Vehicle to Vehicle Power Transfer using Dual Active Bridge Converter.

Under the Guidance of Professor Dr.R. K. Mishra

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ABSTRACT

In today's fast moving world the number of EVs are increasing and so the charging technology, consumers continue to show concern about various shortcomings within the Electric Vehicle Sector. These concerns include battery longevity, the availability of charging stations, the capacity of the electric grid, the restricted driving range, and the slow pace of battery charging. While solutions have been proposed to address these limitations, they do not meet the expectations in terms of cost effectiveness and efficiency. Furthermore, the challenge of on-road EV charging persists and necessitates further innovative solutions.
Recent literature has focused on analyzing power electronics topologies to facilitate successful V2V power transfer, particularly through the utilization of the Dual Action Bridge.
Additionally, technologies relevant to V2V communication were examined, with an emphasis on their potential applications to improve transportation safety and efficiency.
The report shows our study related to the challenges faced by existing Vehicle to Vehicle power transfer solutions and exploring some new solutions present for implementing Vehicle to Vehicle Charging Technology.
This exploratory project report provides an comprehensive overview of V2V energy transfer, highlighting implications for the future of sustainable electrified transportation.

Acknowledgement — We would like to thank Prof R. K. Mishra for his valuable inputs and constant guidance throughout the project timeline which helped shape our idea

I. INTRODUCTION

In the face of growing concerns about pollution caused by gasoline vehicles and their impact on climate change. The transportation industry is experiencing a rapid transition from gasoline vehicles to electric vehicles.
The development of electric automobile industry can significantly reduce carbon dioxide emissions and energy consumption. However, certain challenges such as battery life, charging speed, availability of charging stations and journey time limit the profitability of the electric car sector.
In other words, one of the biggest challenges for widespread adoption of electric cars among people is their limited range, consumers fear finding themselves with
.
discharged battery during long journeys without charging stations. To solve this problem, charging stations have been installed in cities and some remote areas
Also, the number of charging stations are not enough to sustain large number of electric vehicle through out the country. In far areas, the charging stations are very less and very far from other and also there installation is not economical .
One of the other solution is to charge one electric vehicle from other in an emergency situation. In this method, Vehicles can share some percentage of the energy of there batteries to help other vehicles in emergency mode

II. CURRENT CHARGING METHODS FOR ELECTRIC VEHICLE

EV charging technologies can be studied according to various factors such as

- *Battery charging method.*
- *Direction of power flow.*
- *Charger type (on-board/off-board).*
- *Power supply procedure.*
- *State of Charge(SOC)*
- *Power Rating of battery*

EV charging systems are designed to meet the unique needs of different places and situations. At the heart of these systems are EV supply equipment's, which allow electric vehicles to connect with the local power grid. Chargers can either be onboard or offboard, using AC or DC power to link EVs with the grid. Most chargers in use today send power one way from the grid to the vehicle because they're simple, reliable, cost-effective, and easy to control. But bidirectional chargers are gaining interest. They can send power back to the grid, enabling vehicle to grid functionality. These chargers act like mini power plants, helping balance loads, integrate renewable energy, and reduce grid losses. Which serves as a potential interest in a field of EV charging.

Today's EV chargers are smart. They use clever algorithms to charge and discharge batteries efficiently and manage power dynamically by controlling parameters mentioned above for both EVs and the grid containing required controllers which uses algorithms to minimize the losses and error extracted as a feedback provided by one EV and transfer the corrected output to another EV This not only saves energy but also reduces the burden on local power systems. To make sure EVs are universally compatible, there is a need to create a common standards for use of material and power used to charge EV.

Conductive charging involves a physical connection between the charging inlet and the vehicle, typically categorized into three levels: Level 1, Level 2, and Level 3. Level 1 chargers use a 120 V single-phase AC power supply and are suitable for slow charging, taking around 11-36 hours for a full charge. Level 2 chargers, commonly used in both private and public facilities, offer faster charging times (2-3 hours for a full charge) with power up to 19.2 kW. Both Level 1 and Level 2 chargers follow standardized connectors such as IEC62196-2 in Europe and SAEJ1772 in the USA.

Level 3 charging, also known as DC fast charging, delivers high-voltage DC power directly to the EV battery, typically ranging from 20 kW to 350 kW. This enables rapid charging, with times as short as 0.2-0.5 hours for a full charge. However, Level 3 chargers can put significant strain on the local distribution grid during peak times due to their high power usage.

Extrema fast charging (XFC) systems represent the pinnacle of fast charging technology, capable of delivering over 350 kW power with 800 Vdc internal DC bus voltage, resulting in battery recharging times of approximately 5 minutes. However, XFC systems require substantial investment and specialized infrastructure, making them economically feasible only for certain applications.

Additionally, charging modes defined by the International Electrotechnical Commission (IEC) provide standardized protocols for AC and DC charging systems. These modes range from slow charging (Mode 1 and Mode 2) to fast charging (Mode 3 and Mode 4), each offering different levels of safety, power delivery, and integration with the utility grid.

