OPTIMIZED DESIGN OF AN INTEGRATED CONVERTER FOR DUAL MODE ELECTRIC VEHICLE APPLICATION

[1]B.Navya sree , [2]Dr. P. Udaya Bhaskar, [3]G. Kamalaker

[1]Assistant Professor, [2]Professor & Head, [3]Assistant Professor,
Department of EEE, BIET, Hyderabad, (India)

ABSTRACT

A new integrated circuit for motor drives with dual mode control for EV/HEV applications is proposed. The proposed integrated circuit allows the permanent magnet synchronous motor to operate in motor mode or acts as boost inductors of the boost converter, and thereby boosting the output torque coupled to the same transmission system or dc-link voltage of the inverter connected to the output of the integrated circuit. Moreover, a new control technique for the proposed integrated circuit under boost converter mode is proposed to increase the efficiency. The proposed control technique is to use interleaved control to significantly reduce the current ripple and thereby reducing the losses and thermal stress under heavy-load condition. In contrast, single phase control is used for not invoking additional switching and conduction losses under light-load condition. In this paper we can connect more number of batteries. Which are bi directional and these are used for different types of applications by reducing the switches which are used for the required operation. In this paper we may get the output voltage is increased up to 3 times(90v to 270v),only 9 switches are used for the operation of inverting, bidirectional power flow for three sources. When used a conventional existing converter it may use 12 switches for the same operations and efficiency will improve high compared to other methods.

Key Words: EV/HEV, ICE, SMPS, DCM, CCM, PWM

I INTRODUCTION

A hybrid electric vehicle (HEV) is a type of hybrid vehicle and electric vehicle which combines a conventional internal combustion engine (ICE)propulsion system with an electric propulsion system. The most common form of HEV is the hybrid electric car, although hybrid electric trucks (pickups and tractors) and buses also exist.

Modern HEVs make use of efficiency-improving technologies such as regenerative braking, which converts the vehicle's kinetic energy into electric energy to charge the battery, rather than wasting it as heat energy as conventional brakes do Many HEVs reduce idle emissions by shutting down the ICE at idle and restarting it when needed; this is known as a start-stop system

With the advancement of power electronics, micro processors and digital electronics, typical electric drive systems now a day are becoming more compact, efficient, cheaper and versatile. The voltage and current applied to the motor can be changed at will by employing power electronic converters.AC motor is no longer limited to application where only AC source is available, however, it can also be used when the power source available.

A new integrated circuit for motor drives with dual mode control for EV/HEV applications is proposed. The proposed integrated circuit allows the permanent magnet synchronous motor to operate in motor mode or acts as boost inductors of the boost converter, and thereby boosting the output torque coupled to the same transmission system or dc-link voltage of the inverter connected to the output of the integrated circuit. In motor mode, the proposed integrated circuit acts as an inverter and it becomes a boost-type boost converter, while using the motor windings as the boost inductors to boost the converter output voltage. Moreover, a new control technique for the proposed integrated circuit under boost converter mode is proposed to increase the efficiency. The proposed control technique is to use interleaved control to significantly reduce the current ripple and thereby reducing the losses and thermal stress under heavy-load condition. In contrast, single phase control is used for not invoking additional switching and conduction losses under light-load condition. Experimental results derived from digital-controlled 3-kW inverter/converter using digital signal processing show the voltage boost ratio can go up to 600W to 3 kW. And the efficiency is 93.83% under full-load condition while keeping the motor temperature at the atmosphere level. [1] In this we can connect more number of batteries. these batteries are bi directional and these are used for different types of applications. In this paper am reducing the switches which are used for the required operation.

II EXISTING METHODS

The method is interleaved method. It is also called 2phase method. In this method we use 2 inductors 2 switches the operation and simulation results are shown in below.
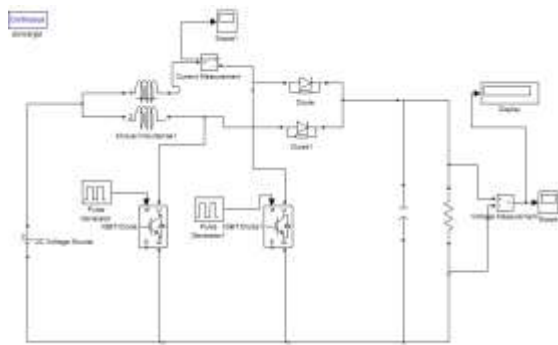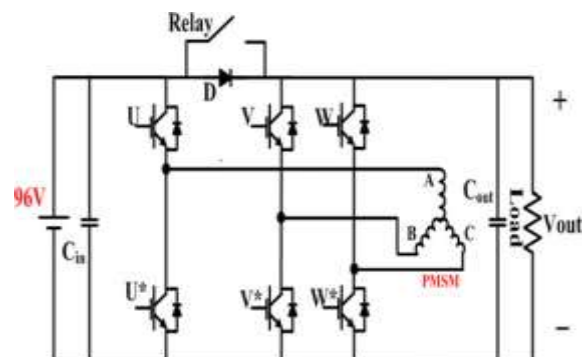

Figure 1 Interleaved Diagram   **Figure 2 Integrated Circuit**

For 50% of duty ratio the output voltage we have 55.37.the output voltage compared to normal boost converter is increased in this method [2]. And another method is integrated inverter/converter method in this method the boost converter and inverter are placed in one circuit only. By this it reduces the size and the cost of the equipment.

Based upon the interleaved control idea, a boost-control technique using motor windings as boost inductors for the proposed integrated circuit will be proposed. Under light load, the integrated circuit acts as a single-phase boost converter for not invoking additional switching and conduction losses, and functions as the two-phase interleaved boost converter under heavy load to significantly reduce the current ripple and thereby reducing the losses and thermal stress [3]-[4]. Therefore, the control technique for the proposed integrated circuit under boost

converter mode can increase the efficiency. Detailed operation of interleaved method and boost converter are shown below.

