DESIGN OF A BIDIRECTIONAL CONVERTER FOR A HYBRID ELECTRIC VEHICLE (HEV)

A PROJECT REPORT

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ABSTRACT

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This project presents a zero-voltage-switching (ZVS) isolated bidirectional dc–dc converter based on a dual full-bridge topology. It deals with design and fabrication of the converter using PIC microcontroller.

Compared to the traditional dc-dc converters for the similar applications, the new topology has the advantages of simple circuit topology with soft-switching implementation without additional devices, high efficiency and simple control.

This converter cost is low and provides buck-boost function in both directions of power conversion. This concept is useful to system applications where batteries and fuel cells are required, such as hybrid electric vehicles in which power transfers have to be managed in both directions.

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1. INTRODUCTION

1.1 Objective

In future, the power requirements in automobiles are likely to increase due to the implementation of power electronics in all the control fields. To meet the power requirement, a power converter is proposed. The objective is to design a bidirectional dc-dc converter which will supply a higher power density more than the existing devices. This bidirectional dc-dc converter will convert 12 Volts to 24 Volts to supply the high power applications and in the reverse direction it will convert 24 Volts to 12 Volts to store them in the battery for future use.

1.2 DC-DC Converter

In many industrial applications, it is required to convert a fixed voltage dc source into variable voltage dc source. A DC-DC converter converts directly from dc to dc and is simply known as a dc converter .A dc converter can be considered as dc equivalent to an ac transformer with a continuously variable turns ratio. Like a transformer, it can be used to step down or step up a dc voltage source.

DC converters are widely used for traction motor control in electric auto mobiles, trolley cars, marine hoists, forklift trucks and mine haulers. They provide smooth acceleration control, high efficiency and fast dynamic response.

A DC-DC converter is also known as chopper. It converts a given constant DC voltage into a variable average DC voltage across load by placing a static switch between the DC source and the load. The switch chops off the dc supply into ON and OFF periods.

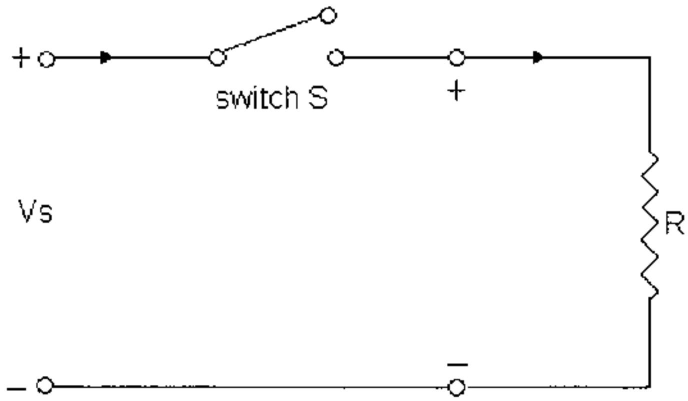


Fig 1.1 DC-DC Converter

Vs = Supply voltage; R= Resistance;

A basic chopper circuit is shown in Figure 1.1. When the switch S is closed, the DC supply voltage V_{dc} is applied across the load and when it is open, the load is disconnected from the supply. By varying the ratio of switch-close time (T_{ON}) to the switch open time (T_{OFF}) at a fixed frequency, the value of the average output DC voltage can be controlled.

The switch S in Figure 1.1 could be either a transistor or an SCR (Silicon Controlled Rectifier) depending on the amount of power involved. An SCR is used in high power applications whereas transistors are used when power involved is low. The output load voltage is in the form of square wave.

If T_{ON} is the ON time and T_{OFF} is the OFF time of the chopper, the duty cycle of the chopper is given by

$$\text{Duty Cycle} = [T_{ON}/T] = T_{ON}/[T_{ON}+T_{OFF}] \quad ...(1.1)$$

The load voltage V_L is given by

$$V_L = V_{dc} * [T_{ON}/T] = V_{dc} * \text{Duty Cycle} \quad \text{(volt)} \quad ...(1.2)$$

$$V_L = f * V_{dc} * T_{ON} \quad \text{(volt)} \quad ...(1.3)$$

Where f is the switching frequency of the chopper and is given by 1/T.

1.3 Step Down Operation

The principle of operation can be explained by referring to Figure 1.2. When a switch is closed for a time t_1, the input voltage Vs appears across the load. If the switch remains off for a period of time t_2, the voltage across the load is zero. The converter switch can be implemented by using MOSFET.

The average output voltage is given by

$$V_a = K * V_s \qquad \text{(volt)} \qquad \dots (1.4)$$

Where $K = t_1/T$ is the duty cycle of the chopper.

The rms value of output voltage is found from

$$V_0 = \sqrt{K}\, V_s. \qquad \text{(Volt)} \qquad \dots (1.5)$$

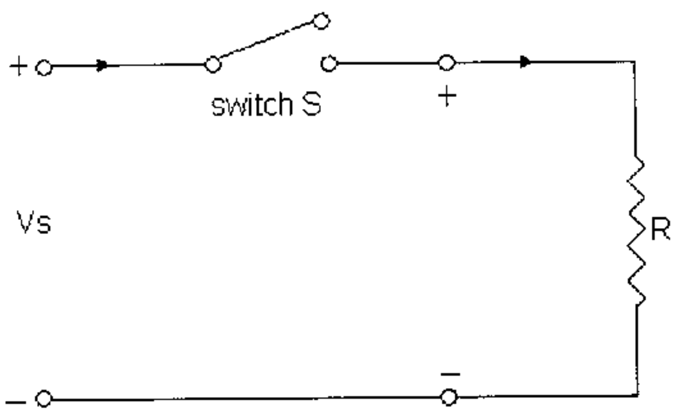


Fig 1.2 Step Down DC-DC Converter

1.4 Step Up Operation

A converter can be used to step up a dc voltage and an arrangement for step up operation is shown in Figure 1.3. When switch S is closed for time t_1, the inductor current rises and energy is stored in the inductor L. If the switch is opened for period t_2, the energy stored in the inductor is transferred to load through diode D_1 and the inductor current falls.

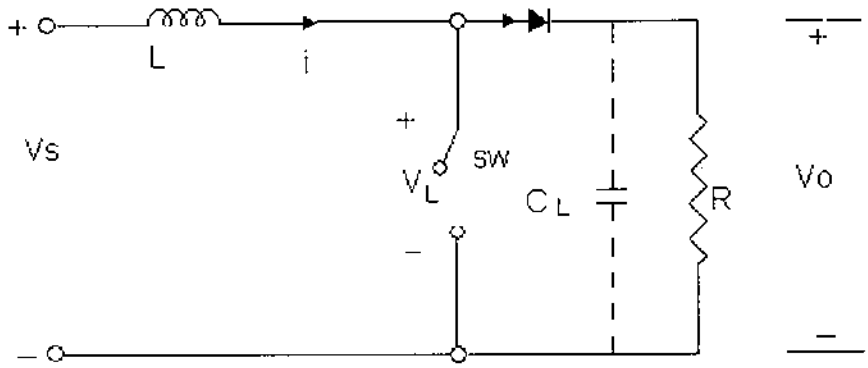


Fig 1.3 Step Up DC-DC Converter

The average output voltage (across the load) is given by,

$$V_0 = V_s\,(1/\,1\text{-}K) \qquad \dots (1.6)$$

1.5 Limitations Of Traditional Converters

- Output power of the converter is small because of the current handling limitation of the single transistor
- At high currents, the size of components to be used will increase with increase in losses with decrease in efficiency.
- There is no isolation between input and output which is not desirable in most applications.

1.6 ZCS Converters

The switches of a zero current switching (ZCS) converter turn ON and turn OFF at zero current. The circuit consists of switch S_1, inductor L, and capacitor C as shown in Figure 1.4. Inductor L is connected in series with a power switch S_1 to achieve ZCS. It is classified into two types L type and M type. In both types, the inductor L limits the di/dt of the switch current, and L and C constitute a series circuit.

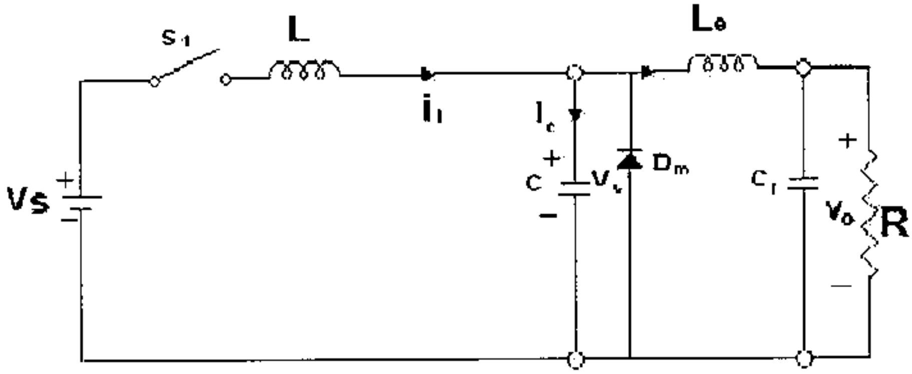


Fig 1.4 ZCS Converter

When the switch current is zero, there is a current I =Cj (dV/dt) flowing through internal capacitance C_j due to a finite slope of switch voltage at turn-off. The current flow causes power dissipation in the switch and limits the high switching frequency. The switch can be implemented either in half wave configuration or in full wave configuration where the diode allows unidirectional and bidirectional current flow respectively.

The practical devices do not turn off at zero current due to their recovery times. As a result, an amount of energy can be trapped in the inductor L of the M type configuration, and voltage transients appear across the switch. This favors L type configuration over the M type one.

1.7 ZVS Converters

The switches of a ZVS Converters turn on and turn off at zero voltage. The circuit is shown in Figure 1.5. The capacitor C is connected in parallel with the switch S_1 to achieve ZVS. The internal switch capacitance C_j is added with the capacitor C, and it affects the frequency only, thereby contributing no power dissipation in the switch.

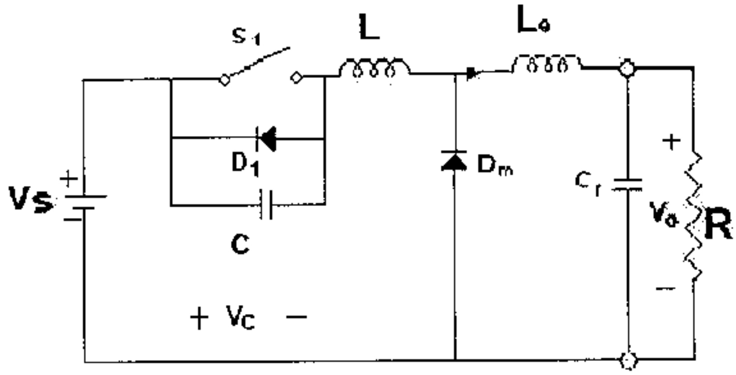


Fig 1.5 ZVS Converter

If the switch is implemented with a transistor and an anti-parallel diode, the voltage across C is clamped by diode and the switch is operated in a half wave configuration.

If the diode is connected in series with transistor, the voltage across C can oscillate freely, and the switch is operated in a full-wave configuration. A ZVS shapes the switch voltage waveform during the off time to create a zero-voltage condition for the switch to turn on.

1.8 Comparison of ZCS and ZVS Converters

ZCS can eliminate the switching losses at turn off and reduce the switching losses at turn on, because a relatively large capacitor is connected across the diode. When power MOSFETs are used for ZCS, the energy stored in the device's capacitance is dissipated during turn on. This capacitive turn–on loss is proportional to the switching frequency.

