A DISSERTATION ON

DESIGN OF BUCK BOOST CONVERTER FOR HYBRID ELECTRIC VEHICLE.

SUBMITTED TOWARDS THE FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

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SUBMITTED BY

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We thank Almighty GOD for his countless blessings.

DECLARATION

We hereby declare that this thesis is based on the results we found in our pre-thesis and thesis work .Contents of work found by other researchers are mentioned by reference. This thesis has never been previously submitted for any degree neither in whole nor in part.

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Supervisor Author

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ABSTRACT

The project is all about step by step process of designing, constructing and testing a Buck-Boost converter for the next generation of Hybrid Electric Vehicles or HEV.In this paper a comprehensive study of use of DC-DC converter in a Hybrid Electric Vehicle , it's designing with proper parameter values and basic construction has been carried out.
This paper discusses the operational characteristics of various topologies for hybrid electric vehicles (HEV) with a brief description of series hybrid, parallel hybrid, and fuel cell-based propulsion systems.The role of Buck-Boost converter and how it is used in an HEV has been explained with the proper case study of its current commercial application.

The basic working and design parameters of a buck-boost converter under certain constraints have been presented with a study and realization of a better design suitable to be used in an Hybrid Electric Vehicle.

The converter is tested under a simulated scenario to verify acceptable functionality and performance. For the demonstration of the working principle of the converter the scale down version has been implemented on a hardware possible under a laboratory environment.

CHAPTER-1

INTRODUCTION

- **Hybrid Electric Vehicles & Why We Need One**

A hybrid electric vehicle (HEV) uses two power sources topower the vehicle. At present, one power source is internal combustion (IC) engine (gasoline or diesel fueled) and the other is chemical batteries plus an electric motor drive. In HEVs, high peak power and quick power response of the electric traction system results in high vehicle performance such as quick acceleration. Small IC engine and optimal operating points and regenerative braking result in much better fuel economy and lower emissions than IC engine-alone powered vehicles.High energy density of petroleum fuel and convenient fueling systems result in long operating range and easy refueling. All these advantages make HEVs the most promising alternatives for the next generation vehicles.

Today the demand for more eco- friendly vehicles and growing concern on CO2 emission and global warming has increased the research in the field of electric vehicles and HEV seems to be a temporary practical alternative .The hybrid electric power train is now accepted as the lowest cost near-term solution. Hybridization provides the following power train features:

• Idle stop

• Torque augmentation

• Regenerative braking

Idle stop and its extensions, early fuel shut off (EFSO) and decel fuel shut off (DSFO), conserve fuel by not burning it for nonpropulsion events. Fuel conservation is obtained by shutting off the engine fuel supply during decelerations and by simultaneously regulating the power train-mounted electric motor-generator (M/G) so that vehicle deceleration does not exceed some prescribed limit, such as 0.05 g, as the vehicle speed decreases. Early fuel shut off can be semantically confused with DSFO but it refers more to a prescribed engine speed below which fuel to the engine is inhibited. For example, ESFO could be enabled should the engine speed drop below 1200 rpm (coasting on a downhill grade, for instance).

Torque augmentation is one of the major performance enhancers offered by hybridization. Since one or more electric motor-generators are present in the power train, it is only a matter of scheduling the M/G torque to coincide with certain driveline events such as transmission shifting, vehicle launch, lane changing, and passing maneuvers. M/G torque response, particularly under field-oriented control, is far faster than ICE response and faster still than fuel cell system response. During gear shifting the M/G can add torque to the driveline, thus filling in for lack of engine-supplied torque. During vehicle launch the M/G can augment the engine torque, particularly since downsized engines are virtually a prerequisite of hybridization, and provide the customer with expected acceleration or, better still, improved performance. The Honda Civic hybrid does exactly this. The engine is far too undersized to deliver the performance drivers expected, so the M/G is sized to augment the driveline over the entire engine operating speed range.

Regenerative braking, or energy recuperation, is the principal means through which kinetic energy of the vehicle is returned to electric energy storage rather than burned off as heat in the brake pads. But there are practical limits to how much and how fast regenerative braking can be applied. Smooth and seamless brake feel is the result of a fine balance between M/G energy recuperation and the vehicle’s foundation brakes. The best brake system for a hybrid is what is known as series regenerative braking system (RBS).

- **Role Of Power Electronics In a HEV.**

Power Electronics plays a major role in HEV and a massive growth is predicted in coming future. Changing scenario demands for increase in electrical consumption to be able to elevate the level of comfort and security. Another vector of improvement is the diminution of fuel consumption per kilometer.

It is clear that, to be able to integrate both aspects, it must use an electrical supply system that fulfills these three general requirements:

1. It makes an optimal transformation of the mechanical energy into electrical energy.
2. It distributes the electrical energy with minimum losses.
3. It supplies the required services (loads) with maximum efficiency.

These facts start to force several future situations:

• Only the alternator will have a mechanical connection with the internal combustion engine. All the other motors, from the conditioned air compressor to the refrigeration water pump, will be electrically driven.
• High-efficiency lamps like the HID ones will increasingly substitute the conventional high-beam lights. Moreover, neon lamps or LEDs will be used for signaling and fluorescent lights for interior illumination.
• Wherever it becomes possible, the use of AC motors, with or without regulation, will be attempted.

Hybrid electric power trains require a large investment in M/G and power electronics technology. Package space is extremely restricted so that even with a ground-up design for a hybrid there is precious little space to put 20 to 100 kW electric machines and the power electronics to drive them. Such machines must not only have the highest power density but they must also be robust and efficient. Packaging an M/G into the vehicle driveline means that repair and replacement would entail significant tear-down if a failed M/G was packaged inside the transmission. The power electronics must be of the highest power density both gravimetrically and volumetrically.

- **Role Of Buck-Boost Converter & Benefits**

The concept of interfacing the vehicle power plant to the electric traction system via a DC/DC converter has considerable merit. Consider the Toyota Motor Corporation Hybrid Synergy Drive (HSD), first unveiled at the 2003 Detroit International Auto Show for initial release on its RX400H in 2005 as their second generation power split hybrid technology,the THS-II. This is pointed out because the Hybrid Synergy Drive retains the 274 V NiMH battery pack but has a traction inverter that operates off of a 500 V bus. An interface DC/DC buck/boost converter processes the full traction system power. The HSD vehicle is claimed to achieve 52 mpg on the U.S. metro-highway drive cycle, compared to 48 mpg for its predecessor. The 8% increase is due entirely to operating at higher voltage. A similar strategy could be applied to any of the other hybrid propulsion architectures. Operating at higher voltage is not new. Many investigators have proposed operating the traction system at upwards of 900 V to even 5 kV. The issue of exceeding 600 V lies in the manner in which cabling and switch gear must be treated, as well as personal safety in the presence of high voltage (not to mention cost).

Hybrid propulsion architectures that do not require the battery to be designed at voltages above 300 V have benefits in that reliability can be maintained at present levels or increased because additional terminations and cell balancing hardware along with monitoring hardware would not be increased. Instead, the battery would interface to the DC bus through a high-power DC/DC converter (i.e., DC transformer), thereby reducing the size and cost of the semiconductor switching devices.

The other use of the Buck-Boost converter is in driving the auxiliary equipment which run on lower voltage rating and are powered by the battery pack which is at higher voltage rating. The regenerative braking is also applied using the bidirectional buck-boost converter which increases the mileage of the vehicle and the overall efficiency.

And for vehicle applications, the efficiency and the size are the two most important aspects to be considered. So the isolated converter is not suitable in this case. We have chosen to build the buck-boost converter because of its versatility and wide range of uses in today's market. The largest problem with these converters is still efficiency although there is also an interest to make these converters as small as possible and to control the heat dissipation.

For the converter that to be build will have a range of inputs of 5v-10v and an out put range of 1.5-19v. The output ripple is specified to be less than +/-1%. The output power requirements will range from 2w to 20w. A 90% efficiency rating will be attempted and a thermal dissipation in the FET of less than 75 degrees Celsius which is 50% of the rating.

CHAPTER-2

LITRETURE REVIEW

Here we present the in depth study of materials from various international research papers of renowned research scholars .

- **ARCHITECTURE OF HEV DRIVETRAINS**

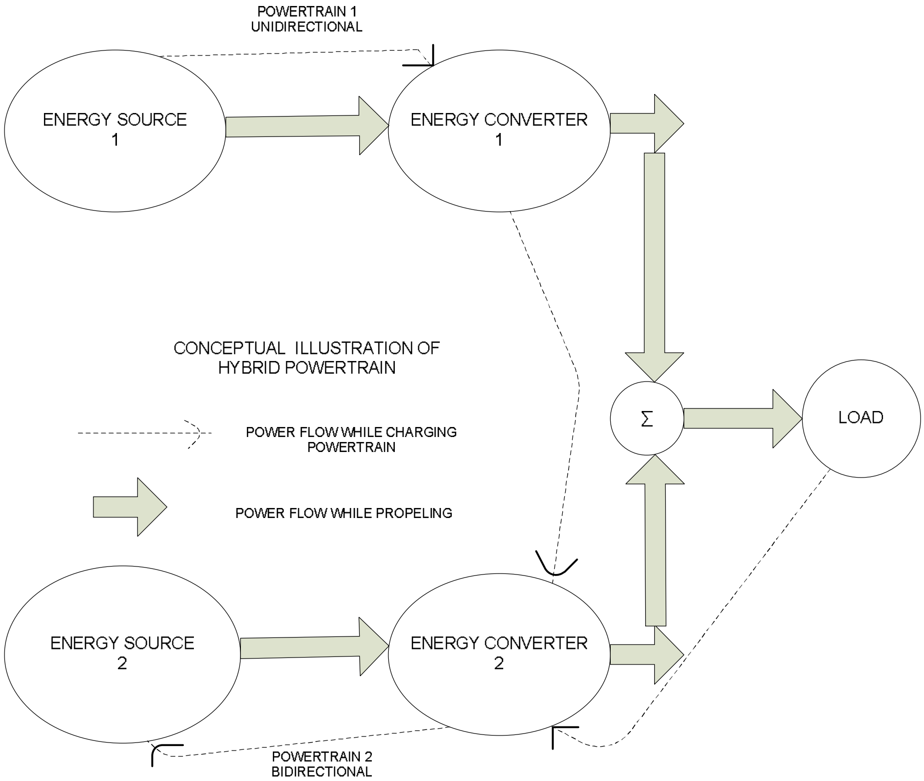


Fig.1

1) Concept of Hybrid Drivetrain: Fig. 1 shows the concept of a hybrid drivetrain and possible energy flow route. There are many available patterns of combining the power flows to meet load requirement as described in the following

1) powertrain 1 alone delivers power to load;

2) powertrain 2 alone delivers power to the load;

3) both powertrain 1 and 2 deliver power to load at

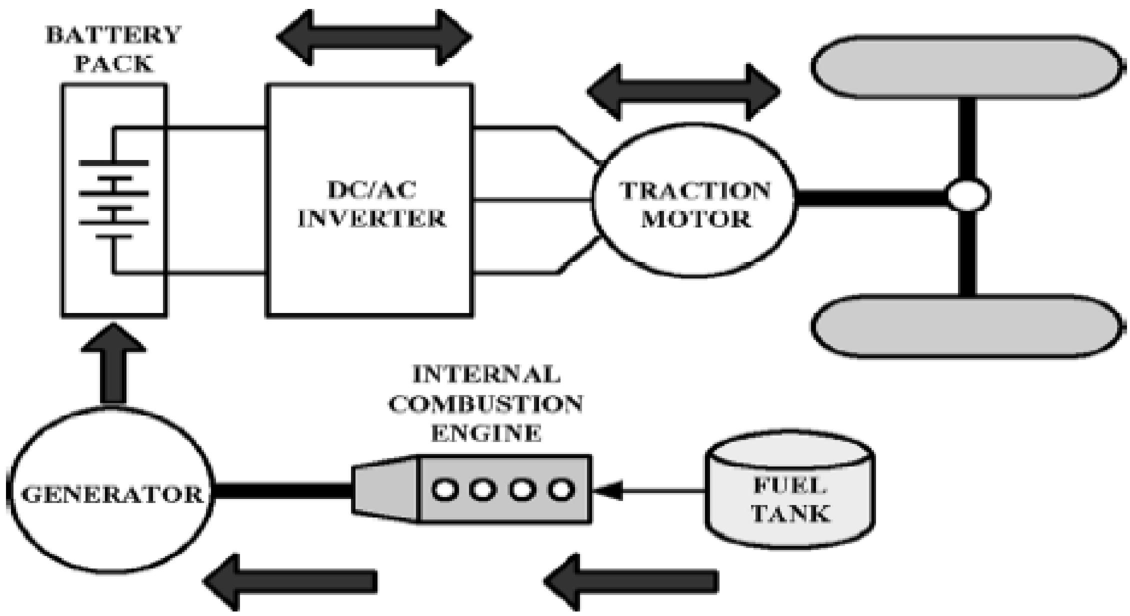
the same time;
4) powertrain 2 obtains power from load (regenerative braking);
5) powertrain 2 obtains power from powertrain 1;
6) powertrain 2 obtains power from powertrain 1 and load at the same time;
7) powertrain 1 delivers power to load and to powertrain 2 at the same time;
8) powertrain 1 delivers power to powertrain 2, and powertrain 2 delivers power to load;
9) powertrain 1 delivers power to load, and load delivers power to powertrain 2.
This hybrid drivetrain concept can be implemented by different architectures (configurations) as follows.