2.1 Interleaved Operation

The interleaved boost converters consists of several identical boost converters connected in parallel and controlled by the interleaved method which has the same switching frequency and phase shift. Ripple cancellation both in the input-output voltage and current waveforms, reduced current peak value, and high ripple frequency are some of the benefits of interleaving operation in converters. Moreover, increased efficiency and high reliability can be achieved. Also, by high frequency, the size and losses of the magnetic components can be reduced. These interleaved boost converters are distinguished similar with conventional converters by critical operation mode, discontinuous conduction mode (DCM), and continuous conduction mode (CCM).
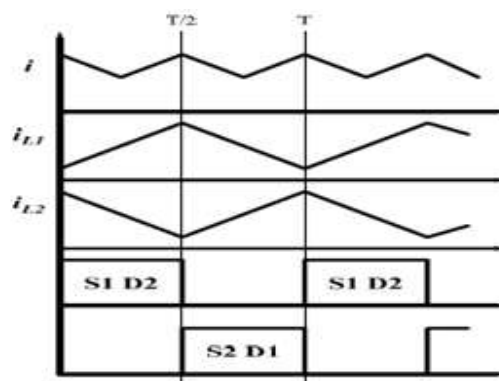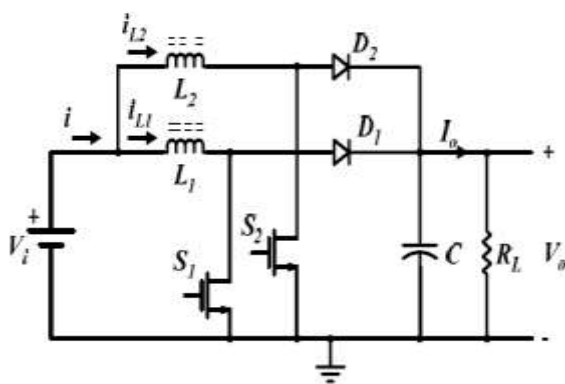

Figure 3 Two-phase interleaved boost converter   Figure 4 Ideal waveforms of the currents in the inductors L1 and L2 for interleaved boost converter operating at CCM.

These methods are primarily used in the design of inductors for switching-mode power supplies (SMPS) [5]. In this paper, core geometry approach used to select magnetic core. For interleaved operation two identical boost converter parallel connected and operated with 180° phase shifted. Designed inductor will used for both phases.
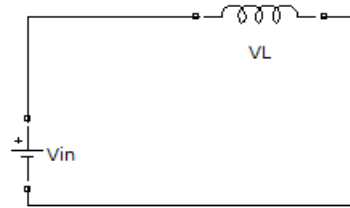
2.2 Integrated Circuit Method
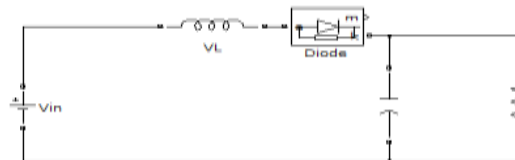
Solution of gain equation for the boost converter:

Normal boost converter

CASE 1: When the switch is in ON position

$$V_{in} = V_L$$

CASE 2: When the switch is in OFF position

$$V_L = V_{in} - V_o$$

$$V_{in} = V_L + V_o$$

As we know Duty ratio

$$D = \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

$$D = \frac{T_{ON}}{TS} \qquad T_{ON} = DT_S \qquad T_{OFF} = (1 - D) \cdot T_S$$

Average voltage across inductor =0

$$\frac{V_{in} \cdot D \cdot T_S + (V_{in} - V_o) \cdot (1 - D)T_S}{T_S} = 0$$

$$V_{in}D + (V_{in} - V_0)(1 - D) = 0$$

$$V_{in} - V_0(1 - D) = 0$$

The final gain equation is $\dfrac{V_0}{V_{in}} = \dfrac{1}{1 - D}$

In Parallel hybrid electric vehicle (HEV) and electric vehicle (EV) system as shown in Fig. 5 the converter is used for boosting the battery voltage to rated dc bus for an inverter to drive motor. In the multi motor drive system the system will use two or more motors to boost torque, especially under low speed and high-torque region as shown in Fig. 6. For such applications, two or more inverters/ converters are required. Fig. 7 shows the application of the proposed integrated circuit for motor drives with dual-mode control for EV/HEV applications. As shown in Fig. 7, the proposed integrated circuit allows the permanent magnet synchronous motor.
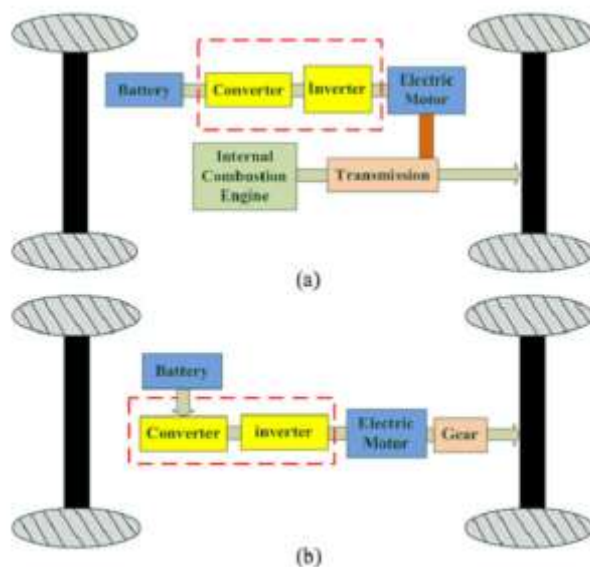
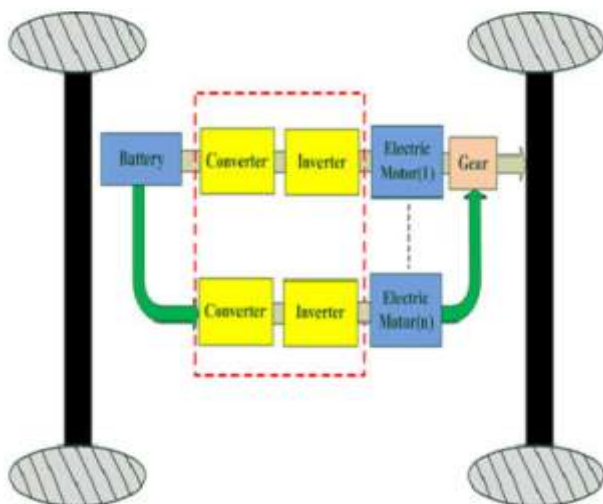**Figure 5 HEV and EV system. (a) Parallel HEV drive train. (b) EV drive train**

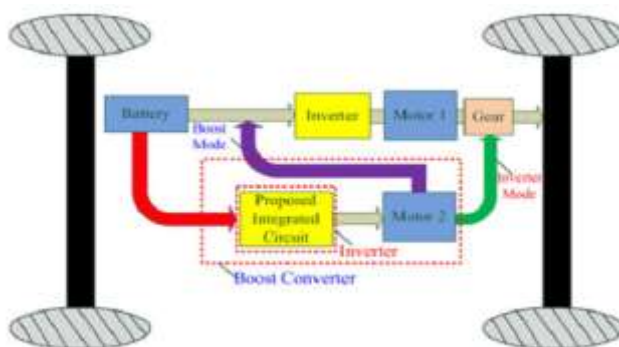**Figure 6 Conventional multi motor drive system of EV/HEV.**

Figure 7 Proposed integrated inverter/converter for the multi motor drive system of EV/HEV.

