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Multifunctional and Integrated Onboard EV Charger

G.Laxman Nayak , J.Sanjay , S.Sai Ganesh , K.Nithin
Department of Electrical and Electronics Engineering,
Anurag University
Venkatapur, Ghatkesar, Hyderabad, Telangana, India, 500088

ABSTRACT:

This paper presents a multifunctional and integrated onboard electric vehicle (EV) charger that improves system efficiency, reduces component count, and supports bidirectional power flow. The proposed charger integrates Power Factor Correction (PFC), DC-DC conversion, and Dual Active Bridge (DAB) control to enable both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes. Simulation results validate high efficiency and compact design, making the system ideal for modern electric mobility solutions.

Keywords: EV Charger, PWM Rectifier, Dual Active Bridge, Totem-Pole PFC, V2G, G2V, MATLAB Simulation, Power Factor Correction

1)INTRODUCTION:

The adoption of electric vehicles (EVs) is rapidly increasing worldwide, driven by environmental concerns, advancements in battery technology, and supportive government policies. As EV penetration grows, the demand for efficient, compact, and intelligent charging systems has become more critical than ever. Onboard chargers (OBCs) serve as a vital component in this ecosystem, responsible for converting alternating current (AC) from the grid into direct current (DC) suitable for charging the vehicle's battery.

Traditional OBC architectures often rely on multiple isolated stages for power conversion, which not only increase the overall size, cost, and weight of the system but also reduce the overall efficiency. The proposed multifunctional and integrated onboard EV charger addresses these limitations by adopting a streamlined architecture that eliminates the need for separate isolated converters. This integration enhances the power density of the charger, reduces electromagnetic interference (EMI), and improves thermal management through consolidated design.

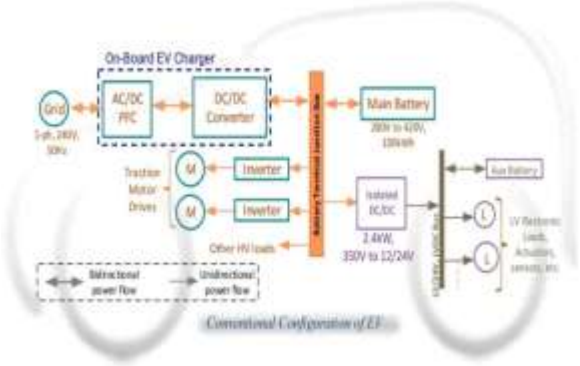


Fig-1 Block Diagram of EV Charger

Furthermore, the multifunctional nature of the proposed charger supports bidirectional energy flow, enabling both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operations. This feature allows the EV to act as a mobile energy storage unit, contributing power back to the grid during peak demand or outages—a key requirement for future smart grid infrastructures. It also facilitates Vehicle-to-Home (V2H) and vehicle-to-load (V2L) applications, offering power for auxiliary systems and emergency scenarios.

In addition, the integration of renewable energy sources such as solar or wind with this charger becomes more feasible due to its intelligent control and adaptable power conversion capabilities. By aligning with the goals of sustainable transportation and decentralized energy management, the proposed charger not only meets current technological demands but also paves the way for next-generation EV charging systems.

2) System Architecture and Functional Design:

- **Totem-Pole PFC:** Achieves near-unity power factor and significantly reduces harmonic distortion.
It replaces the traditional diode bridge with fast-switching transistors, improving conduction efficiency.
This topology is ideal for high-power applications and supports continuous conduction mode (CCM) operation.
As a result, it enhances input current waveform quality and meets stringent power quality standards.
- **RPC Integration:** Mitigates second-order ripple, enabling the use of smaller DC-link capacitors.
RPC dynamically compensates for power fluctuations caused by single-phase AC input.
By reducing stress on the DC-link, it enhances system reliability and lifetime.
It also helps maintain a stable output voltage, crucial for sensitive power electronics.
- **Dual Active Bridge Converter:** Enables bidirectional isolated power transfer with soft-switching capability for high efficiency.It consists of two full-bridge converters connected via a high-frequency transformer.
Zero Voltage Switching (ZVS) minimizes switching losses, making it suitable for bidirectional EV charging.
The DAB supports seamless transition between charging and discharging modes (V2G and G2V).
- **Interleaved Buck Converter:** Re-purposes PFC switches in drive mode to supply 24V for low-voltage (LV) auxiliary loads.
Multiple interleaved phases reduce input/output current ripple, enhancing dynamic response.
This improves thermal performance and reduces magnetic component sizes.
It's a compact and efficient solution for powering auxiliary EV systems like lights and control units.