Series Hybrid Drivetrain

The series hybrid drivetrain was developed by adding a small IC engine/generator to the battery powered pure electric vehicle (EV) in order to make up the energy shortage of the batteries, as shown in Fig. 2. The prominent advantages of series hybrid drivetrains are:
1) mechanical decoupling between the IC engine and the driven wheels allows the IC engine operating at its very narrow optimal region as shown inFig. 2;
2) single torque source (electric motor) to the driven wheels simplifies the speed control (similar as throttle control by accelerator pedal);
3) nearly ideal torque-speed characteristic of electric motor makes multigear transmission unnecessary; and
4) simple structure and drivetrain control and easy packaging (the engine/generator, batteries, and the traction motor are connected by only electrical cables).
However, a series hybrid drivetrain also bears some disadvantages such as:
1) twice the energy form conversions (mechanical from engine to electric through generator and then to mechanical again through traction motor) cause more energy losses;
2) two electric machines are needed (electric generator and traction motor); and
3) a big traction motor since it is the only torque source of the driven wheels.

Taking advantage of its simple structure, simple control, and easy packaging, the series hybrid drivetrain is usually used in heavy vehicles, such as heavy commercial vehicles, military vehicles, buses, and even locomotives. The major reason is that large vehicles have enough space for the bulky engine/generator system. The hybrid electric city buses usually use this configuration, such as manufactured by Ebus, Electric Vehicles International, ISE ResearchVThunder-Volt, etc.

Fig 2.Series Hybrid System



Parallel Hybrid Drivetrain

In a parallel hybrid drivetrain, as shown in Fig. 3, the engine and electric motor can directly supply their torque to the driven wheels through a mechanical coupling. This mechanical coupling may simply be a gearbox, pulley-belt unit or sprocket-chain unit, even a single axle.

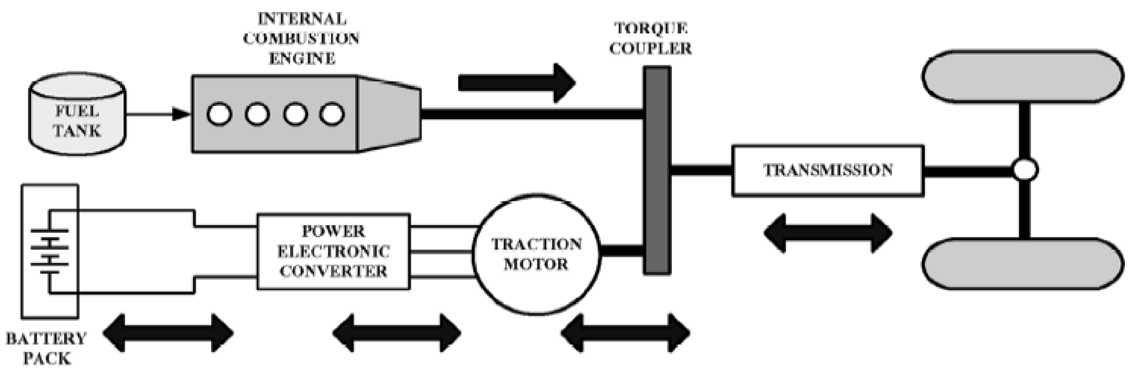
The major advantages of the parallel hybrid drivetrain are:

1) both engine and electric motor directly supply torques to the driven wheels and no energy form conversion occurs, thus energy loss is less and

2) compactness due to no need of the generator and smaller traction motor.

One major disadvantage of parallel hybrid drivetrains are the mechanical coupling between the engine and the driven wheels, thus the engine operating points cannot be fixed in a narrow speed region. Another disadvantage is the complex structure and control. Due to its compact characteristics, parallel configuration is used by small vehicles. Most passenger cars employ this configuration, such as the Honda Insight, Honda Civic, Ford Escape, etc.

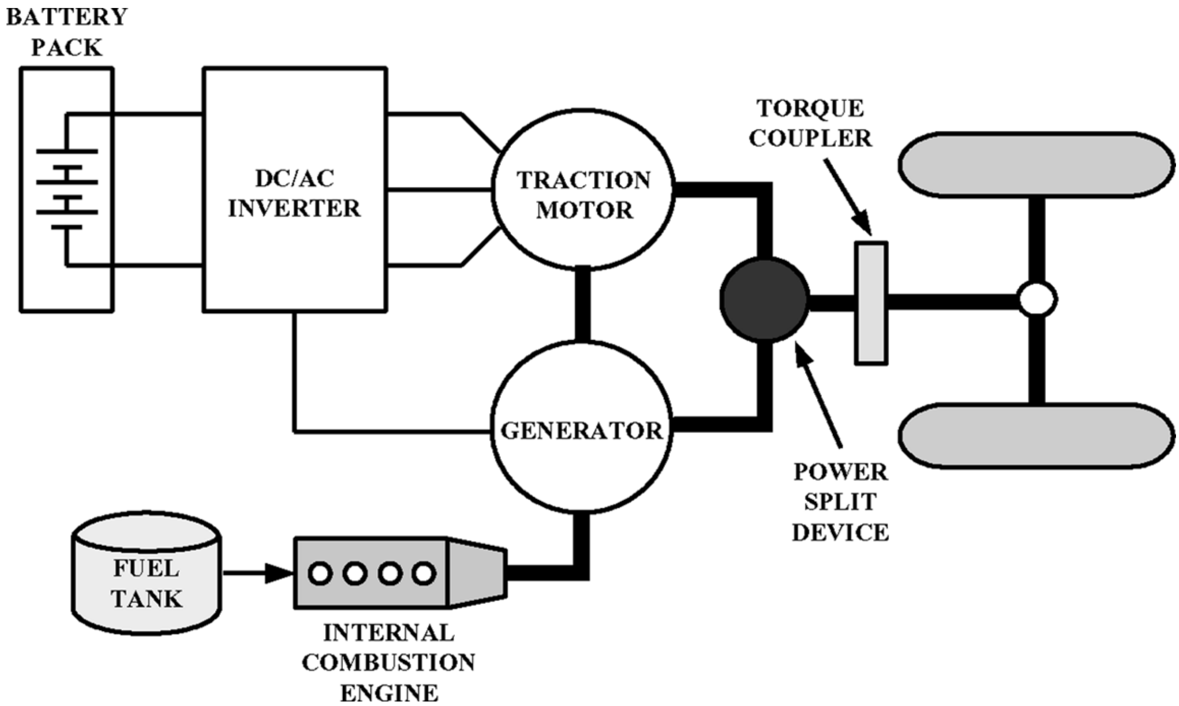
Fig 3. Parallel Hybrid Drivetrain



Series–Parallel Hybrid Drivetrain

The series-parallel HEV is a combination of the series and parallel hybrids. There is an additional mechanical link between the generator and the electric motor, compared to the series configuration, and an additional generator compared to the parallel hybrid, as shown in Fig. 4.With this design, it is possible to combine the advantages of both the series and parallel HEV configurations. It must be highlighted here that the series-parallel HEV is also relatively more complicated and expensive. There are many possible combinations of the ICE and traction motor. Two major classifications can be identified as electric-intensive and engine-intensive. The electric-intensive series-parallel HEV configuration indicates that the electric motor is more active than the ICE for propulsion, whereas, in the engine-intensive case, the ICE is more active. A common operative characteristic for both types of series-parallel HEV systems is that the electric motor is used alone at start with ICE turned off.

Fig 4. Series Parallel Hybrid Drivetrain



ROLE OF DC-DC CONVERTER IN HEV

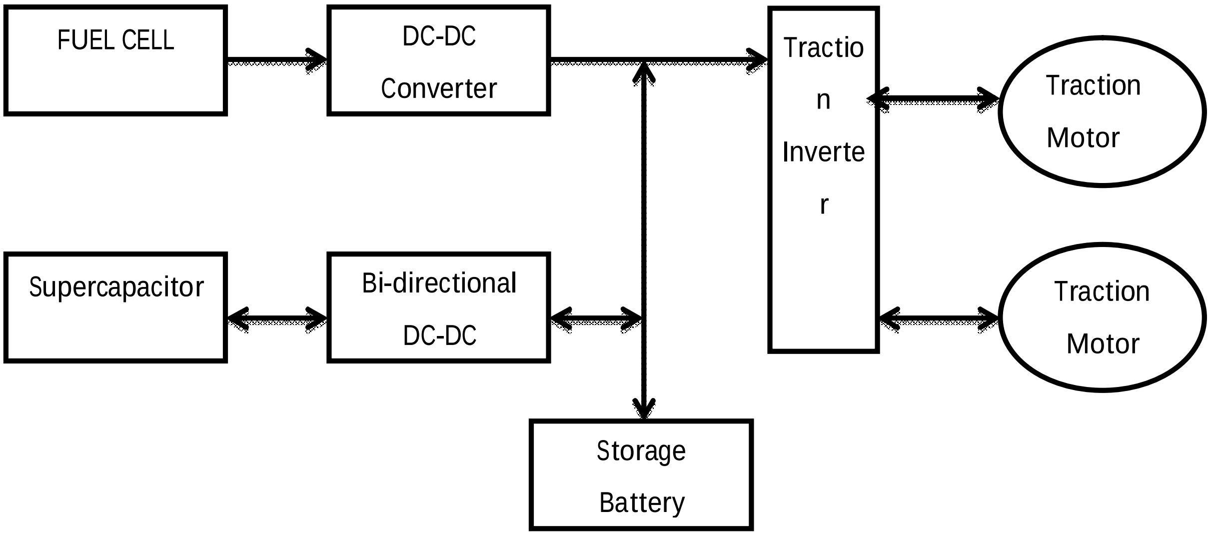
Linear voltage regulators convert one level of DC to another, typically using a series pass transistor circuit. The main problem with linear regulators is that the series pass transistor usually operates in the linear region of its characteristic curves, and thus exhibits a much higher loss when compared to a switching converter. The efficiency of this system is highly dependent on the difference in potential across the series pass device. With switching converters, the power semiconductor device operates in either a fully “on” or fully “off” mode, and thus in the on state operates in the nonlinear “low voltage drop” region, exhibiting a lower V×I conduction loss across the device. As pulse width modulation (PWM) of the power switch is used to control the power through the DC-DC converter, its efficiency is less dependent on the voltage difference from input to output, allowing operation with a wider input voltage range and higher efficiencies.

DC-DC converters may include galvanic isolation from input to output in the form of a transformer, or they may be nonisolated. High-frequency switching of a power semiconductor device utilizing PWM is the core of DC-DC converters.

The use of high-frequency switching allows expensive and bulky transformers and filter components (inductors and capacitors) to be reduced in size, reducing cost, weight, and packaging requirements. The limitations of high-frequency switching are switching losses in the power semiconductor devices and the practical limits on the size of high-frequency transformer core materials such as ceramics. Another factor is the higher initial cost of development of larger high-frequency magnetic components and associated packaging.

Hybrid systems use an auxiliary energy system that is able to receive regeneration from the drive train and that serves as a power cache for peak power phenomena. This allows using energy systems (gas turbines, fuel cells, etc) with lower power ratings, similar to the mean power consumption, and at the same time increase the overall vehicle efficiency.

Considering a typical city drive cycle, the auxiliary energy system should have regeneration capability, medium-low energy content (enough for enduring short acceleration periods and accepting regenerative braking), a high power capability (in order to complement the mean-power-sized energy storage device to satisfy peak power demand) and low-losses characteristic . These requirements lead to such storage devices as high-power batteries, flywheels and Ultracapacitors as the most adequate for auxiliary energy systems.



The vehicle uses a brushless dc motor with a nominal power of 32 kW, and a peak power of 53 kW. The main energy storage system consists of 26 lead-acid batteries connected in series. These batteries have a high internal resistance; producing considerable loses at high power demand and also shortening batteries life whenever hydrogen evaporation is produced (when any battery's voltage surpasses 13.8V). The auxiliary energy system is intended to prevent batteries from delivering or accepting high currents by sensing the load current and delivering or accepting the difference. Batteries are also not capable of properly accepting regenerative braking energy when recently charged, generally resulting in battery damage; this would also be fixed with the auxiliary system by preventing batteries from overcharging.