During turn-on, a high rate of change of voltage may appear in the gate drive circuit due to the coupling through the MILLER Capacitor, thus increasing the switching loss and noise. Another limitation is that switches are under high-current stress, resulting in higher conduction. It should, however, be noted that ZCS is particularly effective in reducing switching loss for power devices (such as IGBTs) with large tail current in the turn-off process.

By the nature of ZCS, the peak switch current is much higher than that in a square wave. In addition, a high voltage becomes established across the switch in the off-state. When the switch is turned on again, the energy stored in the output capacitor becomes discharged through the switch, causing a significant power loss at high frequencies and high voltages. This switching loss can be reduced by using ZVS.

ZVS eliminates the capacitive turn-on loss. It is suitable for high-frequency operation. Without any voltage clamping, the switch is may be subjected to excessive voltage stress, which is proportional to the load.

For both the ZCS and ZVS, the output voltage control can be achieved by varying the frequency. ZCS operates with a constant on-time control, where as ZVS operates with a constant off-time control.

HYBRID ELECTRIC VEHICLE

2. HYBRID ELECTRIC VEHICLE (HEV)

Hybrid electric vehicles (HEVs) combine the internal combustion engine of a normal vehicle with the battery and electric motor of an electric vehicle. This results in twice the fuel economy of conventional vehicles. Also offers the extended range and rapid refuelling that consumers expect from a normal vehicle, with all the energy and environmental benefits of an electric vehicle. Can be used in a wide range of applications, from personal transportation to commercial hauling.

Hybrid power systems were designed as a way to compensate for the shortfall in battery technology. Because batteries could supply only enough energy for short trips, an onboard generator, powered by an internal combustion engine, could be installed and used for longer trips. This is the concept of the HEV. Electric vehicles are only being used in selected market applications where fewer kilometres are travelled. Conventional motor vehicles powered by internal-combustion engines (ICE) pose substantial economic, environmental and energy security issues for the planet.

The development of a compact, high efficiency dc-dc converter can introduce several modifications to the overall automobile design. The overall performance of the bi-directional dc-dc converter will be improved if the dual bus system will be a successful and cost effective solution for future automobiles. Especially in automotive applications where high ambient temperature (~200°C) is present, conventional dc-dc converters with magnetic elements can be very inefficient, and dc-dc converters with bulky inductors can suffer from limited space issue.

The other criterion that needs to be fulfilled from this bi-directional converter is high efficiency even in partial loads. Classical dc-dc converters suffer from limited efficiency at partial loads, and the maximum efficiency is achieved at full load. Thereby, a new dc-dc converter having an operating principle other than the inductive energy transfer method could be advantageous.

Several capacitor clamped converters can be considered as a solution to meet this criterion to achieve high efficiency operation and bi-directional power handling capability.

Bi-directional power management is an important attribute of a dc-dc converter used in several applications. In a hybrid automobile, there are many electrical loads grouped into two main categories depending on the voltages they use. The main traction motor is powered from the high voltage bus (around 500 V). There are also low voltage loads that need to be powered from a low voltage source in the range of 40-50 V.

The low voltage source could be a battery or a stepped down voltage from the high voltage battery pack or any source. When the high voltage source is a fuel cell, the low voltage source is normally a battery pack. During the start up time of the vehicle, the low voltage battery pack delivers power to the fuel cell system and to the main motor, and the low voltage loads in the vehicle; the dc-dc converter works in the up conversion mode.

Once the fuel cell is ready, it provides power to the main motor and low voltage loads. The low voltage battery is also charged from the fuel cell if required. During this time, the dc-dc converter works in the down conversion mode. Thus, a dc-dc converter used in the system must have the capability to deliver power in both directions depending on the state of the fuel cell or the battery voltage.

2.1 Why HEV?

More efficient cars can make a big difference to society in terms of environmental benefits, and the state of the urban air has motivated buyers to purchase cleaner cars. Use of HEVs will reduce smog-forming pollutants over the current national average. Hybrids will never be true zero-emission vehicles, however, because of their internal combustion engine. But the first hybrids on the market will cut emissions of global-warming pollutants by a third to a half, and later models may cut emissions by even more.

One of the most important differences between a HEV and a normal vehicle is the HEV's ability to reclaim a portion of the energy lost to braking. In a HEV, when the driver brakes, the motor becomes a generator, using the kinetic energy of the vehicle to generate electricity that can be stored in the battery for later use. Traditional brakes are necessary, as well as a consistent strategy for smoothly blending the two braking systems. Regenerative and friction brakes need to be controlled electronically so that stopping ability is maximized to make the dual brake operation not noticeable to the driver. Regenerative braking capability helps minimize energy loss and recover the energy used to slow down or stop a vehicle.

Engines can be sized to accommodate average load, not peak load, which reduces the engine's weight. Fuel efficiency is greatly increased (hybrids consume significantly less fuel than vehicles powered by gasoline alone). Emissions are greatly decreased. HEVs can reduce dependency on fossil fuels because they can run on alternative fuels. Special lightweight materials are used to reduce the overall vehicle weight of HEVs.

2.2 HEV Components

A HEV is an optimised mix of many components. The vehicle drive train consists of:

- Electric traction motors/controllers
- Electric energy storage systems, such as batteries, ultra capacitors, and flywheels
- Hybrid power units such as spark ignition engines, compression ignition direct injection (diesel) engines, gas turbines, and fuel cells
- Fuel systems for hybrid power units
- Transmissions

The model of an hybrid electric vehicle is shown in Figure 2.1. HEVs are now at the forefront of transportation technology development. They are reducing critical resource consumption, dependence on foreign oil, air pollution, and traffic congestion. Their widespread penetration into the automotive market depends mainly on the economics of producing a complex hybrid power system, rather than the inherent capabilities of the technology itself.

Hence this project is initiated to design and develop a bidirectional dc-dc converter which is a component of power supply to the HEV.

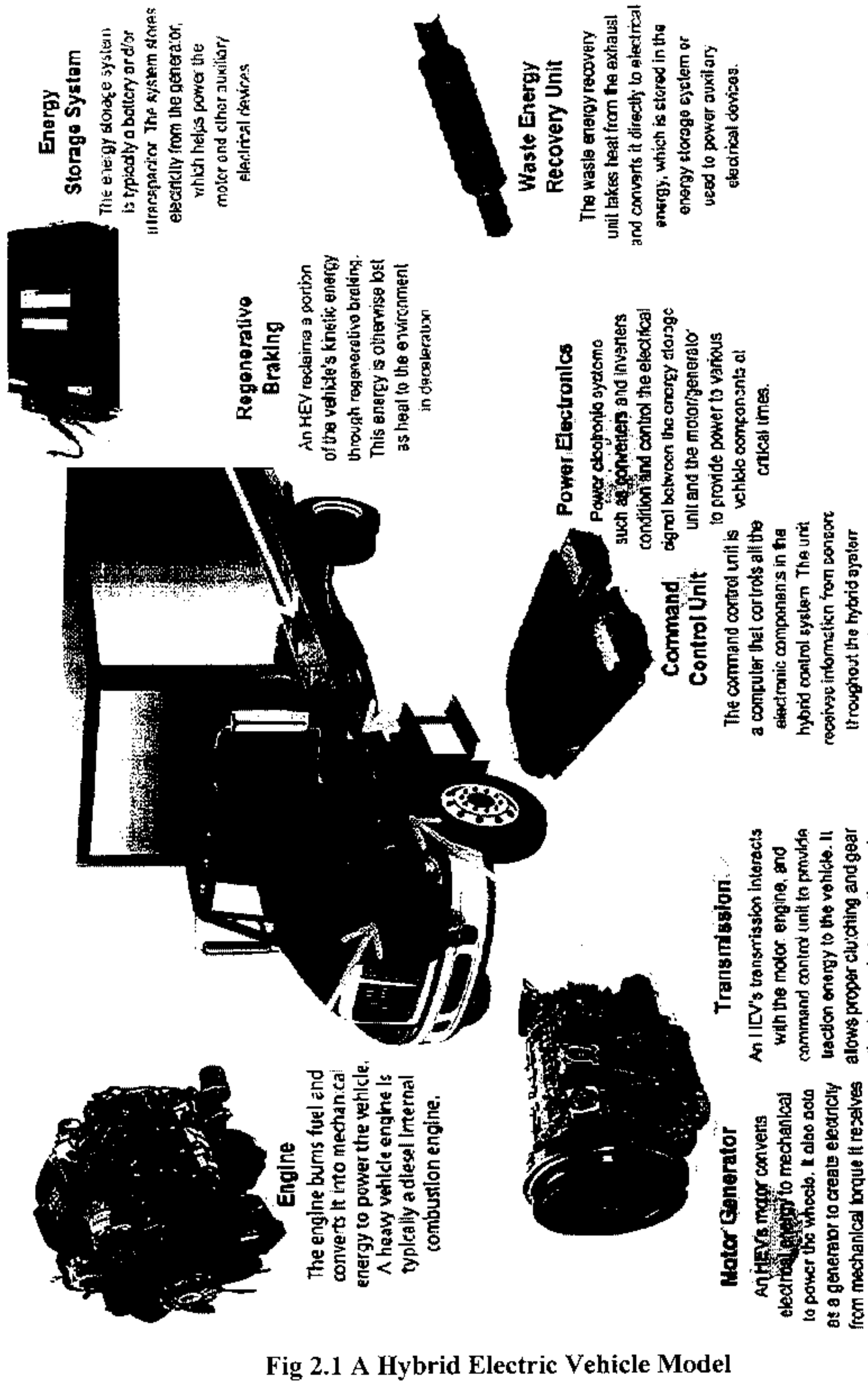


Fig 2.1 A Hybrid Electric Vehicle Model

ZVS FULL BRIDGE BI-DIRECTIONAL DC-DC CONVERTER

3. ZVS FULLBRIDGE BI-DIRECTIONAL DC-DC CONVERTER

In recent years, growing concerns about environmental issues have demanded more energy efficient nonpolluting vehicles. The rapid advances in fuel cell technology and power electronics have enabled the significant developments in fuel cell powered electric vehicles. The fuel cells have numerous advantages such as high density current output ability, clean
electricity generation, and high efficiency operation . However, the fuel cell characteristics are different from that of the traditional chemical-powered battery. The fuel cell output voltage drops quickly when first connected with a load and gradually decreases as the output current rises.

The fuel cell also lacks energy storage capability. Therefore, in electric vehicle applications, an auxiliary energy storage device (i.e., lead-acid battery) is always needed for a cold start and to absorb the regenerated energy fed back by the electric machine.

In addition, a dc–dc converter is also needed to draw power from the auxiliary battery to boost the high-voltage bus during vehicle starting.

Until the fuel cell voltage rises to a level high enough to hold the high-voltage bus, the excess load from the battery will be released. The regenerated braking energy can also be fed back and stored in the battery using the dc–dc converter.

A full-bridge bidirectional dc–dc converter, shown in fig 3.3, is considered one of the best choices for these applications. However, this system has a complicated configuration, high cost, and large size. Several half-bridge based topologies have been published in the literature to reduce the device count and increase efficiency. A voltage imbalance exists between the two split capacitors, thus an additional control circuit to eliminate the voltage imbalance problem is required. In this project, the design of a new bidirectional dc–dc converter is undertaken.

3.1 Operation

To overcome the limitations of the traditional converter, this project considers a ZVS Bi-Directional Full Bridge DC-DC Converter and its controller method for implementing dc-dc power management. It consists of a battery, low voltage side converter, isolation transformer, high voltage side converter and DC motor. The two modes of operations in this converter are :

1. Forward mode of operation
2. Reverse mode of operation

3.1.1 Forward mode of operation

In the forward mode of operation, DC voltage from battery is inverted by the low voltage side converter. The inverted AC voltage from the low voltage side converter is fed to the isolation transformer. From the Isolation transformer, the inverted AC voltage is stepped up and also the high voltage side converter is isolated from low side converter. The Figure 3.1 shows the block diagram for forward mode of operation of the converter.