In summary, conductive charging technologies offer a range of options for EV owners, from slow overnight charging to rapid DC fast charging. Standardized connectors and charging modes ensure interoperability and safety across different charging infrastructure, while advanced technologies like XFC systems push the boundaries of charging speed and efficiency.

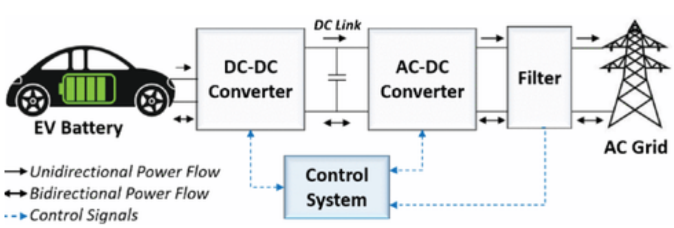


Fig 1. Conventional EV charging system

III. CURRENT DEVELOPMENT IN THE FIELD OF V2V CHARGING

Vehicle-to-Vehicle (V2V) charging stands as a revolutionary concept in electric vehicle (EV) technology, aiming to charge vehicles on-the-move. While the potential benefits are compelling, the path to realizing V2V charging is fraught with significant challenges that demand innovative solutions and concerted efforts.

One of the foremost challenges is efficiency. Maintaining high charging efficiency while vehicles are in motion presents a complex engineering problem. V2V systems must deliver consistent power to moving vehicles, accounting for varying speeds and distances. Achieving this without excessive energy loss or compromising vehicle performance is a formidable task.
Safety is another critical concern. V2V charging systems must operate seamlessly without interfering with vehicle operation or posing risks to road users. Ensuring that the technology is robust, reliable, and safe under real-world conditions is paramount to gaining public trust and regulatory approval.
Infrastructure poses yet another challenge Developing a network of V2V charging lanes or routes requires significant investment in infrastructure planning, design, and implementation. Establishing a reliable and accessible charging infrastructure that can support widespread adoption of V2V charging is a complex undertaking that requires collaboration between multiple stakeholders.
Standardization is also a pressing issue. With various V2V charging technologies and protocols in development, establishing industry standards is crucial to ensure interoperability and compatibility. Without standardized protocols, the market could become fragmented, hindering adoption and innovation.

In addition to infrastructure costs, the cost of equipping vehicles with V2V charging capabilities must also be considered. Integrating V2V charging technology into vehicles can increase manufacturing costs, potentially impacting vehicle affordability and consumer adoption rates.
Reducing the cost of V2V charging infrastructure and technology is essential to making it accessible to a broader range of users.

IV. DUAL ACTION BRIDGE

Dual Active Bridge (DAB) converters forms the switch mode power supplies, utilizes the concept of AC power transfer. Dual indicates two H-bridges, it is a bridge constructed with transistors hence the name is derived as active. DAB consists
of two controllable bridges, power is sent from one place to another by using AC voltages and currents.

The main configuration of DAB consists of two bridges connected via a transformer. In the first converter DC to AC conversion happens and in the second converter AC to DC i.e., rectification process happens.

Reasons to choose DAB:
- Wide voltage transfer ratio
- Circuit is isolated
- Zero voltage switching
- High power handling capability
- Bidirectional power transfer
- Current fed DAB

Applications of DAB:
- Photovoltaics
- Electric vehicle
- On-board charger
- Microgrid

Dual Active bridge converters are categorized into two types:
- Non-isolated Dual active bridge
- Isolated Dual active bridge

V. ISOLATED DUAL ACTIVE BRIDGE

This type of converter is used to in Electric Vehicle for galvanic isolation in between two H-bridges with the help of high frequency transformer. This achieve more flexible conversion gain. Practically, this type of topology is a bit more complex when compared to isolated DAB converter the
reason is DC voltage is provided to high frequency AC voltage and then rectify the high frequency AC voltage to DC voltage again