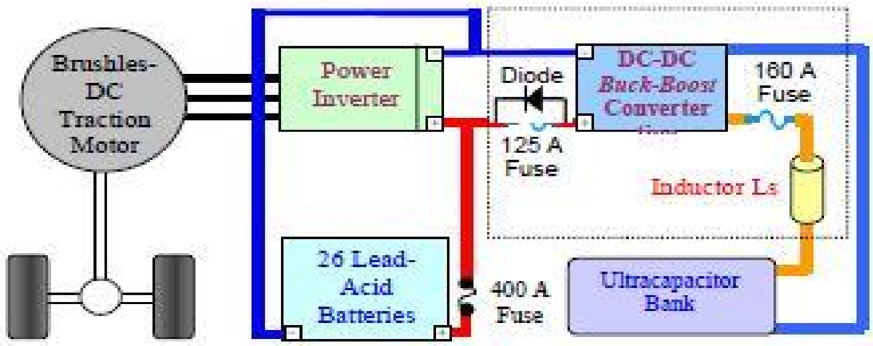
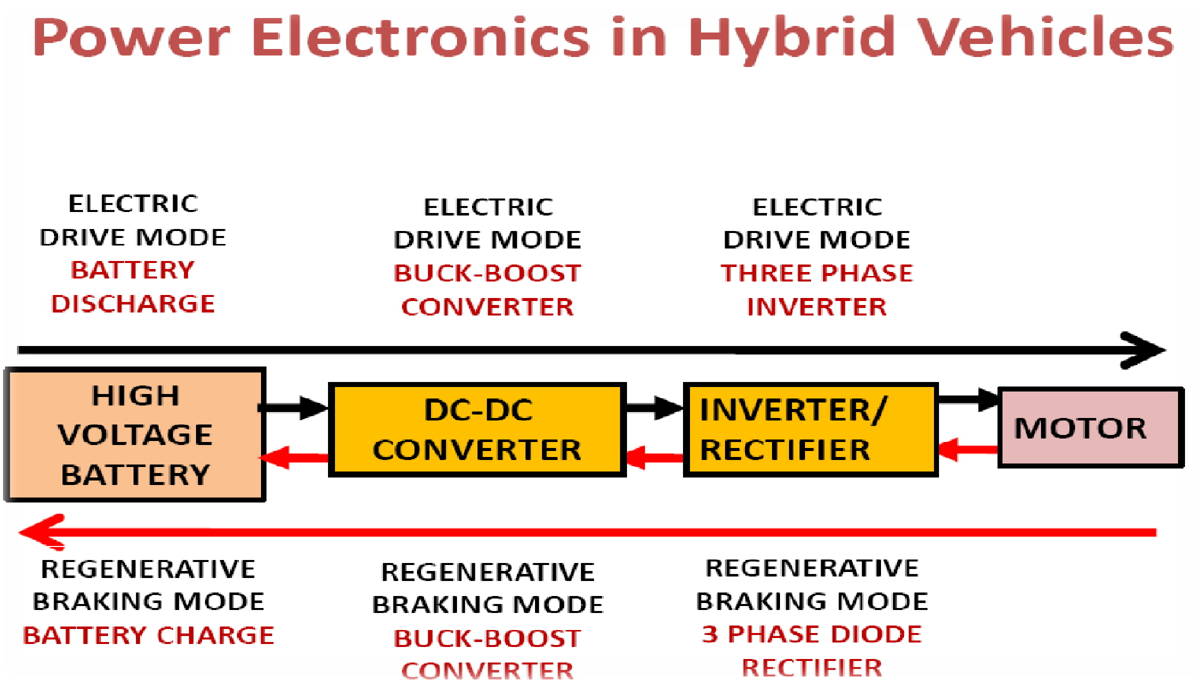


Fig. 2. Resulting power circuit in electric vehicle.

II. BUCK-BOOST TOPOLOGY ANALYSIS

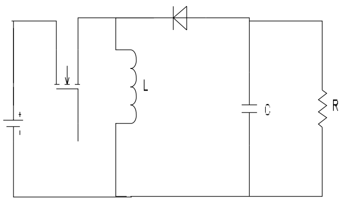
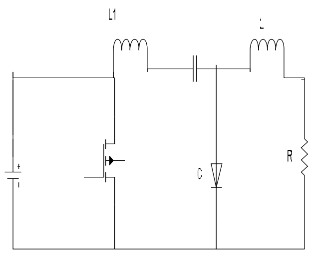
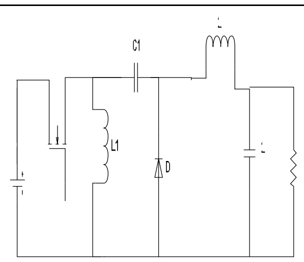
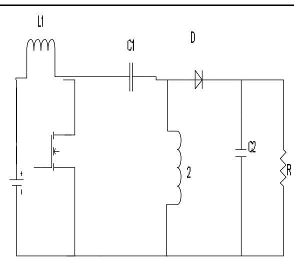


TOPOLOGIES OF DC-DC CONVERTERS

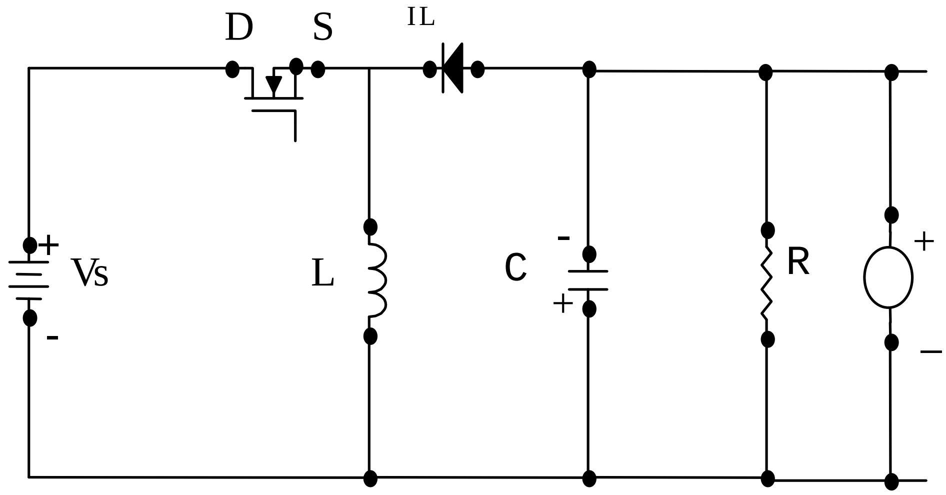
According to isolation schemes between the input and theoutput, DC-DC converters could be divided into two basictopologies: non-isolated converters and isolated converters.The isolated converter can provide isolation between its inputand output, and is widely used in the situations where morethan one output is needed. However, it has a larger sizecompared with the non-isolated one. And for vehicleapplications, the efficiency and the size are the two mostimportant aspects to be considered. So the isolated converter isnot suitable in this case.

There are four basic topologies of non-isolated buck-boostconverters: buck-boost, Cuk, Zeta and SEPIC. Table I lists theadvantages and disadvantages of these four topologies.

TABLE-1
EVALUATION RESULTS OF BASIC BUCK-BOOST CONVERTER

Circuit Configuration	Advantage	Disadvantage
	Simple configuration, fewer components high erreliability	Large input and output currents, reversed output polarity
	Continuous input and output currents, zero-ripple output current by coupling the two inductors	Larger size of L, larger voltage and current in IGBT,D and C, reversed output polarity.
	Lower voltage of C1,non-reversed polarity, zero ripple output currents by coupling the two inductors	Larger voltage and current in IGBT and D, larger size higher weight
	Zero-ripple output current by coupling the two inductors, non-reversed polarity	Larger inrush current of C2,more components, less reliability.

According to Table I , buck-boost should be the best choice. It has the least components, the highest reliability. However because of large inrush output current and reversed outputvoltage polarity, a high volume energy storage capacitor is needed at the output. Sometimes additional componentsshould be used to further reduce inrush current.



STUDY OF APPLICATION OF BUCK-BOOST IN TOYOTA PRIUS

Toyota Prius is an advanced technology parallel hybrid vehicle. It has a high-efficient 1.5 liter engine, a power split device, continuously variable drive train, permanent magnet generator and the PM propulsion motor, two IGBT inverters, and high-power NiMH battery pack. The main attributes of the Toyota Prius are 52 mpg, City; 45 mpg, Highway; SULEV operation; 0–60 mph in approximately 12.5 seconds; and 100 mph top speed. Toyota Prius system has a power split device in the transmission that sends engine power either directly to the wheels or the electric generator.

Its five main operating modes, which are shown in Figure 16.3, are :

1. When pulling away from a stop or under a light load, only the electric motor powers the vehicle.
2. Under normal driving operation, a combination of gasoline and electric power is used. The engine drives the generator and provides power to run the electric motor. The excess power of the generator is used for charging the battery.
3. Under full-throttle acceleration, the full power of the engine and the electric motor, powered by the battery, are used together to provide the maximum torque.
4. During deceleration or braking, the electric motor functions as a generator to recharge the batteries.
5. When charging of the battery is needed, power from the engine is used to drive the generator. This eliminates the need for an external charger or power connection.

The 2004 Toyota Prius is the first Toyota equipped with the new high-voltage/highpower full Hybrid Synergy Drive powertrain . The new drive has a 50% more powerful 50 kW drive-motor, operating at up to 500 V. The generator has a higher peak operating speed that increases electric-mode operation in city and freeway slow-and-go operation. With 50% more electric power available and improved low-end torque from the drive motor, a significant boost in acceleration performance is possible. The Hybrid Synergy Drive enables Prius to be nearly 30% lower in emissions than the first-generation Prius and has higher fuel economy.

Table below shows that there is a small trade-off between Toyota Hybrid System(THS) and Toyota Hybrid System II(THS -II) which is the picture of HEVs now.

TOYOTA PRIUS COMPARISION

Quantity	THS('97 PRIUS)	THS-II ('04 PRIUS II)
HV Battery Voltage	273.6V max (1.2V*6cell*38modules)	201.6Vmax (1.2V*6cell*28modules)
Power Of Motor	33kW max	50kW max
Buck/Boost Converter	Not Available	201.6V↔500V
Switching Frequency (fs)	Not Available	15kHz
Max Torque(N.m)	350	400
Cooling System		By using coolent

The main difference between Toyota THS and THS-II is the adoption of buck-boost converter between the inverter and the battery . Compared that THS provides 273.6Vmax, in THS-II, the boost converter provides the power source voltage of 500Vmax to the electric motor, so that this high voltage of THS-II helps the electric motor be supplied with lower current and highefficiency . Toyota was able to achieve a 50% improvement in the motor power output with the boost converter.

CHAPTER-3

SOLUTION TECHNIQUES FOR DESIGN OF BUCK BOOST CONVERTER.

A DC-DC converter is nothing more than a DC transformer or a device that provides a loss less transfer of energy between different circuits at different voltage levels. When dc-dc conversion is needed there is also a need for control and a need for higher efficiencies. If the latter were not important we could just use a voltage divider and get the change in voltage we are looking for. In modern dc electronics we need more than just voltage reduction. What really are needed are voltage transfers, polarity reversals, and increased and decreased voltages with control. One method of building a dc transformer is to use switching converters called choppers. The provided switching function requires a duty ratio, which will give us the control that has been needed. In many converter applications such as battery charging anddischarging, power factor correction, fuel cell regulation, maximum power point tracking of solar panels, a DC-DC converter is used to obtain a regulated voltage from an unregulated source. When the regulated voltage is within the voltage range of the unregulated voltage source, a step-up/stepdown DC-DC converter is required.

In the Buck-boost converter achieving outputs of any magnitudes are possible. The buck boost converter has two main restrictions. They are KVL and KCL has to be satisfied. This means that only one switch is on at a time. When switch 1 (FET) is on the voltage V_t (Figure 1) is just V_{in} and when switch 2 (diode) is on $V_t$is just $-V_{out}$. Then the duty ratio can be related to $V_{out}$by saying $V_{out}=\frac{D_1 * V_{in}}{1-D_1}$. The input and output currents are determined by the switching action. Since $I_s=<i_{out}>+<i_{in}>$ then $D_1 * <i_{out}> = D_2 * <i_{in}>$ and because of the cascading process this converter requires a negative output with respect to the input. In theory if D_1 is 0 then the output is zero and if D_1 is 1 then the output is infinity and if D_1 is $\frac{1}{2}$ then the output is equal in magnitude to the input. The capacitor at the output is there to give the output voltage source properties. The method of determining the other elements of the circuit is discussed in some depth in the results.

Probably the most important consideration of all the elements is the inductor. The inductor value is important to not be below the critical value so that the converter will not have a discontinuous mode. This happens when the inductor is too small to maintain current flow at all times. When the converter is in discontinuous mode its output becomes load dependent.

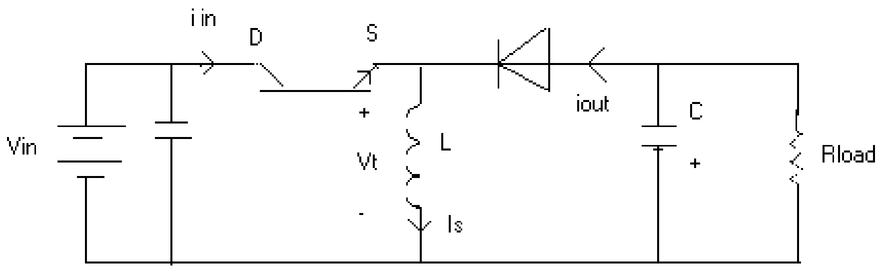


Figure 1

The single inductor non-inverting buck-boost converter isused in applications where it is important to have low size and cost of the magnetic elements. However, when the voltages are high, the size of the capacitors of this converter is also important. In that case, it can be interesting to use the cascade buck-boost power converter that has two inductors, one at the input and another at the output. With these inductors, the input and output currents are non-pulsating, the noise level is lower and the control and the limiting of the currents can be easier than in the pulsating case.

Here we develop the mathematical background and component parameter calculation equations for single inverternon-inverting buck-boost converter.