(PMSM) to operate in motor mode or acts as boost inductors of the boost converter, and thereby, boosting the output torque coupled to the same transmission system or dc-link voltage of an inverter connected to the output of the integrated circuit.

The integrated circuit presented in this paper can act as an inverter and a boost converter depending on the operation mode[9]. For the integrated circuit, it not only can reduce the volume and weight but also boost torque and dc-link voltage for motor/converter modes, respectively. Moreover, a new control technique for the proposed integrated circuit under boost converter mode is proposed to increase the efficiency.

Based upon the interleaved control idea, a boost-control technique using motor windings as boost inductors for the proposed integrated circuit will be proposed.
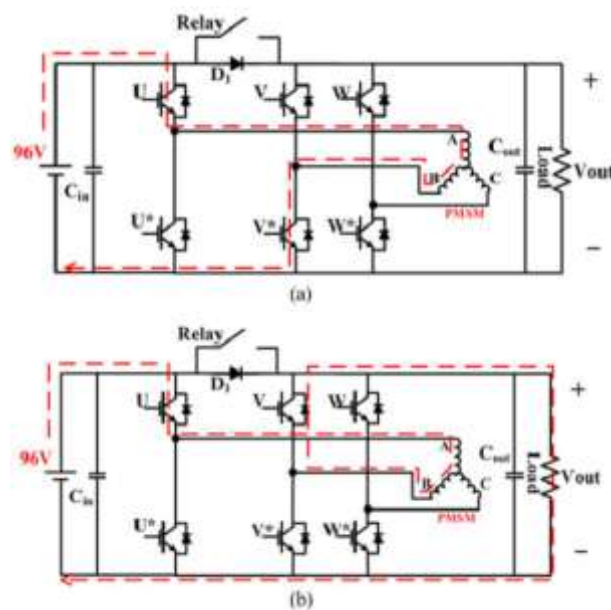

Figure 8 Single-phase boost mode. (a) Charge path for inductor. (b) Discharge path for inductor.
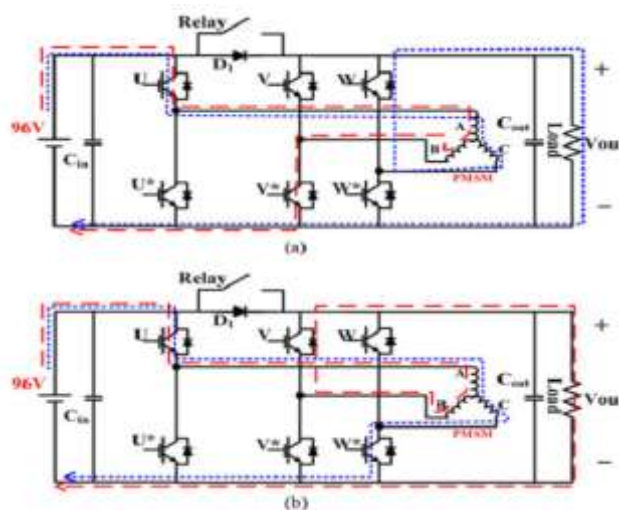

Figure 9 Proposed interleaved boost mode. (a) Phase B: Charge; Phase C: Discharge. (b) Phase B: Discharge; Phase C: Charge.

Therefore, the proposed control technique for the proposed integrated circuit under boost converter mode can increase the efficiency. Fig above shown the integrated circuit for dual-mode control. In that fig Cin and Cout can stabilize the voltage when input and output voltages are disturbed by source and load, respectively. Diode (D) is used for preventing output voltage impact on the input side. When the integrated circuit is operated in inverter (Motor) mode, relay will be turned ON and six power devices are controlled by pulse width modulation (PWM) control signals. When the proposed integrated circuit is operated in the converter mode, relay is turned OFF. And a single-phase or interleaved control method will be applied to control of the power devices depending upon the load conditions. Figs. 8 and 9 show the single-phase and two-phase interleaved boost converters. In the above Fig 8 the single-phase boost converter uses power switch V∗, stator winding "A" and winding "B" to boost the output voltage. In Fig. 9 two-phase interleaved boost converter uses power switches V ∗ and W∗, stator winding "A" winding "B" and winding "C" to boost the output voltage and reduce the current ripple.

III MODELLING AND CONTROLLER DESIGN UNDER BOOST MODE

This section will introduce the model of boost converter and derive the transfer function of the voltage controller. Fig. 10 shows the non ideal equivalent circuit of the boost converter, it considers non ideal condition of components: inductor winding resistance R_L, collector-emitter saturation voltage V_{CE}, diode forward voltage drop V_D, and equivalent series resistance of capacitor Resr. Analysis of the boost converter by using the state-space averaging method, small-signal ac equivalent circuit can be derived, as shown in Fig. 11. By Fig. 11, the transfer function of the voltage controller can be derived, at the bottom of the next page.
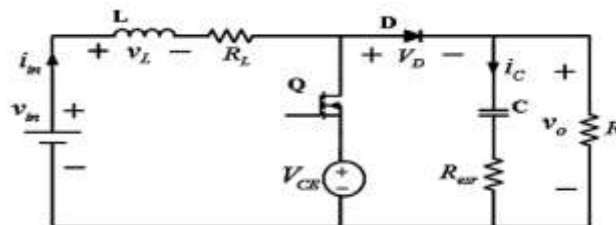

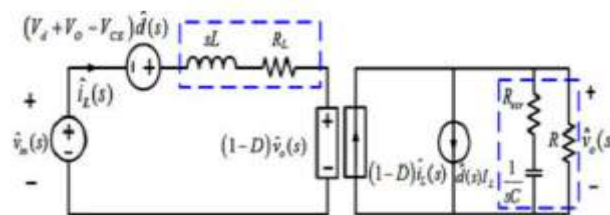**Figure 10 Equivalent circuit of the boost converter.**

