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A Double Active Bridge Converter for High and Low Power Aerospace Applications

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ABSTRACT: The aerospace industries are promoting the use of more electrical technologies, to compensate the increasing proportion of dc electrical loads. By using dual active bridge (DAB) topology for dc–dc conversion has been popular among researchers over the past two decades due to its high performance, high efficiency, galvanic isolation, and inherent soft-switching property. These features make the DAB dc–dc converter a strong candidate for high & low power-density aerospace applications. An analysis of zero-voltage switching (ZVS) boundaries for buck and boost modes , the effect of snubber capacitors on the DAB converter is effective. Thus the operating principle of the DAB dc–dc converter, a novel steady-state model of the converter and its ZVS limits for buck and boost modes has been verified through extensive simulations.

KEYWORDS: Double Active bridge , Zero Voltage source , aerospace

I.INTRODUCTION

Aeronautical power distribution technology is moving toward dc due to the increasing proportion of dc electrical loads. As a result, the aerospace industry is promoting the use of more electrical technologies to enhance the performance and increase the reliability of aircraft systems and sub systems. The power generation capacity of the more electric Boeing 787and Airbus A380 airplanes is about 1.4MW and 850kW, respectively. In order to reduce weight, electrical power should be transmitted around the aircraft at a high voltage (HV) with low current and low conduction losses. In this context, dc power distribution system architecture is found to be the most reliable configuration for sustaining aircraft operations even under severe supply transients. Electric airplanes are broadly classified into three types i) Small electric airplanes: Unmanned Aircraft Vehicles (UAV) ii) Medium electric airplanes: Sport airplanes iii) Large electric airplanes

II.LITERATURE SURVEY

In order to reduce weight, electrical power should be transmitted around the aircraft at a high voltage (HV) with low current and low conduction losses. In this context, dc power distribution system architecture is found to be the most reliable Configuration for sustaining aircraft operations even under severe supply transients [1] **.** Bidirectional power flow capability is a key feature of DAB dc–dc converters, permitting flexible interfacing to energy storage devices. Although the DAB converter has an inherent soft-switching attribute, it is limited to a reduced operating range depending on voltage conversion ratio and output current. This is a drawback for applications that operate mainly with variable or low loads as the overall converter efficiency is reduced.[15] .

The bidirectional dc-dc converter along with energy storage has become a promising option for many power related systems, including hybrid vehicle, fuel cell vehicle, renewable energy system and so forth. It not only reduces the cost and improves efficiency, but also improves the performance of the system. In the electric vehicle applications, an auxiliary energy storage battery absorbs there generated energy fed back by the electric machine. In addition, bidirectional dc-converters also required to draw power from the auxiliary battery to boost the high-voltage bus during vehicle starting, accelerate and hill climbing. With its ability to reverse the direction of the current flow, and thereby power, the bidirectional-dc converters are being increasingly used to achieve power transfer between two dc power sources in either direction [5].

Generally, electric power generated by renewable energy sources is unstable in nature, thus producing a bad effect on the utility grid. The transformer is indispensable for some applications that require voltage matching and/or galvanic isolation between the utility grid and the energy storage device. Replacing the line-frequency transformer with a high-frequency and isolated dc/dc converter would result in a more compact and flexible energy storage system. Various bi-directional isolated dc/dc converters have been proposed as the interface to energy storage devices with focus on automotive or fuel cell applications. Most of the present dc/dc converters have asymmetrical circuit configurations to couple the two dc buses having largely different voltages, several tens volts and several hundred volts.[7].