Circuit diagram and key waveforms

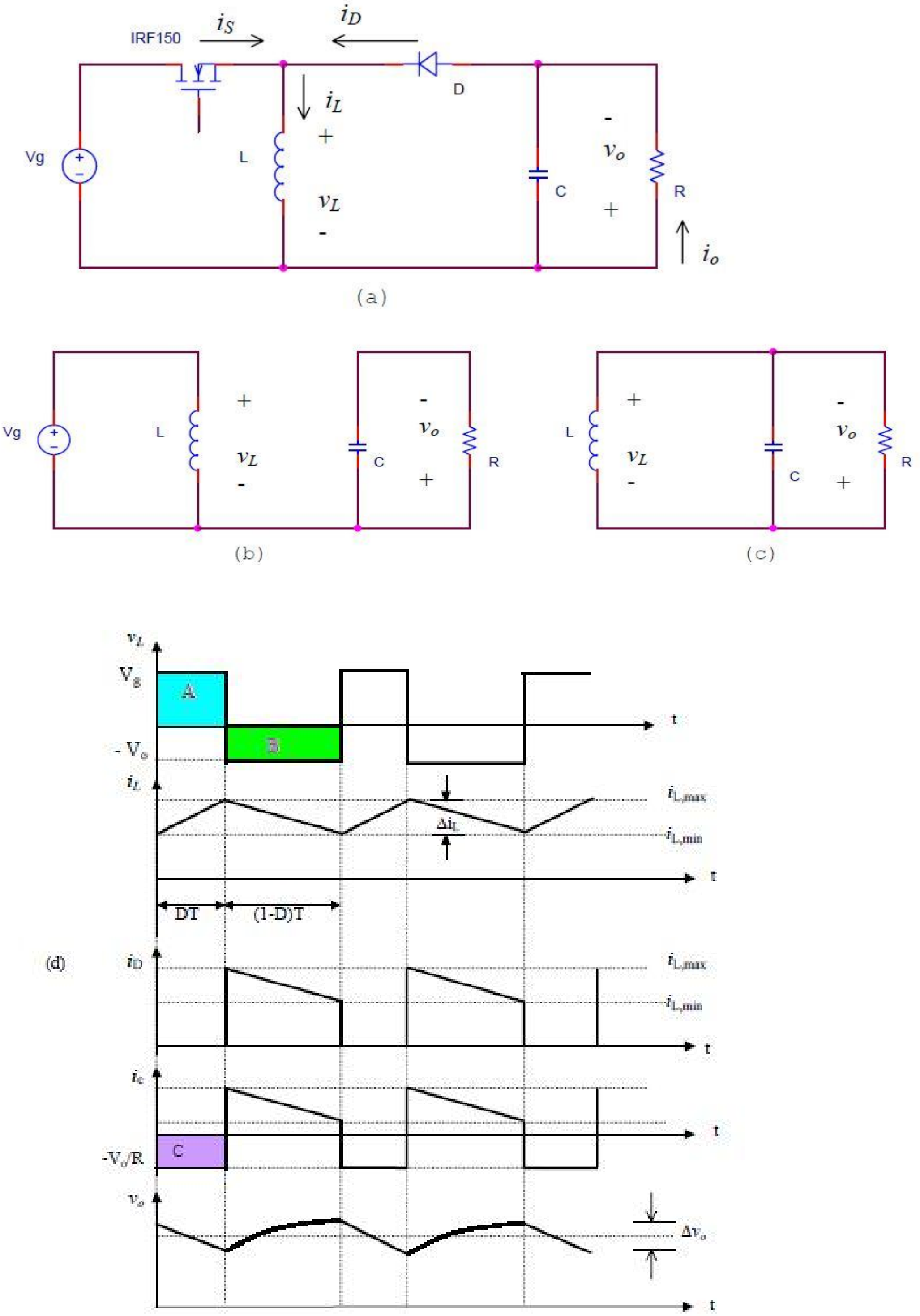


Figure 3-3 (a) Buck-boost converter (b) switch on for a time duration *DT* (c) switch off for a time duration *(1-D)T* (d) key waveforms.

Circuit description. The three basic dc-dc converters use a pair of switches, usually one controlled (eg. MOSFET) and one uncontrolled (ie. diode), to achieve unidirectional power flow from input to output. The converters also use one capacitor and one inductor to store and transfer energy from input to output. They also filter or smooth voltage and current.

The dc-dc coverters can have two distinct modes of operation: Continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In practice, a converter may operate in both modes, which have significantly different characteristics. Therefore, a converter and its control should be designed based on both modes of operation. However, for this course we only consider the dc-dc converters operated in CCM.

Circuit Operation. When the switch is on for a time duration DT, the switch conducts the inductor current and the diode becomes reverse biased. This results in a positive voltage $v_L = V_g$ across the inductor. This voltage causes a linear increase in the inductor current i_L. When the switch is turned off, because of the inductive energy storage, $i_L$continues to flow. This current now flows through the diode, and $v_L = -V_o$ for a time duration (1-D)T until the switch is turned on again.

3-3-3 Analytical expressions for $\frac{V_o}{V_g}$, Δi_L, and Δv_o

Assumptions made about the operation of the converter are as follows:

- The circuit is operating in the steady state
- The circuit is operating in the CCM
- The capacitor is large enough to assume a constant output voltage
- The component are ideal

Equating the integral of the inductor voltage over one time period to zero (Volt-second balance) yields

$$\int_0^T v_L\, dt = \int_0^{t_{on}} v_L\, dt + \int_0^{t_{off}} v_L\, dt = 0$$

$$V_g \times DT + (-V_o) \times (1-D)T = 0$$

$$V_o = \frac{D}{1-D} V_g$$

or

$$\frac{V_o}{V_g} = \frac{D}{1-D}$$

Assuming a lossless circuit, $P_g = P_o$,

Therefore

$$V_g I_g = V_o I_o$$

And

$$\frac{I_o}{I_g} = \frac{V_g}{V_o} = \frac{(1-D)}{D}$$

For a buck-boost converter, it is obvious that

$$I_L = I_g + I_o$$

$$\begin{aligned}\Delta i_L &= \frac{1}{L}\int_0^{DT} v_L dt \\ &= \frac{1}{L}[\text{Shaded area under waveform } v_L \text{ (Area A)}] \\ &= \frac{1}{L}V_g \times DT\end{aligned}$$

From Δi_L we can obtain $i_{L,\min}$ and $i_{L,\max}$

$$i_{L,\min} = I_L - \frac{\Delta i_L}{2}$$

$$i_{L,\max} = I_L + \frac{\Delta i_L}{2}$$

To obtain the average inductor current, we can use this relationship

$$I_D = I_o = (1-D)I_L$$

Therefore

$$I_L = \frac{I_o}{(1-D)} = \frac{V_o}{(1-D)R} \tag{2-14}$$

The peak-peak output voltage ripple, Δv_o. From the information of the capacitor current, i_c, we can obtain Δv_o.

$$\begin{aligned}\Delta v_o = \Delta v_c &= \frac{1}{C}\int i_c dt \\ &= \frac{1}{L}[\text{Shaded area under waveform } i_c] \\ &= \frac{1}{C} \times \frac{V_o}{R} \times DT\end{aligned}$$

therefore

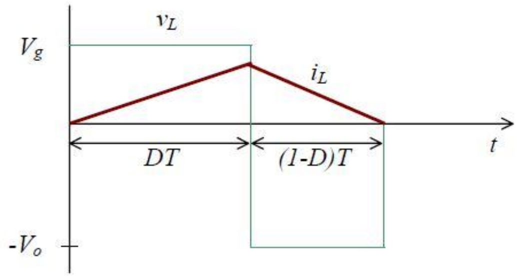
$$\Delta v_o = \frac{1}{C} \times \frac{V_o}{R} \times DT$$

3-3-4 CCM/DCM boundary condition

Being at the boundary between the continuous and the discontinuous mode, by definition, the inductor current i_L goes to zero at the end of the off period. At this boundary, the average inductor current is

$$I_L = \frac{\Delta i_L}{2}$$

the minimum inductor current, $i_{L,\min} = 0$ and the maximum inductor curren $i_{L,max} = \Delta i_L$.



We know that for buck-boost converters $I_D = (1-D)I_L = I_o = \frac{V_o}{R}$ and

$\Delta i_L = \frac{1}{L} V_g DT = \frac{1}{L} V_o (1-D)T$.

Equation at the CCM/DCM boundary, $I_L = \frac{\Delta i_L}{2}$, can be used to determine the combination of L, f and R that will result in CCM. The minimum load current required for CCM operation is:

$$I_L = \frac{\Delta i_L}{2}$$

$$\text{but } I_o = (1-D)I_L$$

$$I_L = \frac{I_o}{(1-D)}$$

$$\frac{I_o}{(1-D)} = \frac{1}{2L} V_o (1-D)T$$

$$\therefore I_{o,\min} = \frac{1}{2L} V_o (1-D)^2 T$$

If the desired switching frequency f and load resistance R are established, the minimum inductor current required for CCM is:

$$I_L = \frac{\Delta i_L}{2}$$

$$\frac{V_o}{R(1-D)} = \frac{1}{2L} V_o (1-D) T$$

$$\therefore L_{\min} = \frac{(1-D)^2 T \times R}{2}$$

$$= \frac{(1-D)^2 R}{2f}$$

If the desired value of the inductor L and the load resistance R are established, the minimum switching frequency required for CCM is

$$f_{\min} = \frac{(1-D)^2 R}{2L}$$

If the desired switching frequency and the value of the inductor L are established, the minimum load resistance required for CCM is

$$R_{\min} = \frac{2fL}{(1-D)^2}$$

CALCULATION FOR BUCK BOOST CONVERTER

Input voltage range : 3 V to 9 V

Desired output voltage = 12 V

Supplied input voltage = 4 V

Output load range = 200mA to 1 A

$$\frac{v_o}{v_{imax}} = \frac{D_l}{1 - D_l}$$

$$\Rightarrow \frac{12}{9} = \frac{D_l}{1-D_l}$$

$\Rightarrow \frac{1}{D_l} = \frac{9}{12} + 1 = \frac{21}{12}$

$\Rightarrow D_l = 0.57 \quad (57\%)$

$$\frac{v_o}{v_{imax}} = \frac{D_h}{1 - D_h}$$

$\Rightarrow \frac{12}{3} = \frac{D_h}{1-D_h}$

$\Rightarrow \frac{1}{D_h} = \frac{3}{12} + 1 = \frac{5}{4}$

$\Rightarrow D_h = 0.8 \quad (80\%)$

Hence, the duty cycle of the converter operating in boost mode must lie between 57% to 80% for good voltage regulation.

For the converter operating under buck mode, duty cycle should lie below 50%.

$R_{max} = \frac{v_o}{I_{omin}} = \frac{12}{0.2} = 300\Omega$

$R_{min} = \frac{v_o}{I_{omax}} = \frac{12}{1} = 60\Omega$

1) Boost Mode :

$$v_{in} = 4V(given\ supply)$$

v_{out} = $12V$

Switching frequency=20 khz

Output load current=500mA

$$\frac{v_o}{v_{in}} = \frac{D}{1-D}$$

$\Rightarrow \frac{1}{D} = \frac{v_{in}}{v_o} + 1 = \frac{1}{3} + 1 = \frac{4}{3}$

$\Rightarrow$ D = $\frac{3}{4}$ = 0.75 (75%)

Now ,

Since switching frequency = 20khz

$\Rightarrow$ T = $\frac{1}{f} = \frac{1}{20000} = 5 \times 10^{-5}$sec = 50 µsec

Therefore,

T_{on} = 50 × 0.75 = 37.5µsec = 38µsec(approx.)

T_{off} = 50 × 0.25 = 12.5µsec= 12µsec(approx.)

Resulting D = $\frac{38}{50} = 0.76$ (76%)

Since for continuous conduction mode of operation

$$I_{omin} = \frac{1}{2L} \times v_o \times (1 - D_l)^2 \times T$$

$\Rightarrow$ L = $\frac{1}{2I_{omin}} \times v_o \times (1 - D_l)^2 \times T$

$\Rightarrow$ L = $\frac{1}{2\times200\times10^{-3}} \times 12 \times (1 - 0.57)^2 \times 50 \times 10^{-6}$

$\Rightarrow$ L = 277.35 μH

Choosing,

L = 300 μH

$\Delta I_l = \frac{1}{L} \times v_o \times (1 - D) \times T$

$= \frac{1}{300\times10^{-6}} \times 12 \times (1- 0.76) \times 50 \times 10^{-6}$

= 0.48A

$$\Delta I_l = 0.48A$$

Using C = 220μF

Voltage ripple, $\frac{\Delta V}{V} = \frac{D_h \times T}{R_{min} \times C}$

$= \frac{0.8 \times 30 \times 10^{-6}}{12 \times 220 \times 10^{-6}}$

$= 0.01515$

$= 1.5\%$

2) Buck mode:

$v_{in} = 6V$

$v_{out} = 2V$, $I_o = 0.1A$

$D = \frac{1}{\frac{v_{out}}{v_{in}} + 1} = 0.25$

$I_l = \frac{I_o}{1-D} = 0.13\text{A}$

$\Delta I_l = \frac{1}{L} \times v_o \times (1 - D) \times T$

$= \frac{1}{300 \times 10^{-6}} \times 2 \times (1 - 0.25) \times 50 \times 10^{-6}$

$= 0.25$

$\frac{\Delta I_l}{2} < I_l \Rightarrow$ circuit is operating under continuous conduction mode.

$R = \frac{v_o}{I_o} = \frac{2}{0.1} = 20\Omega$

$\frac{\Delta v_0}{v_o} = \frac{1}{R \times C} \times D \times T$

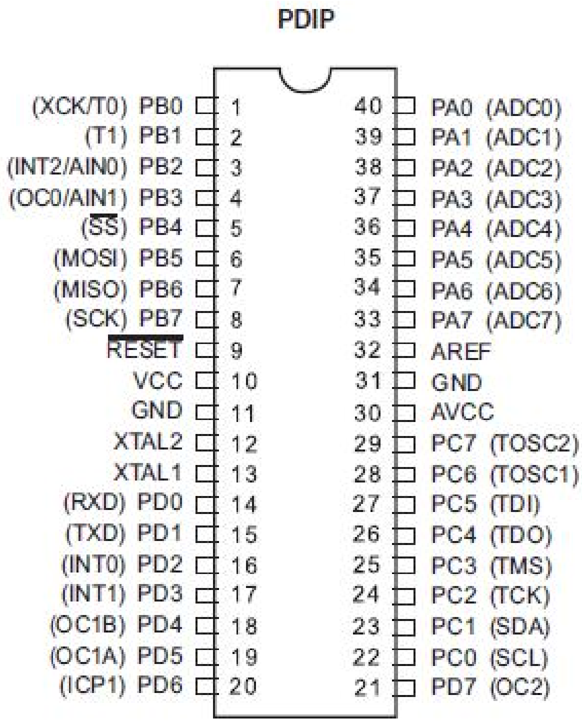
$= \frac{0.25 \times 50 \times 10^{-6}}{220 \times 20 \times 10^{-6}}$

$= 2.84 \times 10^{-3}$

$\Rightarrow$ Ripple voltage = 0.2%.

