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Design of DAB - IBDC for Extreme Fast Charging of Electric Vehicles

M Siddarth, M Madhu Sudhan, Y Vijay Kumar, M Bhavya, Devunuri Sai Koushik, V. Dhanunjaya, B Ravindhar and K Hareesh Kumar
Electrical and Electronics Engineering
B V Raju Institute of Technology
Narsapur, Medak, Telangana, India
21215a0204@bvrit.ac.in, vijaykumar.@bvrit.ac.in, 20211a0255@bvrit.ac.in, 20211a0242@bvrt.ac.in, dhanunjaya.v@bvrit.ac.in, hareeshkumar.k@bvrit.ac.in, , ravindhar.b@bvrit.ac.in, 22215a0345@bvrit.ac.in

Abstract

With rising concerns over climate change and fuel costs, electric vehicles (EVs) have garnered significant interest for personal transportation due to their clean and eco-friendly advantages. However, EVs face a key limitation: restricted driving range, which can't be easily expanded by simply increasing battery size, as this adds weight and reduces efficiency. Addressing this challenge, this project explores the critical role of Extreme Fast Charging (XFC) in enhancing EV reliability and proposes a Dual Active Bridge (DAB) Isolated Bidirectional DC-DC Converter (IBDC) tailored for high-power charging applications. Despite existing state-of-the-art fast-charging solutions, a gap remains in delivering efficient and stable power conversion for XFC in EVs. The primary objective is to develop a converter that maximizes charging efficiency and power stability through three distinct phase shift strategies—single phase shift, extended phase shift, and dual phase shift. Using these configurations, the DAB IBDC design ensures bidirectional power flow and galvanic isolation, meeting XFC requirements. Key findings from detailed simulations demonstrate that each phase shift approach optimizes converter efficiency, power quality, and stability differently, with the proposed method showing improvements in overall performance. These findings have significant implications for reducing EV range limitations and enhancing the viability of EVs as a reliable alternative to traditional vehicles.

Keywords
Keywords-DAB-IBDC, electric vehicle, Internal Combustion Engine (ICE), Extreme Fast Charging (XFC)

1.Introduction
To achieve voltage matching and galvanic isolation Power conversion systems (PCSs) mainly employ line- frequency (LF) transformers (Song and Huang, 2005, Bendre et al. 2003, Gu et al. 2013, Li et al. 2003, De et al, 1991, Krismer and Kolar 2006). The growing acceptance of PCSs as a permanent essential interface, along with the quick advancement of distributed generation and energy storage, has led (Schibli 1999, Zhou and Khambadkone 2009, Bai and Mi, 2008, Myoungho Kim ,Rosekeit 2011, Wang 2009, Feng , 2011).

Our Objective is to design a simulation model for the Dual Active Bridge Isolated Bidirectional DC-DC Converter (DAB IBDC) to investigate and analyze the impact of different phase shift configurations on charging efficiency. The goal is to identify the optimal phase shift strategy that maximizes power transfer while minimizing losses during extreme fast charging scenarios. Through a comparison of extended, single, and dual phase shift configurations, the study aims to understand their respective advantages and limitations, ultimately determining how each configuration affects converter performance, efficiency, and overall system dynamics.

A comparison image of the 20-kHz HF and 50-Hz LF transformers is displayed in Figure 1. Low cost, light weight and low volume are the advantages of HF transformers. Furthermore, the core saturation of LF transformers can result in distortion of the voltage and current waveforms, which can be avoided by high-frequency-link (HFL) PCSs based on HF transformers. Additionally, PCS noise can be significantly decreased when the switching frequency is higher than 20 kHz. With the fast growth of PCS, HFL- PCSs have a wide range of potential applications. IBDC topologies for HFL-PCSs come in a wide variety.

The DAB-IBDC has the highest power capacity since, for instance, the power capacity of a four-switch IBDC is double that of a dual-switch IBDC but only half that of an eight-switch IBDC. Additionally, from the perspective of the filter, full-bridge half-bridge, and the push-pull, converters' output pulsation frequencies are double those of the forward converters, meaning that with the same output voltage, the DAB-IBDC filter is likewise small.