Figure 11 Small-signal equivalent circuit

$$G_{vd}(s) = \frac{\vec{V_o}(s)}{d(s)} = \frac{s^2 \cdot L \cdot C \cdot (R + R_{esr}) + s[L + C \cdot R_L (R + R_{esr})] + (1-D)^2 C \cdot R \cdot R_{esr}] + [(1-D)^2 R + R_L]}{-s^2 \cdot C \cdot R \cdot R_{esr} \cdot L \cdot I_L + s[C \cdot R \cdot R_{esr} [(V_d + V_o - V_{CE})(1-D) - R_L I_L] - R_L I_L] + R[(V_d + V_o - V_{CE})(1-D) - R_L I_L]}$$

Fig. 12 shows the block diagram of voltage loop, using a proportional-integral (PI) controller for the compensator. In this paper, the switching frequency is 20 kHz and voltage loop bandwidth will be less than 2 kHz. And the phase margin should be more than 45° to enhance the noise immunity.
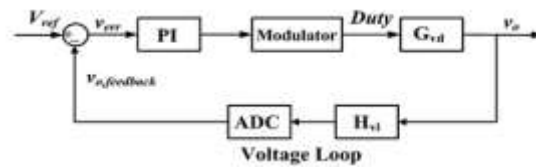
$$C(s) = \frac{0.0248387 \quad s + 13.073}{s}$$

Figure 12 Block diagram of voltage loop.

IV SIMULATION RESULTS

CASE 1: Interleaved boost mode: B phase discharges the power until the C phase charges, after c is charged this phase will send the power to the load in that time B is going to charge. Fig 13 and Fig.14 shows the block diagram and output results of the two phase mode operation.

CASE 2: Single phase to two phase interleaved mode: In this mode of operation the both single phase and two phase operation is performed. From single phase to two phase conversion is performed in this case, the below figures shows the circuit and output results. In this circuit contains switch,

this is used to phase conversion.

CASE 3: Two phase interleaved to single phase mode: In this mode also same operation is performed as case3. But the phase conversion is from two phase to single phase.
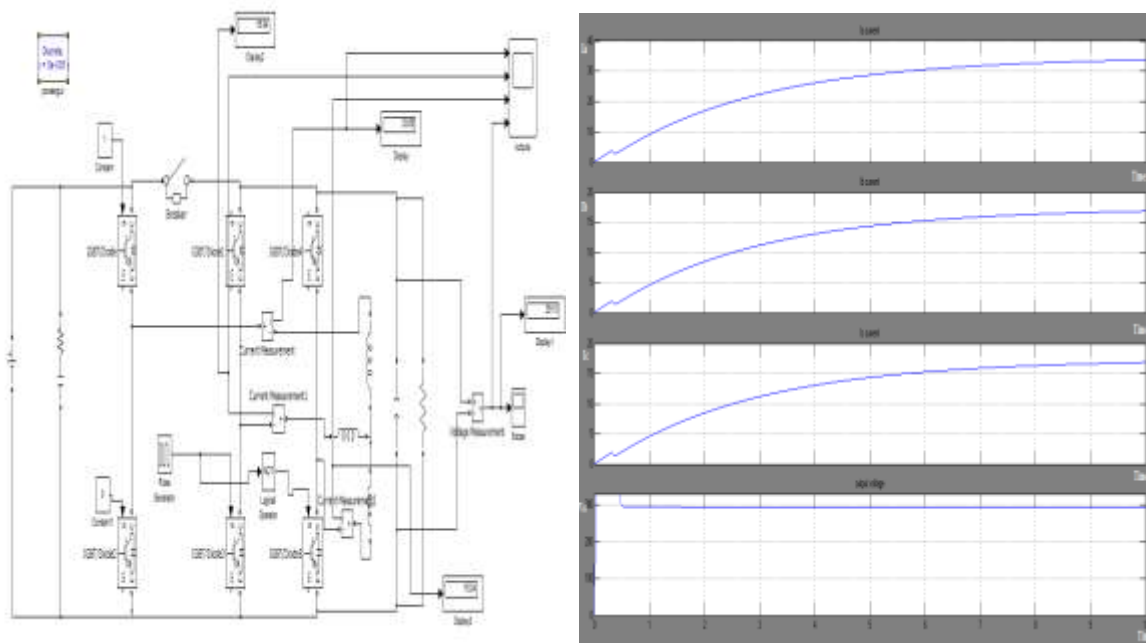

Figure 13 interleaved boost mode   Figure 14 output results of interleaved boost mode
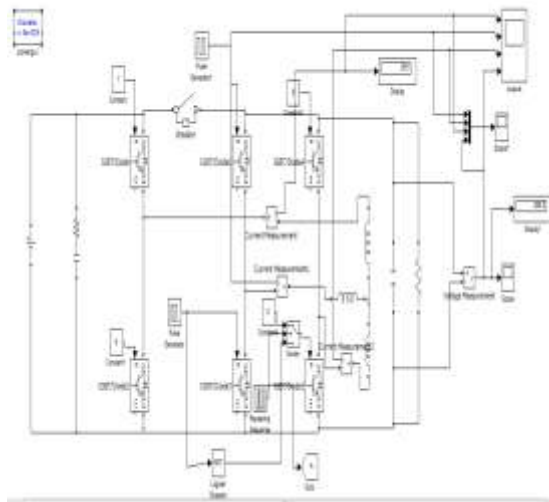
Figure 15 single phase to two phase interleaved mode.   **Figure 16 output results**
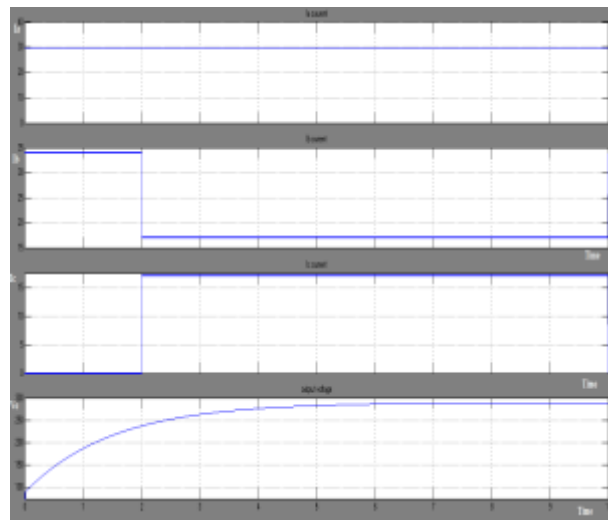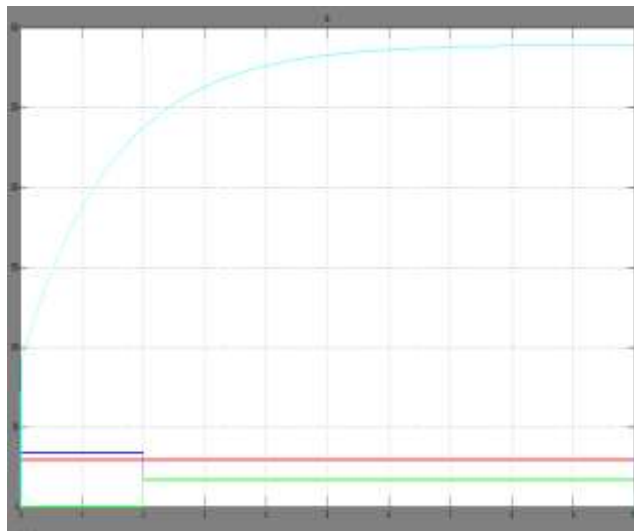

