Phase Shifted Full Bridge Converter with Hybrid Energy Storage for Electric Vehicles

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Abstract - *An integral part of any modern day electric vehicle is power electronic circuits comprising of DC-DC converters and Energy storage devices. This thesis presents the design of Phase Shifted Full Bridge (PSFB) converter with hybrid energy storage device for Electric Vehicles (EVs). The energy storage devices are Battery and Super Capacitor. A control strategy was implemented to determine which energy storage device to be utilized for operating the vehicle. Phase Shifted Full Bridge converter employed in Electric vehicles acts as DC-DC converter which supplies conventional low power and low voltage loads. The control algorithm functions with help of a selector switch which determines the energy storage used to drive the vehicle. The PSFB converter and Control algorithm for Hybrid energy storage for EVs was simulated by using MATLAB/Simulink environment*.

Key Words: **Phase Shifted Full Bridge Converter, Electric vehicles, Battery, Super Capacitor.**

1. INTRODUCTION

The developments of global economy integration, with the environmental problems have become the important factors that influence the future situation of the world and the development and safety of each country. One of the environmental pollution problems due to burning of fossil fuels (coal, oil, and natural gas) are becoming dominant issues in our society. The pollutant gases causes global warming, acid rain and urban pollution problem. The pollution problems can be mitigated by emphasizing safe and clean environment, to development of the HEV fulfills and reduce the environmental pollution issues [2-3]. The HEV has an electric drivetrain like an electric vehicle (EV) and a regenerative breaking mode recharge the ESD, such as Super Capacitor (SC), battery (lithium-Ion). The SC is electrical ESD, which offer significantly better energy densities than conventional capacitors, better power densities than conventional batteries, its provides the lowest costs per farad, has extremely high cycling capability and environmentally safe [4]. SC is utilized for applications, such as electric vehicles [5]. Lithium-ion batteries are suitable as HEV because of their high energy densities and long lifetimes. There is no memory effect and no scheduled cycling is required to prolong the battery's life.

DC-DC converters are used to convert DC voltage from one voltage level to another. They can be step up or step down. Mostly power electronic converters consist of semiconductor switches like MOSFETS and IGBTs [1]. DC-DC converters are classified into non isolated and isolated converters. A transformer is present in the isolated topology which provides isolation between the input and the output. The non-isolated converters are buck (step down) converter, boost converter (step up) converter, buck boost converter, and cuk converter. The various isolated converters are forward converter, fly back converter, push pull converter, half bridge converter and full bridge converters.

In recent years the high power isolated DC-DC converters has developed in the market due to its requirement in the applications like fuel cell applications, battery based storage systems and telecommunications systems etc. The advantages of using isolated are the transformer present in the isolated topology can provide large step up or step down conversion ratio, multiple dc outputs can be obtained by providing multiple secondary windings, voltage and current stress in the transistors can be reduced by proper design of turns ratio.

The basic requirement of converters is small size and high efficiency. To achieve small size high switching frequency operation is necessary but the switching losses increases with increase in switching frequency. The solution for this problem is using soft switching techniques such as ZVS (zero voltage switching) and ZCS (zero current switching). These techniques provide zero voltage or current during switching transitions and thus reduce switching losses.

2. ENERGY STORAGE DEVICES

The electric powertrain basically required to develop sufficient power to meet the demands of vehicle performance, carry sufficient energy on-board to support vehicle driving in the given range, high efficiency, and emit less environmental pollutants. The EV consists of two power sources; one is primary power source and another one is secondary power source. For the purpose of recapturing part of the breaking energy, EV has at least one bi-directional energy source, typically chemical battery (LIB) or SC.

2.1. LITHIUM-ION BATTERY (LIB)

The selection is a battery is best achieved by setting a list of minimum requirements, conditions and limitations as follows

1. Maximum permissible voltage at the beginning of discharge.
2. Normal voltage during discharge (voltage stability on load).
3. End-voltage, that is, voltage at which equipment ceases to function properly.
4. Current-voltage relations: constant current (amps), constant resistance (ohms), and constant power (watts). High energy storage and service life.
5. Environmental conditions in storage and in service.
6. Physical restrictions such as dimensions and weight.