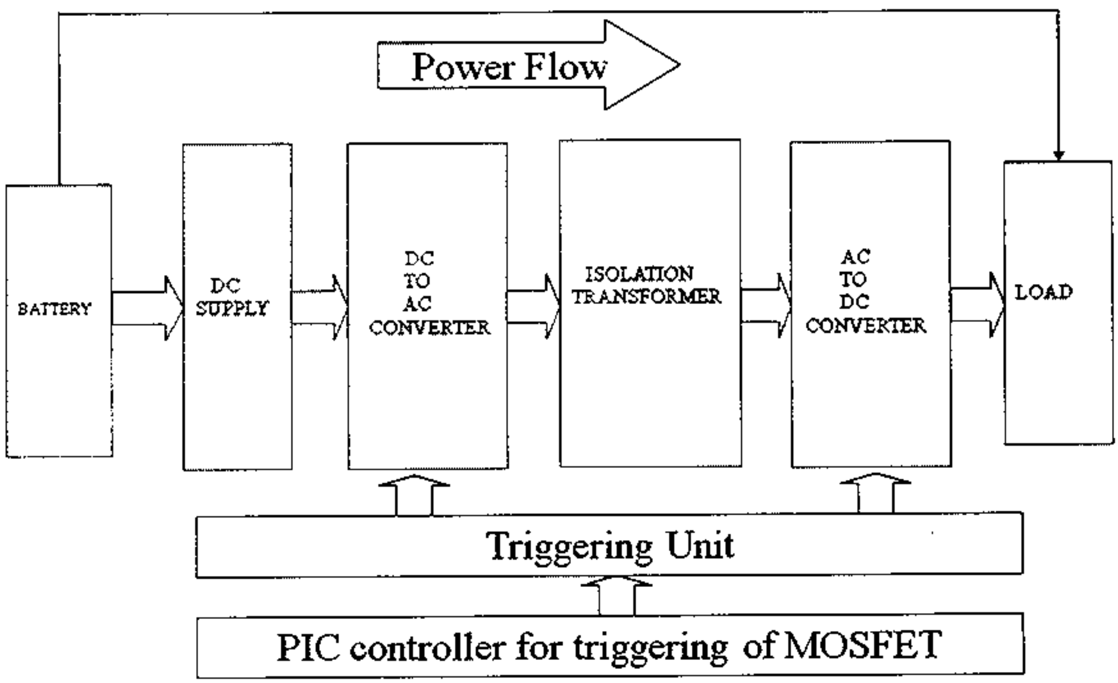


Fig 3.1 Block Diagram for forward mode operation

3.1.2 Reverse mode of operation

In the reverse mode of operation, the input given to the high voltage side converter is inverted and is fed to the isolation transformer where it is stepped down. Then it is rectified by the low voltage side converter to recharge the battery. Hence the DC power has been managed in both forward and reverse directions.

The block diagram for reverse mode of operation of converter is shown in Figure 3.2.

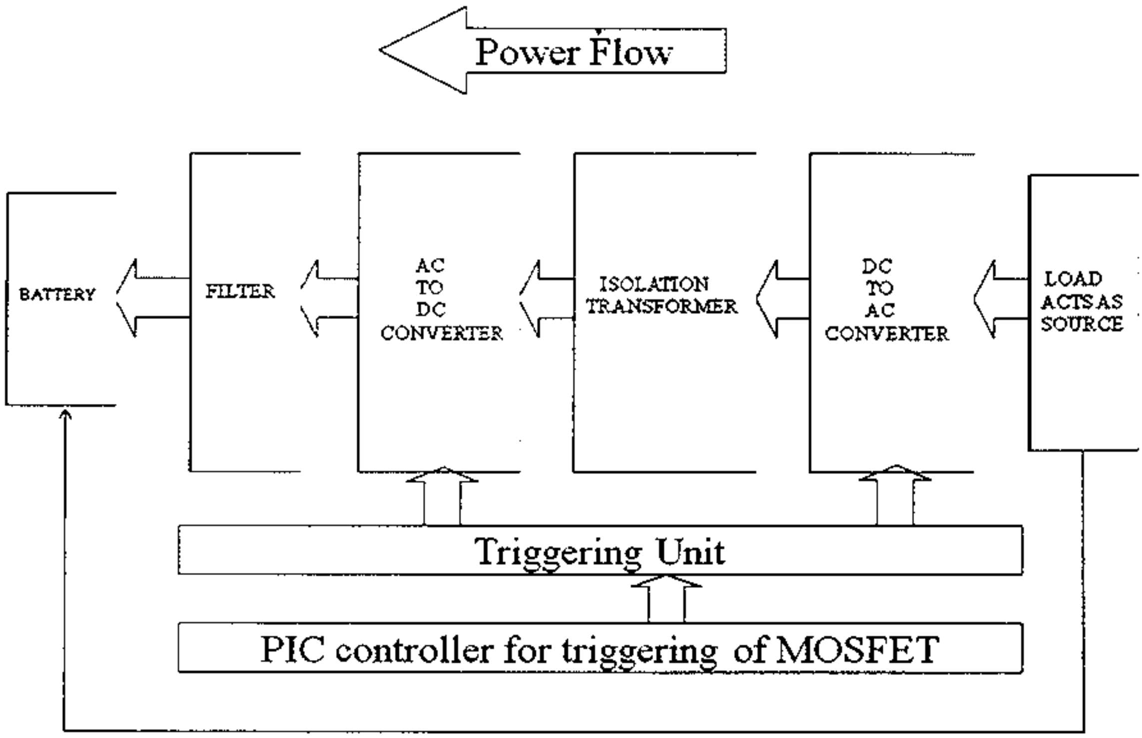


Fig 3.2 Block Diagram for reverse mode operation

3.2 Circuit Diagram

The circuit diagram for ZVS Full Bridge Bi-Directional DC-DC Converter is shown in figure3.3. Input signals from the micro controller are given to drive circuits of MOSFETs where the triggering pulses are generated. The triggering pulses are applied across gate-source terminals of each MOSFET. MOSFETS which are to be conducted is given with drain-source voltage in addition to the triggering pulses provided. The drain-source voltage magnitude depends on the power transfer in both forward and reverse directions.

During forward mode of operation the MOSFET 1 and MOSFET 3 are given with similar triggering sequence while MOSFET 2 and MOSFET 4 are given with exactly opposite pulses when compared to the pulses provided for MOSFET 1 and MOSFET 3.

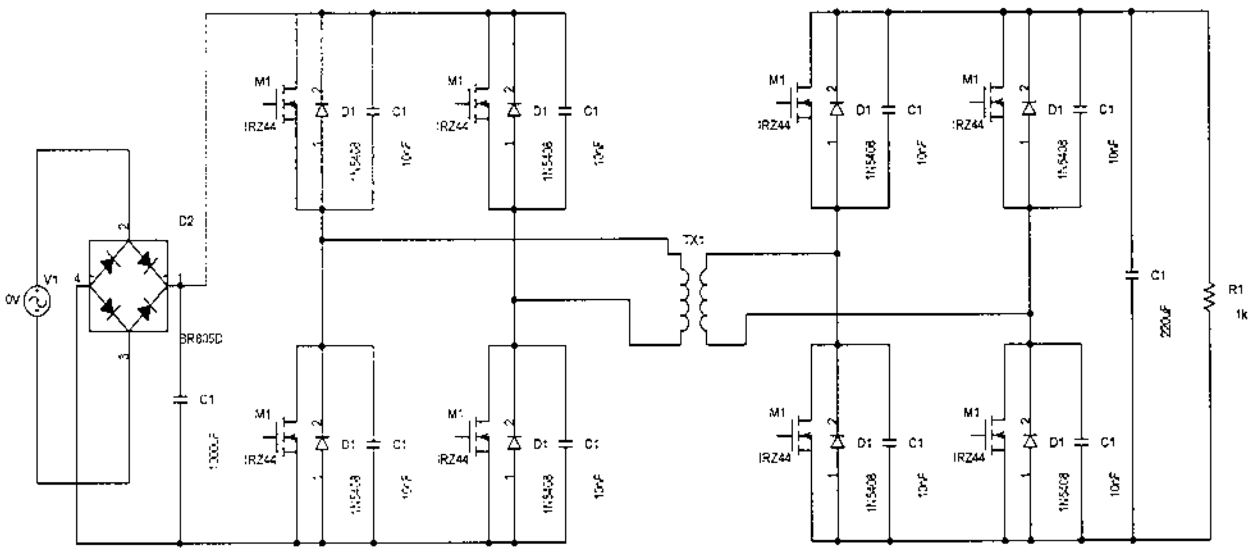


Fig 3.3 Circuit Diagram for ZVS Full Bridge Bi-Directional DC-DC Converter

Now the LVS bridge operates as an INVERTER and provides continuous AC voltage to the isolating transformer. This transformer provides an increased voltage to the HVS bridge.

Now the HVS bridge acts as a rectifier as its MOSFETs are not provided with triggering pulses and only the diodes in that bridge will conduct thereby supplies DC input voltage to the load.

While this, during reverse mode operation HVS bridge receives triggering pulses as well as the source voltage from the fuel cell unit(here it is a battery) and acts as an inverter as stated in the forward mode of operation.

At this instant LVS bridge acts like a rectifier and provides DC supply to the battery for recharging (if not so it may be utilized for running any other accessories in case of hybrid electric vehicle).

DRIVER CIRCUIT

4. DRIVER CIRCUIT

The driver circuit is designed using totem pole arrangement and it uses opto-coupler to provide bias for the transistors in the totem pole arrangement. The driver circuit is shown in figure 4.1. Here MCT2E is the opto-coupler that comprises a photo transistor and an LED. The input pulse to this driver circuit is given from the programmable interrupt controller (PIC).

Set of codings has been embedded on PIC using embedded C in order to generate triggering pulses to excite the driver circuits for purpose triggering MOSFETs.

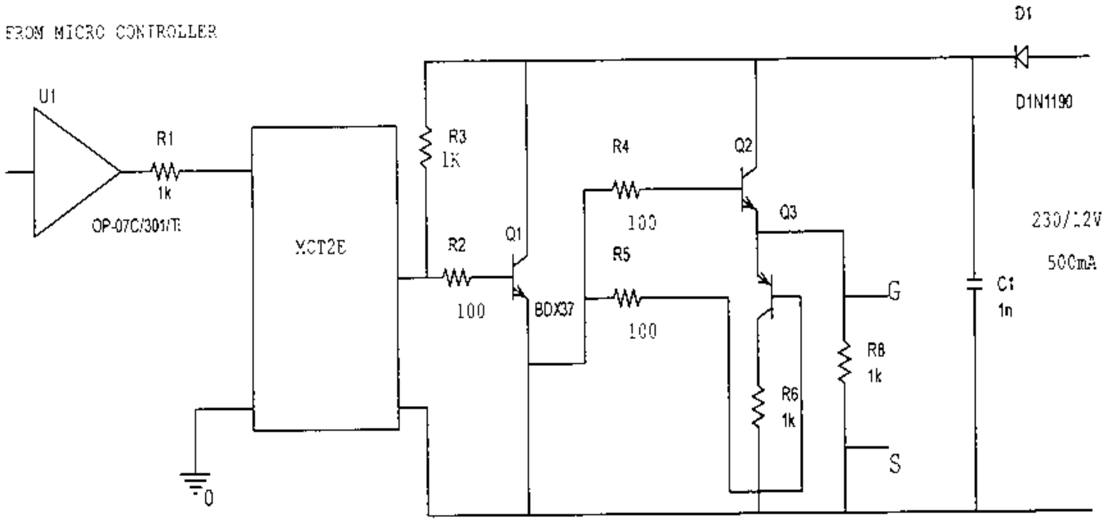


Fig 4.1 Driver Circuit

When a LOW level signal is received from the PIC, LED is forward biased and the phototransistor will conduct thereby giving biasing signal to the transistors Q1 and Q2. Hence a positive triggering pulse for gate of the MOSFET is obtained.