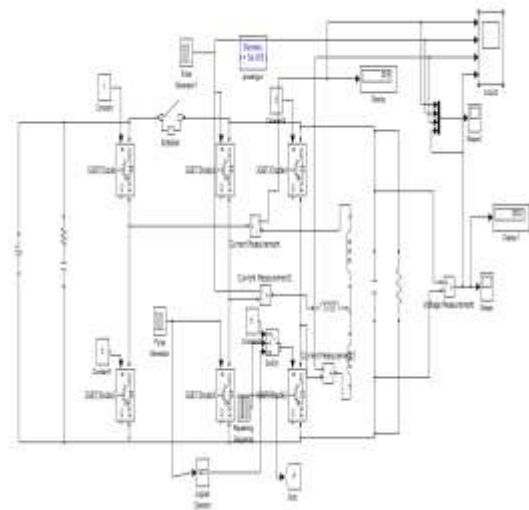**Figure 17 combined output results   Figure 18 Two Phase interleaved to single phase mode**
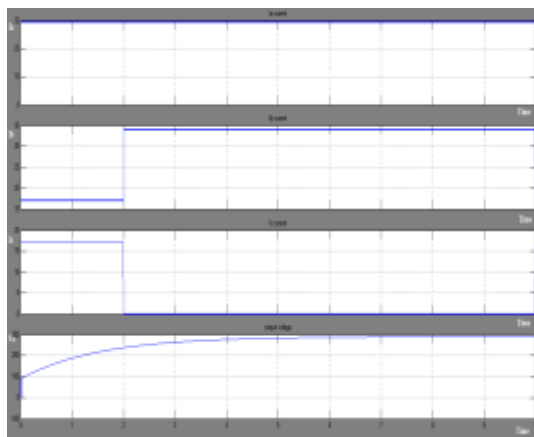
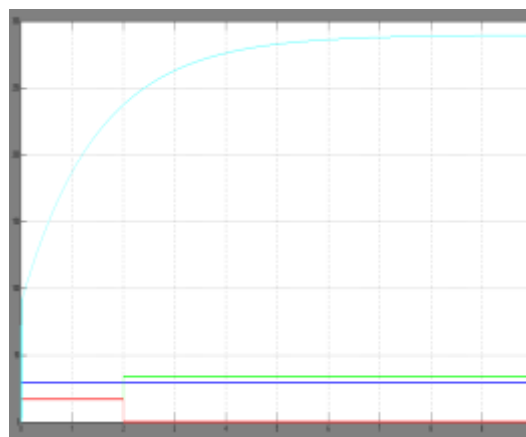**Figure 19 output results of two phase interleaved Figure 20 combined results of two phases**

to single phase mode   interleaved to single phase mode

Table 1 CALCULATION FOR RIPPLE CONTENT MEASURE

Normal boost converter			
Duty ratio	Higher point of ripple in current	Lower point	Total ripple content(subtract from higher to lower)
50	3.4	0	3.4
40	3.6	0	3.6
60	-	-	-
Interleaved Boost Converter			
50	3.7	3.4	0.3
40	2.6	3.2	0.6
60	4.1	4.5	0.4

From normal boost converter ripple content is for 50% duty ratio ripple is 3.45.for 40% also same ripple content, for 60% no ripple is appear. In interleaved boost converter the ripple content is reduced compared to normal boost converter. for 50%,the ripple content is 0.3,for 60% it is 1,and for 40% the current ripple content measured is 0.6.But in new integrated converter topology no ripple content is observed, if appear it will be very small and neglected quantity But In this only converter operation is explained and in this method it uses many switches for connecting of bidirectional batteries. And the output voltage is 288v.So in proposed method we used to make many change for better efficiency and less switches and for low losses.

V PROPOSED CIRCUIT AND CONTROL TECHNIQUE

In this circuit we are using bidirectional batteries as multiple batteries. These are because of when we are using one battery, it causes discontinue of supply when the charged battery is complete .and also when one of the battery is not working also vehicle works because of other batteries, for this batteries it required more number of switches, but am reducing switches. By this same results are getting, and by this circuit complexity reduced, cost of the circuit also decreases. And in integrated circuit the inverter operation is not explain. In this extension automatically inversion operation is performing after the converter operation. By this it is proved that efficiency improved and current ripples are reduced and the cost also less for this circuit.
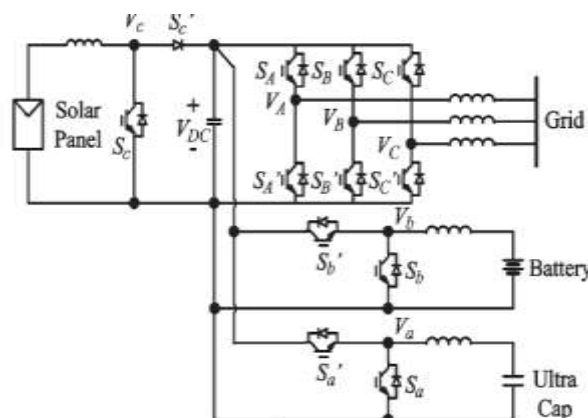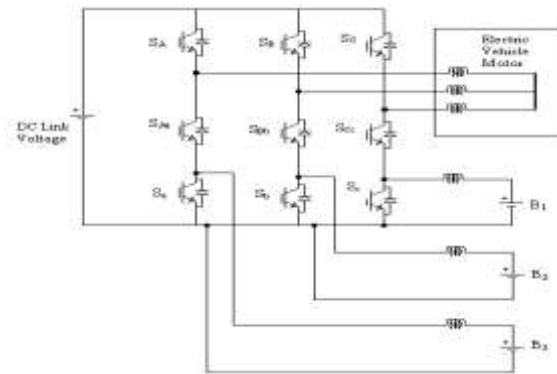