Bidirectional power transfer capability, Soft-switching, symmetric structure, and realizing modularity are the advantages of DAB-IBDCs, so in recent years they have been attracting more and more attention. For next- generation HFL PCSs, DAB-IBDC will serve as the core circuit in 2007.

On the following factors, DAB-IBDC mainly focuses: hardware design and optimization, soft-switching solution and variant, control strategy, and basic characterization. For HFL PCSs, future trends based on the typical applications of DAB-IBDC will be discussed. We first proposed the typical applications of DAB-IBDC, which will be discussed. The bidirectional power conversion converter has now become the most popular topology, and its applications are uninterruptible power systems (UPS), energy storage systems (ESS), micro grid applications and electric vehicles (EVs) (Krismer and Kolar 2006).

With climate change and rising fuel prices on the horizon, electric vehicles (EVs) are gaining popularity for eco-friendly personal transportation. Yet, EVs face a challenge – limited range. Simply adding more batteries isn't the solution due to added weight and reduced efficiency. This project aims to make EVs are liable alternative to traditional cars by focusing on fast charging. We're designing a special converter, the Dual Active Bridge Isolated Bidirectional DC-DC Converter (DAB IBDC), for Extreme Fast Charging (XFC) in EVs. Our converter stands out with three unique phase shift configurations – single, extended, and dual phase shifts.

These are chosen carefully to optimize high-power EV charging. Using the bidirectional power flow and galvanic isolation of the DAB IBDC, we aim to meet the demands of Extreme Fast Charging. Through detailed simulations, we're evaluating each phase shift's impact on efficiency, power quality, and system stability. The ultimate goal is to overcome EV range challenges, reducing range anxiety by creating an efficient Extreme Fast Charging solution. This project not only pushes the boundaries of EV technology but also aligns with global efforts for sustainable transportation.

2. Methodology

In existing article, we introduce clamping diodes and resonant inductance. A zero-voltage-switching (ZVS) full-bridge converter can remove the voltage oscillation across the rectifier diodes and increase the load range. The inductance of the resonant is shorted, and when the clamping diode is conducting, its current stays constant. If the output filters, the inductance is relatively larger, causing significant reverse recovery loss and it is hard turned off. In addition to lowering conduction losses, the reset winding prevents reverse recovery and causes the clamping diodes to naturally shut off. An analysis is conducted on the suggested converter's operation concept. It is discussed how the transformer's turn ratio is designed. To confirm the working principle, a 1 kW prototype converter is constructed, and the experimental findings are also presented (Song and Huang, 2005).

We present a novel isolated high-frequency, high- power DC-DC converter complete bridge topology that employs one resonant "soft" switching pole with zero- voltage switching and one phase-shifted hard switching pole with loss-limited switching for primary switching. Due to the finite energy stored in the leakage inductance, the devices in the loss-limited pole show substantially lower losses than typical hard switching, even if they lack resonant capacitors across them. All primary devices have lower switching losses thanks to this special mix of loss-limited switching and zero-voltage switching. Excellent control over reverse recovery energy is made possible by a unique non dissipative secondary rectifier clamp. Commercially available converters capable of producing 128 kW at 25 kHz have been created. This design is easily scalable to greater power levels because it shows total control over all parasitic loss mechanisms (Bendre et al. 2003).

This study offers a hybrid-switching step-down dc-dc converter initially, and then it derives a novel hybrid- switching phase-shift full-bridge dc-dc converter for electric vehicle battery chargers by introducing transformer isolation. In order to avoid freewheeling circulating losses in the primary side, the proposed converter uses a hybrid switching technique. It also provides a wide range of zero- current and zero-voltage switching for lagging-leg and leading-leg switches. The efficacy of the suggested converter was confirmed by experimentation with a 3.6-kW prototype circuit intended for on board chargers for electric vehicles. The hardware prototype's experimental findings demonstrate that the converter maintains high system efficiencies and a peak efficiency of 98.1% throughout an extensive range of output power and voltage.