2. Operating Modes: There are two types of operating modes

A. Grid-Connected Mode (G2V and V2G):

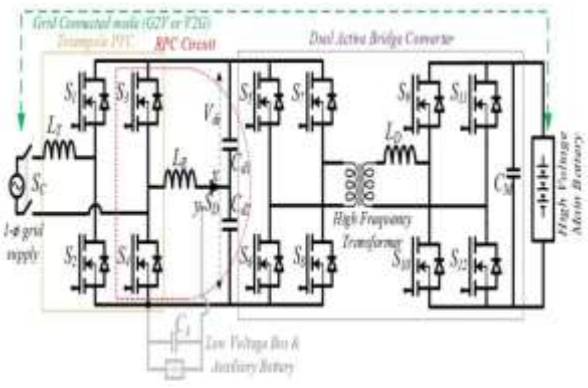


Fig-2:Operation in grid connected mode (G2V & V2G)

In this mode, the system pulls power from the AC grid (240V, 50Hz), rectifies it through the Totem-pole PFC, and delivers regulated DC via the DAB. V2G is achieved by reversing the power flow through the same path. The RPC branch compensates for second-order harmonics without bulky electrolytic capacitors

B. Driving Mode (V2L):

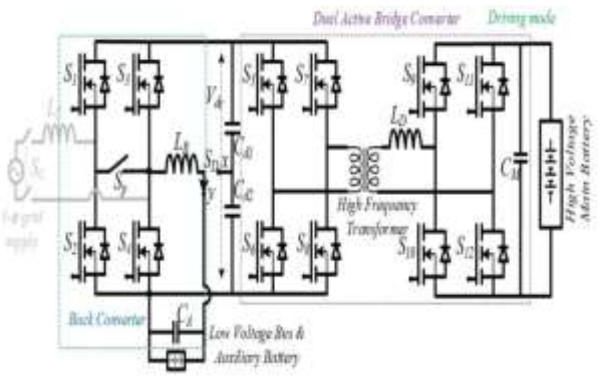


Fig-3:Operation in driving mode(Forming buck converter)

In vehicle motion, the DAB generates a 72V bus from the HV battery. The interleaved buck converter, formed from reused PFC legs, steps down voltage for 24V auxiliary loads. This mode ensures minimal switching losses and balanced current distribution.

3. Advanced Rectifier Integration:

A)Single-Phase PWM Rectifier:

A single-phase PWM rectifier is a power electronic converter that converts alternating current (AC) to direct current (DC) using pulse-width modulation (PWM) techniques. Unlike passive diode rectifiers, it actively controls input current wave forms to achieve near-unity power factor, low harmonic distortion, and bidirectional power flow (in some topologies).

- **Matlab Simulation:**

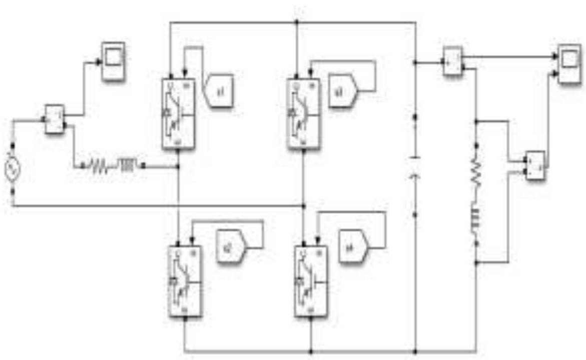
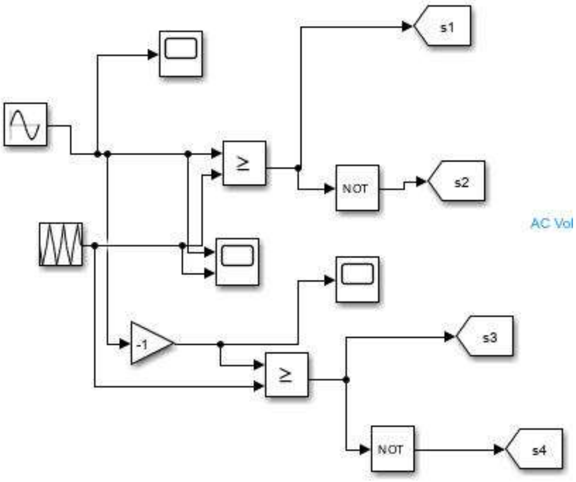


