZS Boost Converter High Frequency

Fig. 2. Proposed power circuitry of WPT rapid charger for EV

This characteristic allows for efficient energy balancing, particularly in renewable energy systems where generation swings are prevalent. Furthermore, bidirectional power flow improves grid stability by allowing power injection or absorption based on demand changes. This adaptability is critical for smart grid applications and microgrid operations, which require dynamic energy management to ensure stability and resilience. Overall, bidirectional power flow capabilities in QZSIs enables New opportunities for optimizing energy use, enhancing grid performance, and encouraging sustainable energy habits.

4. ADAPTING QUASI ZSI TECHNOLOGY FOR WIRELESS POWER TRANSFER IN EVS

Quasi-Z-Source Inverters provide effective voltage management and flexibility to different charging distances, which maximizes power transmission during wireless power transfer for electric vehicles applications. They are a reliable option for WPT systems due to their bidirectional power flow capability, which lowers electromagnetic interference (EMI) and facilitates grid integration. Additionally, by decreasing energy losses when charging, quasi-Z-Source inverters increase total efficiency. Furthermore, by regulating and controlling power flow, they improve safety in WPT systems and support an effective and dependable way to charge electric vehicles.

5.BLOCK DIAGRAM DESCRIPTION

Input Power Source

transmitter. The emitter coil creates
anoscillating magnetic field surrounding
it as AC current passes through it.

This is the major energy source for the system, which might be a battery pack or renewable energy sources like solar panels. It supplies the initial DC power to the quasi-Z source inverter (QZSI) system. The input can be three phase ac supply along with the rectifier to convert Ac supply to DC supply to QZSI.

Quasi Z Source Inverter

The Quasi-Z Source Inverter (QZSI) is the primary component, consisting of a boost converter and an inverter stage. It transforms DC input power into high-frequency AC power that may be sent wirelessly. The boost converter, which consists of a capacitor and an inductor that create an impedance-source network, raises the DC input voltage to the appropriate level for effective wireless power transfer. The inverter step, which uses an H-bridge structure of power switches, creates the AC output signal required for wireless power transmission. It manages the switching of these power switches, regulating the frequency and amplitude of the output voltage.

Wireless Power Transfer (WPT) System

This block contains the components used in the wireless power transfer procedure. It consists of transmitter and receiver coils, resonance tuning circuits, and control mechanisms that regulate power transfer efficiency.

Electromagnetic induction is used in inductive wireless power transfer (WPT), a technique for short-range electrical power transmission. This technique uses two coils—a receiver coil, or receiver—and an emitter coil, or transmitter—to transfer power without requiring any physical connections. Inductive WPT operates as follows:

Emitter coil(transmitter): A power source
that uses alternating current (AC) is linked
to the emitter coil, also known as the transmitter.
The emitter coil creates

an oscillating magnetic field surrounding it as AC current passes through it.

Receiver Coil: Although not in direct physical touch, thereceiver coil is positioned close to Transmitter coil. An alternating voltage is induced in the receiver coil by the emitter coil's pulsating magnetic field As it approaches the receiving coil.

Rectifying Unit: The rectifying device, located at the output of the wireless power receiver, transforms the AC signal received from the wireless power transfer system into a DC voltage appropriate for charging the electric vehicle's battery. It generally comprises of a rectifier circuit, which converts the alternating current voltage to a pulsing direct current voltage. Furthermore, the rectifying unit may incorporate voltage control circuitry to guarantee that the output voltage maintains within the appropriate range when charging the EV battery safely and effectively.

Buck Converter

A buck converter's output voltage must always be lower than its input voltage. A simple buck converter circuit has a MOSFET, diode, inductor, capacitor, and load. Theinductor allows current to pass through the load when the

MOSFET is turned on. In addition to resisting variations in current flow, an inductor can store energy. Because the inductor stores energy drawn from the growing output, the MOSFET output cannot rise directly to its peak value. When the switching MOSFET's current is abruptlycut off, the stored energy is returned to the circuit as a back-electromotive force, or back-EMF.