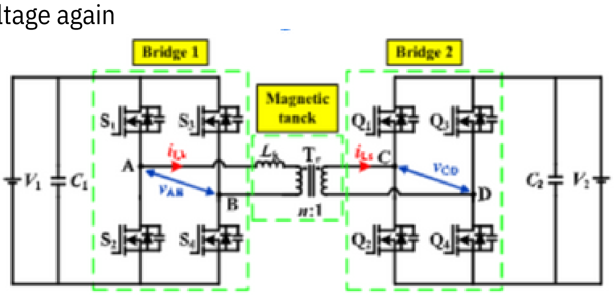


Fig 2. Dual Active Bridge Converter

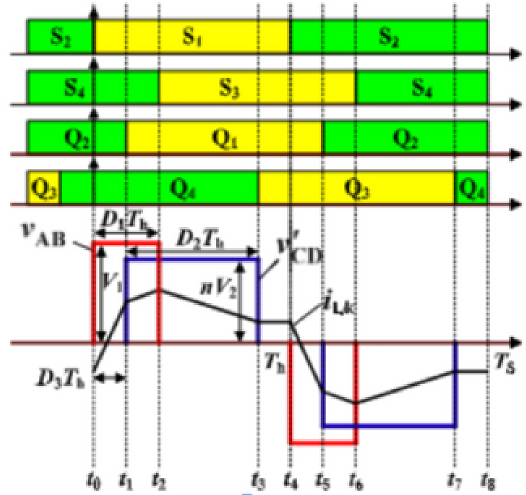


Fig3.Waveform of Output and Input

The waveforms of the Dual Active Bridge converter by using Phase Shift modulation is shown in the figure, where Vcd indicates the voltage between the secondary side . The three phase-shift angles (D1, D2, D3) are shown in the above figure, where D1 is the phase-shift angle between S1 and S4, D2 is the phase-shift angle between Q1 and Q4, and D3 denotes the phase-shift angle between S1 and
Q1.
It is Single Phase Shift modulation if D1 = D2 = 1,It can also be considered as the Extended Phase Shift modulation if D1 = 1 or D2= 1,
It can be considered as the DPS modulation if D1 = D2. As seen from the different arrangements under full, partial, and no overlaps, six operation modes and six corresponding complemented modes can be obtained, which are shown in the above table .The mode operation constraint are also shown .
The Maximum Transmitted power Pomax can be described as

$$\mathrm{Pomax} = \frac{nV_1V_2}{8LfsK}$$

TABLE I
MODE OPERATIONAL CONSTRAINTS AND THE POWER RANGE

Modes	Constraints	Power range (Pu)
1 and 1′	$D_1 \geq D_2$, $0 \leq D_3 \leq (D_1\text{-}D_2)$	-0.5~0.5
2 and 2′	$D_2 \geq D_1$, $(1+D_1\text{-}D_2) \leq D_3 \leq 1$	-0.5~0.5
3 and 3′	$D_2 \leq (1\text{-}D_1)$, $D_1 \leq D_3 \leq (1\text{-}D_2)$	-0.5~0.5
4 and 4′	$D_1 \leq D_3 \leq 1$, $(1\text{-}D_3) \leq D_2 \leq (1\text{-}D_3+D_1)$	-0.67~0.67
5 and 5′	$(D_1\text{-}D_3) \leq D_2 \leq (1\text{-}D_3)$, $0 \leq D_3 \leq D_1$	-0.67~0.67
6 and 6′	$(1\text{-}D_2) \leq D_1$, $(1\text{-}D_2) \leq D_3 \leq D_1$	-1~1

TABLE II

CLASSIFICATION OF THE POWER LOSSES

Losses	Classification	Value
Power switches losses (P_S)	Conduction losses (P_{C_S})	$R_{DSon} \cdot I_{Drms}^2$
	Switching losses (P_{Sw_S})	$(E_{onM} + E_{offM}) \cdot f_{sw}$
	Gate driver losses (P_{Gat_S})	$Q_g \cdot V_{gs} \cdot f_s$
Magnetic losses (P_M)	Copper losses (P_{Cop_M})	$I_{Tr\_rms}^2 \cdot [R_{Tr\_pri} + n^2 \cdot R_{Tr\_sec}]$
	Core losses (P_{Cor_M})	$k \cdot f_s^{\alpha} \cdot B_{Tr}^{\beta} \cdot V_e$

The normalized transmitted power can be defined as
Ppu = Po/Pomax (2)
where Po is the transmitted power of the converter.
Thus, the power range and the corresponding operations modes of the TPS modulation can be summarized in Table I . For a specific transmitted power, several different operation modes can be used
to meet the power requirement.

VI. LOSS ANALYSIS

There are essentially three types of power losses in the Dual Active Bridge converter: PS power losses, PM magnetic losses and PU unknowns.
Switching losses can also be classified as conduction losses Pcs and switching losses Psw gate control losses Pgate..
The magnetic losses Pm is divided into the copper losses PCop and the core losses PCore of the power transformer .

The unknown losses PU mainly includes losses due to temperature-dependent copper and conduction loss relevant to the magnetic devices and the power switch modules slightly increased copper loss of Litz wires in the magnetic devices due to skin and proximity effects, and the ohmic losses caused by the dc-link capacitors.

The unknown losses Pu is ignored in the power losses as it is very small and to simplify the theoretical analysis.

Thus, all power losses P_{A_Loss} can be expressed as

$$P_{A\_\text{Loss}} = \sum_{i=1}^{8} P_{S_i} + P_{M\_Tr} + P_{M\_L_k}$$

Here first term shows the power switching losses due to eight power switches Pmtr represents the magnetic losses happened inside of the transformer and Pmlk represent the magnetic losses occurs in the inductor.