A novel isolated, bidirectional DC-DC converter is presented in this study. An example of a common use for this converter is in the auxiliary power supply of electric hybrid cars. Using the fewest amounts of devices possible, a dual half-bridge topology has been created to accomplish the necessary power rating. Without the use of additional switching components, resonant elements, or a voltage- clamping circuit, unified zero-voltage switching was accomplished in both directions of power flow. Compact packaging, effective power conversion, and great power density are made possible by all these new features. This document includes detailed explanations of the operating concept and design requirements. To forecast the converter's small and large signal characteristics in both directions of power flow, an extended state-space averaged model is created The created averaged model, simulation analysis, and soft-switching operation are validated by the experimental findings of the converter's steady-state operation. (Li et al. 2003)

For high power density high-power applications this paper presents three dc/dc converter topologies suitable. Low R.M.S current ratings are achieved for both the input and output filter capacitors, in contrast to single phase ac link dc/dc converters that are currently on the market. The input and output waveforms' greater frequency content results in smaller filter element values in addition to this. Additionally, the power density achievable can be greatly increased by using a three-phase symmetrical transformer rather than a single-phase transformer and by making greater use of the apparent power that is available (De et al, 1991).

The primary goal of this work is to enhance the wide voltage range operation of high current dual active bridge converters. Fuel cell vehicles are a common application where a high voltage DC bus and a 12V battery need to communicate bi-directionally. A thorough examination indicates that major design problems are brought about by the large battery side currents, which are necessary to achieve high efficiency. High conduction and switching losses may arise from using the conventional phase shift modulation technique. In order to lower losses over a broad working range, this research suggests a combined triangular and trapezoidal modulation technique. One could expect a gain in efficiency of about 2% (Krismer and Kolar 2006).

2.1 Existing Methodology

The Single Phase Shift (SPS) and Dual Phase Shift (DPS) control methodologies are foundational in DAB converter applications, each with its unique control approach. In SPS, a single phase shift angle between the voltage waveforms of the primary and secondary bridge controls the power transfer. By adjusting this angle, SPS regulates the direction and magnitude of power flow between the bridges. Although straightforward, SPS lacks flexibility in managing load variations and generates high circulating currents, which reduce efficiency under partial or light-load conditions.

DPS, on the other hand, enhances control by introducing an additional phase shift within each bridge, effectively creating two adjustable phase shift angles. One phase shift controls the primary bridge, while the other governs the secondary bridge, allowing DPS to independently regulate power transfer and manage circulating currents. This added flexibility reduces losses and improves efficiency over a broader range of operating conditions, making DPS more suitable for variable loads. However, the complexity of DPS's dual-phase control requires more advanced control algorithms and hardware, as it introduces a higher degree of interaction between the bridge legs. Together, SPS and DPS address different operational needs, with SPS focusing on simplicity and DPS on enhanced efficiency and control flexibility.

2.2 Proposed Solution

Extreme Fast Charging (XFC) in electric vehicles (EVs) represents a major leap forward, enabling EVs to recharge in as little as 10–15 minutes, similar to the time it takes to fill a gasoline tank. To achieve this rapid charge rate, XFC relies on high-power charging stations and advanced power conversion technologies that safely deliver large amounts of energy in a short period. This process involves high-power DC-DC converters, such as the Dual Active Bridge (DAB) architecture, which enables efficient and bidirectional power flow while maintaining galvanic isolation between the EV and the charging station. XFC chargers also incorporate sophisticated thermal and battery management systems (BMS) that monitor battery state and temperature to prevent overheating and ensure safety. These management systems are essential in preserving battery health and longevity under the stress of high charging currents. The advantages of XFC include dramatically reduced charging times, which alleviate range anxiety and make EVs more convenient for everyday and long-distance travel. Additionally, by establishing high-power stations along highways and urban centers, XFC provides a robust charging network that improves EV accessibility and user experience. Furthermore, XFC can be integrated with renewable energy sources and potentially support vehicle-to-grid (V2G) capabilities, allowing EVs to supply power back to the grid during peak times, which contributes to energy stability. This technology thus not only enhances the practicality of EVs but also fosters a more sustainable energy ecosystem.

2.3 Circuit Diagram of Dual Active Bridge-Isolated Bidirectional DC-DC Converter

Importance of DC-DC Converters

Due to the harmful environmental effects of fossil fuels, the limited availability of all conventional power sources, and the inefficient generation of power plants, there is an increasing need for clean energy on a daily basis. However, because of their high reliance on environmental conditions, renewable energy sources (RESs) are not able to function as independent power-generating units. One of the primary and practical solutions to this issue is to combine various RESs, which is impossible without power electronic converters.