When the input pulse from the PIC is HIGH level then the LED is reverse biased. At this time the photo transistor would not conduct and therefore transistors Q1 and Q2 in the circuit will be turned OFF.

Hence a negative triggering pulse for the gate of MOSFET is obtained in this case. The transistor Q3 is provided to maintain a zero level after a pulse has been produced in order to maintain a sequence of HIGH and LOW level pulses.

SWITCHING PULSE SEQUENCE

5. SWITCHING SEQUENCE

Soft switching can mitigate some of the mechanisms of switching loss and possibly reduce the generation of EMI. Semiconductor devices are switched on or off at the zero crossing of their voltage or current waveforms:

Transistor turn-on transition occurs at zero voltage.

- Diodes may also operate with zero-voltage switching.
- Zero-voltage switching eliminates the switching loss induced by diode
- Stored charge and device output capacitances.
- Zero-voltage switching is usually preferred in modern converters.

Switching pulse for Forward Direction

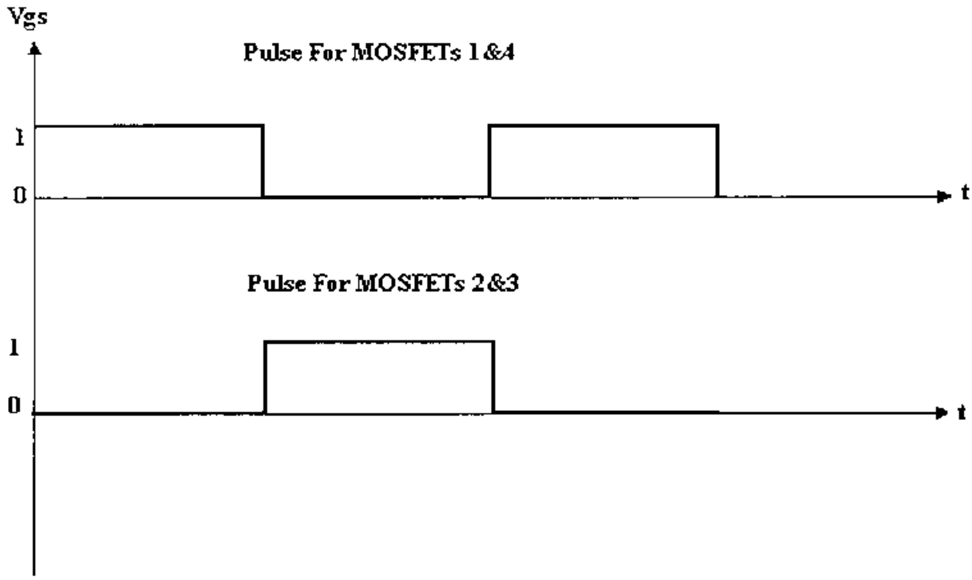


Fig 5.1 Triggering Pulse Sequences for forward mode

Switching pulse for Reverse Direction

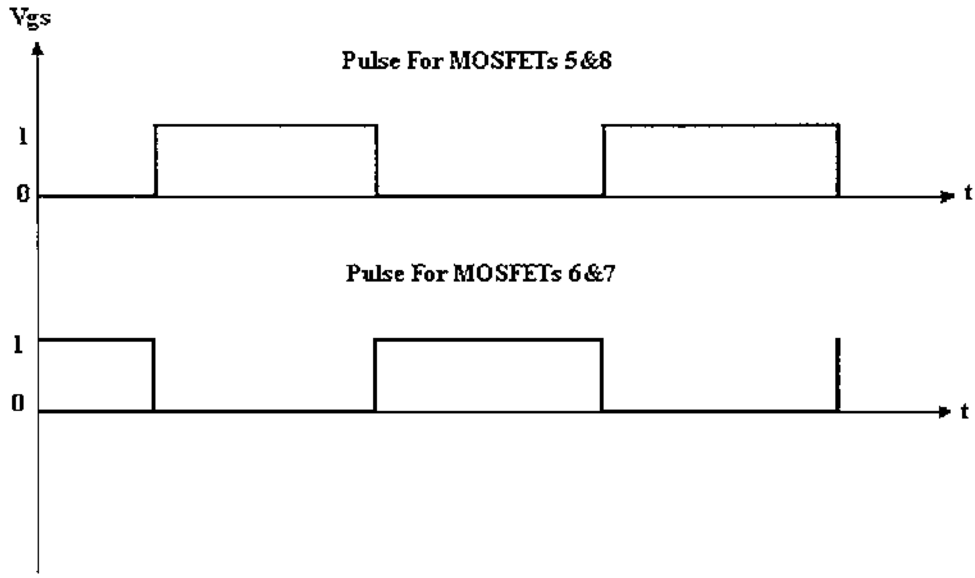


Fig 5.2 Triggering Pulse Sequences for reverse mode

PROGRAMMABLE INTERRUPT CONTROLLER

6. PROGRAMMABLE INTERRUPT CONTROLLERS (PIC)

The microcontroller that has been used for this project is from PIC series. PIC microcontroller is the first RISC based microcontroller fabricated in CMOS (complementary metal oxide semiconductor) that uses separate bus for instruction and data allowing simultaneous access of program and data memory.

The main advantage of CMOS and RISC combination is low power consumption resulting in a very small chip size with a small pin count. The main advantage of CMOS is that it has immunity to noise than other fabrication techniques.

Various microcontrollers offer different kinds of memories. EEPROM, EPROM, FLASH etc. are some of the memories of which FLASH is the most recently developed.

Technology that is used in pic16F877 is flash technology, so that data is retained even when the power is switched off. Easy Programming and Erasing are other features of PIC 16F877.

Figure 6.1 shows the pin diagram of programmable interrupt controller 16F877. Here the output is taken from PORT C. The controller is given with a clock signal of 2 MHz. A crystal oscillator of maximum frequency of 4MHz is used to give clock signal to the programmable interrupt controller.

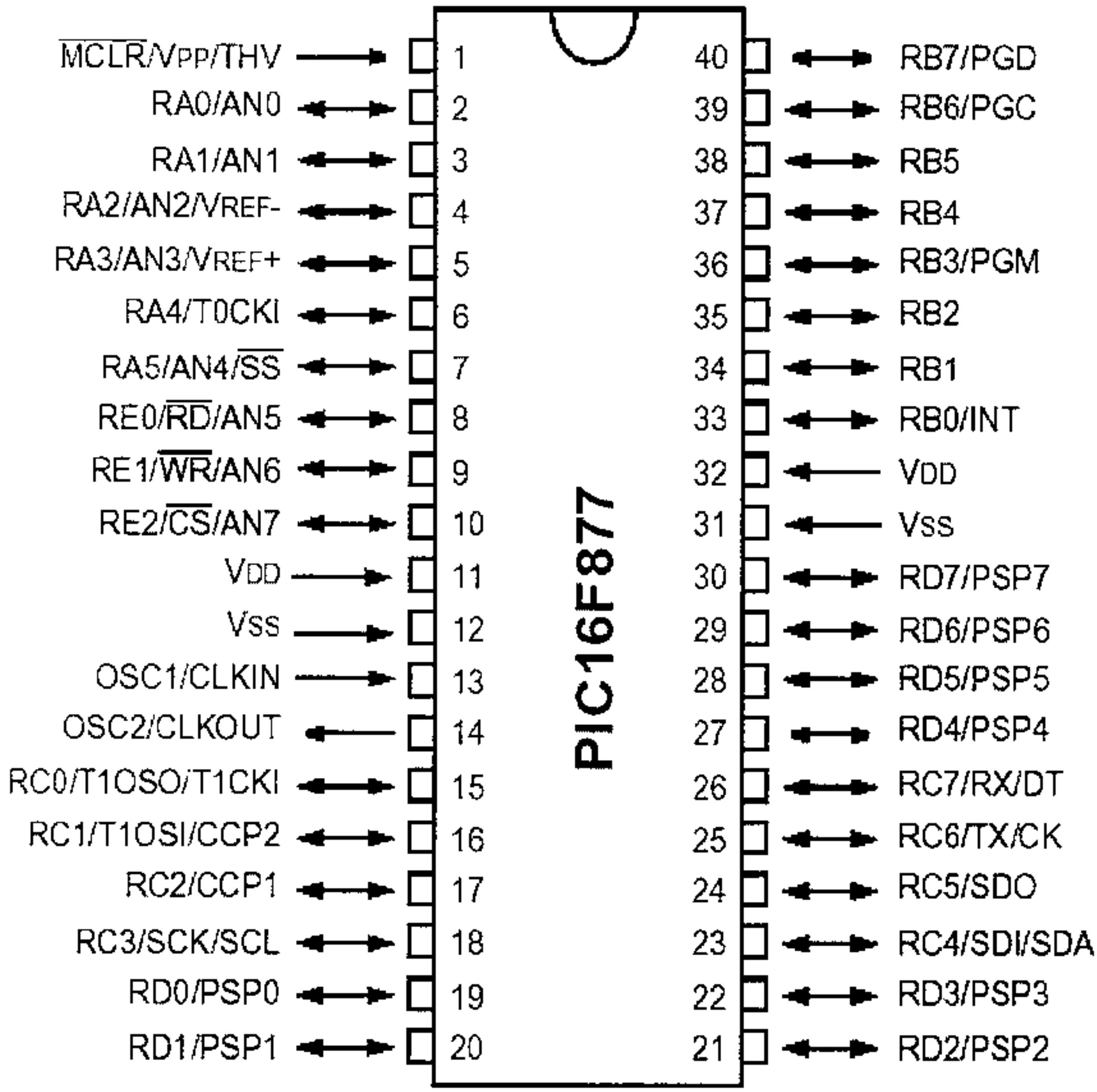
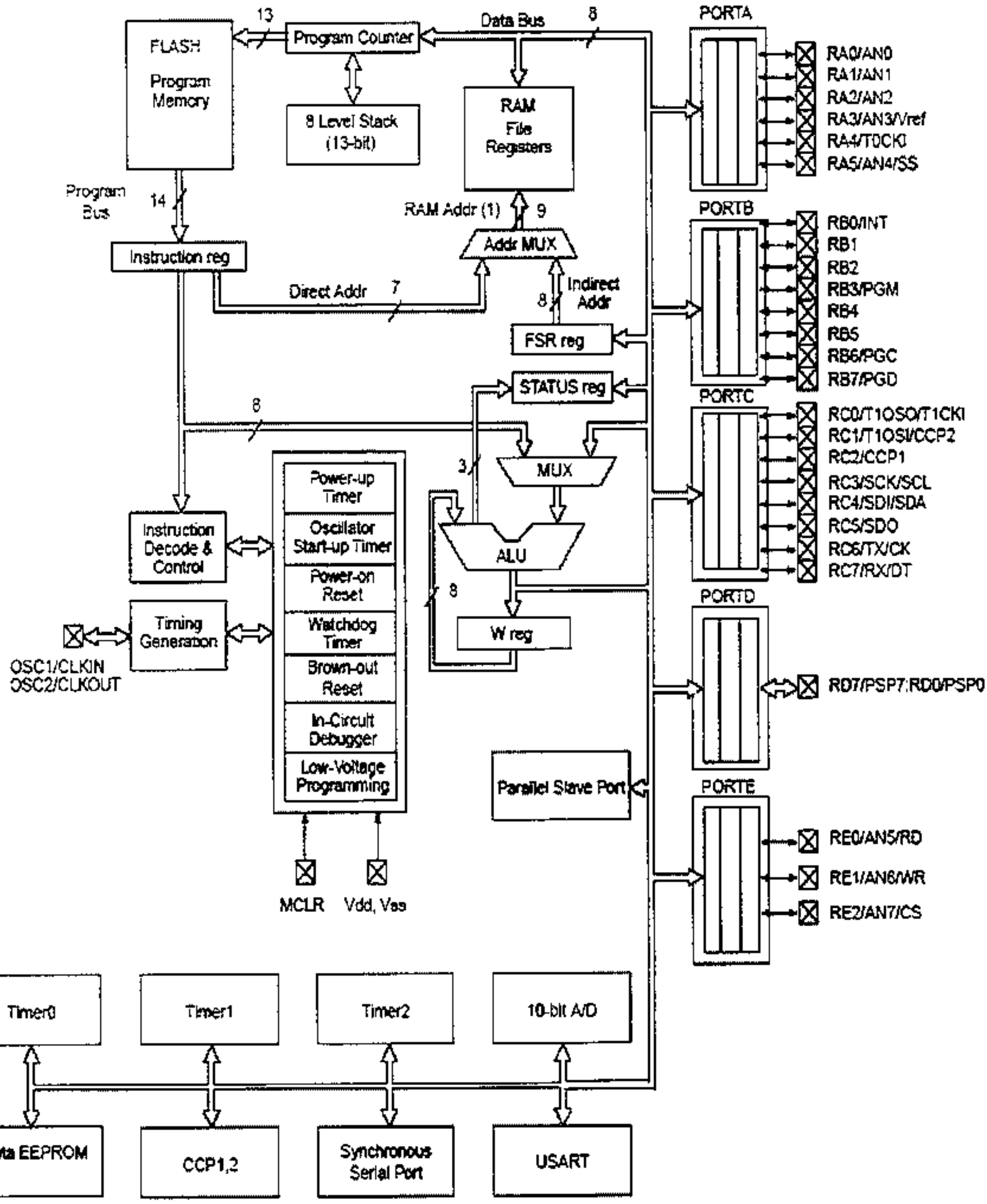