This converter may perform in two ways. When the switch is in position 2 (off), which is the first mode, the MOSFET is in position 1 (on). When the MOSFET is turned on, as shown in the circuit in Figure 14, it delivers current to the load. Because energy is also being stored in the inductor, current flow to the load is first limited. As a result, both the capacitor's charge and the load's current gradually grow. Because of the large positive voltage, the diode will be reverse biased and serve no purpose in the circuit while it is turned on. The following equations represent the inductor's voltage and the capacitor's current flow. The energy stored in the magnetic field around the inductor is released back into the circuit during the off state, as shown in Figure 15. The collapsing magnetic field stores enough energy to sustain current flow for at least a portion of the transistor switch's open period, and the voltage across the inductor does not reverse polarity with the voltage across the inductor during the on period. The current now flows between the load and the forward-biased diode as a result of the inductor's back-EMF. When the load voltage begins to decline and the inductor has mostly returned its stored energy to the circuit, the charge in the capacitor becomes the dominant current source, maintaining current flow across the load until the start.

6. CONTROL ALGORITHM

Both the CC and CV charging modes are required for electric vehicle rapid charging operation. The current State of Charge (SOC) value is detected into the systemin order to choose the charging mode of operation.

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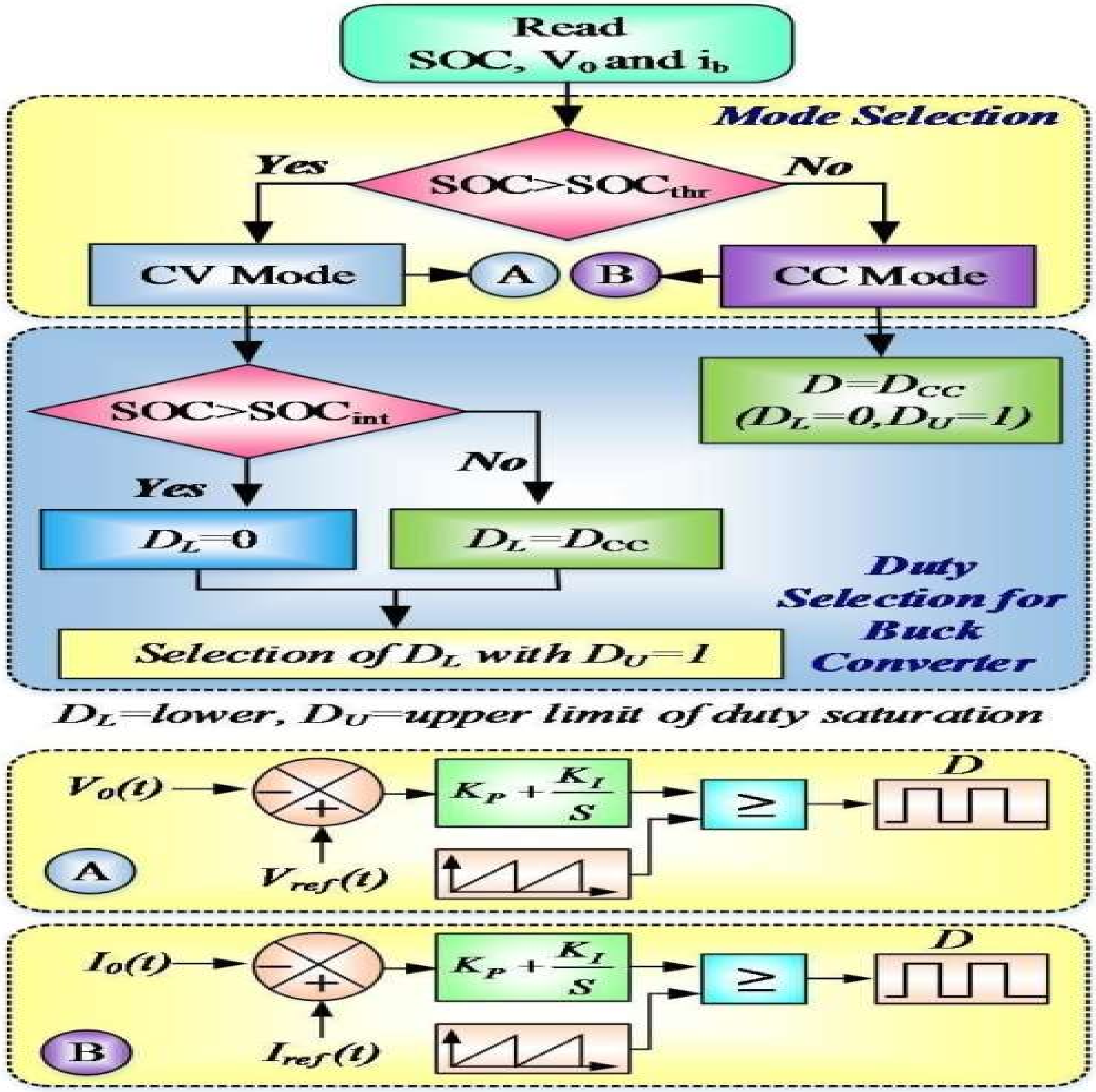