VII.VEHICLE TO VEHICLE ENERGY TRANSFER

The image of Vehicle to vehicle energy transfer concept is shown . In the given example there are

two vehicles, 1st vehicle work as the energy provider, while 2nd vehicle work as the energy receiver. These Vehicles can also work other the way around
The power transfer can be achieved using different methods such as onboard converters ,wireless power transfer or using an offboard converter.
Electric Vehicles can gain huge benefit from using Vehicle to vehicle energy transfer by providing longer
ranges, added convenience, decreased dependence on limited number of Charging stations, and many other things.
The power grid efficiency can also be increased by using Electric vehicle batteries as energy storage systems. This would allow them to store extra energy generated by renewable system and feed it back to the grid when required

We have mainly studied about wireless power transfer The key features of technology in Electric vehicles have improved significantly over the years, which includes improved coil design , less misalignment of coils , higher linking efficiency and coupling factor . This has made Wireless Power Transfer a aspiring technology for charging of vehicles as shown by numerous research studies.
The newly researched wireless power transfer system have many advantages that make it a promising technology which can be used for the future of electric mobility. Removing need for physical cables and connectors make the charging process more
convenient for customers. The non presence of physical connections in this method increases safety and also increases reliability

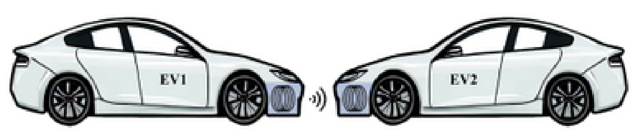


Fig4.Wireless Vehicle to Vehicle Power Transfer

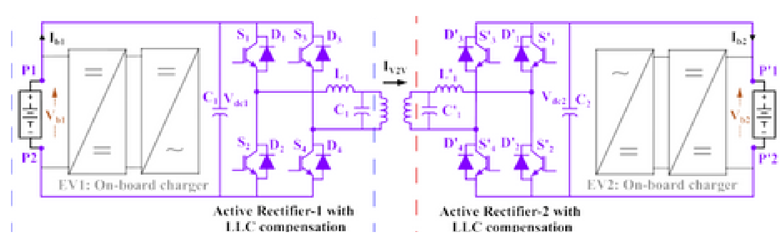


Fig5.AC Power Transfer with active rectifier plus LLC compensation

VIII. LLC RESONANT CONVERTER

The LLC resonant converter is a type of resonant converter widely used in power electronics applications, including electric vehicle charging, renewable energy systems, and high-power electronic devices. It combines the benefits of both resonant and traditional converters to achieve high efficiency and reduced electromagnetic interference (EMI).

The components form a resonant tank circuit that allows the converter to operate at high efficiency by minimizing switching losses.

The operation of an LLC resonant converter involves the use of resonant frequencies in both the voltage and current waveforms, which enables soft switching of the power switches (usually MOSFETs or IGBTs). Soft switching minimizes switching losses, leading to higher efficiency and reduced stress on the components.

One of the key advantages of the LLC resonant converter is its ability to regulate output voltage over a wide range of load conditions while maintaining high efficiency, voltage regulation and lower slew rate. This makes it suitable for various applications where the load may vary significantly, such as electric vehicle charging.

A.) Working

The DC input voltage (Vin) is directed to a full bridge switching circuit. The H bridge switches are turned on with a fixed duty cycle along with variable switching frequency (fs) depending on line and load conditions. The bridge's output comprises rectangular pulses oscillating between Vin and -Vin at a constant duty cycle.

This output voltage is then transmitted to the resonant tank circuit, where operation near the resonant frequency (fr) induces a near-sinusoidal current. The voltage at the transformer primary terminals is an amplified version of the input signal, with the ratio of the magnitude of the input to the transformer primary (Vo_AC) to the input to the tank circuit (Vin_AC) termed as tank circuit gain. Adjusting the switching frequency allows for modification of the tank circuit gain useful for
large range of operation for different loads and load nature.

The transformer's secondary side is connected to a full-wave rectifier, and the required output is followed by filtrations using a filter before being supplied to the load. Voltage regulation is performed via frequency modulation.

To attain Zero Voltage Switching (ZVS) for the input side MOSFETS used as switches and Zero Current Switching (ZCS) for the diodes on output side, the tank circuit current should lag behind the MOSFET bridge output voltage, which occurs when the converter operates in the inductive region.