Fig 6.1 Pin Diagram of Programmable Interrupt Controller

Figure 6.2 shows the internal block diagram of programmable interrupt controller 16F877. Some pins of these I/O ports are multiplexed with an alternate function for the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin. Additional Information on I/O ports may be found in the IC micro™ Mid-Range Reference Manual.



Note 1: Higher order bits are from the STATUS register.

Fig 6.2 Architecture of Programmable Interrupt Controller

Program :

```
#include<pic.h>
#include<stdio.h>
#include "delay.c"
_ CONFIG(0*3f71);
unsigned char n=1;
void main()
{
  RBPU=0;
  TRISC=0x00;
   PORTC=0x00;
    while(1)
    {
     if(RB0==0)
       n=1:
     if(RB1==0)
        n=2;
       if(n==1)
       {
        PORTC =0x09;
                DelayMS(20);

        PORTC=0x06;
                DelayMS(10);
       }
       else if(n=2)
       {
           PORTC=0x09;
                      DelayMS(20);
```

```
        PORTC=0x60;
            DelayMS(10);
    }
  }
}
```

SIMULATION RESULTS

7. SIMULATION RESULTS

Simulation test for ZVS Full Bridge Bi-Directional DC-DC Converter done using MATLAB SIMULINK. The components involved are chosen from SIMPOWER SYSTEMS. In the test triggering pulses for the MOSFETs generated from pulse generator and the drain source voltage is supplied from separate DC source.

7.1 Forward Mode

A soft switching ZVS Bi-Directional Full Bridge DC-DC Converter has been built in simulation and tested to validate the soft switching analysis. Here the simulation is done in MATLAB simulink and compared with the experimental results.

In the forward mode of operation,6V DC voltage from battery is inverted by the low voltage side converter. The inverted AC voltage from the low voltage side converter is fed to the isolation transformer.

From the isolation transformer, the inverted AC voltage is stepped up and also the high voltage side converter is isolated from low side converter.Thus12 V DC voltage can be obtained in output of the high voltage side converter.

Attractive feature of this converter is reduction of magnetic saturation due to asymmetricity of circuits or transient phenomenon. The maximum efficiency can be obtained which more applicable to high power traction systems.

The circuit for forward mode operation is shown in the figure 7.1. The Fig 7.2 shows the input and output waveforms of forward mode of operation.

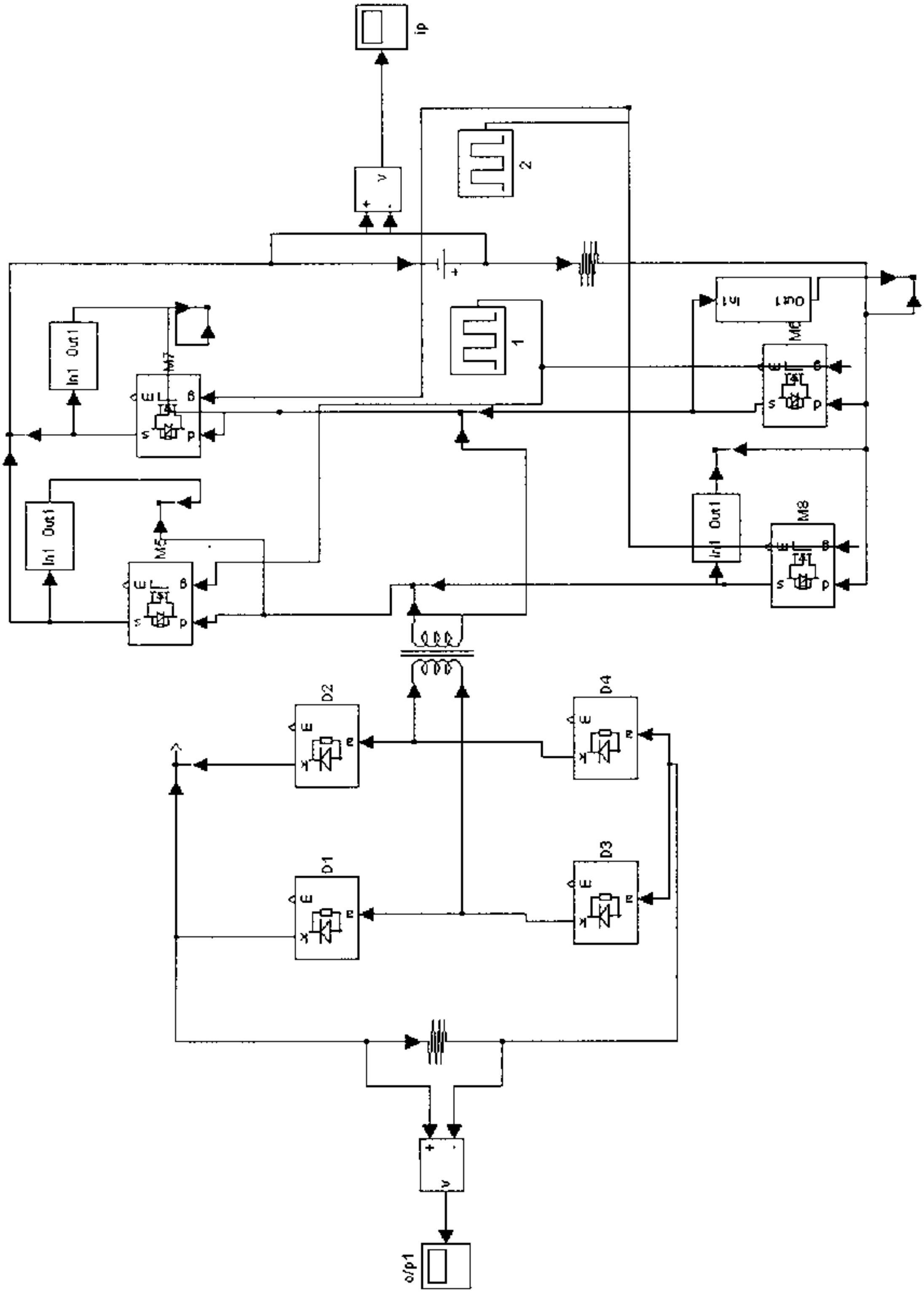
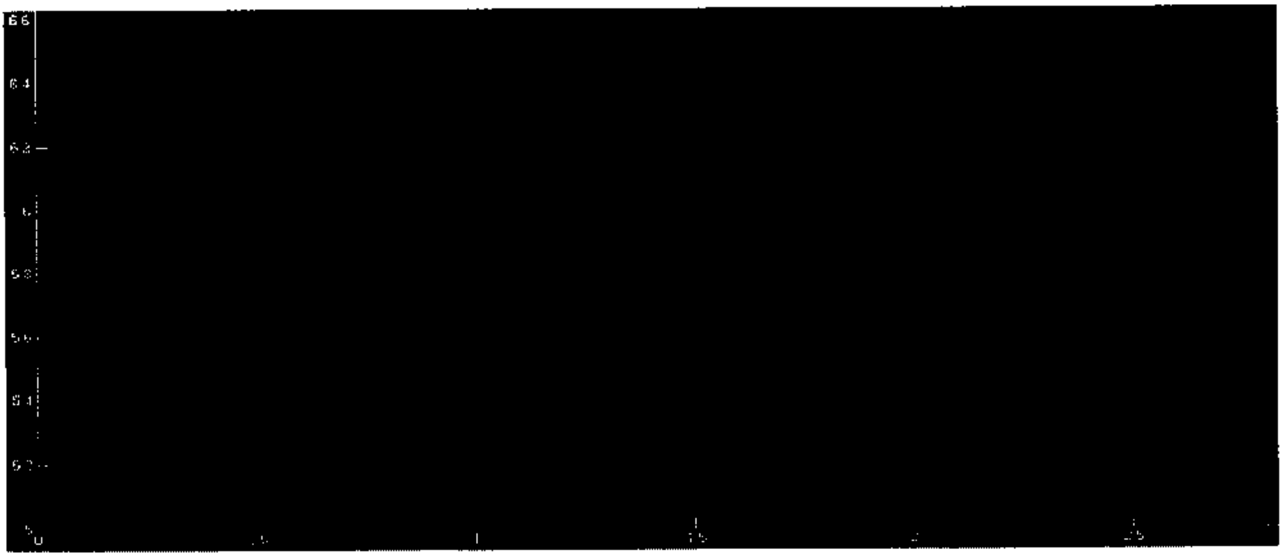
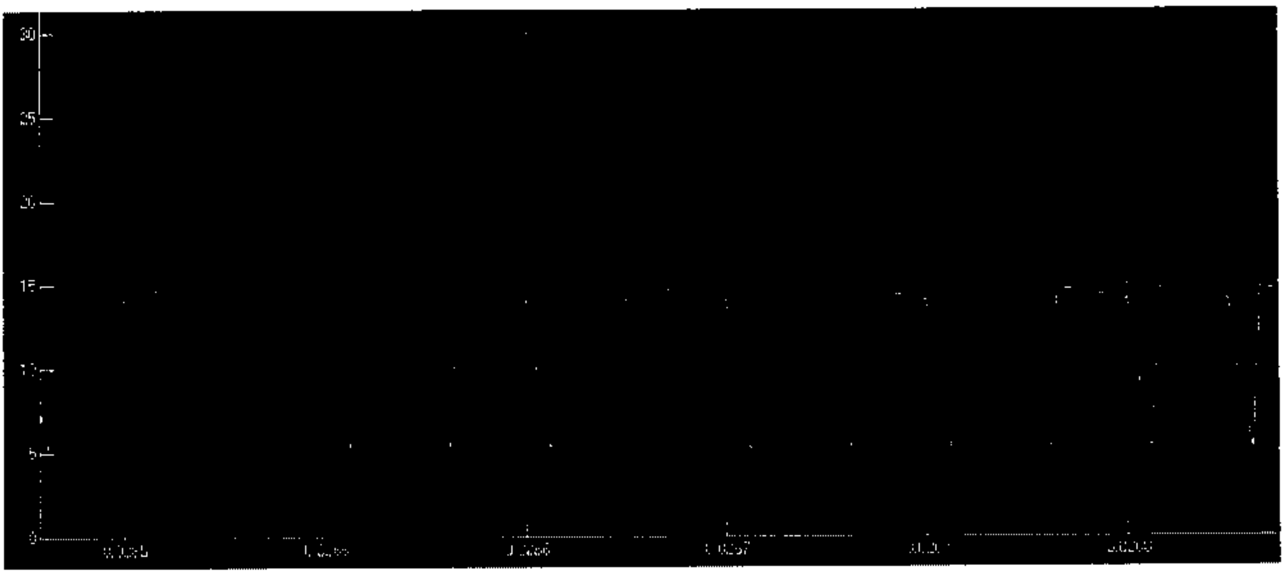