Fig 3: Control Algorithm Flowchart

This SOC present value is contrasted with the SOC threshold value, which is usually sets at 80%. The CC mode of operation is chosen if the current SOC value is less than the SOC threshold; otherwise, the CV mode of operation is chosen. Battery current (ib) is sensed into the control system when operating in the CC mode. The battery current reference is chosen based on the current SOC value. To get the battery current error, the reference battery current and the actual value of (ib) are compared. Duty cycle reference value will be generated by the inbuilt saturation PI controller. The carrier signal and this reference are then compared to provide a switching pulsefor the buck converter.

CC and CV charging modes

"SOC" stands for State of Charge, "CC" for Constant Current, and "CV" for Constant Voltage in the context of electrical engineering. These phrases are frequently used while discussing battery charging, particularly in regard to lithium-ion batteries, which are utilized in a variety of applications, such as electric cars and portable gadgets. Let's examine the various charging methods:

1. Constant Current (CC) Mode:

Under this mode, the battery receives a steady current from the charger during the first stages of

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charging. Usually, the charger's design and the battery's parameters are used to determine the current. In this stage, the battery charges and the voltage across it rises gradually, but the current stays constant. It is effective to quickly charge a battery from a low state of charge using constant current charging.

2. Constant Voltage (CV) Mode:
The charger enters constant voltage mode when the battery achieves a specific voltage level, usually its maximum voltage rating. The charger keeps the voltage across the battery terminals constant while in CV mode. The battery's internal resistance rises as it gets closer to full charge, which lowers the charging current. Until the battery is completely charged, the charger modifies the voltage to maintain the charging current within safe bounds. By regulating the voltage across the battery terminals, CV mode guards against overcharging.
Often used in tandem, these two modes are referred to as a "CC-CV charging profile." When the battery hits a specific voltage threshold, the charger begins charging it rapidly in constant current mode.It then shifts to constant voltage mode to finish charging the battery securely. These modes can be used in different ways by different charging systems based on things like battery chemistry, capacity, and desired charging time. To maximize battery health and safety, advanced chargers may also include extra features like temperature monitoring, current limiting, and trickle charging.