Figure 21more switches connected integrated circuit

Figure 22 integrated less switches circuit

Table 2 switching states and output voltages of figure 21

S_A	S_A	S_a	S_a	V_A	V_a
ON	OFF	ON	OFF	V_{DC}	V_{DC}
ON	OFF	OFF	ON	V_{DC}	0
OFF	ON	OFF	ON	0	0
OFF	ON	ON	OFF	0	V_{DC}

Table 3 switching states and output voltages of figure 22

S_A	S_{Aa}	S_a	V_A	V_a
ON	ON	OFF	V_{DC}	V_{DC}
ON	OFF	ON	V_{DC}	0
OFF	ON	ON	0	0

Fig.21 shows integrated 6 switch circuit here 11 controllable switches are used, in which 6 switches are for integrated circuit and 4 switches for 2 batteries.1 for supply, When 3 batteries connected it uses 2 more batteries extra.Table3,4, Shows The Switches Operation, Means On Or Off Operation Of Switches.

The further development is made by integrating the above circuit by reducing the number of switches to 9 instead of 12 as shown in fig. In that upper 6 switches $\{S_A, S_B, S_C, S_{Aa}, S_{Bb}, S_{Cc}\}$ are used for inversion and lower 6 switches $\{S_a, S_b, Sc, S_{Aa}, S_{Bb}, S_{Cc}\}$ are for conversion. In that switches the switches in the middle $\{S_{Aa}, S_{Bb}, S_{Cc}\}$ are common for both inversion and conversion processes.

Operation:

A control circuit is designed which creates a reference signal for AC and DC. This reference is made ripple free using a PI controller. In closed loop circuits we use PI controller for better operation. with these reference signals the triggering pulses are generated using PWM technique which helps in switching operation. 3 batteries are connected, each battery voltage is 30v.these will help to supply power to load when more power required for the vehicle. When one battery is not working also the other 2 batteries give the supply to load. From this no interruptions accrue in the vehicle. And for upper switches a reference AC voltage also supplied to the circuit, for better operation.

Table 4 Parameter values of circuit

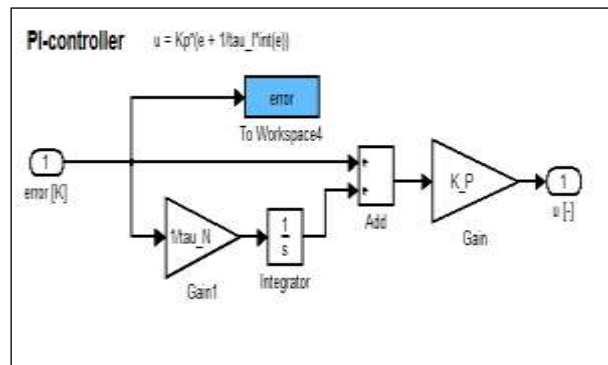| V_{in}	$175 V_{dc}$
Battery voltage	30
Inductor value	5mh
RC	1ohm,$2200\mu f$
RL	13ohm,1mh

Figure 23 PI Controller

The definition of proportional feedback control is still

$u = K_p e$

where

$\qquad$ e = is the "error"

$\qquad$ K_P = Proportional gain

The definition of the integral feedback is

$u = K_I \int e \cdot d\tau$

where K_I is the integration gain factor.

In the PI controller we have a combination of P and I control, i.e.: $\qquad u = K_p e + K_I \int e \cdot d\tau$

$$u = K_p e + \frac{1}{\tau_I} \int e \cdot d\tau$$

$$u = K_P \left[e + \frac{1}{\tau_N} \int e \cdot d\tau \right]$$

Where, τ_I = "Integration time" [s]

τ_N = "Reset time" [s]

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error. The PID controller block is reduced to P and I blocks only as shown in figure 24
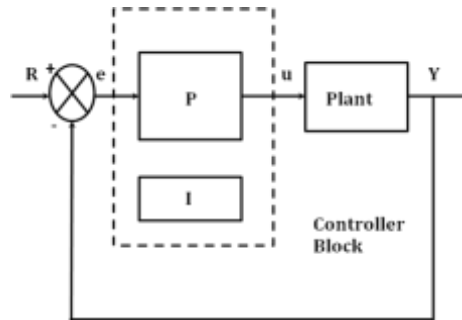
Figure 24 Proportional Integral (PI) Controller block diagram

The proportional and integral terms is given by:

$$u(t) = K_P \cdot e(t) + K_I \int e(t) \cdot dt$$

PWM Technique:

Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a modulation technique that controls the width of the pulse, formally the pulse duration, based on modulator signal information. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. In addition, PWM is one of the two principal algorithms used in photovoltaic solar battery chargers, the other being MPPT. the two basic approaches used to generate the PWM signals for multilevel inverters are:

- Sub harmonic or Sub-Oscillation carrier based PWM-modulating waveform comparison with offset triangular carriers.

- Space Vector PWM-space vector modulation based on a rotating vector in multilevel space.

These are the extensions of traditional two level control strategies to several levels. The two main advantages of PWM inverters in comparison to square-wave inverters are

- control over output voltage magnitude

- Reduction in magnitudes of unwanted harmonic voltages.

Good quality output voltage in SPWM requires the modulation index (m) to be less than or equal to 1.0. For m>1 (over-modulation), the fundamental voltage magnitude increases but at the cost of decreased quality of output waveform. The maximum fundamental voltage that the SPWM inverter can output (without resorting to over-modulation) is only 78.5% of the fundamental voltage output by square-wave inverter.

The merits and demerits of these two PWM techniques are compared under comparable circuit conditions on the basis of factors like (i) quality of output voltage (ii) obtainable magnitude of output voltage (iii) ease of control etc. The peak obtainable output voltage from the given input dc voltage is one important figure of merit for the inverter.