2.1.1 LIB ADVANTAGES

1. Virtually unlimited shelf life.
2. Wide operating temperature range.
3. High energy and voltage density.
4. No gassing, corrosion or leakage and safety.

2.1.2 LIB DISADVANTAGES

1. Low voltage regulation.
2. High initial cost.
3. Allows only a limited number of full discharge cycles.

2.2. SUPER CAPACITOR

SC is electrical ESDs which offer high power density and extremely high cycling capability. Recent developments in basic technology have made SCs an interesting option for short-term energy storage in low-voltage power electronic systems. Usually, SCs are modeled using simple RC circuits. However, these models cannot accurately describe the voltage behavior and the energy efficiency of these devices during dynamic current profiles.

2.2.1 SC ADVANTAGES

1. Long life cycle (> 500000) and efficiency (>95%)
2. Power density is higher there are no chemical reactions during charging and discharging.
3. Less weight, cost and size.
4. Large current/power capabilities over a wide range of operating temperature
5. High power density in both directions (charge and discharge)
6. Very high rate of charge and discharge.
7. Require less maintenance

2.2.2 SC DISADVANTAGES

1. Low energy density.
2. Requires sophisticated electronic control and switching equipment.

3. PROPOSED CONTROL STRATEGY

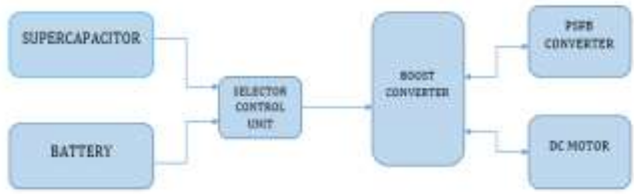

Fig -1: Phase shifted full bridge dc-dc converter

The proposed control strategy for Electric Vehicles is to utilize the energy storage in an efficient manner. The control strategy makes use of the selector control unit which utilizes the energy storage efficiently by determining the actual driving speed of the vehicle. If the vehicle is driving at high speed, the super capacitor utilized and in normal speed it utilizes the Battery pack provided in the vehicle. The selector control unit acts like a switch across energy storage devices.

The utilization of both Battery and Super capacitor will increase the efficiency of the vehicle and also the life of energy storage devices.

4. PHASE SHIFTED FULL BRIDGE CONVERTER

Phase shifted full bridge dc-dc converter (PSFB) is similar to the conventional full bridge dc-dc converter, but with a phase shifting control. In phase shifted full bridge dc-dc converter, the switches attain zero voltage switching which reduces the switching losses. The converter can attain high efficiency at high switching frequencies and also has benefits such as low EMI; low switching noise doesn't require additional snubber circuits to reduce losses. PSFB converters are used to step down high dc voltages and to provide isolation in medium to high power applications such as renewable energy systems, telecom rectifiers, battery charging systems, server power supplies etc.

4.1. OPERATING PRINCIPLE

The phase shifted full bridge dc-dc converter is as shown in the fig 1. This converter are used to step down high voltages and used in medium to high power applications. The PSFB converter consists of a full bridge inverter, a high frequency transformer, a full bridge diode rectifier, and a low pass filter at the output. The gating signals given to the switches in a phase shifting manner to facilitates ZVS operation for switches.