Duty Cycle Control Mechanism in Buck-Boost Converter

PWM (pulse width modulation) signals play a significant role in any power electronics converter. This signal is used for triggering the semi-conductor switches used in converter at high frequency. There are a number of PWM generation techniques which is used for generating PWM e.g (a) Fast PWM, (b) phase correct mode, (c) frequency correct mode & (d) CTC mode. In our project we are using fast PWM mode as well as delayed on/off techniques for PWM signal generation.



An overview of ATMEGA 16

The ATmega16 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega16 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

The ATmega16 provides the following features: 16 Kbytes of In-System Programmable Flash Program memory with Read-While-Write capabilities, 512 bytes EEPROM, 1 Kbyte SRAM, 32 general purpose I/O lines, 32 general purpose working registers, a JTAG interface for Boundary scan, On-chip Debugging support and programming, three flexible Timer/Counters with compare modes, Internal and External Interrupts, a serial programmable USART, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain (TQFP package only), a programmable Watchdog Timer with Internal Oscillator an SPI serial port, and six software selectable power saving modes.
ATMEGA 16 has 4 PWM channels. We are using TIMER/COUNTER 0 to generate PWM signals .There are two techniques commonly employed to generate PWM signals :-

1.) To generate PWM using any of four PWM channels of ATMEGA-16.
2.) To generate PWM using by delayed on-off technique.

C-code for PWM using 1st method :-

```
#include<avr/io.h>
#include<util/delay.h>


voidADC_init(void);
unsignedintADC_read(unsigned char ch);
voidInitPWM();
voidSetPWMOutput(unsigned int duty);
void wait();

// -----------------------------------------------
int main(void)
{


ADC_init();




InitPWM();

unsignedint input;

while(1)
  {
input=ADC_read(0);
        SetPWMOutput(input);
  }

}
//-----------------------------------------------

voidADC_init(void)          // Initialization of ADC
{
        ADMUX=(1<<REFS0)|(1<<ADLAR);        // AVcc with external capacitor at AREF
        ADCSRA=(1<<ADEN)|(1<<ADPS2)|(1<<ADPS1)|(1<<ADPS0);
                                        // Enable ADC and set Prescaler division factor as
128
}

unsignedintADC_read(unsigned char ch)
{
```

```
        ch= ch& 0b00000111;                    // channel must be b/w 0 to 7
        ADMUX |= ch;                                    // selecting channel

        ADCSRA|=(1<<ADSC);                              // start conversion
        while(!(ADCSRA & (1<<ADIF)));   // waiting for ADIF, conversion complete
        ADCSRA|=(1<<ADIF);    // clearing of ADIF, it is done by writing 1 to it

        return (ADC);
}
voidInitPWM()
{

  TCCR0|=(1<<WGM00)|(1<<WGM01)|(1<<COM01)|(1<<CS01)|(1<<CS00);

  DDRB|=(1<<PINB3);
}

voidSetPWMOutput(unsigned int duty)
{
  OCR0 =  duty;

 }
void wait()
{
   _delay_us(4000);
}
```

C-code for PWM using delayed on-off method

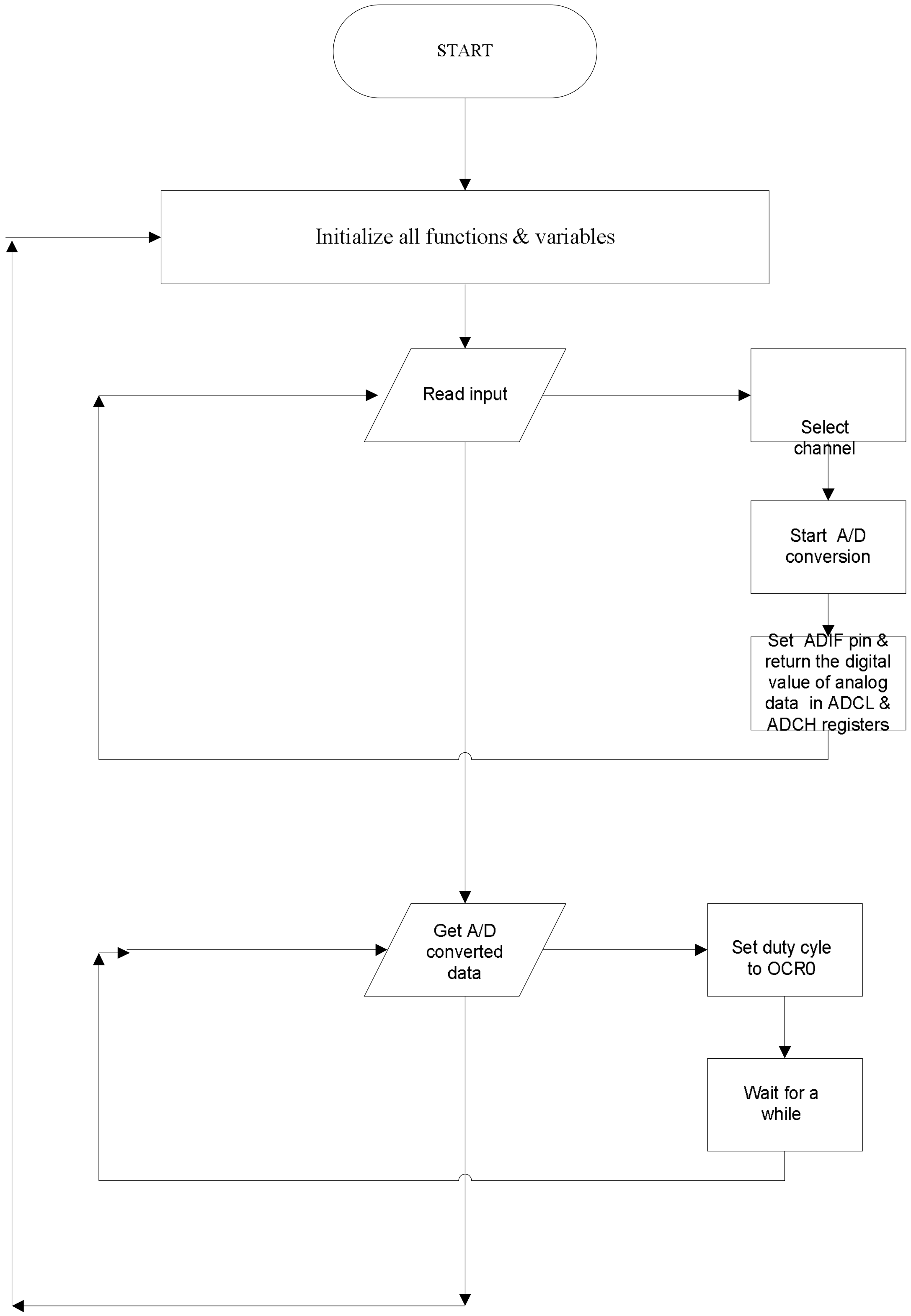
```
#include<avr/io.h>
#include<util/delay.h>

int main(void)
{
DDRB|= (1<<PINB3);    // set PIN 4 as output pin

while(1)
{
PORTB= (1<<PINB3);    // set PIN 4 high (+5 volts)
_delay_us(50);                // on –time of the  pulse
PORTB = ~(1<<PINB3);  // set PIN  4  low (0 volts)
_delay_us(20);                 //off-time of  the pulse
}

}
```

Flow chart for PWM generation using PWM channel of Timer/Counter 0



CHAPTER-4

CASE STUDIES & RESULTS FOR A SIMULATED BUCK BOOST CONVERTER

We designed a single inductor buck boost converter and performed simulation experiment using multisim software.

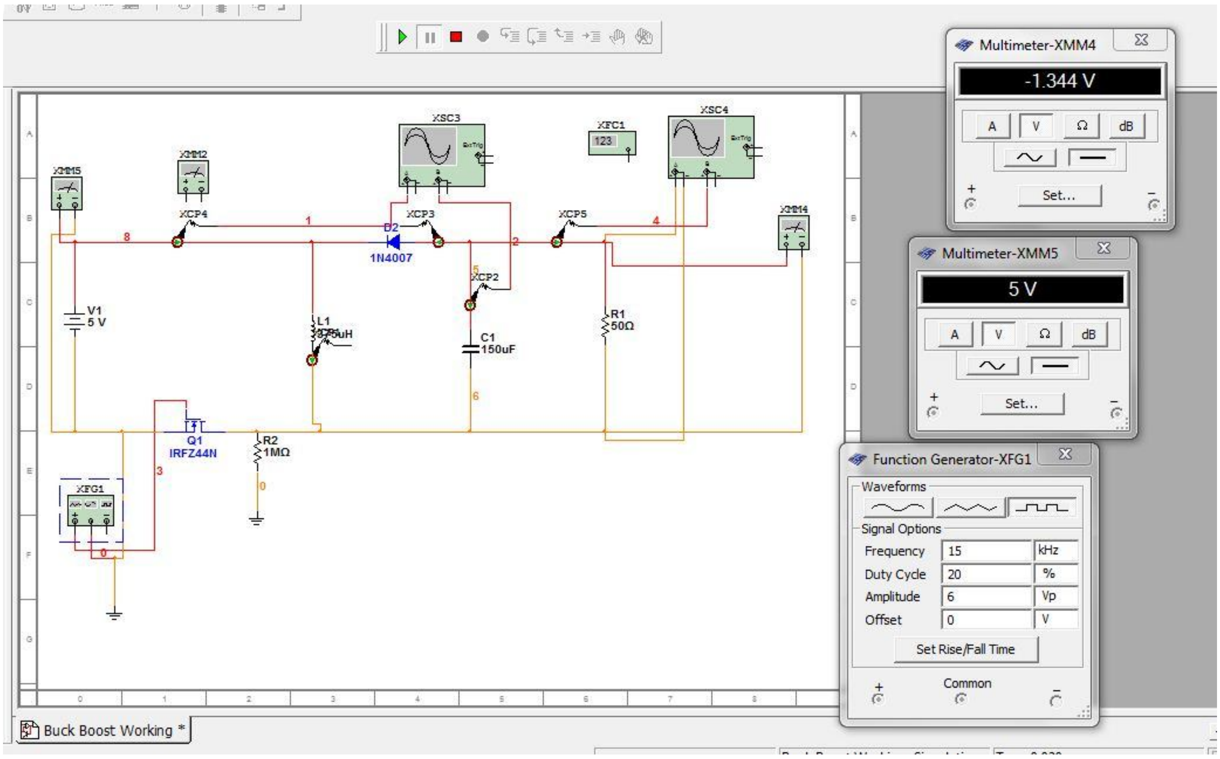


Fig.-Simulation in Buck Mode

$V_{in=}$ 5V V_{out} =-1.344V Frequency=15Khz Duty Cycle=20% R_L=50 ohm

Buck converter
We use one 50Ω resistor as the load . MOSFET IRFZ44N is used as switch.
Duty cycle of the PWM we used is 20% ,freq varies from 10kHz ~ 20kHz.
Buck converter with 20% of the duty cycle,

V_{in}	5	5	5	5
V_{out}	-2.36	-2.385	-1.782	-1.826
Frequency	10Khz	12Khz	15Khz	20Khz
Input Current	32mA	32mA	20mA	20mA
Output Current	48mA	47.8mA	35mA	35mA
Efficiency	71.04%	71.25%	62.37%	65%

Table 1 : Buck converter output with 20% of duty cycle

From the table above, we can conclude that :
1. Higher PWM signal frequency lead to lower output voltage.
2. In the beginning the Vout increased with PWM frequency, thenVoutdecreased &remain stable.
3.Efficiency decreased with increase in switching frequency.