Types of DC - DC Converters

DC-DC converters can be categorized based on various criteria, such as their voltage gain (bucks or boost mode) and the region of their operational characteristics on the I-V plot. For instance, a 2-quadrant converter, which operates bi-directionally and is particularly beneficial for applications with constant voltage polarities like batteries, is an example. Another type of 2-quadrant converter works with a DC motor where the voltage polarity may change, but power transfer is always from input to output. On the other hand, a 4-quadrant converter becomes valuable when power transfer and voltage polarity need to be inversely controlled, as seen in applications like using a DC-DC converter with a DC motor requiring regenerative braking**.**

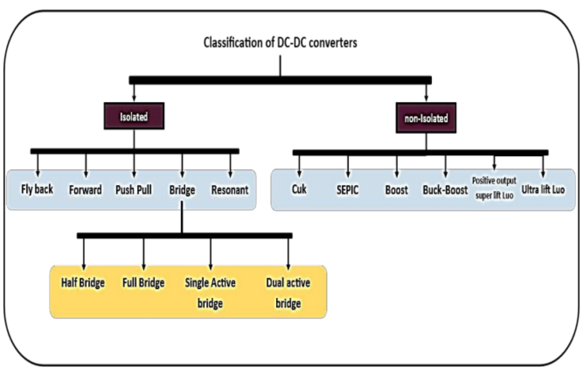

Figure 1. Classification of DC-DC Converters

The primary objective behind the utilization of insulated converters lies in their ability to achieve high gain, owing to the potential for a high transformer ratio. Depending on the specific converter topology, it becomes feasible to attain either positive or negative output polarity. Conversely, non-insulated topologies, while characterized by fewer components, lack galvanic isolation.

Advantages of Isolated DC-DC Converters in EV

Isolated DC-DC converters play a crucial role in electric vehicles (EVs), offering several advantages that contribute to the efficiency and reliability of the overall system. One key benefit is galvanic isolation, which ensures electrical separation between input and output circuits. This feature enhances safety by preventing potential ground loops and reducing the risk of electrical faults. Additionally, isolated converters facilitate voltage matching between different components in the EV system, allowing for optimal power transfer and preventing damage to sensitive electronics. Moreover, they enable flexible design configurations, supporting various voltage levels and topologies to accommodate the diverse requirements of EV power systems. Isolated DC-DC converters also aid in minimizing electromagnetic interference (EMI) and improving system robustness by isolating noise and disturbances from the high-voltage traction system. In summary, the advantages of isolated DC-DC converters in EVs encompass safety, efficient power transfer, flexibility in design, and enhanced system resilience.

Disadvantages of Isolated Dc-Dc Converters in EV

Isolated DC-DC converters in Electric Vehicles (EVs) bring certain advantages, such as galvanic isolation that helps enhance safety and reliability. However, they are not without their disadvantages. One notable drawback is the additional weight and volume associated with the isolation components, primarily transformers and inductors, which can contribute to reduced overall efficiency and increased manufacturing costs. The size and weight of these components are crucial considerations in the automotive industry, where minimizing both is paramount for achieving optimal performance and extending driving range. Additionally, the isolation components introduce complexities in terms of thermal management, as they may generate heat during operation. This necessitates the incorporation of additional cooling systems, adding further weight and cost to the overall EV design. Moreover, the presence of galvanic isolation can limit the achievable power density of the converter, impacting its ability to meet the compact size requirements of modern EVs. Balancing the advantages of isolation with these drawbacks remains a key challenge in the design and implementation of isolated DC-DC converters in the context of Electric Vehicles**.**

Dual Active Bridge Converters

In Figure 2- Figure 11 shows the dual active bridge (DAB) topology. There are 3 main parts of DAB. An inductance, An H-bridge on the secondary side, and an H-bridge on the primary side. Due to its set switching frequency, zero voltage switching, buck-boost capabilities, and bi-directionality, which facilitates filter design, DAB is widely used.