The dual active bridge (DAB) topology for dc–dc conversion has been popular among researchers over the past two decades due to its high performance, high efficiency, galvanic isolation, and inherent soft-switching property [3]. These features make the DAB dc–dc converter a strong candidate for high-power-density aerospace applications

III. PROPOSED SYSTEM CONFIGURATION

Two separate DAB is used for high power and low power load as shown in the fig 1. In high power DAB IGBT is used as large IGBT modules typically consist of many devices in parallel and can have very high current handling capabilities in the order of hundreds of amperes with blocking voltages of 6000 V, equating to hundreds of kilowatts. In lower DAB MOSFET is used as the power MOSFET is the most widely used low-voltage (that is, less than 200 V) switch

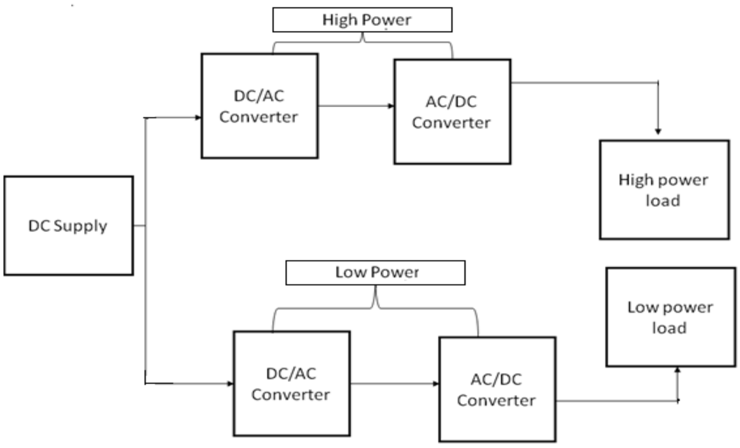

Fig 1 Block diagram of dc–dc converter for high & low power application

Future aircraft are likely to employ electrically powered actuators for adjusting flight control surfaces and other high-power transient loads. To meet the peak power demands of aircraft electric loads and to absorb regenerated power, an ultra capacitor based energy storage system is examined in which a bidirectional DAB dc–dc converter is used. The DAB converter shown in Fig.2 consists of two full-bridge circuits connected through an isolation transformer and a coupling inductor L, which maybe provided partly or entirely by the transformer leakage inductance. The full bridge on the left hand side of Fig.2 is connected to the HV dc bus and the full bridge on the right hand side is connected to the low-voltage (LV) ultra capacitor. Each bridge is controlled to generate an HF square-wave voltage at its terminals. By incorporating an appropriate value of coupling inductance, the two square-waves can be suitably phase shifted with respect to each other to control power flow from one dc source to another.

Thus, bidirectional power flow is enabled through a small lightweight HF transformer and inductor combination, and power flows from the bridge generating the leading square-wave. Although various modes of operation of the DAB converter have been presented recently for high power operation, the square-wave mode is supposedly the best operating mode. This is because imposing quasi-square-wave on the transformer primary and secondary voltages results in trapezoidal, triangular, and sinusoidal waveforms of inductor current in the DAB converter ac link. These modes are beneficial for extending the low-power operating range of the converter. Although these modes tend to reduce the switching losses, the voltage loss is significant due to zero voltage periods in the quasi-square-wave, which reduces the effective power transfer at high-power levels.