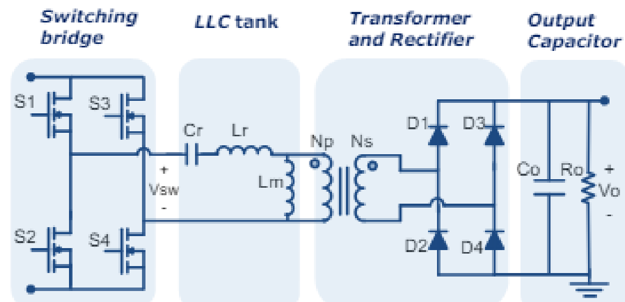


Fig 6. Circuit Diagram Of a Full Bridge LLC Resonant Converter

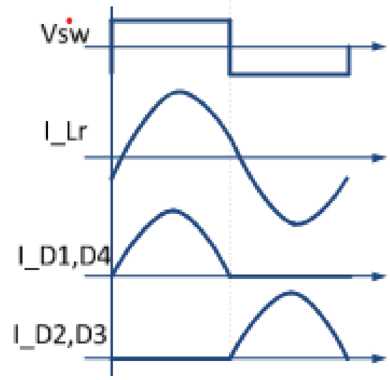


Fig 7. Output Waveform of a LLC resonant Converter

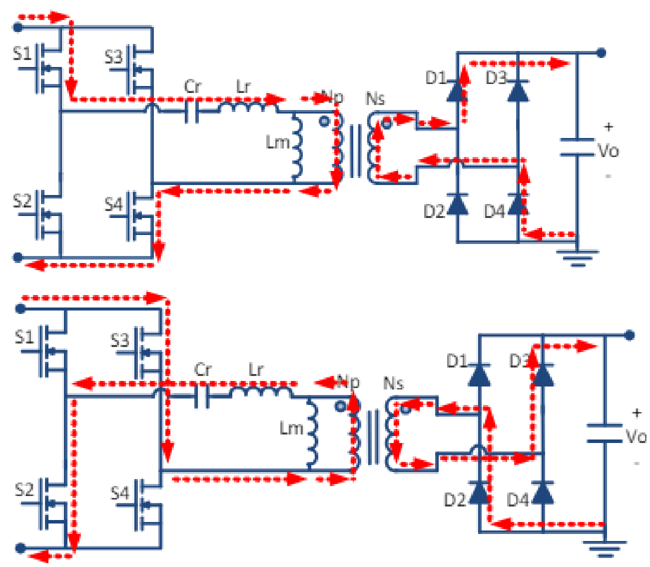


Fig 8. Positive Power Delivery operation

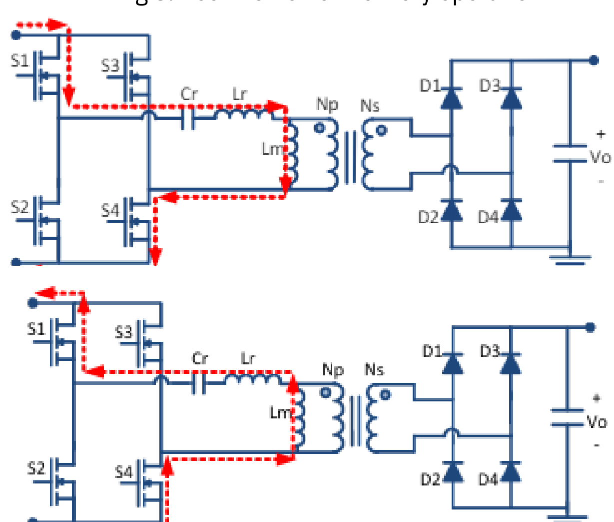


Fig 9. Free wheeling operation

B.) Operation Mode Based On Frequency Of Switching

B.1.) When the switching frequency equals the resonant frequency (fs=fr)

The tank circuit's voltage gain is unity. In this mode, power is delivered to the load throughout the entire switching half cycle, as the duration matches that of the resonant half cycle. Towards the end of the switching half cycle, the resonant inductor current (ILr) decreases and aligns with the magnetizing current (ILm), resulting in the secondary side current reaching zero only at the end of the half cycle. The transformer turns ratio (Np/Ns) is selected to ensure this mode operates under rated conditions.

B.2.) If The Switching Frequency Exceeds The Resonant Frequency (fs>fr)

It indicates a higher input voltage than rated (requiring a buck operation), power delivery to the load occurs partially in each half of the switching cycle. However, the start of the switching cycle precedes the completion of the resonant half cycle, leading to increased MOSFET turn-off losses on the primary side and hard commutation on the secondary side diodes.

B.3.) When The Switching Frequency is Lower Than The Resonant Frequency (fs<fr)

It is required for a boost operation when the input voltage is lower, the entire power is delivered to the load. The switching half cycle duration exceeds that of the resonant cycle, initiating freewheeling operation after the completion of the resonant half cycle and until the switching half cycle concludes. Consequently, primary side MOSFET conduction losses rise due to circulating energy.