Fig. 25 shows generation of reference and carriers signal for SHPWM technique, which is used to control the switches of TBMCSL H- bridges inverter.
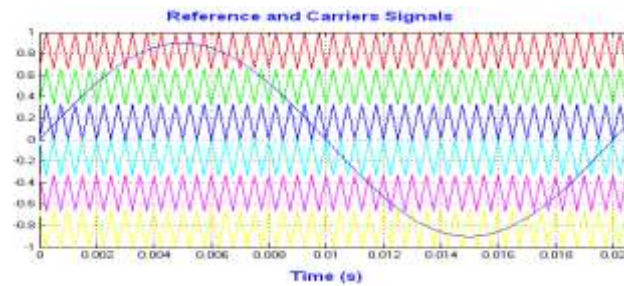
Figure 25 Reference and carriers signals for SHPWM technique.

VI EXPERIMENT RESULTS AND DISCUSSIONS

Experiment results of proposed circuit are given below. In this source voltage is 89.5v.In the above circuit we have 9 switches instead of 12 switches, the operation is explained in previous chapter .Error free reference signals are generated by the control circuit and by using this, pulses are generated by pwm technique.
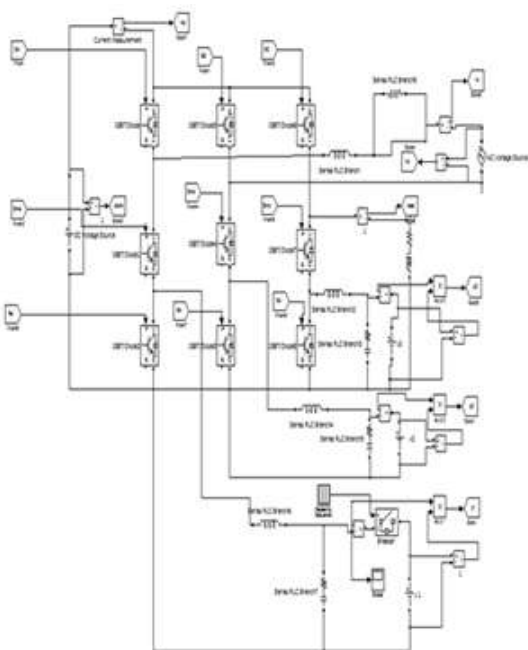

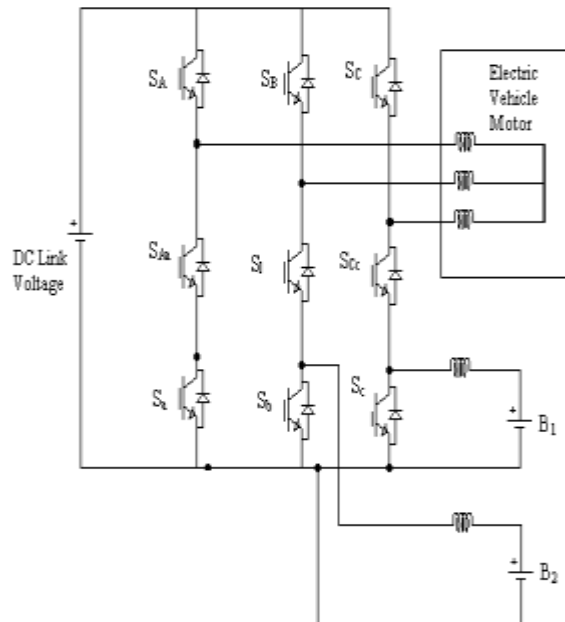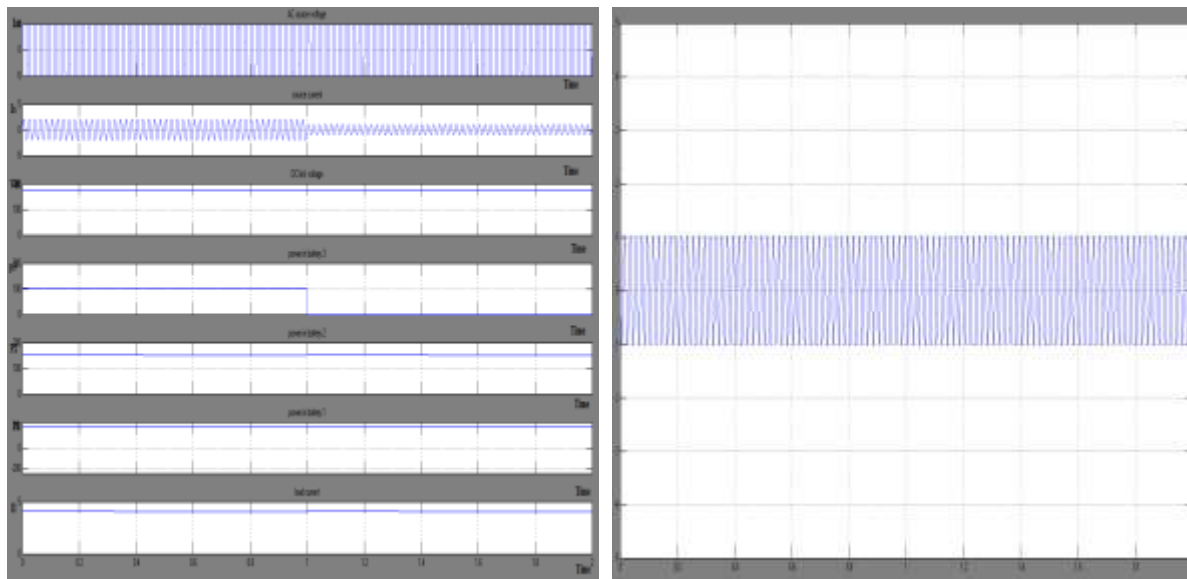**Figure 26 proposed extension circuit**   **Figure 27 absence of one battery**

In this circuit no load is connected means we can connect any type of load to this circuit. And it gives both AC And DC output, so we can connect both type of loads and we can use it for AC and DC type of applications For example in car we use many applications, in that some are AC And some are DC. And the use of bidirectional batteries are when the charged power is completed in the vehicle, the bidirectional batteries supplies the power to the vehicle.

In the above 26 figure we have 3 batteries .Actually In the proposed concept if one battery not working also the other batteries will supply the power to load, the fig.27 shows absence of one battery but basically in the circuit we placed one breaker to connect the battery or disconnect the battery, and also the repeating sequence values will decide the battery to what time it should ON, and what time it should OFF. These Will Show the Results.