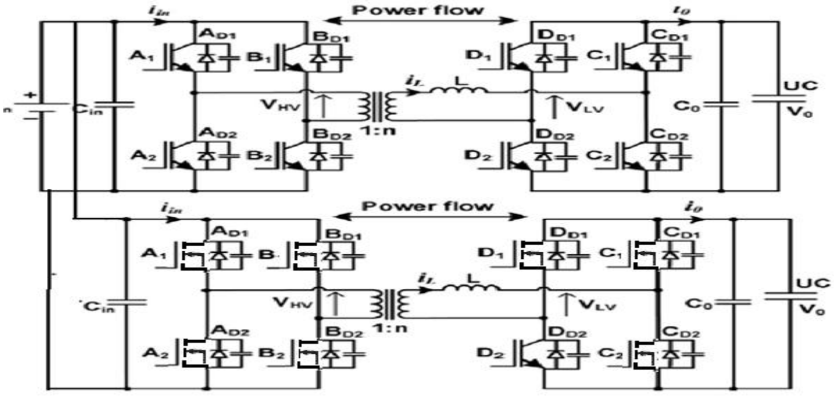

Fig 2 DAB Bridge Circuit Diagram

IV. POWER STAGE TOPOLOGY AND OPERATION PRINCIPLE

Fig3 shows the proposed soft-switching bidirectional dc-dc circuit topology. A Battery pack or other energy source such as ultra-capacitor is placed on the low-voltage side, and a primary energy source such as fuel cell or generator-set is placed on the high voltage DC bus, which also contains a high-frequency capacitor as the energy buffer. The high-voltage DC bus also serves as the main power bus that provides power output to the main load which is typically an inverter motor drive for vehicle applications. The bidirectional dc-dc converter is placed in between low-voltage and high-voltage sources to allow energy transfer. In many applications such as vehicles and stationary power, the battery pack or energy storage handles quick start-up before the primary source is warmed up. Also during transient load conditions, the energy storage supplements the power for the generator output. This is considered as the "boost mode." When the energy stored in battery or energy storage element is low, and the high side bus has excess energy, the converter can then be operated in "buck mode" to charge the low side auxiliary energy storage. In Fig 3, IGBT switches S1u-S3u and S1d-S3d serve as the main switches for either buck mode or boost mode. Each switch has its own anti-paralleled diode which is carrying current during free-wheeling period. Each switch is paralleled with a lossless snubber capacitor. Three inductors Ld1-Ld3 can be used as the boost inductor under boost mode operation or low-pass filter inductor under buck mode operation. Capacitor C_{low} and C_{high} serve as the smoothing energy buffer. With interleaved inductor currents, the ripple current going into these capacitors is minimized.

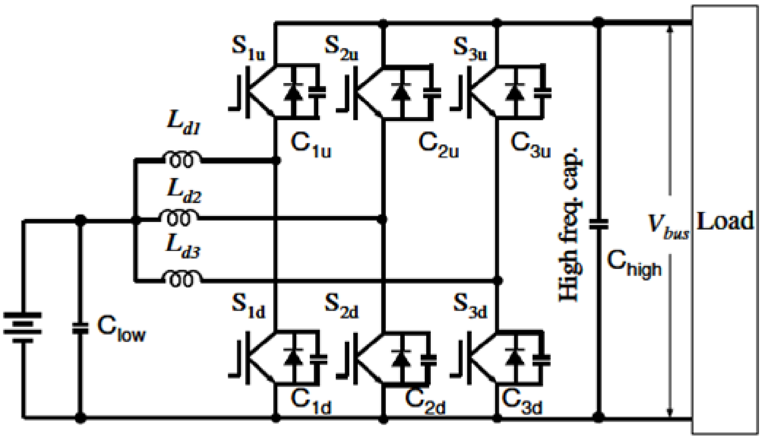

Figure 3 Circuit diagram of three phases interleaved synchronous mode ZVS bidirectional dc-dc converter

Fig 4 shows the proposed complimentary gating control for one phase-leg Operation. The inductor current, rather than operating in a traditional DCM condition, goes from positive to negative direction and then swings back to positive. Using the upper switch *Su* as the main switch for buck mode operation, lower switch S_d becomes the auxiliary switch.

Initially when the main gate signal $Gate_u$ is on, switch *Su* conducts, and the low-side battery is charged. During the dead time t_d, all switches are turned off, so the inductor current i_L will charge *Cu* and discharge C_d. The device voltage charge and discharge rates are slowed down, and the turn-off loss is reduced. After they are fully charged and discharged, which means the V_{CEd} becomes zero, diode D_d will take over the inductor current. Auxiliary switch *Sd* is gated on under zero-voltage condition because diode D_d is carrying the freewheeling current. With the voltage *VL* against the inductor the current continuously decreases until it passes through zero and changes its direction. At this time the current will go through the auxiliary switch *Sd*. It is easily noted that the diode turnoff naturally without having reverse recovery loss. The parasitic ring is also fully avoided.