Fig 7.1 Simulation Circuit for Forward Mode Operation



Input waveform



Output waveform

Fig 7.2 Input & Output Waveforms for Forward Mode Operation

7.2 Reverse Mode

In the reverse mode of operation, 12V DC input is given to the high voltage side converter and is inverted. The inverted AC voltage is then fed to the isolation transformer where the voltage is stepped down. In this reverse mode of operation, the isolation transformer acts as a step down transformer.

Then it is given to the low voltage side converter where it is rectified to DC voltage which has a measurable quantity of 6V that can be used to recharge the battery.

Due to its simplicity and robustness, the ZVS Bi-Directional Full –Bridge DC-DC converter is suitable for low power to high power and high power to low power applications. The simulation circuit for reverse mode operation is shown in the figure 7.3. The input and output voltage waveforms using MATLAB are shown in the figure 7.4.

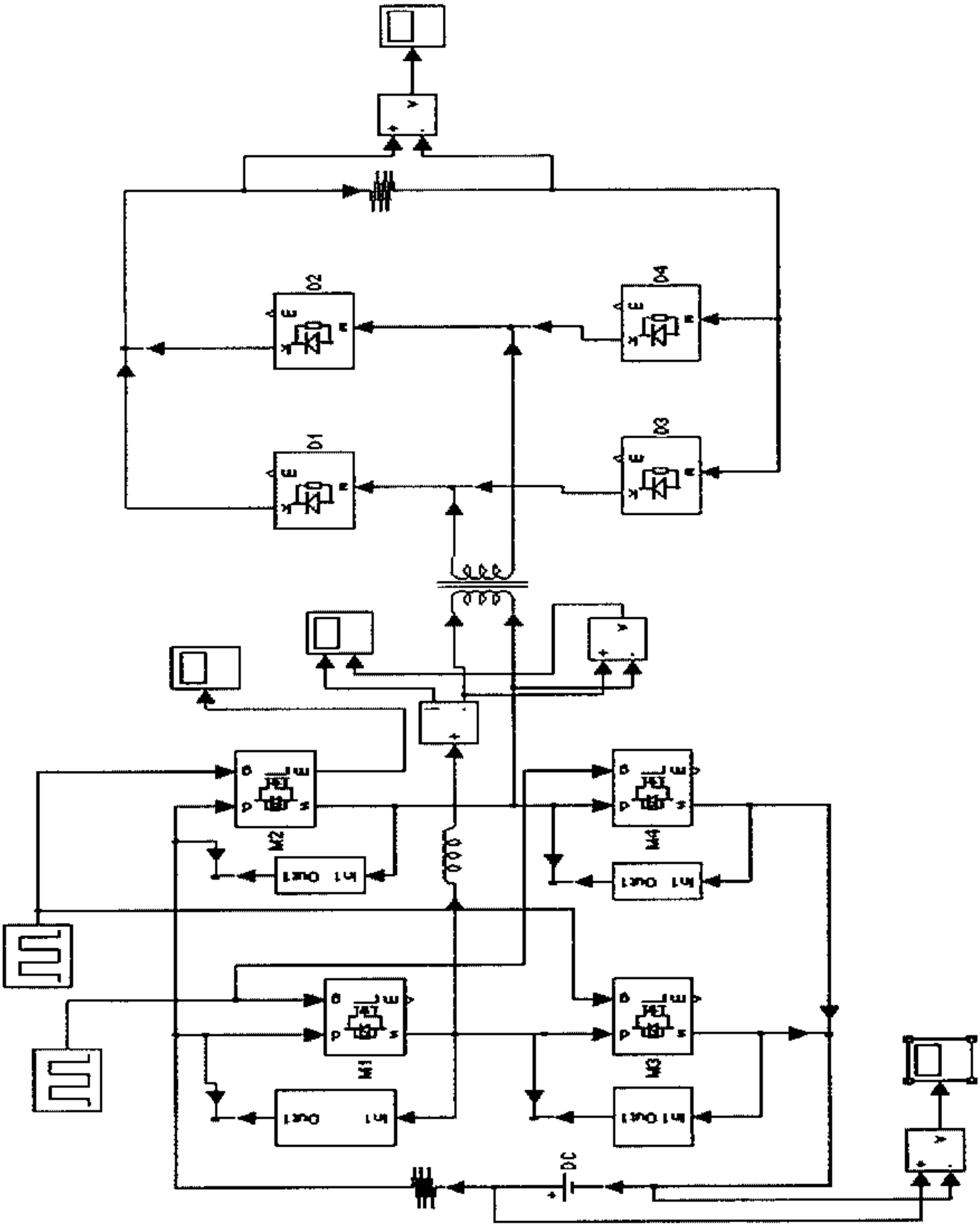
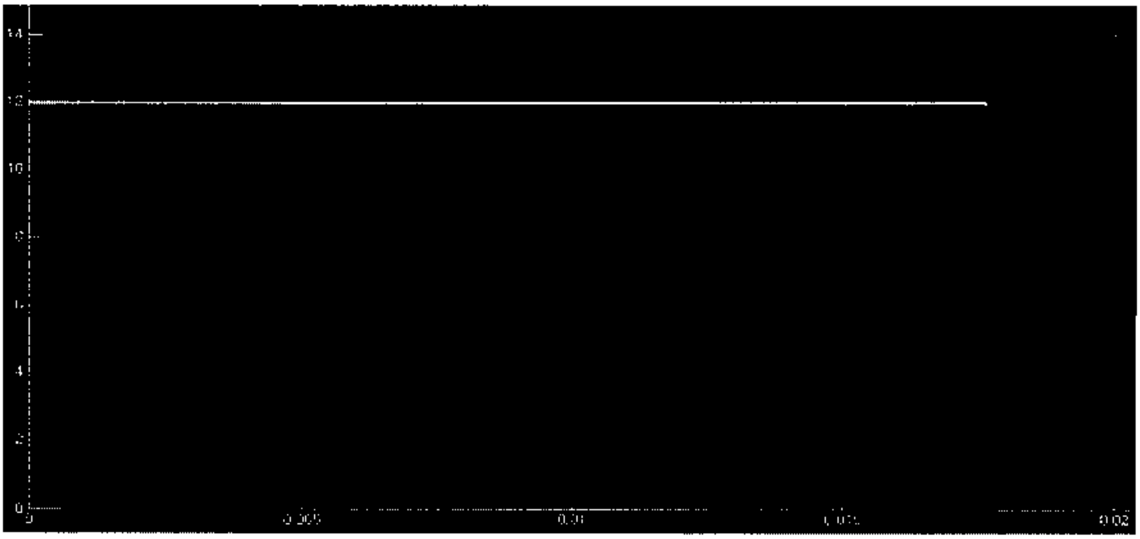
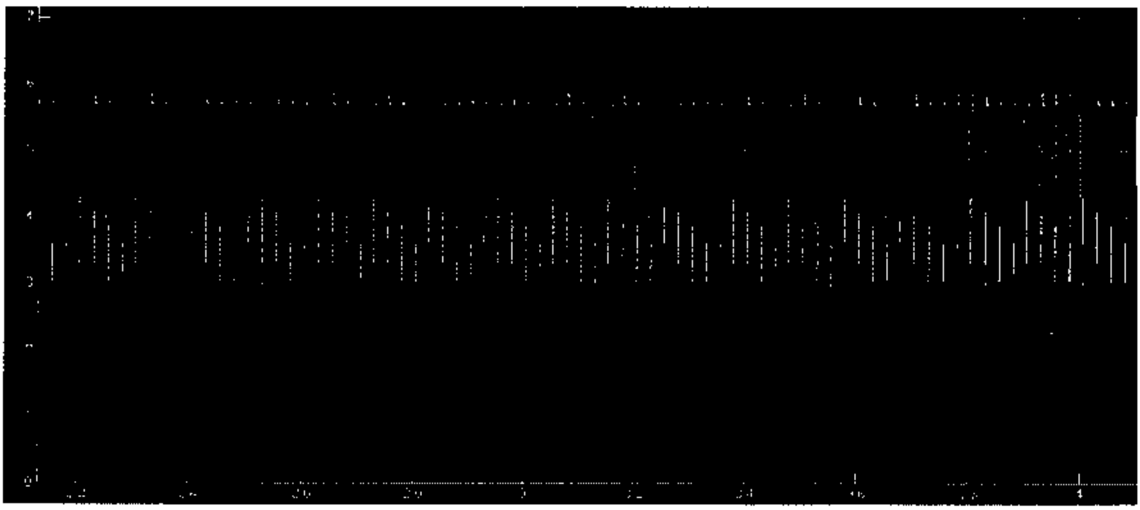


Fig 7.3 Simulation Circuit for Reverse Mode Operation



Input waveform



Output waveform

Fig 7.4 Input & Output Waveforms for Reverse Mode Operation

EXPERIMENTAL RESULTS

8. EXPERIMENTAL RESULTS

A DC/DC converter which can be operated alternately as a step-up converter in a forward direction of energy flow and as a step-down converter in a reverse direction of energy flow is disclosed. Potential isolation between the low-voltage side and the high-voltage side of the converter is achieved by a magnetic compound unit, which has not only a transformer function but also an energy store function.

The converter operates as a push-pull converter in both directions of energy flow. The DC/DC converter can be used for example in motor vehicles with an electric drive fed by fuel cells.

A bi-directional converter for converting voltage bi-directionally between a high voltage bus and a low voltage bus bridges.

DC-DC converters are devices which change one level of direct current voltage to another (either higher or lower) level. They are primarily of use in battery-powered appliances and machines which possess numerous sub circuits, each requiring different levels of voltage.

A DC-DC converter enables such equipment to be powered by batteries of a single level of voltage, preventing the need to use numerous batteries with varying voltages to power each individual component.

In its simplest form, a DC-DC converter simply uses resistors as needed to break up the flow of incoming energy – this is called linear conversion. However, linear conversion is a wasteful process which unnecessarily dissipates energy and can lead to overheating.

A more complex, but more efficient, manner of DC-DC conversion is switched-mode conversion, which operates by storing power, switching off the flow of current, and restoring it as needed to provide a steadily modulated flow of electricity corresponding to the circuit's requirements. This is far less wasteful than linear conversion, saving up to 95% of otherwise wasted energy.