7. SIMULATION RESULTS AND DISCUSSION

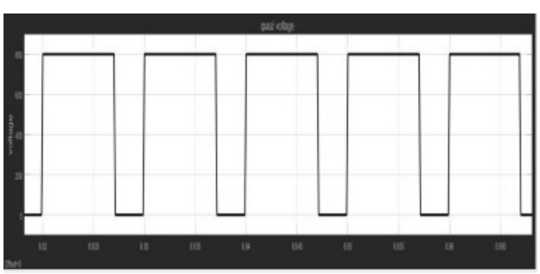

Fig4:Quasi Boost Voltage Output Waveform

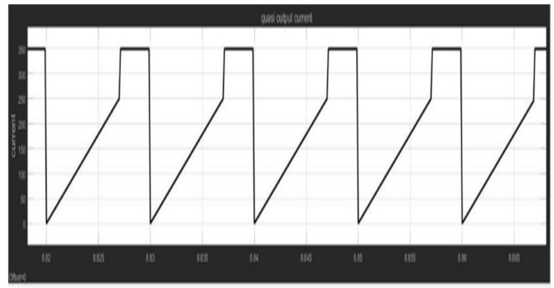

Fig 5: Quasi Boost Current Output Waveform

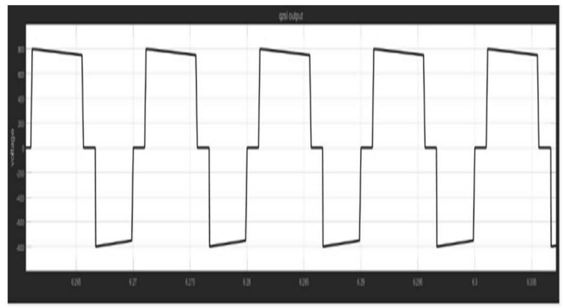

Fig 6: QZSI Output Voltage Waveform

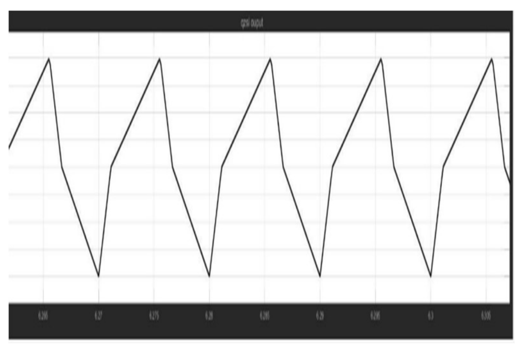

Fig 7: QZSI Output Current Waveform

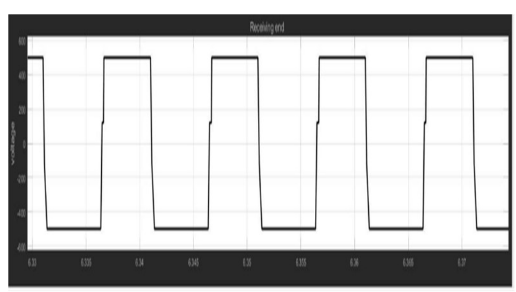

Fig 8: Receiver End Voltage Waveform

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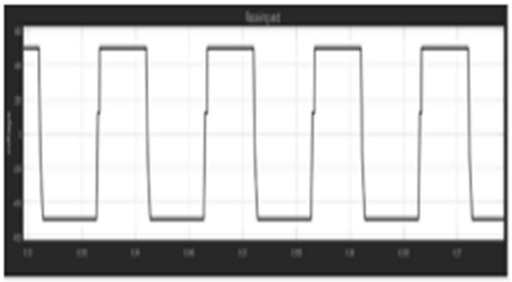