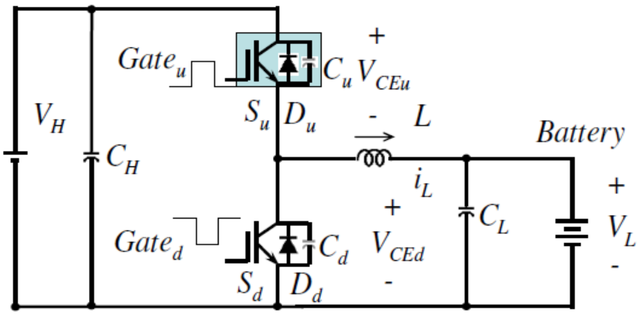

Fig 4 Circuit diagram for buck mode single phase

The auxiliary switch S_d creates a negative current, which helps charge C_d and discharge C_u when S_d is turned off into the dead time period. After *Cu* is fully discharged, the voltage across the main switch V_{CEu} becomes zero, diode *Du* will carry the inductor negative current. Then the main switch *Su* is turned on at zero-voltage condition. Thus both upper and lower switches are all turned on at zero voltages. After the upper diode conducts, the voltage difference between high side bus voltage *VH* and battery voltage V_L will apply across the inductor *L*, and the inductor current *IL* will increase until it passes through zero and changes into positive direction, and the main switch *Su* naturally takes over the current.

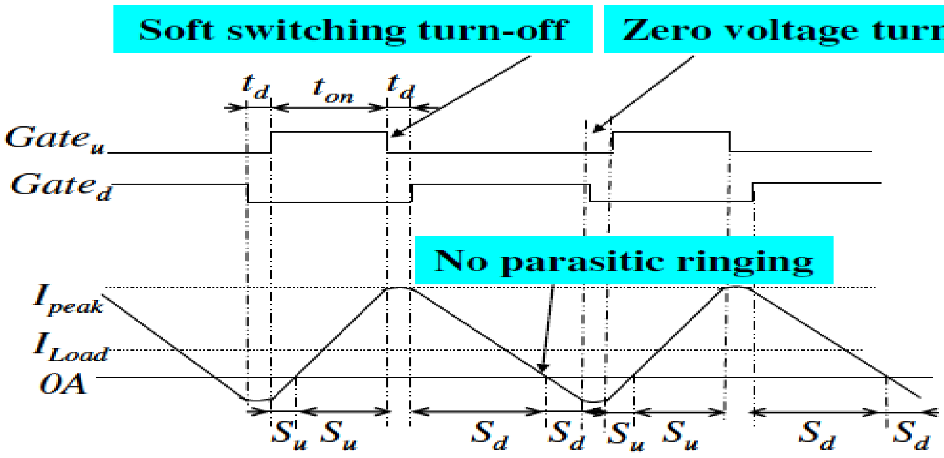

Fig 5 Gate signal and inductor current waveform

The benefits of complementary control ZVRT are noticed in two fold. One is less heat sinking requirement and the other is that a higher switching frequency can be implemented for further reduction of the inductor size. The major additions are the need for the complementary gate signal and the added snubber capacitors that may introduce some tail current during turn-off condition.