Fig-4:Single Phase PWM Rectifer

1) Full-Bridge Topology: Four switching devices (e.g., IGBTs) Arranged in an H-bridge configuration.
2)AC Inductor: Smooth-ens input current and enables energy transfer.
3)DC Link Capacitor: Filters and stabilizes the output DC voltage.
4)Control System: Monitors input current and DC voltage, adjusting PWM signals to maintain desired performance.



- **Logic circuit:**

Fig-5:Single phase PWM rectifer logic circuit

1) It consists of " Sine wave as reference wave "and "Triangular wave as carrier wave".
2) The modulation index for sine wave is "0.8" and frequency is "2*pi*50".
3) In carrier wave the switching frequency arranged is 10khz
4) In FFT Analyzer the harmonics are doubled the switching frequency

Results:

The output of current and voltage.

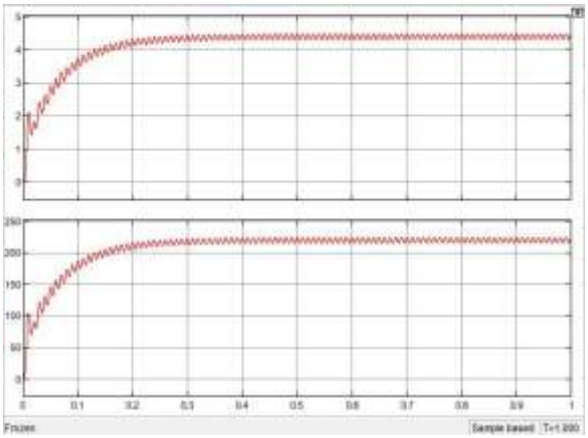


Fig-6:(Single phase PWM rectifer results)

B) Three-Phase PWM Rectifier:

A three-phase PWM rectifier is a power electronic converter that converts three-phase alternating current (AC) to regulated direct current (DC) using Pulse Width Modulation (PWM) techniques. It employs active semiconductor switches (e.g., IGBTs, SiC MOSFETs) to achieve precise control over input currents and output voltage, enabling high power quality, bidirectional power flow, and near-unity power factor. It is widely used in industrial and renewable energy systems due to its efficiency and flexibility.

- **Matlab simulation:**

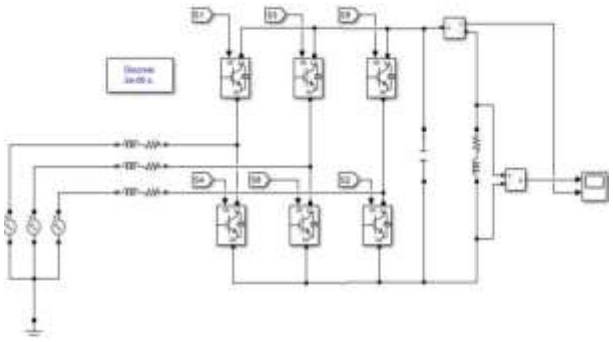
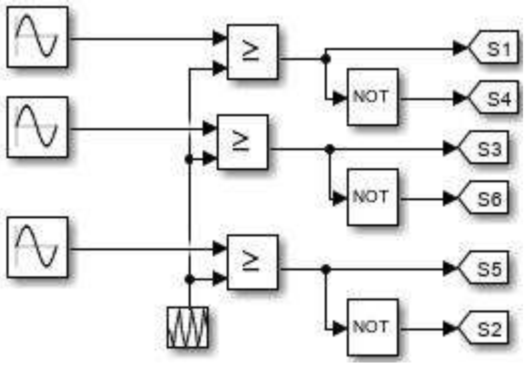


Fig-7: Three phase PWM Rectifier



- **Logic circuit:**

Fig-8: Three Phase PWM Rectifier Logic Circuit

The logic circuit in a three-phase PWM rectifier primarily controls the switching of power devices (IGBTs/MOSFETs) to regulate DC voltage, power factor, and input current waveform. It consists of three main functions.