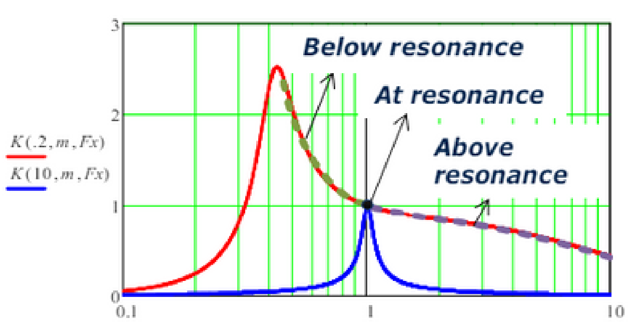


Fig :-Bode plot for LLC Network gain(k) Vs Switching Frequency(w)

C.) Efficiency Analysis for DAB and LLC Converter

V_{in} (V)	OUTPUT POWER (% OF 600W)				
	100%	*80%*	*60%*	*40%*	*20%*
340	91.13	96.42	93.92	94.73	94.49
320	95.64	93.23	97	92.45	96.9
280	95.2	92.82	97.03	92.3	95.53
240	96.83	94.29	97.32	94.67	95.46

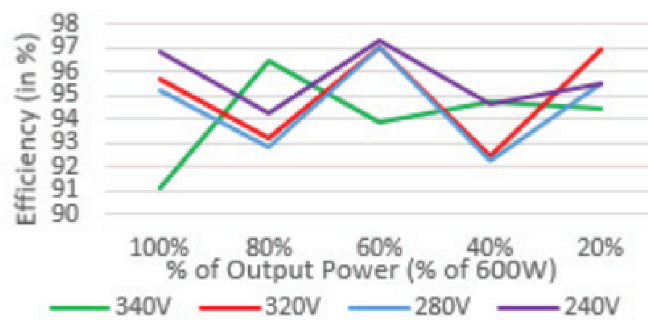


Fig :- Efficiency (in %) Vs (% load)(in W) for DAB

V_{in} (V)	OUTPUT POWER (% OF 600W)				
	100%	*80%*	*60%*	*40%*	*20%*
340	97.06	97.16	97.29	97.592	97.25
320	97.69	97.85	97.89	97.92	97.74
280	97.74	97.53	97.71	97.76	96.48
240	96.76	97.148	97.56	97.71	97.31

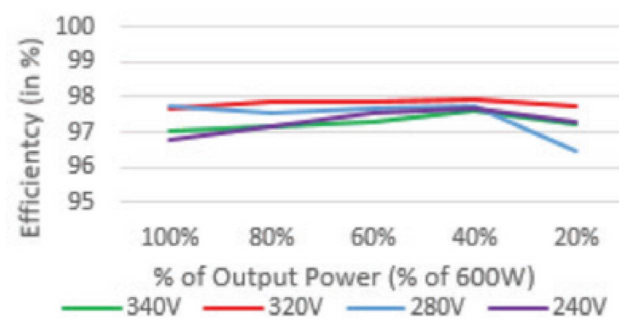


Fig :- Efficiency (in %) Vs (% load)(in W) for LLC

X.CONTROLS FOR DAB DC-DC CONVERTER

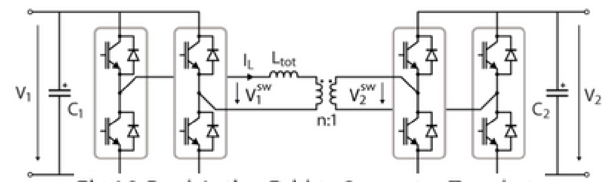


Fig 10.Dual Active Bridge Converter Topology

The main challenges faced by the control system for DAB Converters are:-

1.)Maintaining precise voltage regulation under varying load conditions and input voltage levels Due to the direct AC to bipolar DC conversion, achieving tight voltage regulation can be challenging, especially at low and high voltage levels.

2.)Minimizing current ripple to ensure smooth DC output.

3.)Minimizing current ripple to ensure smooth DC output as The control strategy must address challenges like transient response, stability, and dynamic performance to ensure reliable and efficient operation.

4.)Mitigating harmonic distortion to comply with power quality standards. as The direct AC to bipolar DC conversion can introduce harmonic distortion, which needs to be minimized to meet regulatory requirements.

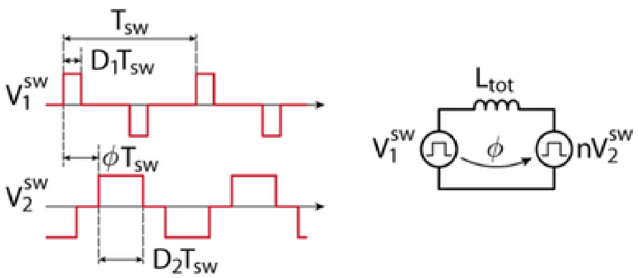


Fig 11. Simpified loss less scheme of the Dual Active Bridge converter

the model above shows that the transfer of power between the primary and secondary sides is mainly driven by the current through the inductance. Here we have assumed that the entire load and source are ideal and there are no magnetic losses.
which in turn is It comes in, accelerator voltage
. Therefore, the supply current is controlled by taking action on the parameters that determine the inductor voltage, which are:
3-level switching voltage duty cycle D1
3-level switching voltage duty cycle D2
Phase change between V1 and V2 for the switching time period .
.