V. SIMULATION RESULTS

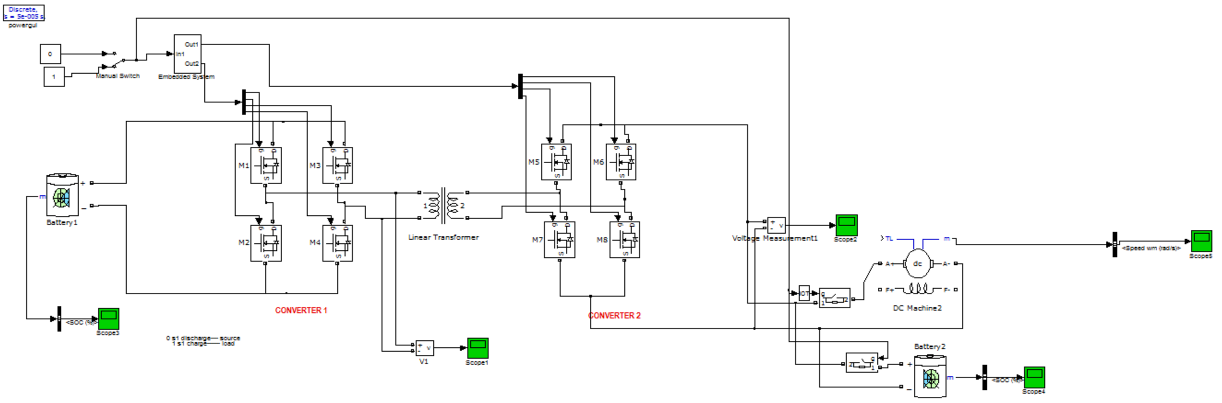

Fig 6 DC – DC Bidirectional converter

Fig 6 Shows the proposed system configuration which consists of two batteries one is at input side and second one is at output side. The input voltage is 12 V and current is 10 A.

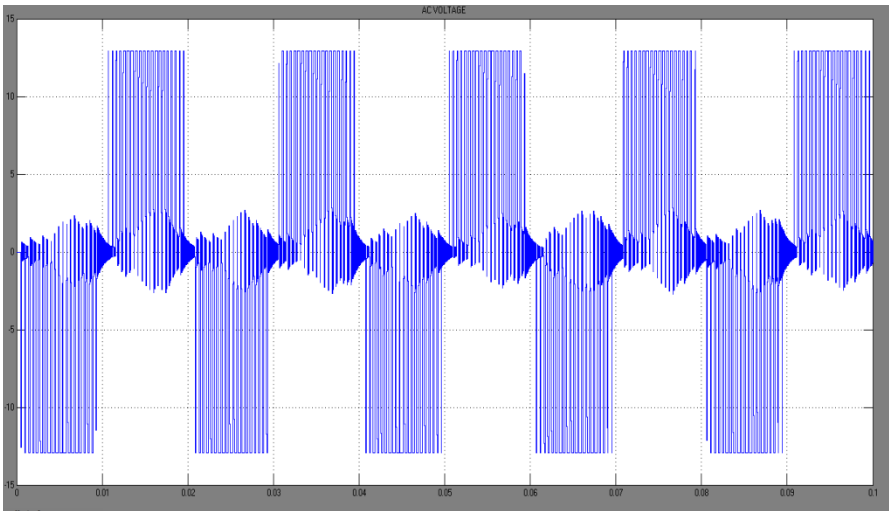

Fig. 7 Output Voltage of the DC-AC Converter

The output voltage of the DC-AC converter is shown in Fig 7 . Here 12V DC is converted into 12V AC. The output of this converter is fed to AC-DC converter through linear transformer

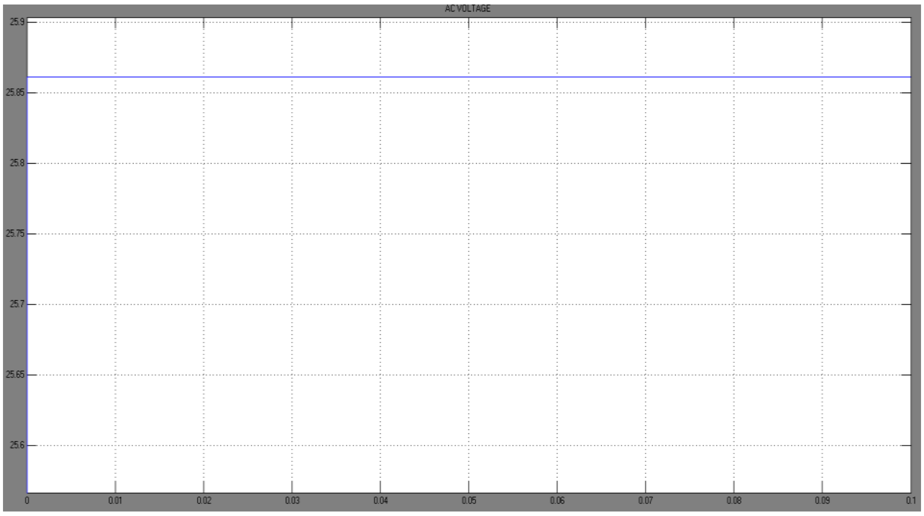

Fig. 8 Output Voltage of the AC-DC Converter

The figure 8 Shows the output voltage of AC-DC Converter. Here 12V AC is Converted into 25V DC