Advantages of ZVS full bridge bidirectional dc- dc converter:

- Promising for medium and high power applications.
- Auxiliary power supply in fuel cell vehicles and power generation.
- High power density.
- Low cost.
- Light weight.

Applications of ZVS full bridge bidirectional dc- dc converter:

- Fuel cell vehicles
- Power generators
- Variable dc voltage application
- Bio medical applications

CONCLUSION

CONCLUSION

The design of a new soft-switched isolated bidirectional dc–dc converter is presented in this report. The operation, analysis, features and design consideration are illustrated. Simulation and experimental results for the prototype are shown to verify the operation principle. It is shown that ZVS (Zero Voltage Switching) in either direction of power flow is achieved with no lossy components and no additional active switch. With the dual functions (simultaneous boost conversion and inversion) provided by the low voltage side full bridge, current stresses on the switching devices and transformer are kept minimum. The advantages of the new circuit include ZVS with full load range, decreased device count, high efficiency, and low cost as well as less control and accessory power needs. The proposed converter is very promising for medium power applications with high power density.

REFERENCES

REFERENCES

1. Fang Z. Peng, Hui Li, Gui-Jia Su, Jack S. Lawler "A New ZVS Bidirectional DC–DC Converter for Fuel Cell and Battery Application", IEEE transactions on Power Electronics, vol. 19, no. 1, January 2004
2. Muhammad H. Rashid, "Power electronics – Circuits, Devices and applications" Third edition (2004), Pearson Education.
3. D. Roy Choudhury, Shail B. Jain, "Linear Integrated Circuits" Second edition(2003), New Age International Publishers.
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5. http://www.microchip.com

APPENDIX

FAIRCHILD SEMICONDUCTOR®

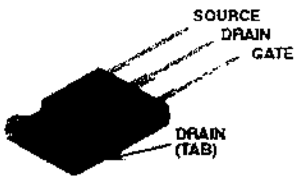
January 2002

IRFP250N

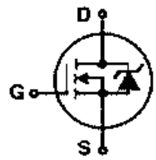
N-Channel Power MOSFET
200V, 30A, 0.075Ω

Features

- Ultra Low On-Resistance
  - $r_{DS(ON)} = 0.052\Omega$ (Typ), $V_{GS} = 10V$
- Simulation Models
  - Temperature Compensated PSPICE® and SABER© Electrical Models
  - Spice and SABER© Thermal Impedance Models
- Peak Current vs Pulse Width Curve
- UIS Rating Curve



TO-247



MOSFET Maximum Ratings $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Ratings	Units
V_{DSS}	Drain to Source Voltage	200	V
V_{GS}	Gate to Source Voltage	±20	V
I_D	Drain Current Continuous ($T_C = 25°C$, $V_{GS} = 10V$)	30	A
	Continuous ($T_C = 100°C$, $V_{GS} = 10V$)	21	A
	Pulsed	Figure 4	A
E_{AS}	Single Pulse Avalanche Energy (Note 1)	315	mJ
P_D	Power dissipation Derate above 25°C	214 1.4	W W/°C
T_J, T_{STG}	Operating and Storage Temperature	-55 to 175	°C

Thermal Characteristics

$R_{\theta JC}$	Thermal Resistance Junction to Case TO-247	0.70	°C/W
$R_{\theta JA}$	Thermal Resistance Junction to Ambient TO-247	40	°C/W

Package Marking and Ordering Information

Device Marking	Device	Package	Reel Size	Tape Width	Quantity
IRFP250N	IRFP250N	TO-247	Tube	N/A	30

Electrical Characteristics $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Test Conditions		Min	Typ	Max	Units
Off Characteristics							
B_{VDSS}	Drain to Source Breakdown Voltage	$I_D = 250\mu A$, $V_{GS} = 0V$		200	-	-	V
I_{DSS}	Zero Gate Voltage Drain Current	$V_{DS} = 200V$	$V_{GS} = 0V$	-	-	25	µA
		$V_{DS} = 160V$	$T_C = 150°$	-	-	250	
I_{GSS}	Gate to Source Leakage Current	$V_{GS} = \pm 20V$		-	-	±100	nA
On Characteristics							
$V_{GS(TH)}$	Gate to Source Threshold Voltage	$V_{GS} = V_{DS}$, $I_D = 250\mu A$		2	-	4	V
$r_{DS(ON)}$	Drain to Source On Resistance	$I_D = 18A$, $V_{GS} = 10V$		-	0.052	0.075	Ω
g_{fs}	Forward Transconductance	$V_{DS} = 50V$, $I_D = 18A$ (Note 2)		17	-	-	S
Dynamic Characteristics							
C_{ISS}	Input Capacitance	$V_{DS} = 25V$, $V_{GS} = 0V$, f = 1MHz		-	4023	-	pF
C_{OSS}	Output Capacitance			-	880	-	pF
C_{RSS}	Reverse Transfer Capacitance			-	240	-	pF
$Q_{g(TOT)}$	Total Gate Charge at 20V	$V_{GS} = 0V$ to 20V	$V_{DD} = 160V$, $I_D = 18A$, $I_g = 2.0mA$		215	280	nC
$Q_{g(10)}$	Total Gate Charge at 10V	$V_{GS} = 0V$ to 10V		-	114	140	nC
$Q_{g(TH)}$	Threshold Gate Charge	$V_{GS} = 0V$ to 2V		-	8	10	nC
Q_{gs}	Gate to Source Gate Charge			-	14	-	nC
Q_{gd}	Gate to Drain "Miller" Charge			-	44	-	nC
Switching Characteristics ($V_{GS} = 10V$)							
t_{ON}	Turn-On Time	$V_{DD} = 100V$, $I_D = 18A$ $V_{GS} = 10V$, $R_{GS} = 3.9\Omega$		-	-	69	ns
$t_{d(ON)}$	Turn-On Delay Time			-	16	-	ns
t_r	Rise Time			-	30	-	ns
$t_{d(OFF)}$	Turn-Off Delay Time			-	78	-	ns
t_f	Fall Time			-	40	-	ns
t_{OFF}	Turn-Off Time			-	-	177	ns
Drain-Source Diode Characteristics							
V_{SD}	Source to Drain Diode Voltage	$I_{SD} = 18A$		-	-	1.3	V
t_{rr}	Reverse Recovery Time	$I_{SD} = 18A$, $dI_{SD}/dt = 100A/\mu s$		-	-	279	ns
Q_{RR}	Reverse Recovered Charge	$I_{SD} = 18A$, $dI_{SD}/dt = 100A/\mu s$		-	-	2000	nC

Notes:
1: Starting $T_J = 25°C$, L = 1.9mH, $I_{AS} = 18A$.
2: Pulse width ≤ 300µs; duty cycle ≤ 2%.