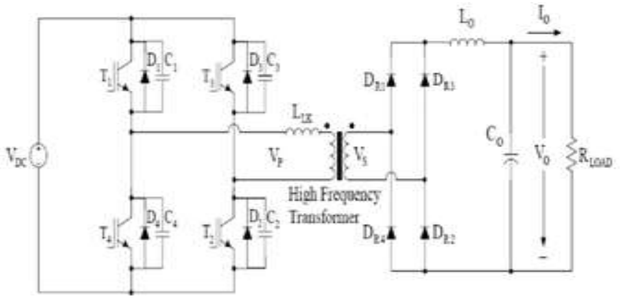

Fig -2: Phase shifted full bridge dc-dc converter

The full bridge inverter consists of four semiconductor switches such as IGBTs or MOSFETs with their diodes. In phase shifted control, the gate signals of T2 and T3 are phase shifted with respect to T1 and T4. The high frequency transformer is used and the high frequency AC voltage at the secondary is rectified using full wave rectifier and filtered using a low pass filter to obtain smooth DC output voltage. The parasitic capacitance (C1, C2, C3, C4) are connected across the switches in figure 1. The inductor connected in series with the primary winding of the transformer emphasizes the leakage inductance of the high frequency transformer. If required additional inductor can be connected in series with the transformer primary winding. The two components, the switch output capacitance and transformer leakage inductance decreases the performance of the converter in hard switching but is utilized advantageously in phase shifted converter to achieve ZVS. Hence attaining ZVS condition and elimination of switching losses, the phase shifted full bridge inverter consists of four semiconductor full bridge dc-dc converter topology for medium to high power applications.

4.2. MODES OF OPERATION

The first half cycle modes of operation are explained by 6 circuit modes of operation. The second half cycle the event repeats in the same as that of first cycle.

Mode 0

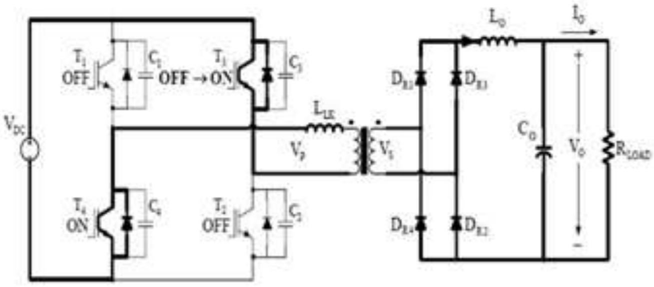

Fig -2(a)

In this mode, the switches T_1, T_2 are on and power is transferred from input to output. The mode is shown in figure 2(a).

Mode 1

In mode 1, the switch T_1 is turned off and the primary current flows through C_1 and C_4. The primary current charges C_1 to V_{DC} and discharges C_4 to zero. The energy required to charge and discharge is provided from the energy stored in the leakage inductor L_{lk}.

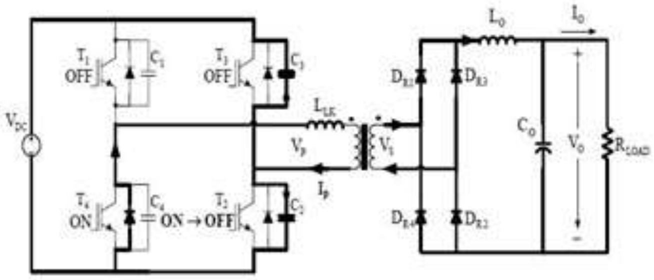

Fig -2(b)

Mode 2

In mode 2, the capacitor C_4 is discharged to zero and the freewheeling diode D_{R4} of switch T_4 is forward biased and starts conducting. Beyond this, the switch T_4 can be turned on with zero voltage across it and zero voltage switching turn on can be obtained. This is shown in fig 2(c).

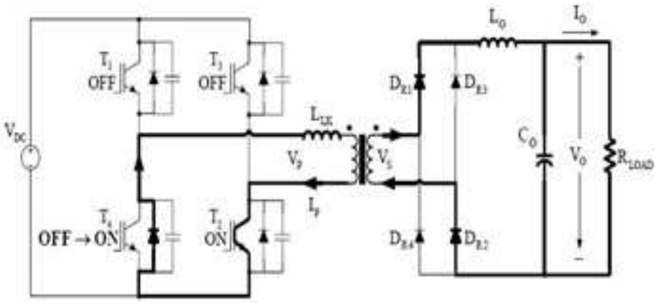

Fig -2(c)

Mode 3

In this mode, switch T_2 is turned off and the primary current flows through the capacitors C_2 and C_3. This current charges C_2 and discharge C_3. The capacitor charges to V_{DC} and the capacitor C_3 discharges to zero. This is shown in Fig 2(d). The energy required to charge and discharge the capacitors are provided by not only the leakage inductance of the transformer but also the energy stored in the output inductor.