XI. MODULATION TECHNIQUES FOR DUAL ACTIVE BRIDGE CONVERTER

A.)Phase-shift modulation

Phase-shift modulation is one of the simplest modulation method for dual active bridge converters. It uses D1=D2=0.5(2-leveled switched voltages), reducing the degrees of freedom to only one.
The switched voltage and inductor current waveforms are depicted below:

The switched voltage and inductor current waveforms are depicted below:

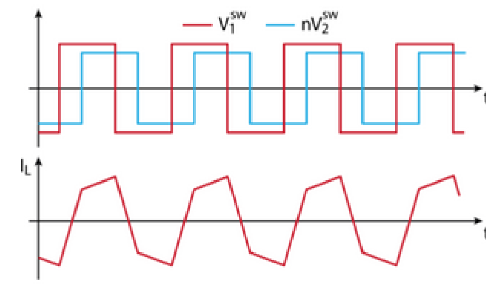


Fig 12. Dual Active Bridge switched Voltage and Inductor Current Waveforms

Due to the high RMS current and high switching losses, phase shift modulation is not suitable in high efficiency applications.
The best ratio between transmitted power and inductor RMS current is optimal when V1 = nV2.

B.)Triangular modulation

In Triangular modulation, both the H-bridges generates 3-level alternating voltage waveforms.

The waveforms are such that the beginnings of the pulses are aligned and the secondary turns off as soon as coil current passes
In this case, the secondary H-bridge always switches below zero current .

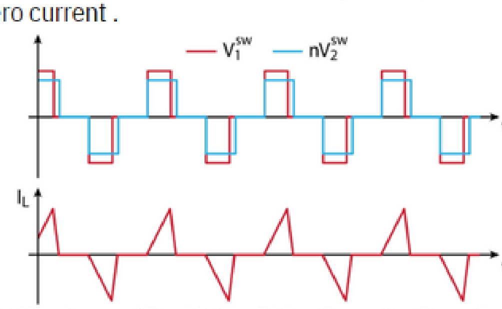


Fig 13. Waveforms of Dual Active Bridge Converter Operation With Triangle Modulation

C.)Trapezoidal modulation

The limited maximum power transfer in triangular modulation is increased by using trapezoidal modulation. Through this way zero current switching is achieved two times per period on both the sides of H-bridges. Expected waveforms are shown below.

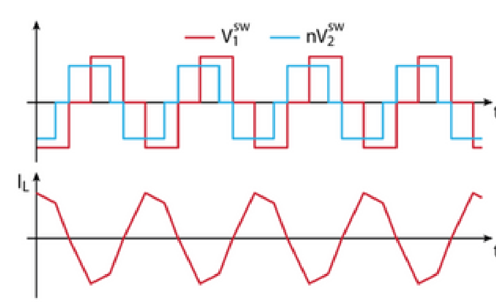


Fig 14. Waveforms of Dual Active Bridge Converter Operation With Trapzoidal Modulation

We primarily studied Phase shift modulation as a control and modulation for our DAB converter

Phase-Shift Modulation (PSM) in a DAB (Direct AC to Bipolar DC) DC-DC converter is a control technique that adjusts the phase shift between the switching signals of the converter to regulate the output voltage and improve efficiency. This modulation technique has gained popularity due to its ability to reduce switching losses, improve power quality, and enhance overall converter performance. Let's delve deeper into the concept and implementation of PSM in DAB DC-DC converters.

In PSM, the phase shift between the switching signals of the AC-side and bipolar DC-side switches is adjusted to control the power flow through the converter. By varying the phase shift, the converter can regulate the output voltage and current, allowing for precise control over the power delivery to the load.

Advantages of Phase-Shift Modulation:

Reduced Switching Losses: PSM enables soft switching, reducing the switching losses associated with hard switching techniques.

Improved Efficiency: By reducing losses, PSM can significantly improve the overall efficiency of the converter.

Harmonic Reduction: PSM can minimize harmonic distortion in the output voltage and current, improving power quality and complying with regulatory standards.

Flexibility: PSM offers flexibility in controlling the converter's operation under different load and operating conditions.

Implementation of Phase-Shift Modulation in DAB DC-DC Converters.

Control Strategy: The control algorithm for PSM in a DAB DC-DC converter adjusts the phase shift based on feedback signals such as output voltage, current, and temperature. The algorithm calculates the required phase shift to achieve the desired output voltage or current regulation and adjusts the switching signals accordingly.