1)PWM Signal Generation – Produces PWM pulses to control six switches (IGBTs/MOSFETs) using SPWM or SVPWM techniques.

2)Feedback Control – Monitors DC voltage and input current, adjusting duty cycles for voltage regulation and power factor correction (PFC).

3)Protection & Fault Handling – Detects over voltage, over current, and faults, automatically disabling switches to prevent damage.

Result:

Output of voltage and current

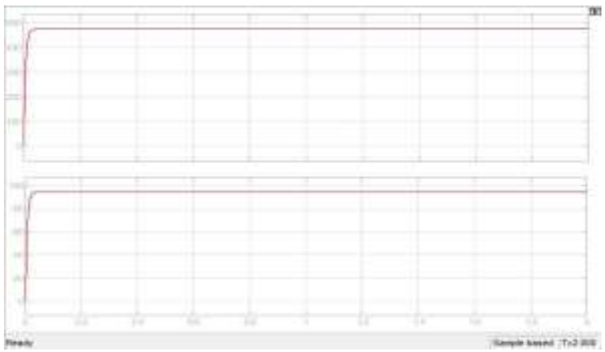


Fig-9:(Three phase PWM rectifier result).

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5) Dual Active Bridge (DAB) Design:

The Dual Active Bridge (DAB) converter is a widely studied and increasingly popular
topology in the realm of power electronics due to its excellent performance in high-efficiency and high-power applications, particularly for DC-DC conversion. It has proven its effectiveness in a range of applications like renewable energy systems, electric vehicle (EV) charging, and
energy storage systems. The DAB converter operates on the principle of isolated power transfer through a high-frequency transformer, with active voltage-source inverters on both the primary and secondary sides of the transformer. This configuration enables efficient power conversion while maintaining electrical isolation between the input and output.

➢ **Matlab simulation:**

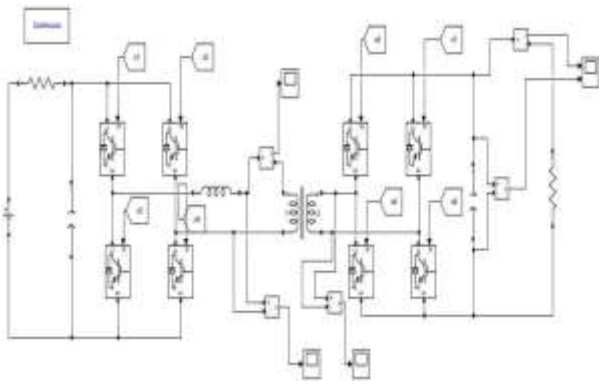

Fig-10:Dual Active Bridge Rectifier
□ Primary and Secondary H-Bridges (Active Switches) :
1) Each side of the DAB converter (primary
2) and secondary) consists of an H-bridge made
up of four power semiconductor switches (typically MOSFETs or IGBTs).
2)These switches generate AC wave forms from DC voltage and enable bidirectional
power transfer based on phase-shift modulation.
□ High-Frequency Transformer:
1)The high-frequency transformer provides galvanic isolation between the input and
output, ensuring safety and voltage level adaptation.
3) It enables voltage step-up or step-down, depending on the application.
□ DC-Link Capacitors :
1)DC-link capacitors are placed across the input and output of the converter to smooth
voltage fluctuations and provide energy buffering.
2)They help in reducing voltage ripples and ensure stable operation under varying loads.
□ Inductor (Leakage Inductance or External Inductor):
1)The leakage inductance of the transformer or an external inductor is crucial for energy
transfer and soft-switching (ZVS/ZCS).
2)It helps in shaping the current waveform and defining power transfer characteristics
during phase-shift modulation.
□ Control Circuitry :
1)A micro controller (MCU) or DSP-based controller is used to regulate the switching of
power devices, ensuring efficient power flow management.