Boost Mode

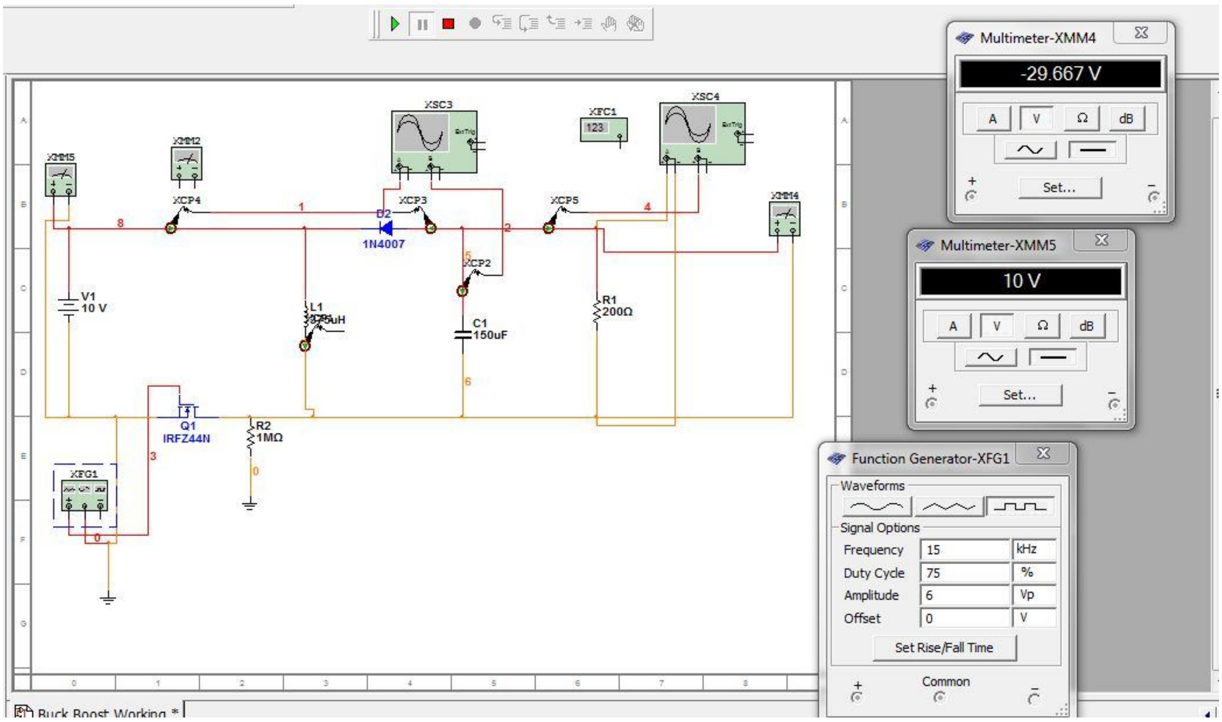


Fig.-Simulation in Boost Mode

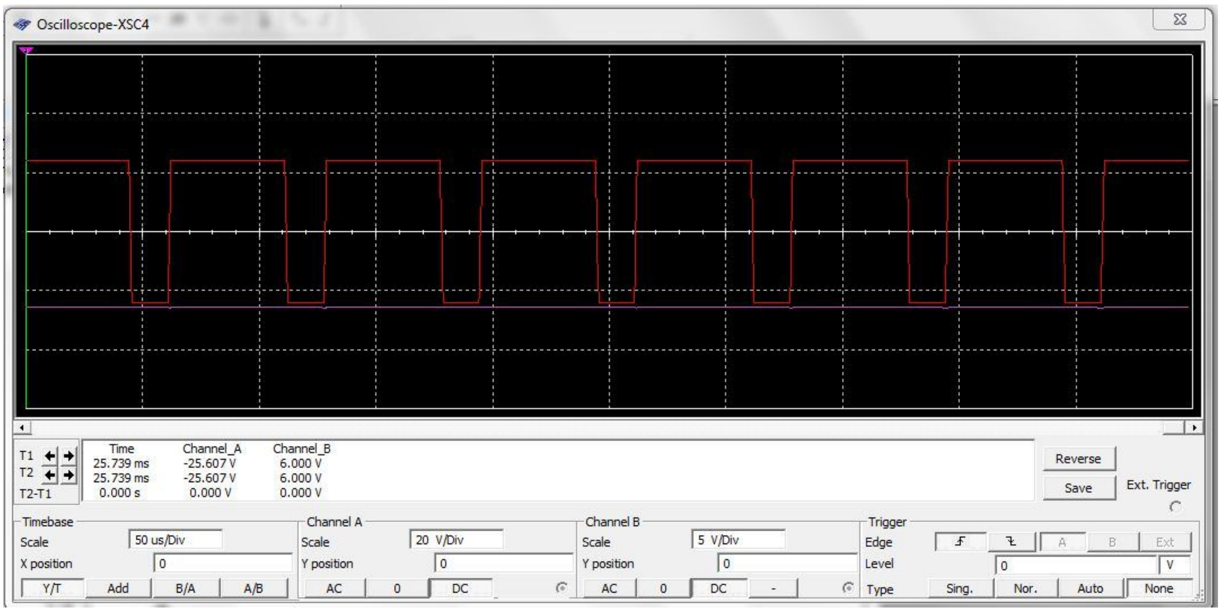
$V_{in=}$ 5V V_{out} =-29.667V   Frequency=15Khz Duty Cycle=75%,R_L=200 ohm

We use one 200Ω resistor as load. Duty cycle of the PWM we used is 75%. Freq varies from 10kHz~ 20kHz
Boost converter with 75% of the duty cycle,

V_{in}	5	5	5
V_{out}	-13.22	-12.23	-11.2
Frequency	10Khz	15Khz	20Khz
Input Current	1.2A	2.13A	3.72A
Output Current	264.5mA	244.5mA	225.390mA
Efficiency	58%	30%	17%

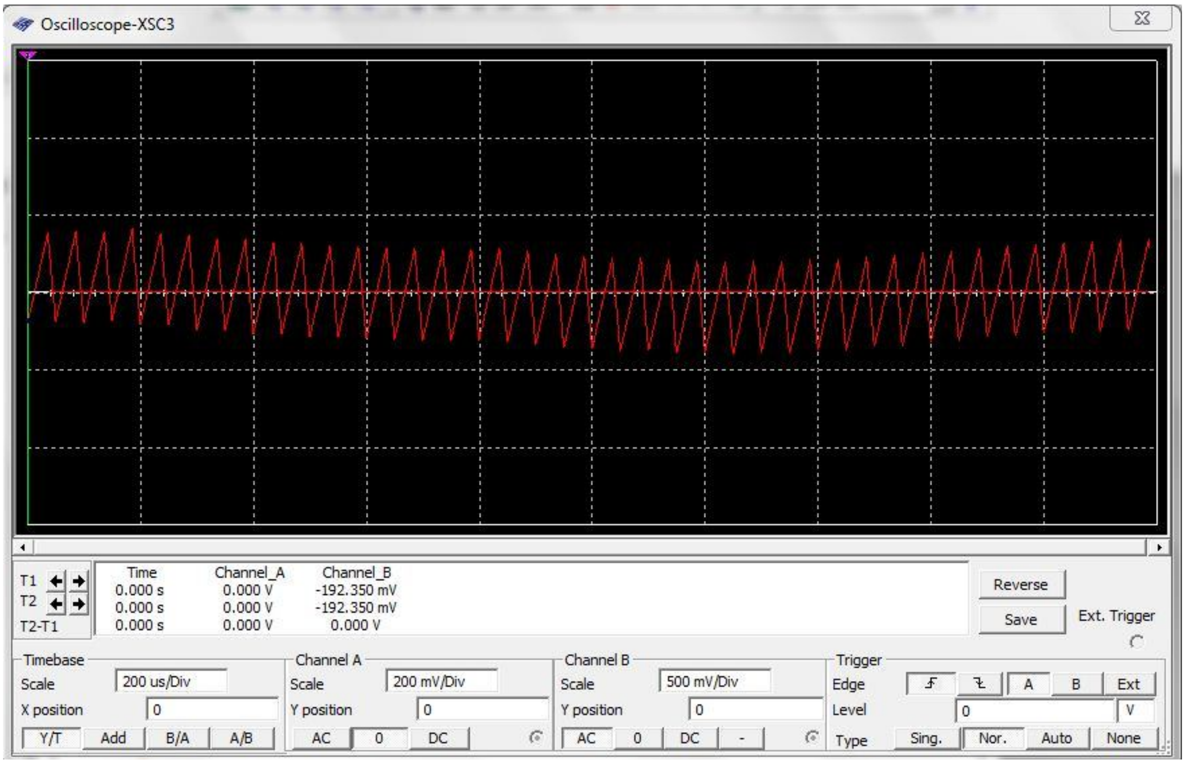
Table 2 : Boost converter output with 75% of duty cycle

Different Waveforms Obtained in simulation

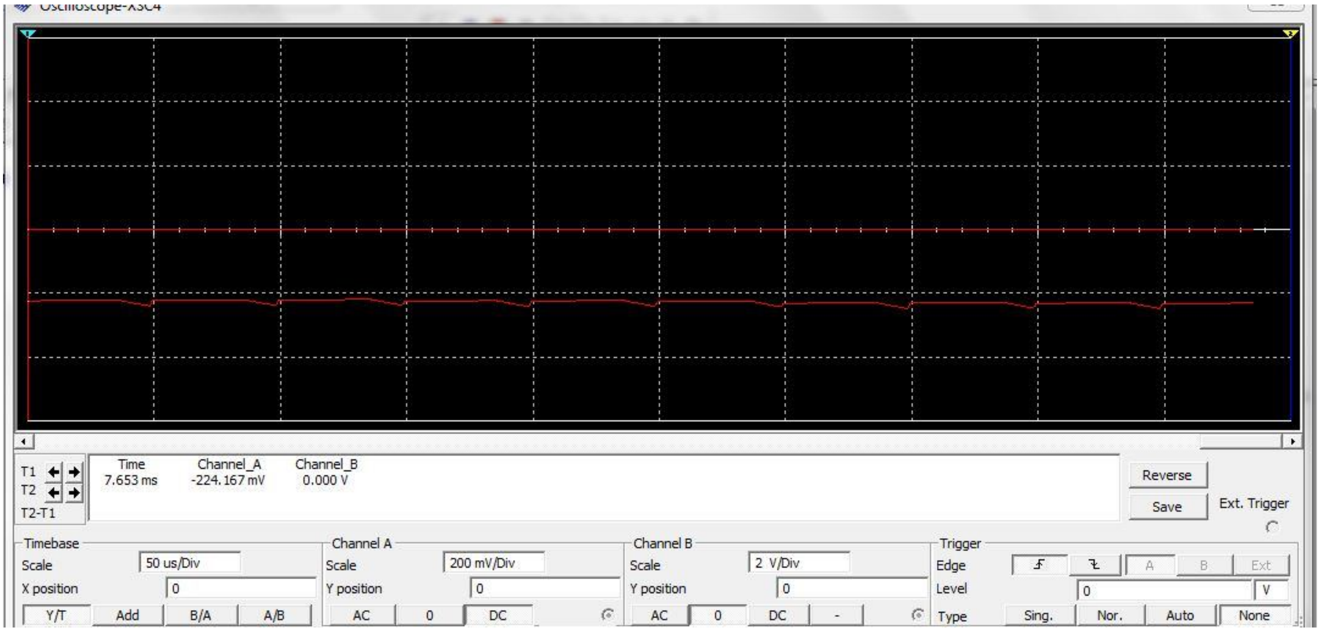


WAVEFORM OF OUTPUT AND CLOCK PULSE

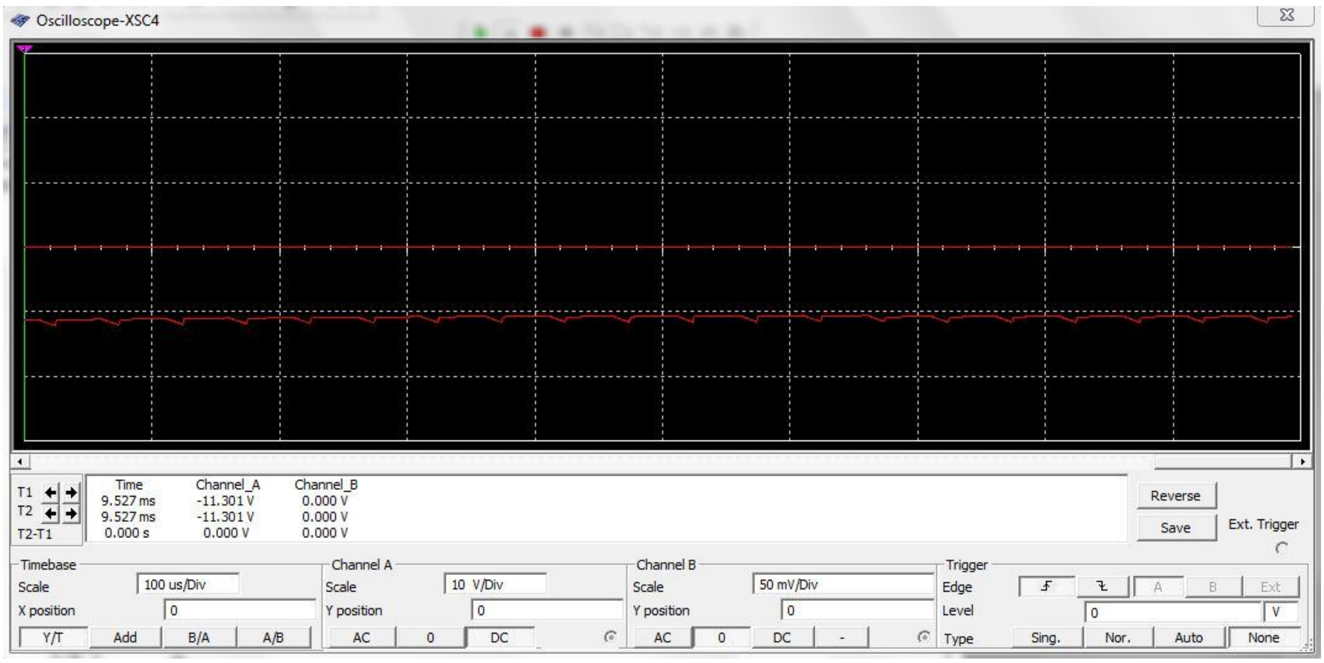
INPUT VOLTAGE=10V OUTPUT VOLTAGE=-25.6V DUTY CYCLE=75%