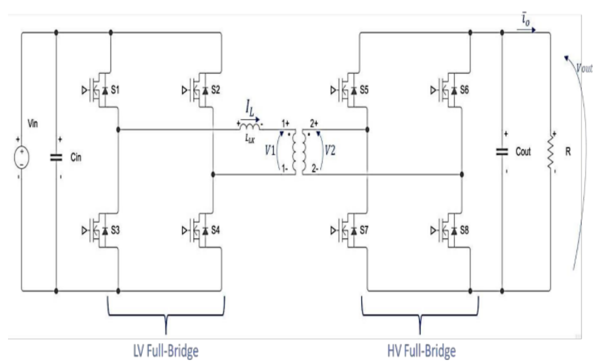

Figure 2. DAB Topology

Extreme Fast Charging (XFC)

In an AC Bus Connected System for electric vehicle (EV) charging, the approach involves introducing additional conversion stages between the distribution network and DC charging ports. This design choice brings both advantages and challenges to the charging infrastructure. One notable advantage is the utilization of matured technology for inverters and AC switchgears, contributing to system reliability and efficiency. Existing standards for AC Bus Extreme Fast Charging (XFC) stations, exemplified by well- established facilities like Tesla superchargers in the USA and ABB fast charging stations in Australia, further support the viability of this approach. However, it's essential to consider that each charging port in this system requires an AC/DC converter, potentially increasing the overall cost of the charging station. Striking a balance between the benefits of standardized technology and the potential cost

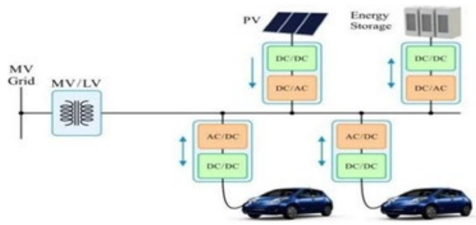

Figure 3. Ac Bus Connected System

implications remains a crucial aspect in the ongoing development of AC Bus Connected Systems for EV charging infrastructure.

DC Bus Connected System

The DC Bus Connected System for electric vehicle (EV) charging stands out with its streamlined approach, employing a single central front-end AC/DC conversion stage to establish a DC bus. This singular conversion stage not only boosts the overall efficiency of the system but also contributes to a potential decrease in overall costs. The simplicity of having a single inverter connection with the grid facilitates easier islanding from the main grid, enhancing the operational flexibility of the charging infrastructure.

Another advantageous feature of the DC bus is the utilization of partial converters, which process only a fraction of the power transferred to the vehicle, thereby reducing the ratings of switches and optimizing the overall design. However, it's crucial to acknowledge that DC systems come with their set of limitations, including challenges related to DC protection and metering. The sensitivity of DC systems to disturbances, coupled with the potential for instability without rapid fault clearance, underscores the importance of robust design and protective measures in ensuring the reliability of DC Bus Connected Systems for EV charging. Balancing the advantages with these considerations remains pivotal in advancing the effectiveness of DC-based EV charging infrastructure.

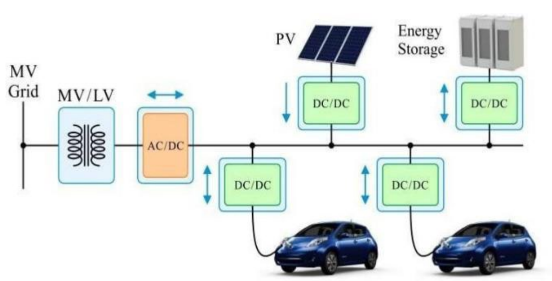

Figure 4. Dc Bus Connected System

3. Result

Here we used Matlab-Simulink software for performance analysis of the proposed work.