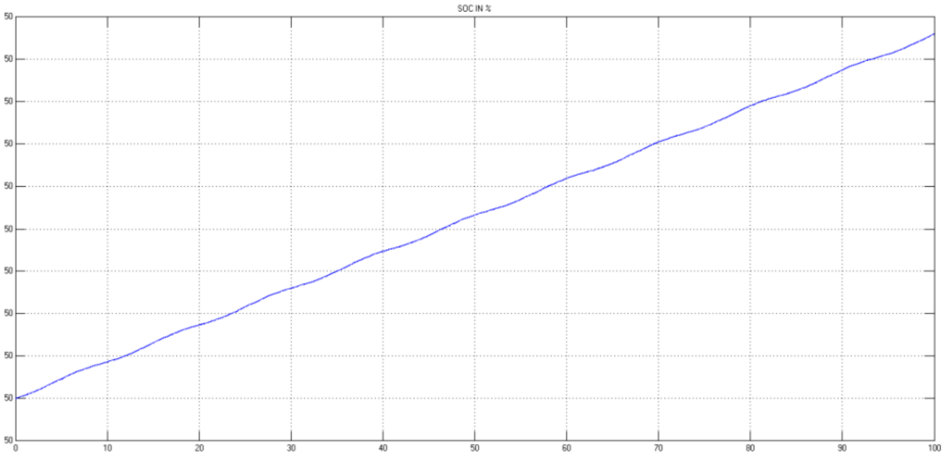

Fig . 9 Battery charging at input side

The figure 9 Shows the charging of the battery at input side.

VI.HARDWARE CIRCUIT DIAGRAM

The external capacitors, diode, coil, and other peripheral components as close to the IC as possible, and make a one-point grounding. When the input voltage is 9 to 10 V, VOUT may vary largely according to the grounding method. When it is difficult to make one-point grounding, use two grounds: one for V_{IN}, C_{IN}, and SD GND, and the other for V_{OUT}, $V_C VR_{EF}$, and I_C GND. Characteristics ripple voltage and spike noise occur in IC containing switching regulators. Moreover rush current flows at the time of a power supply injection. Because these largely depend on the inductor, the capacitor and impedance of power supply used, fully check them using an actually mounted model. If the input voltage is high and output current is low, pulses with a low duty ratio may appear, and then the 0% duty ratio continues for several clocks. In this case the operation changes to the pseudo pulse frequency modulation (PFM) mode, but the ripple voltage hardly increases.

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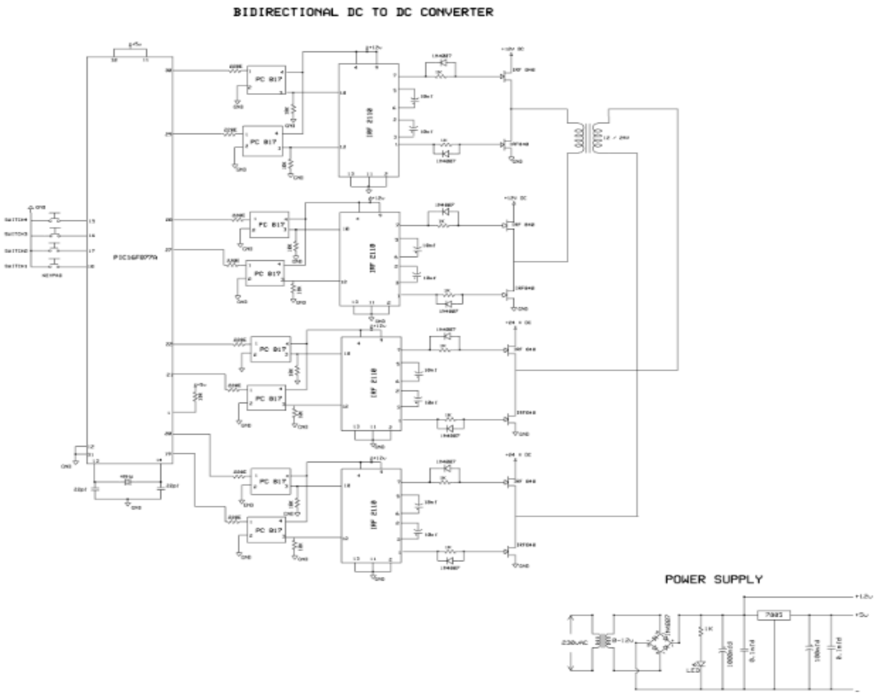