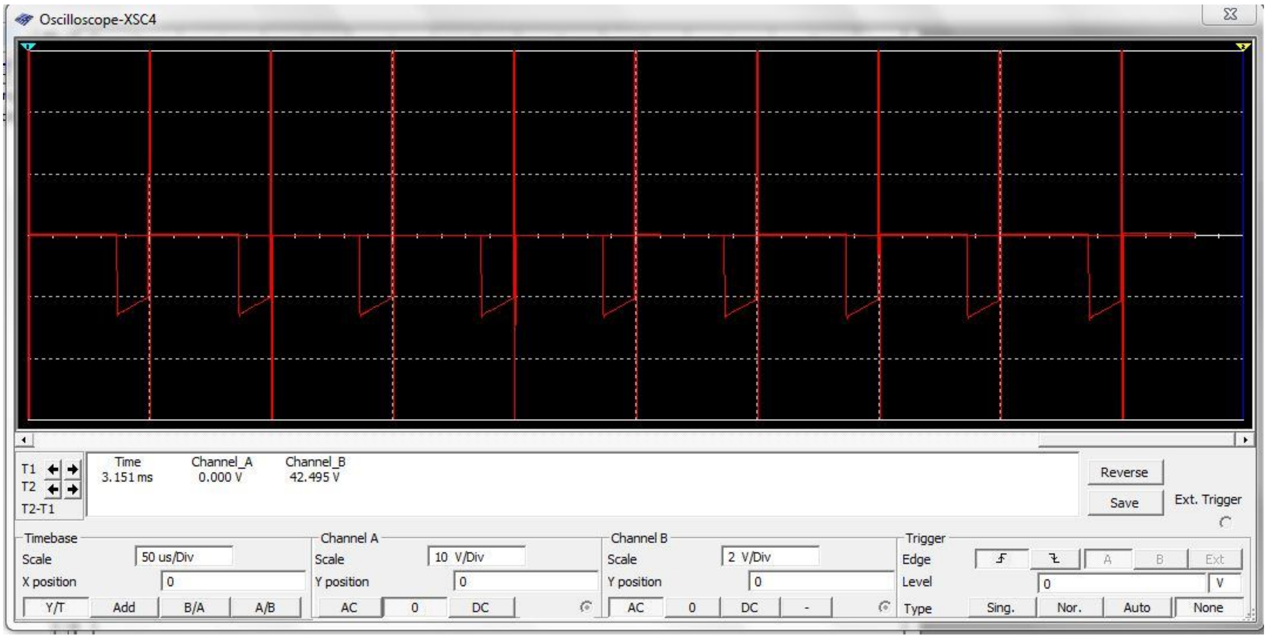
Current Waveform in Inductor in CCM



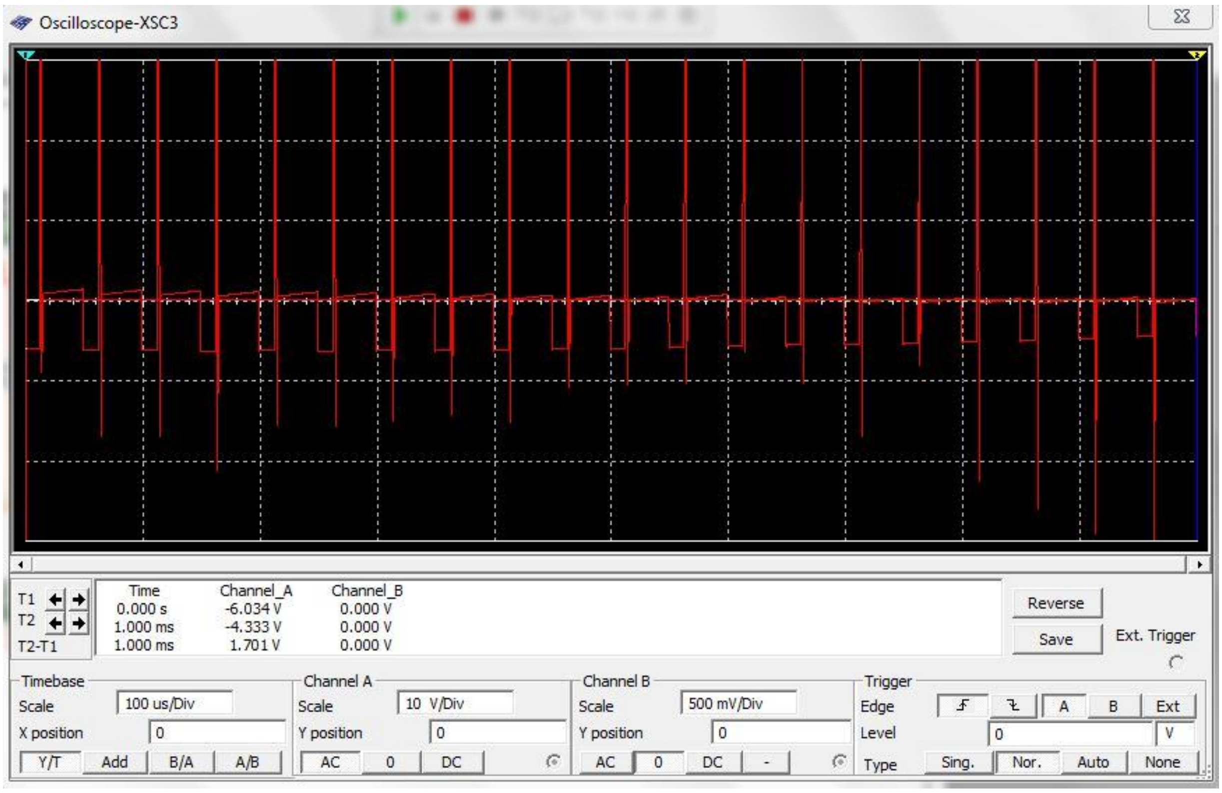
Output DC Current Waveform



Output DC Voltage waveform (Reversed polarity)

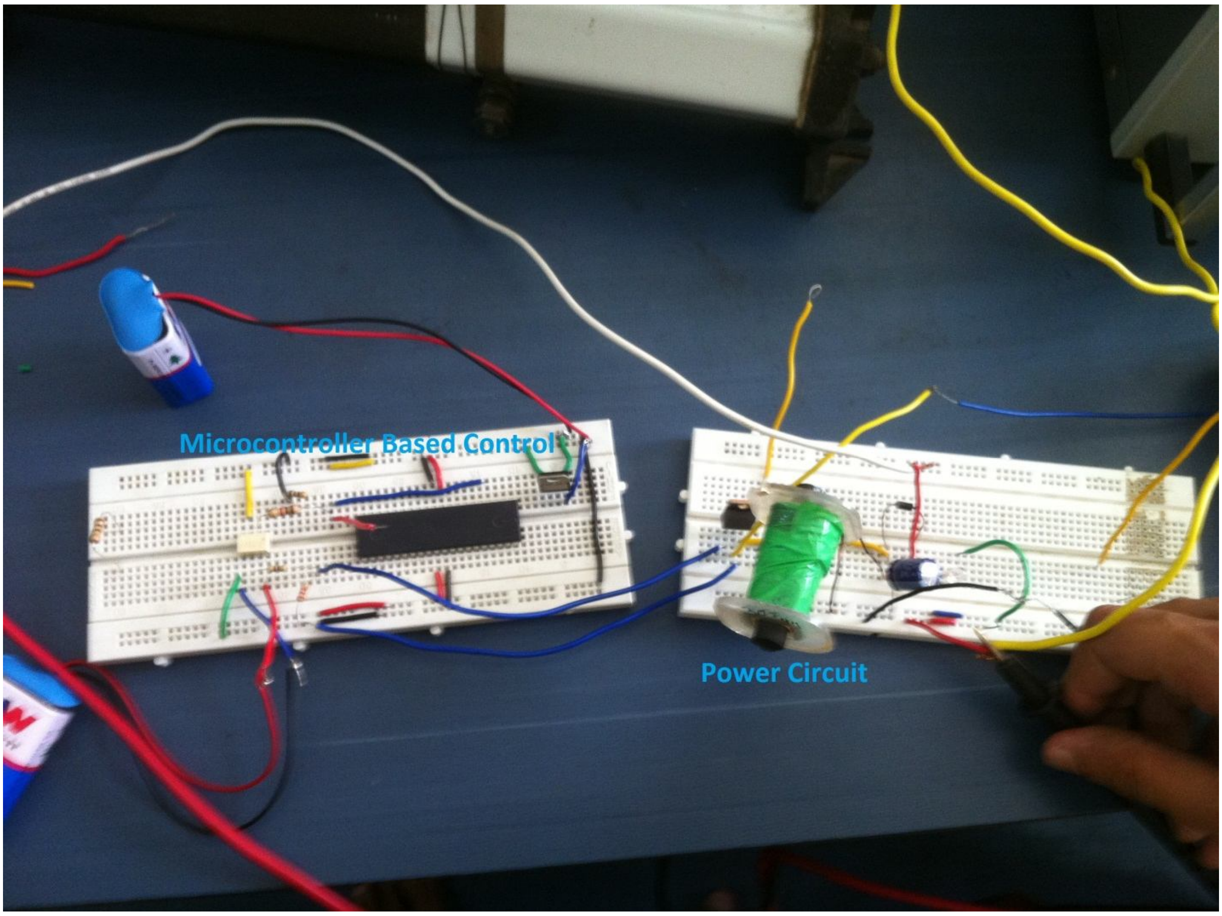


Capacitor Current Waveform



Diode Current Waveform

Hardware Implementation

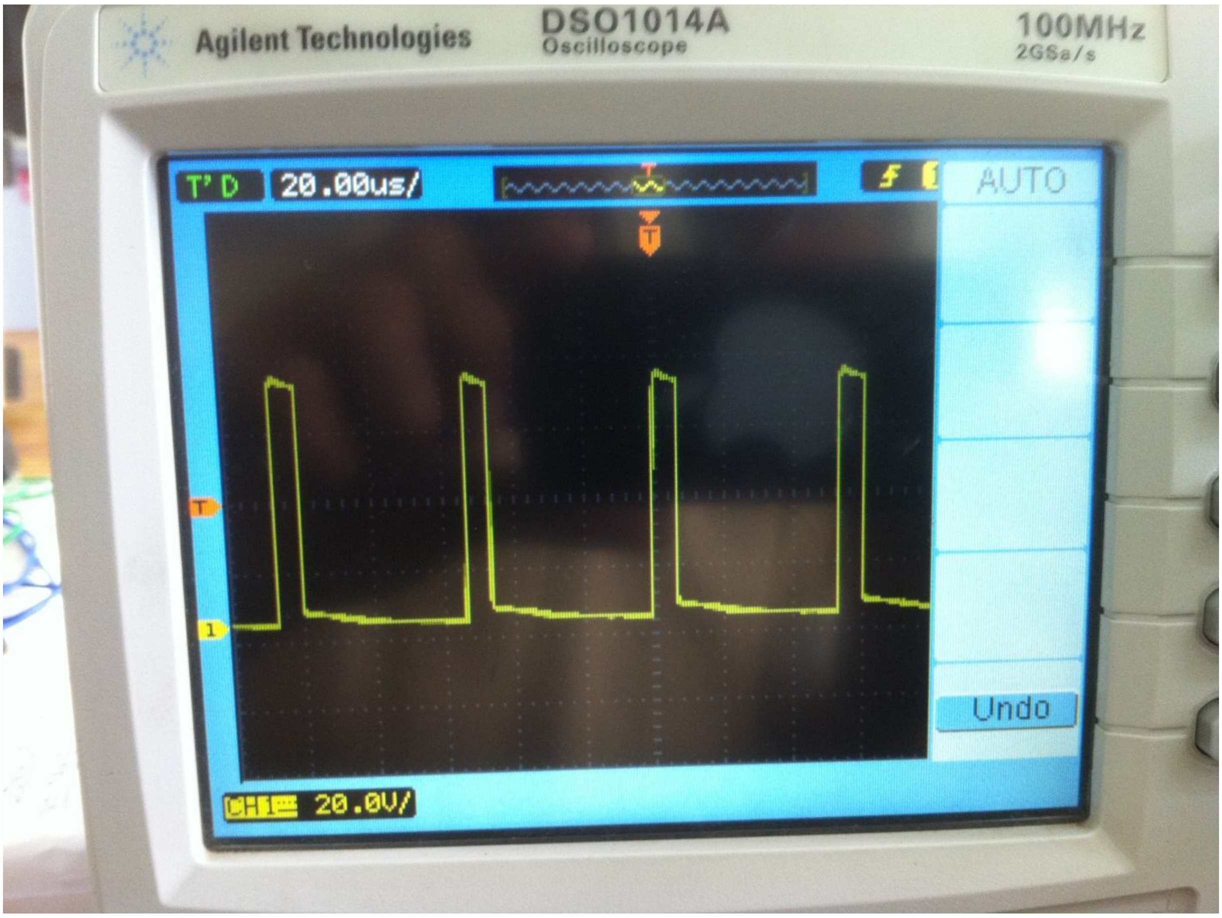


This image shows the hardware implementation of Buck-Boost Converter on the Breadboard .