Table 5 Output values

	For 2 switches	For 3 switches
Source voltage V_s	89.5v	89.5v
I_s	2amp	2amp
DC link	175v	175v
Power in battery1(P_1)	100w	100w
P_2	154w	154w
P_3	203w	0
I_{load}	4amp	4amp

Figure 28 Simulation results of extension circuit   Figure 29 Simulation result of AC reference

In the above results it shows source voltage, source current, DC link voltage, powers flowing in 3 bidirectional batteries, load current. The below fig shows the control circuit of the circuit, in this reference voltage for AC, DC are generated. In battery -3upto time 1sec it is ON, so the power in that battery is appear. But after that it is OFF, so the battery power is zero. But the link voltage is not zero, and the load current also not zero. It means the other remaining 2 batteries will supply the power to load, so it is not zero in that time.

The Figure 30 shows the control circuit and the reference of AC voltage. In that first we fix one value. DC link voltage and the fixed value both are compared and this result given to the PI controller to rectify the errors. After that some additions, multiplications, divisions are performed to get efficient reference voltage. The reference which created by the control circuit is given to the PWM circuit to generate the triggering pulses for the switches in main circuit. In PWM circuit the triggering pulses are created for 9 switches. These are generated according to the logical gates for better operation. After that the switches in main circuit are operated based on these logical gates and operated as inverter and converter in only one circuit. S_A, S_B, S_C Switches are used for inversion and S_{ma}, S_{mb}, S_{mc} are used for both inversion and conversion and $S_a S_b S_c$ switches are used for conversion in main circuit.
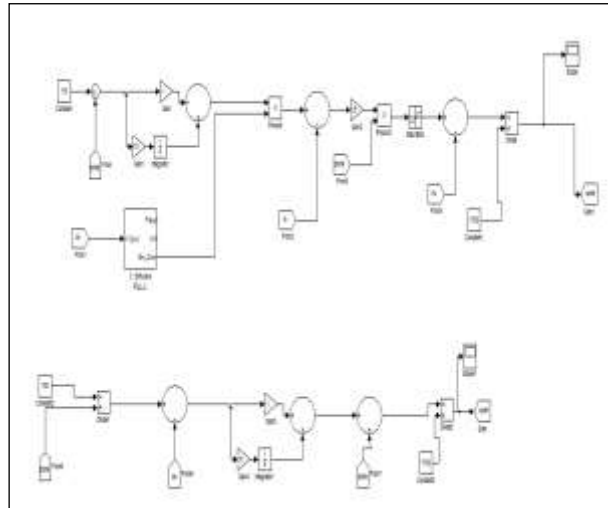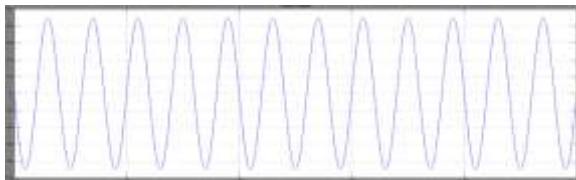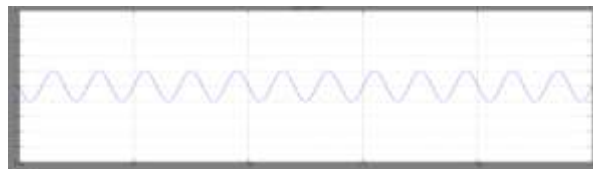
Figure 30 control circuit

Figure 29 source voltage   **Figure 30 source current**
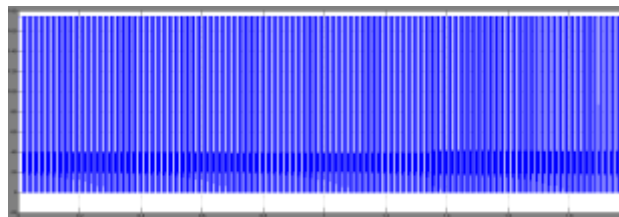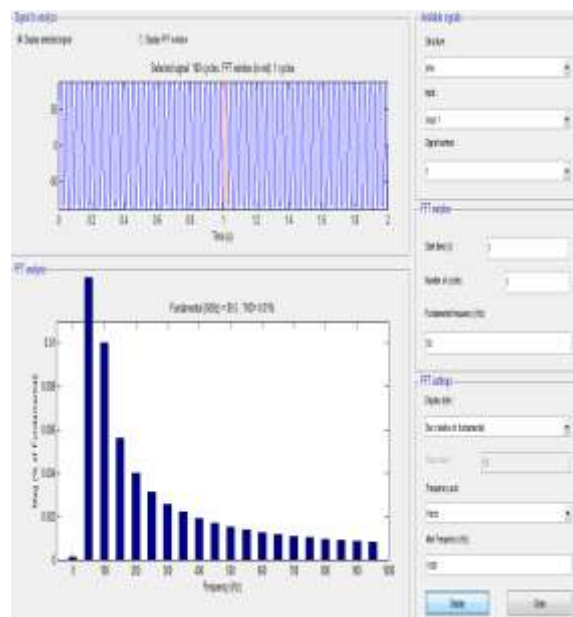
Figure 31 load voltage

Figure 32 FFT analysis

And also from FFT analysis the THD is 0.01% for AC.

The middle switches in the circuit are operated based on XOR gate. When one switch from upper case or 1 switches from lower case should be in ON position, in that position the power flows in the circuit. When one switch or 3 switches in one phase leg is ON it won't work. Means it is in OFF position.
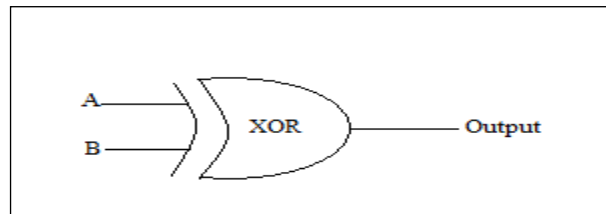

Figure 33 XOR gate block diagram and truth table

Table 6 XOR gate truth table

A	B	OUT
0	0	0
0	1	1
1	0	1
1	1	0

VII CONCLUSION

From the above it is concluded that when charged power is completed in the vehicle, the alternate multiple batteries are supply the power to vehicle. When 3 bidirectional batteries are connected to the vehicle, these will supplies the power to the vehicle without interruption. If any battery is not responding also the other batteries will supplies power to load, the switches also less used in this circuit. By this circuit complexity, cost and ripple content are decreases. And conversion and inversion operation performed in only one circuit. And also it gives good efficiency with these changes

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