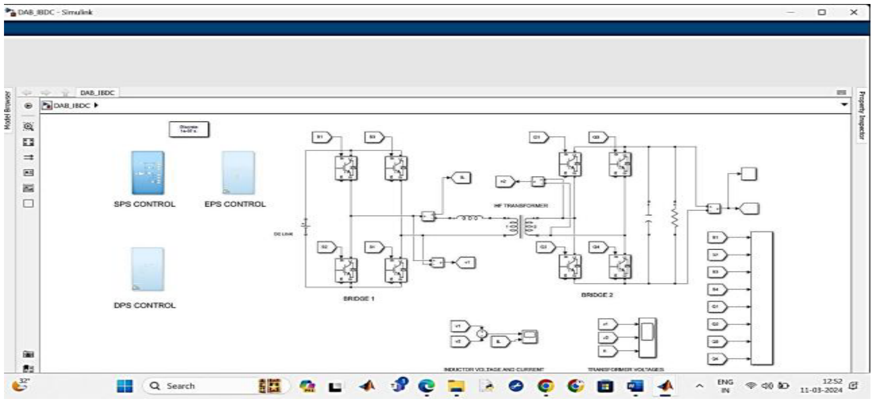

Figure 5. Simulink Model of Proposed System Simulation Results with SPS CONTROL

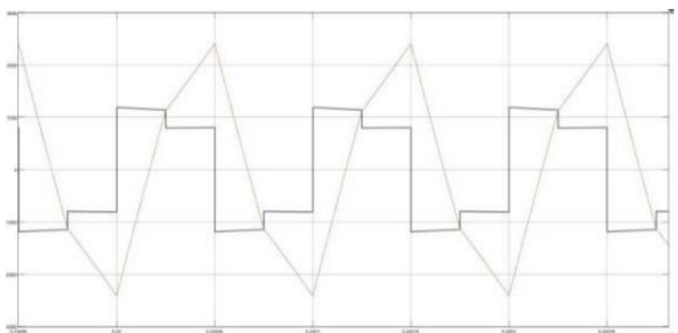

Figure 6. Voltage across leakage inductor and current
Black color: Load Voltage
Brown color: Load Current

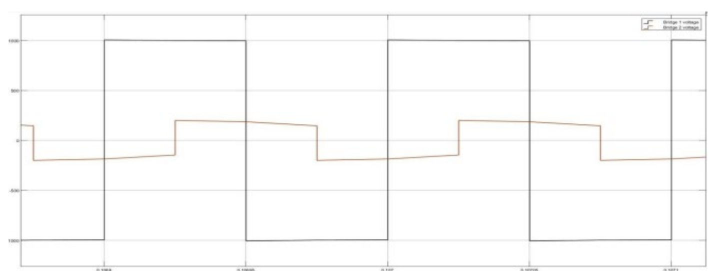

Figure 7. AC voltage output of Bridge 1 and 2
Black color: Load Voltage
Brown color: Load current

Simulation Results with EPS CONTROL:

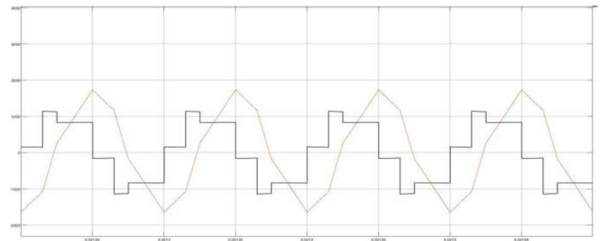

Figure 8. Voltage Across Leakage Inductor and Current.
Black Color: Load Voltage
Brown Color: Load Current

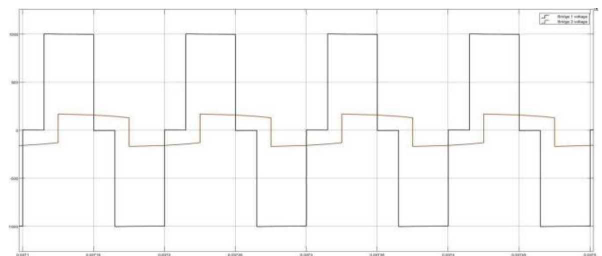

Figure 9. AC Voltage Output of Bridge 1 And 2
Black Color: Load Voltage
Brown Color: Load Current

Simulation Results with DPS CONTROL:

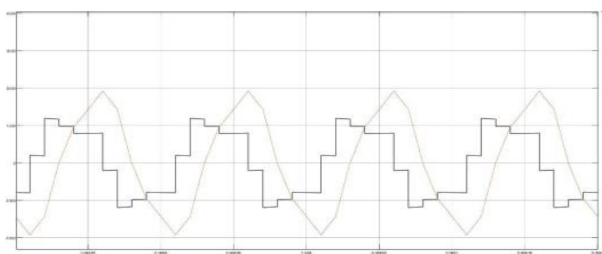

Figure 10. Voltage Across Leakage Inductor and Current.
Black Color: Load Voltage
Brown Color: Load Current