Fig 8: Receiver end voltage waveform

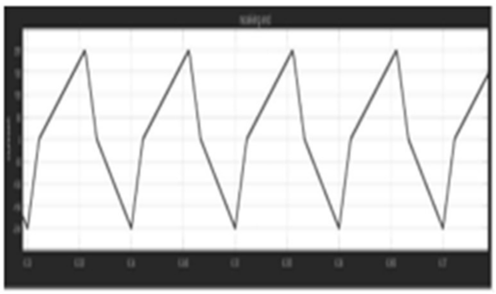

Fig 9: Receiving end current waveform

Fig 10: Rectified dc voltage output waveform

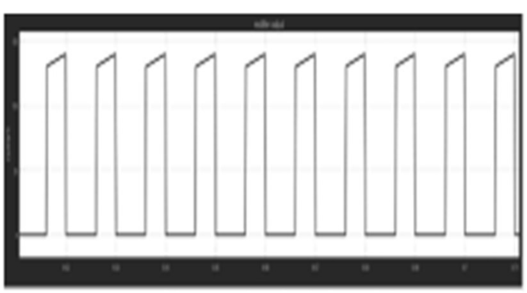

Fig 11: Rectified dc current output waveform

"SoC" stands for State of Charge when referring to batteries. It speaks of the quantity of energy left in a battery relative to its maximum capacity. It basically tellsyou how much of the battery's entire charge is still usable right now. Generally, state of charge is expressed as a percentage, where 100% denotes a fully charged battery and 0% denotes a totally discharged battery. Understanding a battery's state of charge (SoC) is crucial for a number of applications since it guarantees that the system or device it powers has enough energy to function and guards against over-discharge or over-charging, which shortens battery life. In order to give users information, SoC is frequently tracked and presented in gadgets like laptops, cell phones, electric cars, and renewable energy systems. details regarding the battery's remaining life. To obtain a precise estimate of SoC, a variety of methods are used, including as advanced algorithms that consider temperature and discharge/charge rates, coulomb counting, voltage measurements, and impedance spectroscopy.

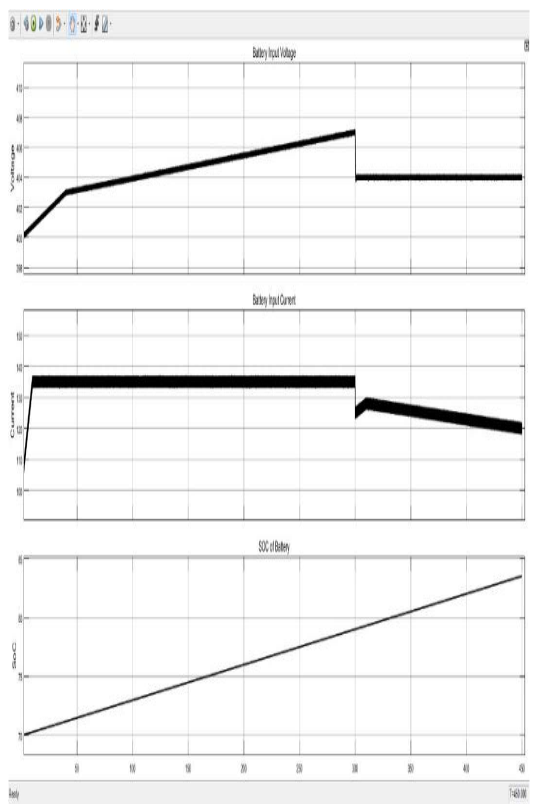

Fig 12 : Simulation Results Of (A) Input Voltage, (B) Input Current For Battery Charging And (C) SOC OfBattery During Charging.

8.CONCLUSION

The proposed QZS based wireless power transfer fast charger has been demonstrated to show the charging of EV in both CC and CV modes. The detailed control technique is presented which explains the control of these two converters in cascade to achieve the desired response. Additionally, an extra section in flowchart is added to eliminate battery current transients during charging mode shift of EV. Simulation results validate the performance of the proposed qZSI based charger. Suitability of thisproposed converter is successfully demonstrated by smooth charging mode change (without transient) and low tracking ripple thereby making the system accurate as well as robust. Hardware results verify the main operation highlights of the two converters.

The simulation study focuses on wireless power transfer and quasi-Z-source inverter (QZSI) for electric vehicle charging, and it presents several intriguing results. Initially, the system efficiently transforms an input voltage of 440V AC into an increased voltage of 800V DC by using quasi-Z-source inverter (QZSI), showcasing its ability to handle high-power applications. The system's capacity to maintain voltage stability is demonstrated by the output voltage's ability to settle at a constant 540V despite this rise due to wireless power transfer across the transformer. Furthermore, the output voltage range's compatibility with the electric vehicle battery which typically operates within the 350–400V range ensures seamless integration with the current auto infrastructure. The efficiency of the system is furtherenhanced by its ability to respond to battery state of charge (SoC) levels by modifying charging parameters based on real-time battery data.
These results show how reliable and practical the recommended method is for wireless charging applications.

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