XII. DIAGRAM AND WORKING

We observed Dual Active Bridge on Matlab with digital controls systems based on the principles of phase shift modulation and noted down the necessary waveforms

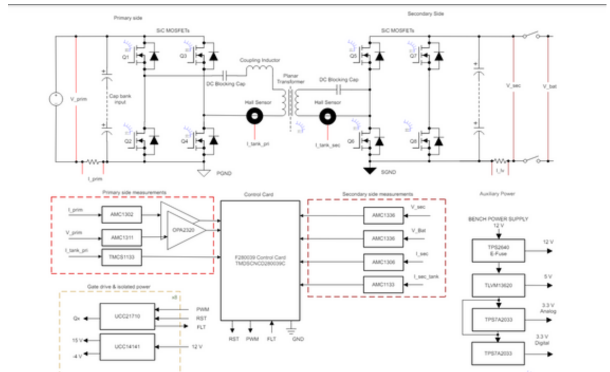
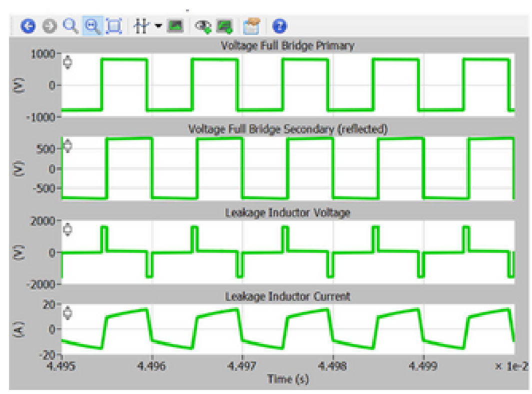


Fig 15. Block Diagram of Dual Active Bridge converter with Controls

This design has four main sections that communicate with themselves:

• A power board having the power stage SiC MOSFETs, a high-frequency transformer, current sensing electronics, gate drivers, voltage and current sensing, and the system power tree

• A TMDSCNCD280039C control card to support digital control



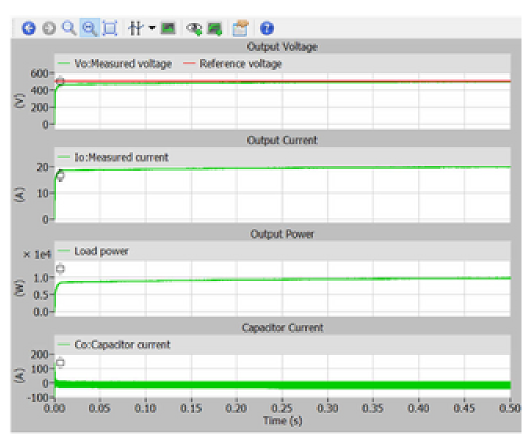


Fig 16 . Output Voltage, Current, And Power, As Well As The Output Voltage Ripple And Capacitor Current.

XII. OUTPUT COMPARISON OF DC-DC CONVERTER WITH AND WITHOUT RESONANT LLC.

$$A_0 = \frac{1}{P}\int_P s(x)\,dx$$

$$A_n = \frac{2}{P}\int_P s(x)\cos\left(2\pi\tfrac{n}{P}x\right)dx \qquad \text{for } n \geq 1$$

$$B_n = \frac{2}{P}\int_P s(x)\sin\left(2\pi\tfrac{n}{P}x\right)dx, \qquad \text{for } n \geq 1$$

$$s_N(x) = A_0 + \sum_{n=1}^{N}\left(A_n\cos\left(2\pi\tfrac{n}{P}x\right) + B_n\sin\left(2\pi\tfrac{n}{P}x\right)\right)$$

Fig 17. Fourier Analysis of output signals for DC DC converter with and Without LLC

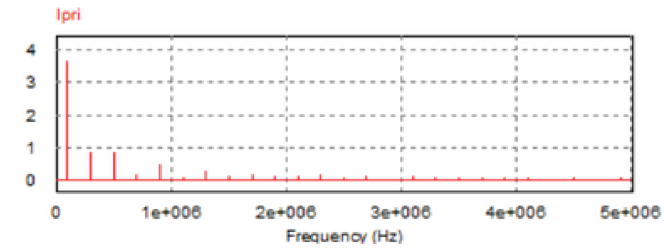


Fig 18. Without LLC resonant circuit we will get bigger harmonics other than fundamental wave which decreases the efficiency

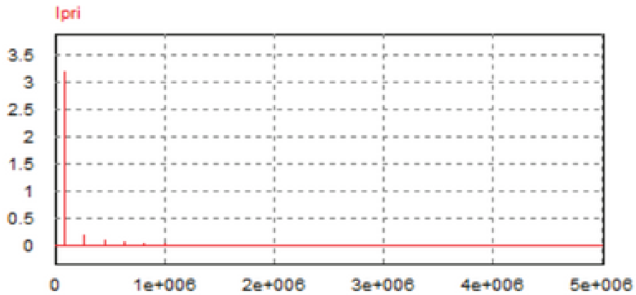


Fig 19. With LLC network installed with the DAB Converter we get higher fundamental wave which increase our efficiency

XIII. FUTURE STRATEGY AND POSSIBLE EXPANSION

1.To try out different control methods for better optimization and control.

2.Work on better coil, transfromer and resonant network design to reduce transmission losses.

3.Work on real model to get better understanding of working and search about innovative ways for better performance.

4.Research about new control strategy with the help of reinforcement learning and Actor Critic algorithm for less power losses and automation.

XIV.REFERENCES AND FOOTNOTES

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