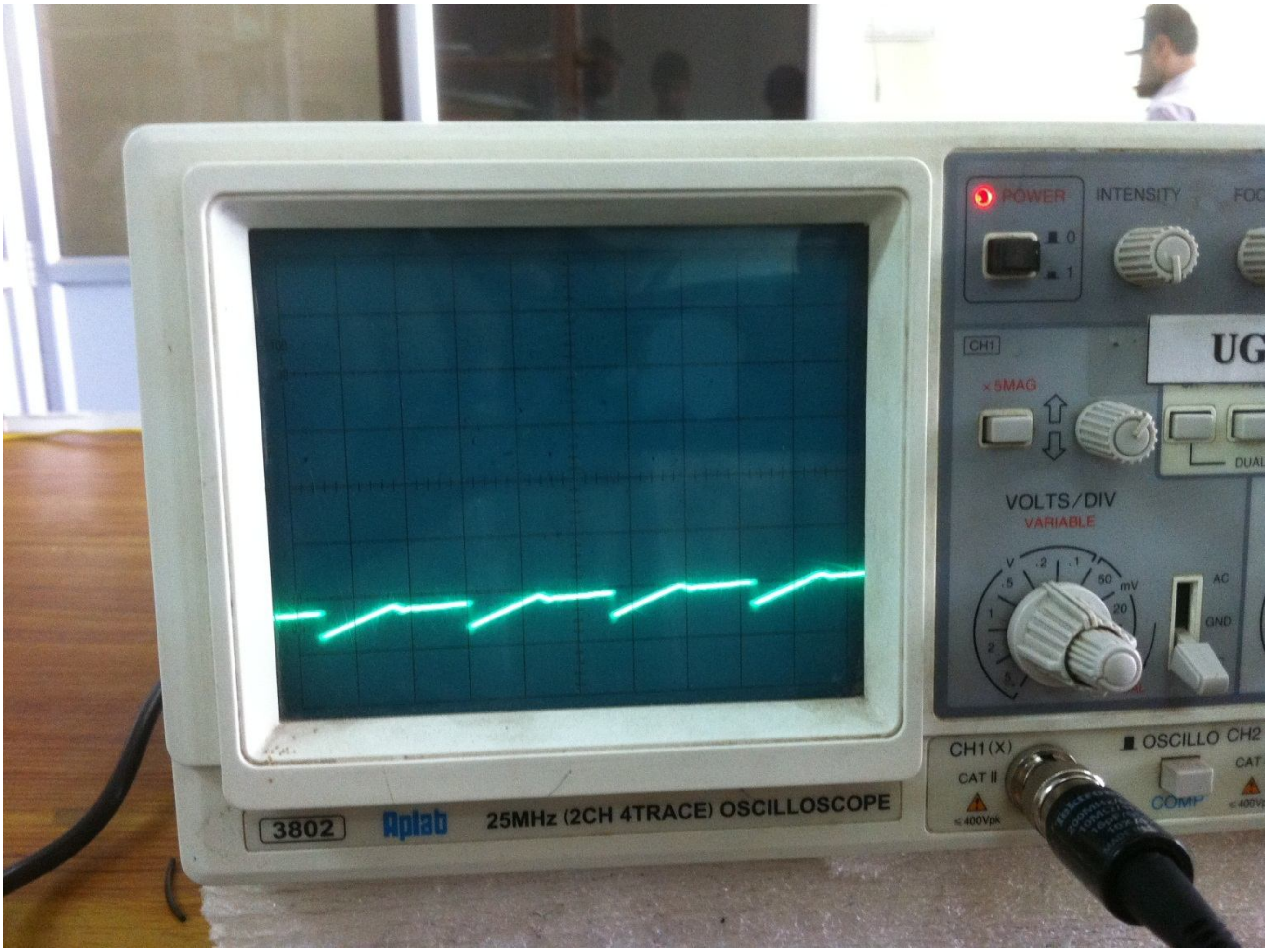
The two part control and power circuit are on two different breadboards and the gating for the mosfet switch IRFZ44N is being given by the pulse generated by the 16bit Atmegamicrocontroller.The pulse before being applied at gate terminal is amplified using an optocoupler TL250.

COMPONENTS OF BUCK-BOOST CONVERTER

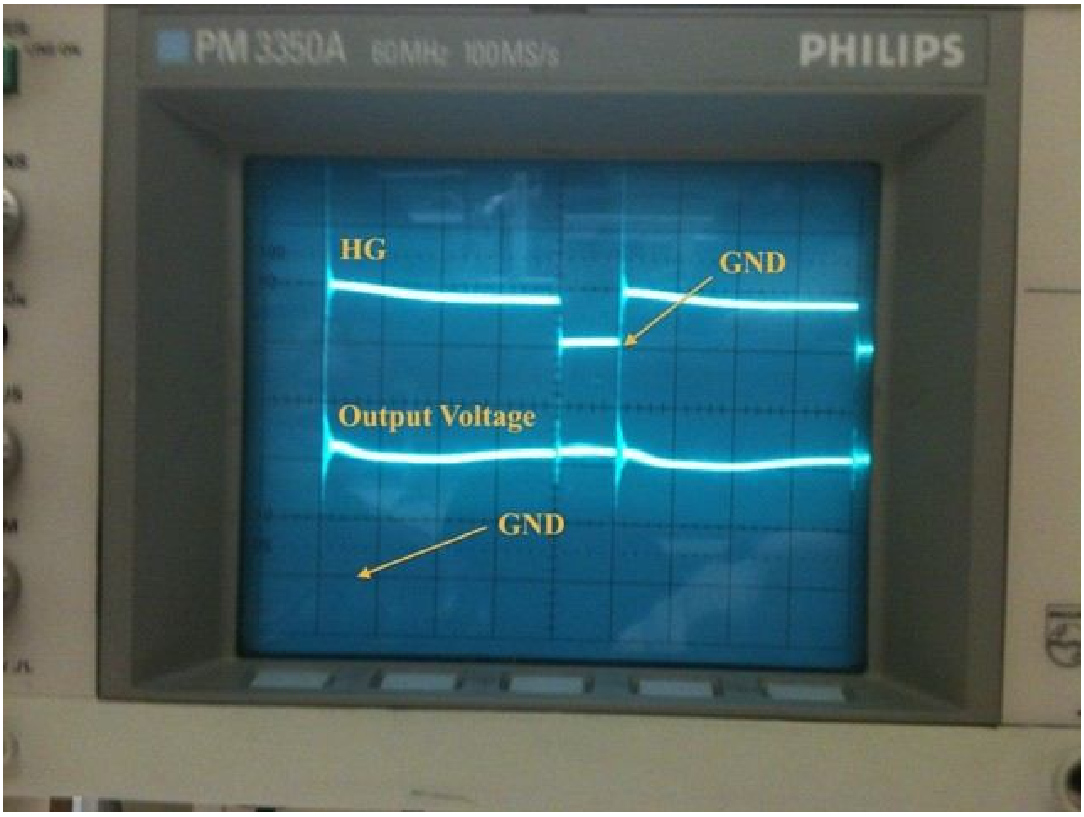
COMPONENT	DESCRIPTION	TYPE
$Q1$	Power MOSFET	IRFZ44N
D1	Diode	IN4007
Lm	Ceramic Core Inductor	*Lm* inductors Wire size: 15 AWGb,300uH
C	Ceramic Capacitor	50uF
PWM	Microcontroller	Atmega 16
Amplifier & Isolator	Optocoupler	TLP250



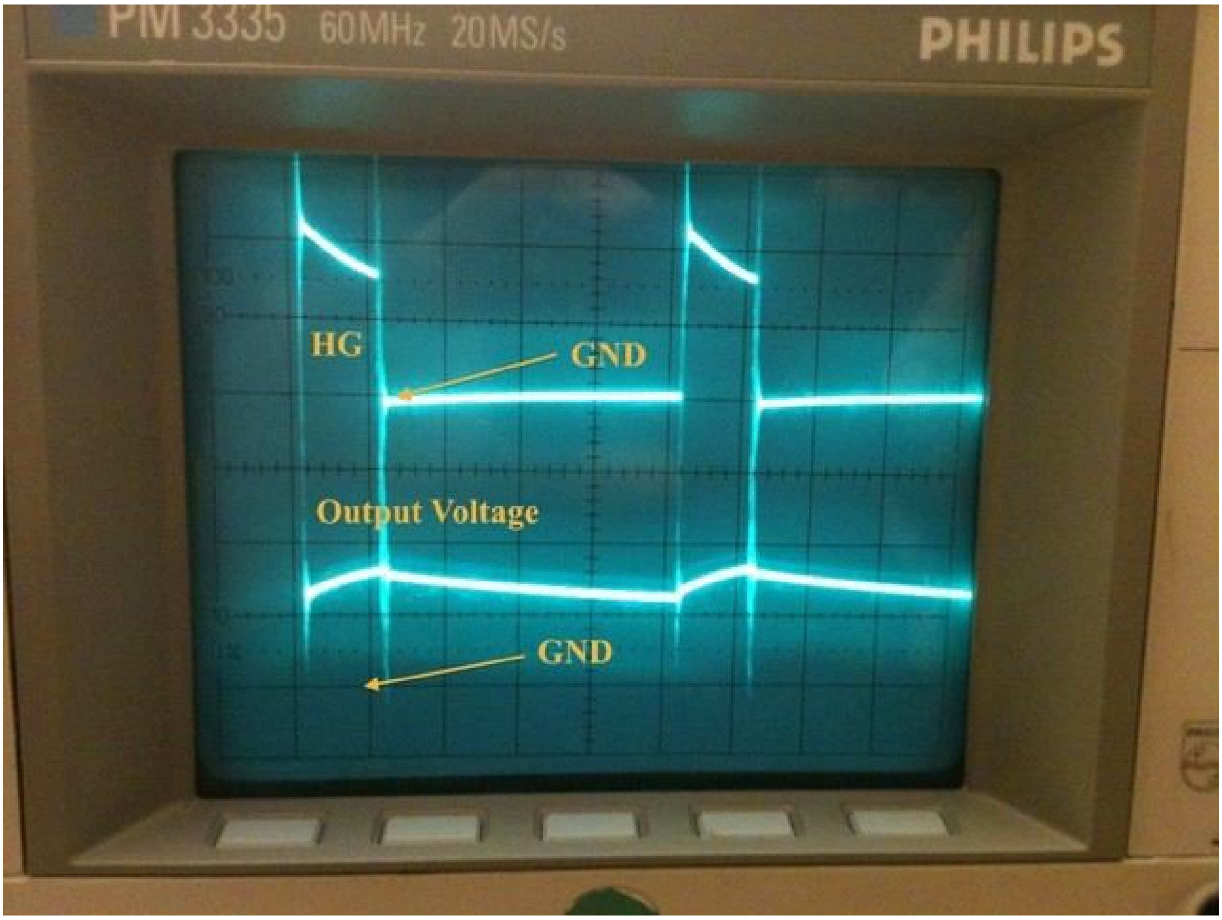
Waveform showing switching pulse generated by microcontroller for 10% Dutycycle.



Output Waveform in Buck Mode

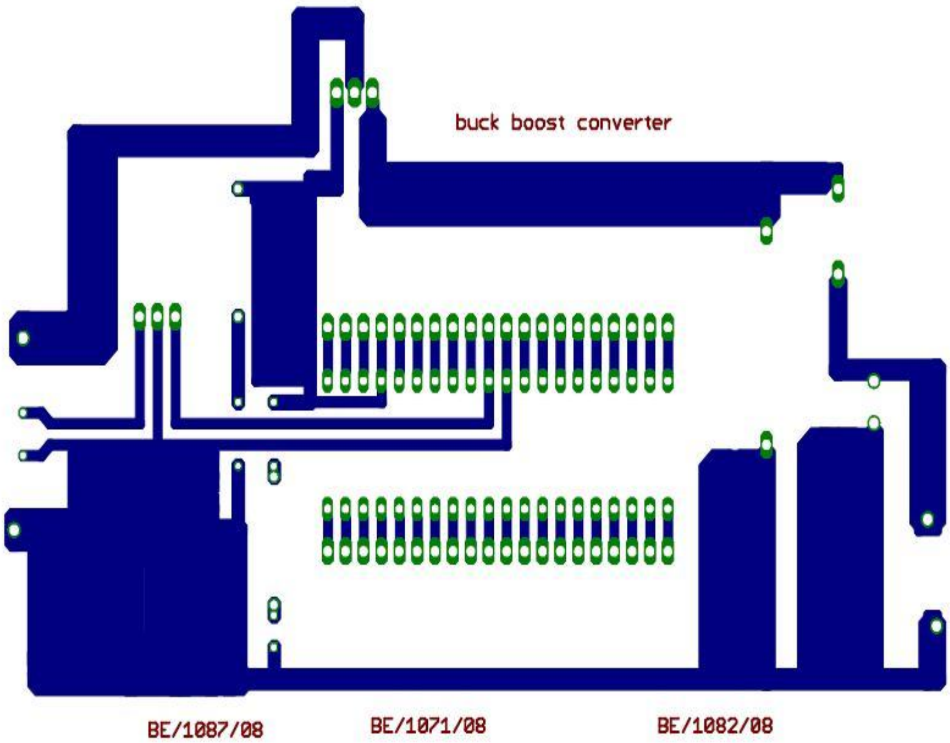


Waves of Boost Converter



Waves of Buck Converter

LAYOUT DESIGN FOR PCB REALIZATION



CHAPTER-5
CONCLUSION

A review of the commercially available vehicles shows thatthe series/parallel HEV system is the most popular for all hybrid vehicles with a relatively large electric motor (in comparison to the ICE). This configuration allows the vehicle to operate in a very diverse set of modes including all-electric operation (series HEV operation, which is utilized at slow cruising speeds).

In the project buck-boost converter are used as a dc-dc converter for boosting and bucking the voltage level of the dc bus in the powertrain of a Hybrid Electric Vehicle. The benefits of using motor/generator set with bidirectional buck-boost converter was obvious from the example given Of Toyota Prius ,a commercially successful Hybrid Electric Vehicle. We see the fual economy as well as the performance of car during acceleration increases by about 25-30%.

We as a case study studied the working of a non-inverting single inductor type buck-boost converter and simulated the circuit with expected results.

It is seen that by suitably choosing the frequency of clock pulse we can have a trade off best between switching loss and quality of dc output current in a buck-boost converter.

Also the current and voltage ripple in the output is a function of inductance and capacitance value used and can be suitably maintained within a practicle limit.

For practical PCB hardware realization we analysed a DC-DC switching converter consisting of a single inductor. We also designed the circuit on PCB and the circuit was compact enough to be of commercial use.

SCOPE FOR FUTURE WORK

- Better Design of Bidirectional Cascade Buck-boost Converter
- Hardware realization of the better coupled inductor DC-DC converter on PCB
- Reducing the Volume and Weight Of the Converter
- Inductor core material design for reducing volume and weight
- Increasing the efficiency and bandwidth of converter
- Reducing the size for isolated type buck-boost converter
- Making the overall price of HEV comparable to present day ICE Vehicles

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