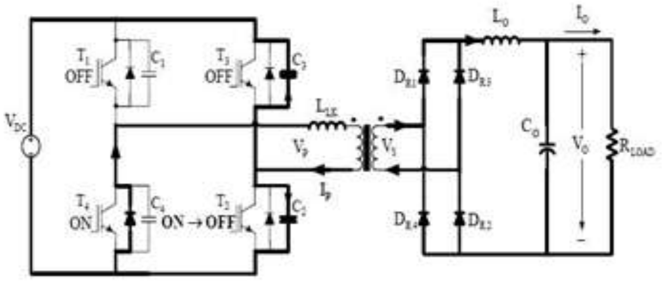

Fig -2(d)

Mode 4

At the end of this mode, the capacitor completely discharges to zero. The freewheeling diodes D_{R3} of switch T_3 becomes forward biased and starts to conduct. The switch T_3 is turned on with zero voltage across the switch and ZVS condition is satisfied. This is shown in Fig 2(e). All the rectifier diodes are conducting in this mode so the secondary winding of transformer is short-circuited.

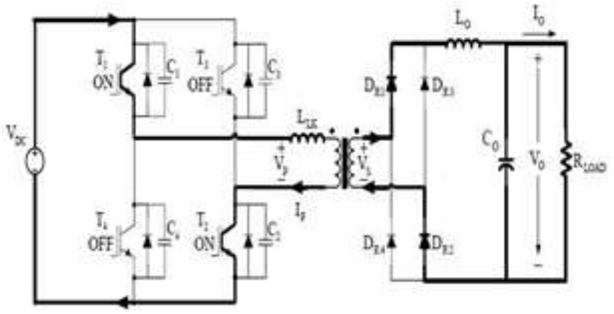

Fig -2(e)

Mode 5

In this mode, the current that flows through the diode D_{R1} and D_{R2} decreases to zero. The load current flows in D_{R2} and D_{R4} as show in figure 2(f). So the secondary voltage build up again and the output filter stores energy while power is transferred from input to the output. The cycle repeats and zero voltage switching is obtained in all the switches of the converter.

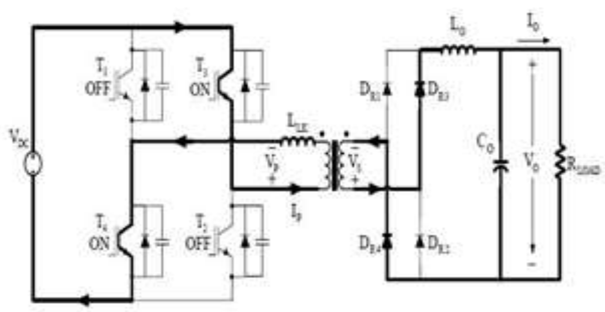

Fig -2(f)

5. SIMULATION RESULTS

Simulation is developed in MATLAB/SIMULINK platform to verify the effectiveness of the proposed control scheme. The PSFB converter will acts as Buck converter and supplies the Low voltage (LV) loads in vehicle system. The Simulink model of PSFB converter is shown in Fig.5. The PSFB converter provides isolation from High voltage side to Low voltage side with the help of isolation transformer.

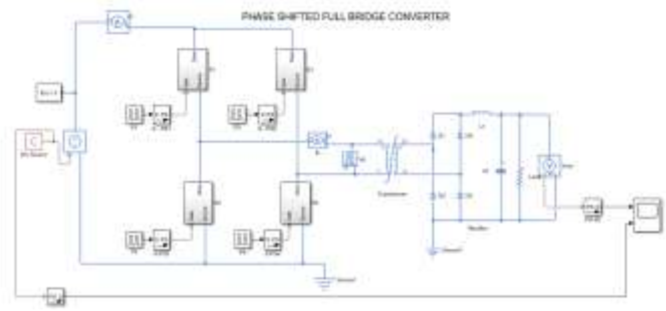

Fig -3: Simulink model of PSFB Converter

The gate pulses to the PSFB converter are phase shifted and the switching of IGBTs will occur with Zero Voltage Switching (ZVS) concept. ZVS switching will reduce the switching losses of the converter.