□ Gate Driver Circuitry :

1)Gate drivers are responsible for providing the necessary voltage and current to switch the MOSFETs/IGBTs efficiently.
2)They include isolated gate drive circuits to maintain electrical safety and avoid ground loops.

□ **Logic Circuit:**

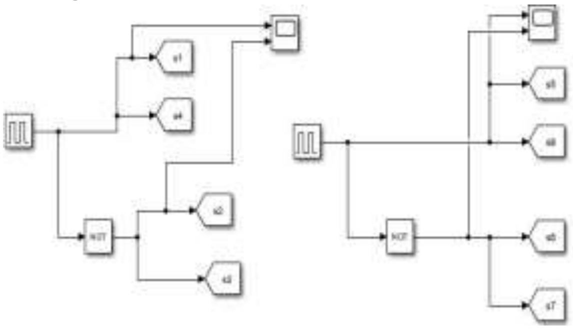

Fig-11:(DAB rectifier logic circuit)

- Controller Generates PWM Signals**:**

1)The DSP/FPGA generates PWM signals based on the required power transfer.
2)Phase shift is calculated dynamically depending on input/output conditions.

□ Phase-Shifted Signals Control H-Bridges**:**

1)The H-bridges on both the primary and secondary sides receive phase-shifted switching signals.
2)This allows AC voltage to be generated from DC sources.

- Gate Drivers Amplify Signals**:**

1)The low-power logic signals are boosted to high-power gate drive signals.
2)These signals control the switching of MOSFETs or IGBTs.

- Power Flow is Managed Dynamically**:**

1)Forward power transfer**:** Phase shift is adjusted to transfer energy from the primary to the secondary side.
2)Reverse power transfer**:** Phase shift is reversed, allowing power to flow from the secondary to the primary.

- Feedback Circuit Optimizes Performance**:**

1)Voltage and current sensors provide feedback to the controller.
2)If voltage ripples, power losses, or faults are detected, adjustments are made in real time.

□ **Result:**

Output of current and voltage

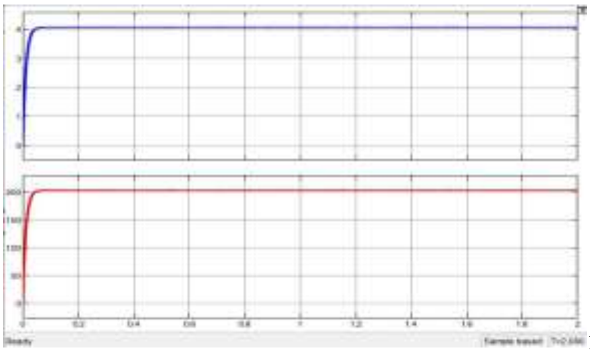

fig-12: (DAB rectifier results)

6) CONCLUSION:

The adoption of Pulse Width Modulation (PWM) rectifiers in multifunctional on-board electric vehicle (EV) chargers has significantly enhanced their efficiency, reliability, and bidirectional energy management capabilities. PWM rectifiers play a crucial role in enabling high power factor correction (PFC), reduced total harmonic distortion (THD), and bidirectional power flow, making them a key technology in next-generation EV chargers. These rectifiers ensure efficient AC-to-DC conversion while maintaining grid stability and reducing power losses, addressing critical challenges in EV charging infrastructure. One of the primary advantages of using PWM rectifiers in on-board EV chargers is their ability to achieve high power factor (close to unity) and minimize grid current harmonics. Unlike conventional rectifiers, which introduce high THD and reduce overall efficiency, PWM-based topologies ensure compliance with grid regulations (such as IEEE 519 and IEC 61000-3-2) by actively shaping the input current waveform. This leads to improved grid interaction and enhanced power quality, making them ideal for smart grid applications. Furthermore, the bidirectional operation of PWM rectifiers enables vehicle-to-grid (V2G) and vehicle-to-home (V2H) functionalities, allowing EVs to serve as mobile energy storage units.
This capability enhances grid resilience by supplying power during peak demand periods, reducing dependence on traditional energy sources.

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