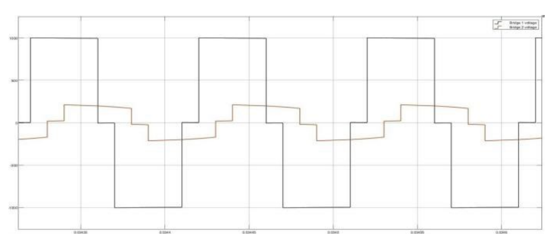

Figure 11. AC Voltage Output of Bridge 1 And 2
Black Color: Load Voltage
Brown Color: Load Current

4. Conclusion

In the recent years due to growing concerns about the climate change and increase in fuel prices, EVs are gaining more attention, especially in the segment of personal mobility. Despite of its clean nature there are many limitations. The biggest limitation of an electric vehicle is its limited range. To increase the range of the vehicle, we can't increase the battery size because that will increase the weight of vehicle and reduces overall efficiency. Fast charging will eliminate the range anxiety make it a reliable alternative of ICE vehicles. This project focuses on the design and analysis of a Dual Active Bridge Isolated Bidirectional DC-DC Converter (DAB IBDC) for Extreme Fast Charging (XFC) applications in Electric Vehicles (EVs). This involves three distinct phase shift configurations-single phase shift, extended phase shift, and dual phase shift to optimize the charging process and enhance the performance of high-power EV charging systems. The DAB IBDC architecture, known for its bidirectional power flow capabilities and galvanic isolation features, is strategically employed to meet the demanding requirements of Extreme Fast Charging. Through simulation, each phase shift configuration is systematically evaluated for its impact on converter efficiency, power quality, and overall system stability. Proposed model provides better solution for fast charging of EV than state of art techniques.

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Biographies

M. Bhavya, M. Siddarth, M. Madhu Sudhan, and Devunuri Sai Koushik are undergraduate students at B V Raju Institute of Technology (BVRIT), Narsapur. Their academic interests include power electronics, dual active bridge (DAB) converters, and electric vehicle (EV) charging technologies.

Y. Vijay Kumar, currently pursuing Ph.D. at NIT Warangal, graduated with a Bachelor's degree from NITS, Miryalaguda, in 2010. He completed his M. Tech in Power Electronics from SVEC, Suryapet, in 2014. Since 2016, he has been working as an Assistant Professor at B V Raju Institute of Technology (BVRIT), Narsapur, where he contributes to both teaching and research. His research interests include power electronics, dual active bridge converters, electric vehicle (EV) charging, and automotive electronics.

Ravindhar Banothu graduated with a Bachelor's degree from SVEC, Suryapet, in 2008. He completed his M. Tech in Alternate Hydro Energy System from IIT Rourke, in 2010. Since 2016, he has been working as an Assistant Professor at B V Raju Institute of Technology (BVRIT), Narsapur, where he contributes to both teaching and research. He is currently pursuing a Ph.D. at University College of Engineering(A), Osmania University Hyderabad. His research interests include Integration of Renewable Energy systems, Distribution System, small-scale hydropower and wind energy conversion systems. Micro grid design, optimization, Battery Management Systems

V Dhanunjaya is an Assistant Professor in Electrical and Electronics Engineering at BVRIT, Narsapur. At present he is pursuing Ph.D. at KL UNIVERSITY, Hyderabad. He completed his M. Tech (Power Electronics) and B. Tech Electrical Engineering from JNTU Hyderabad. He worked as an Assistant Professor at Aurora Scientific Technology Research Academy, Hyderabad for 2years.Since 2014, he holds Assistant Professor at BVRIT, Narsapur. His research interest is on Power Electronics, dual active bridge converters, electric vehicle (EV) charging.

K. Hareesh Kumar is an Assistant Professor at BVRIT, Narsapur in Electrical and Electronics Engineering Department. At present he is pursuing Ph.D. at NIT Surat. Completed his M. Tech (Power Electronics) NIT Warangal and B. Tech Electrical Engineering from JNTU Hyderabad. Since 2016, he is working as Assistant Professor at BVRIT, Narsapur. His research interest is on Power Electronics, dual active bridge converters, electric vehicle (EV) charging.