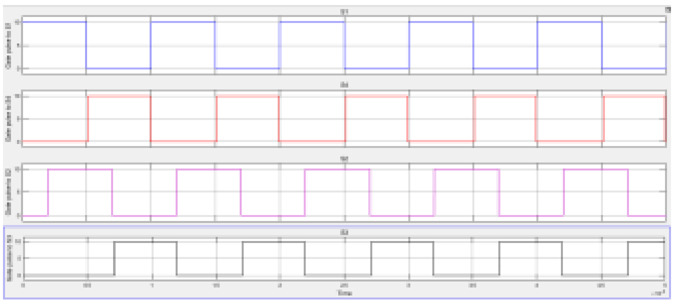

Fig -4: PSFB Converter Gate pulses to IGBT switches

The input voltage of the PSFB converter is magnitude of 400V and the output voltage is magnitude of 12V.

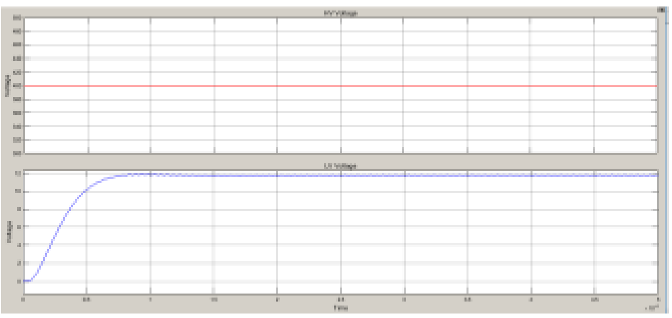

Fig -5: PSFB Converter Input and Output voltage

The proposed control strategy consists of a Selector control unit which determines the energy storage to be utilized for driving the vehicle. The Selector control unit will generates the gate pulse to switch the energy storage. The gate pulse is generated with the help of reference current determined from comparison of the actual speed of motor driving the vehicle.

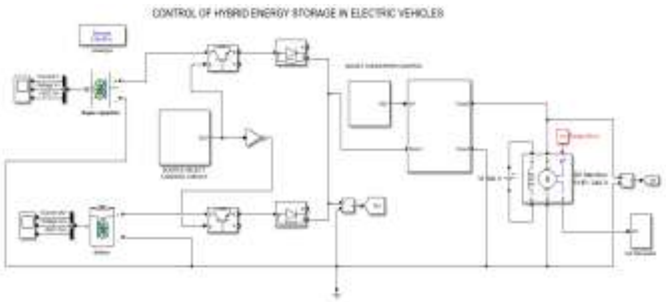

Fig -6: Simulink model for Control of Hybrid Energy Storage

The output of selector control unit switches the Battery and Super capacitor alternatively. Fig shows the switching occurs in Battery and Super capacitor to drive the vehicle.

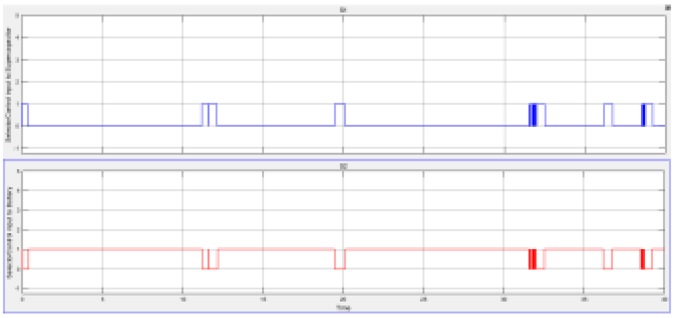

Fig -7: Selector Control unit output to switch Battery and Super capacitor

6. CONCLUSION

The PSFB converter and Control algorithm for Hybrid energy storage for EVs was simulated by using MATLAB/Simulink environment. The results of simulation are found to be satisfactory and the proposed control algorithm verifies the determination of energy storage device to drive the vehicle. The proposed control algorithm will help to increase the health and ageing of Battery by effective utilization of Supercapacitor.

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