Fig 9 Hardware diagram

If the input power supply voltage is lower than 1.0 V, the IC operation is unstable and the external switch may be turned on. If input power supply voltage is 10.0 V or higher, the circuit operation is unstable and the IC may be damaged. The input voltage must be in the standard range (2.5 to 10.0 V).

The current limit circuit of the IC limits current by detecting a voltage difference of external resistor RSENSE. In choosing the components, make sure that over current will not surpass the allowable dissipation of the switching transistor and the inductor.

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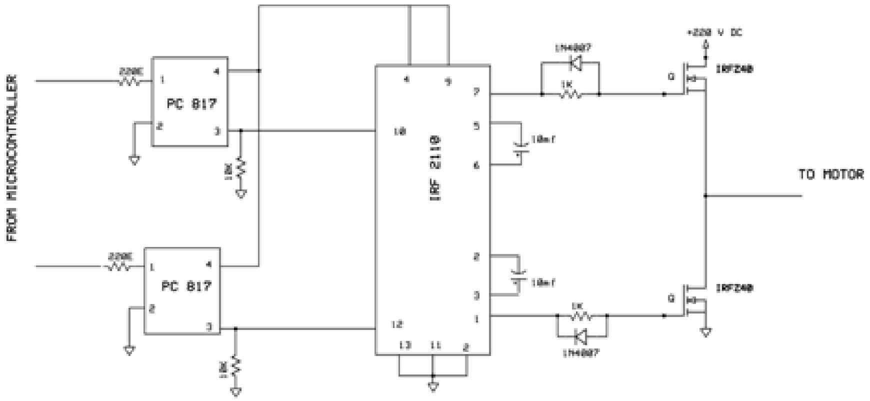

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Fig.10 Driver circuit

The IR2110/IR2113 are high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels. It works on the principle of bootstraps. This driver consists of two inputs and two outputs. When One pair acts for high voltage and another for low voltage.

In this driver unit two IR2110 and 4 MOSFETs are selected to form bridge. Two bootstrap capacitors are used. One is across the high voltage supply and return and another one across low voltage supply and return. Signals from buffer is given to the driver through opto isolator. When the first 2110 receive high voltage input it drives the first MOSFET at the same time second 2110 receives low voltage input which triggers the fourth MOSFET. Now MOSFETs 1 & 4 are conducting which connects the motor to the supply and it forms the positive half cycle in a motor.

When the first 2110 receive low voltage input it drives the second MOSFET at the same time second 2110 receives high voltage input which triggers the third MOSFET. Now MOSFETs 2 & 3 are conducting which connects the motor to the supply and it form the negative half cycle in a motor. Therefore motor gets two half cycles.

VII.CONCLUSION

The operation of the DAB dc–dc converter has been verified through extensive simulations which, in turn, confirm the accuracy of the model. The experimental results confirm that provision of snubber capacitors across the IGBTs reduces switching losses and device stresses and improves the converter performance. The experimental results are presented for high and low power switching operation as well as for ZVS boundary working conditions of the prototype with a improved efficiency.

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