Typical Characteristic

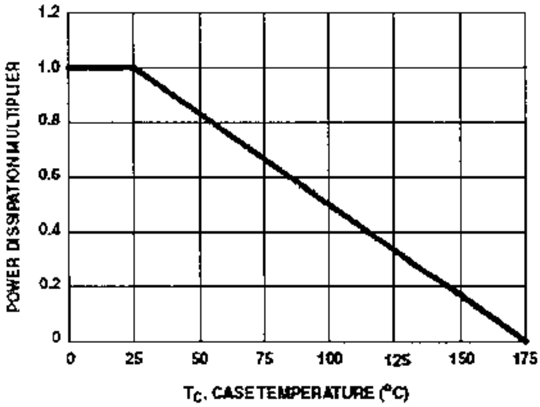


Figure 1. Normalized Power Dissipation vs Ambient Temperature

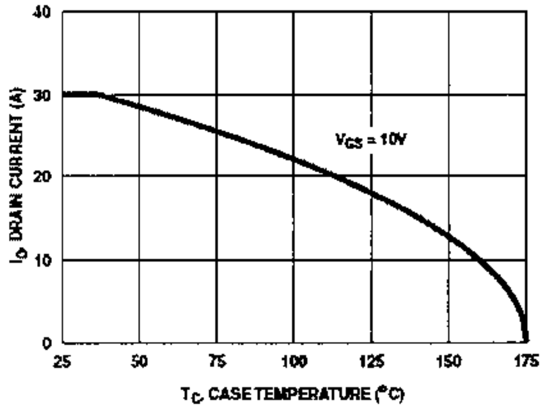


Figure 2. Maximum Continuous Drain Current vs Case Temperature

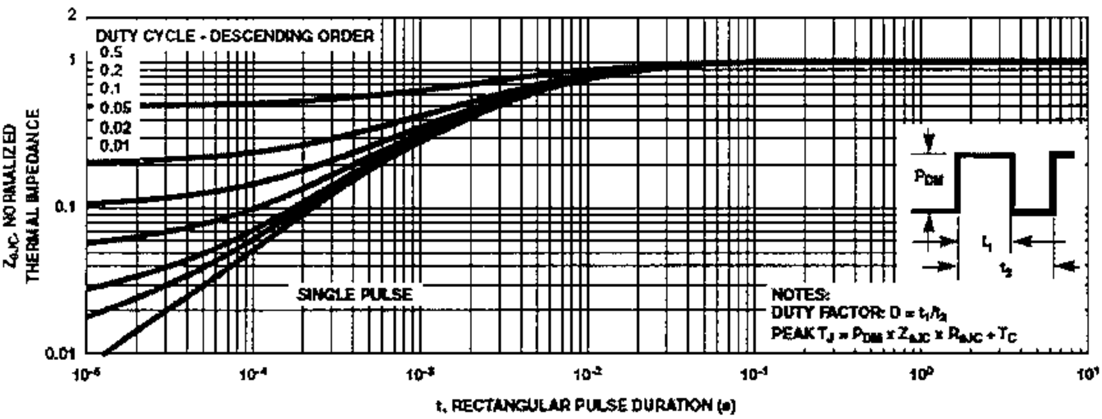


Figure 3. Normalized Maximum Transient Thermal Impedance

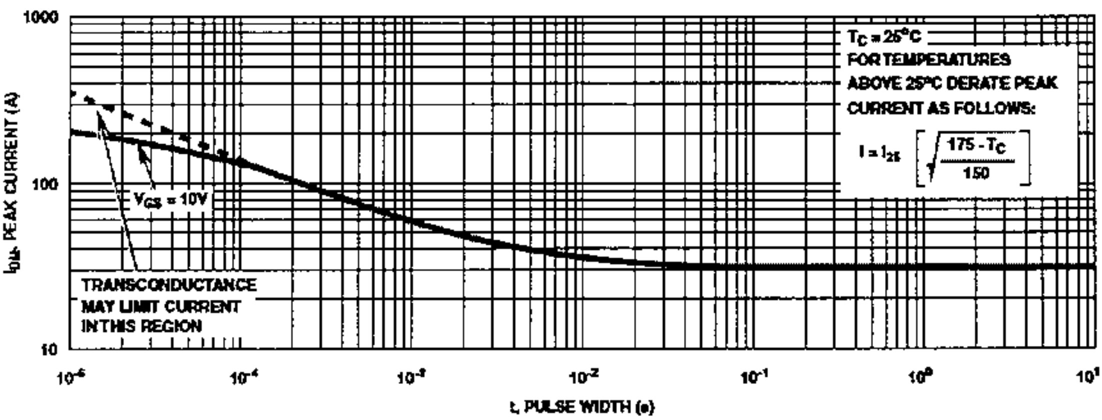


Figure 4. Peak Current Capability

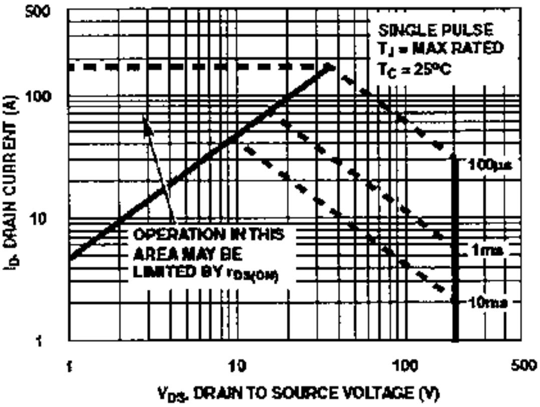


Figure 5. Forward Bias Safe Operating Area

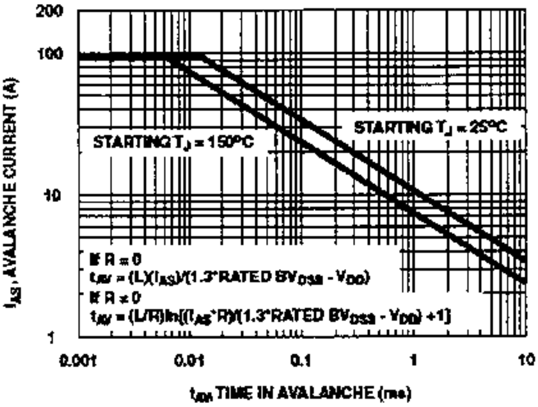


Figure 6. Unclamped Inductive Switching Capability

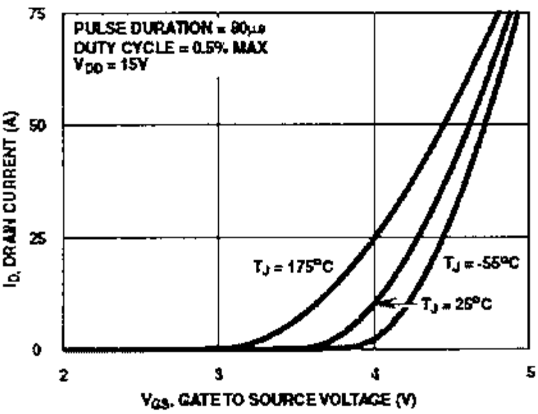


Figure 7. Transfer Characteristics

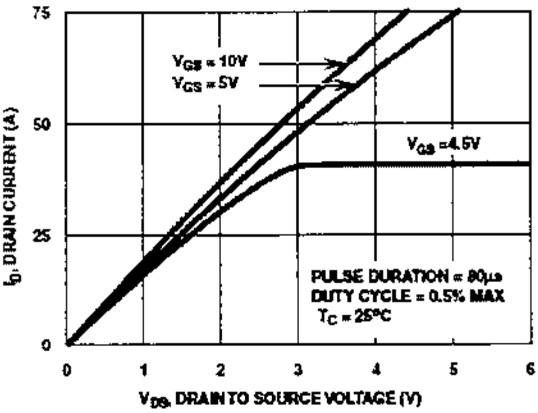


Figure 8. Saturation Characteristics

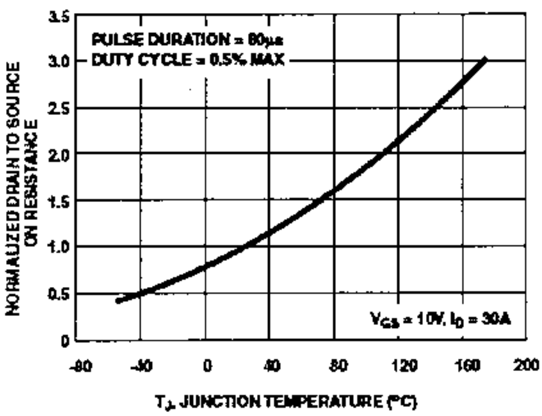


Figure 9. Normalized Drain to Source On Resistance vs Junction Temperature

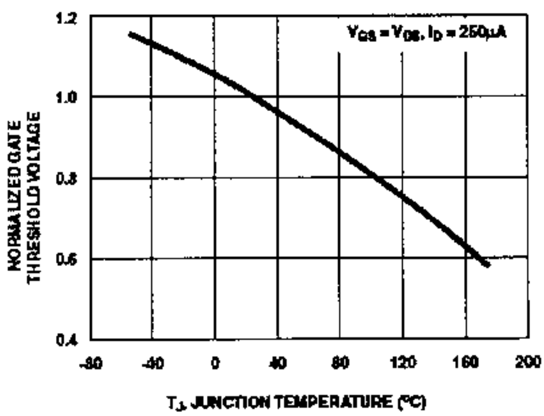


Figure 10. Normalized Gate Threshold Voltage vs Junction Temperature

Typical Characteristic (Continued)

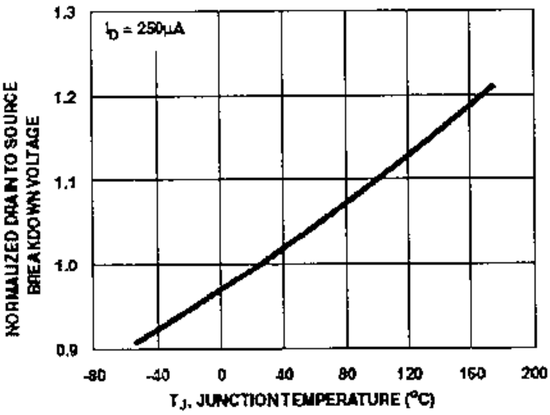


Figure 11. Normalized Drain to Source Breakdown Voltage vs Junction Temperature

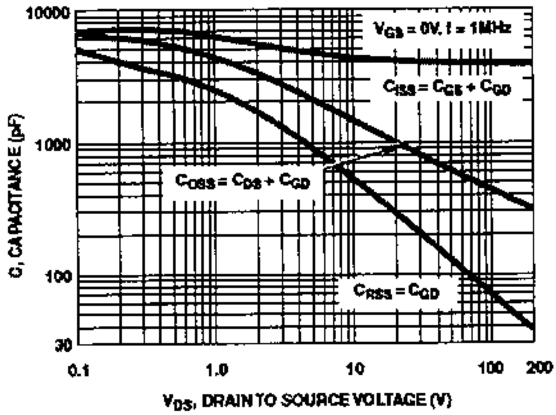


Figure 12. Capacitance vs Drain to Source Voltage

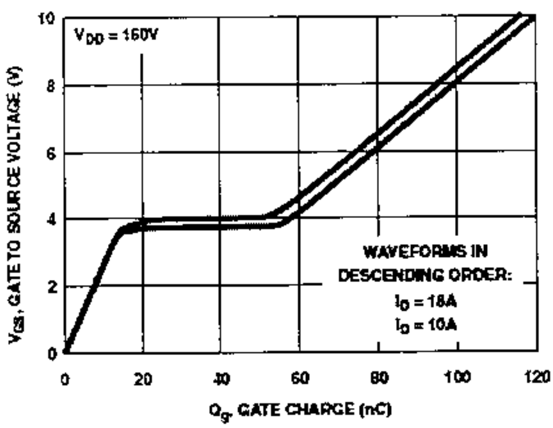


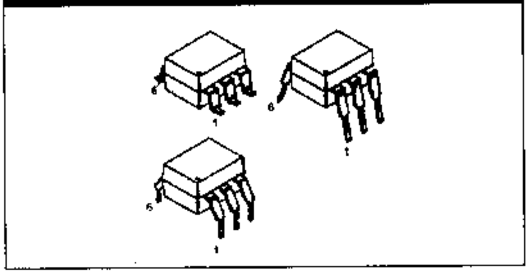
Figure 13. Gate Charge Waveforms for Constant Gate Currents

PHOTOTRANSISTOR OPTOCOUPLERS

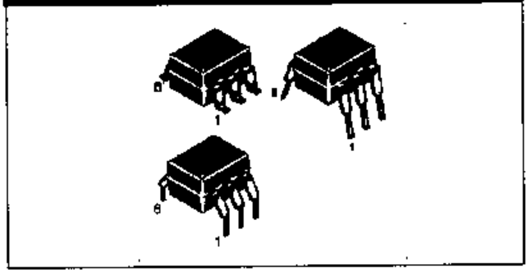
FAIRCHILD SEMICONDUCTOR®

MCT2	MCT2E	MCT210	MCT271
MCT2200	MCT2201	MCT2202	

WHITE PACKAGE (-M SUFFIX)



BLACK PACKAGE (NO -M SUFFIX)



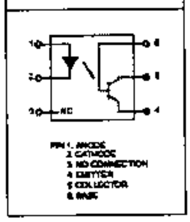
DESCRIPTION

The MCT2XXX series optoisolators consist of a gallium arsenide infrared emitting diode driving a silicon phototransistor in a 6-pin dual in-line package.

FEATURES

- UL recognized (File # E90700)
- VDE recognized (File # 94766)
  - -Add option V for white package (e.g., MCT2V-M)
  - -Add option 300 for black package (e.g., MCT2.300)
- MCT2 and MCT2E are also available in white package by specifying -M suffix, eg. MCT2-M

SCHEMATIC



APPLICATIONS

- Power supply regulators
- Digital logic inputs
- Microprocessor inputs

ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Device	Value	Units
TOTAL DEVICE Storage Temperature	T_{STG}	ALL	-55 to +150	°C
Operating Temperature	T_{OPR}	ALL	-55 to +100	°C
Lead Solder Temperature	T_{SOL}	ALL	260 for 10 sec	°C
Total Device Power Dissipation @ T_A = 25°C	P_D	-M	250	mW
		Non-M	260	
Derate above 25°C		-M	2.94	mW/°C
		Non-M	3.3	
EMITTER DC/Average Forward Input Current	I_F	-M	60	mA
		Non-M	100	
Reverse Input Voltage	V_R	ALL	3	V
Forward Current - Peak (300µs, 2% Duty Cycle)	I_F(pk)	ALL	3	A
LED Power Dissipation @ T_A = 25°C	P_D	-M	120	mW
		Non-M	150	
Derate above 25°C		-M	1.41	mW/°C
		Non-M	2.0	
DETECTOR Collector Current	I_C	ALL	50	mA
Collector-Emitter Voltage	V_{CEO}	ALL	30	V
Detector Power Dissipation @ T_A = 25°C	P_D	ALL	150	mW
Derate above 25°C		-M	1.76	mW/°C
		Non-M	2.0	

ELECTRICAL CHARACTERISTICS (T_A = 25°C Unless otherwise specified.)

INDIVIDUAL COMPONENT CHARACTERISTICS

Parameter	Test Conditions	Symbol	Device	Min	Typ**	Max	Unit
EMITTER							
Input Forward Voltage	(I_F = 20 mA)	V_F	MCT2/-M MCT2E/-M MCT271 MCT2200 MCT2201 MCT2202		1.25	1.50	V
	(T_A = 0-70°C, I_F = 40 mA)		MCT210		1.33		
Reverse Leakage Current	(V_R = 3.0 V)	I_R	MCT2/-M MCT2E/-M MCT271 MCT2200 MCT2201 MCT2202		0.001	10	µA
	(T_A = 0-70°C, V_R = 6.0 V)		MCT210				
DETECTOR							
Collector-Emitter Breakdown Voltage	(I_C = 1.0 mA, I_F = 0)	BV_{CEO}	ALL	30	100		V
	(T_A = 0-70°C)		MCT210				
Collector-Base Breakdown Voltage	(I_C = 10 µA, I_F = 0)	BV_{CBO}	MCT2/-M MCT2E/-M MCT271 MCT2200 MCT2201 MCT2202	70	120		V
	(T_A = 0-70°C)		MCT210	30			
Emitter-Collector Breakdown Voltage	(I_E = 100 µA, I_F = 0)	BV_{ECO}	MCT2/-M MCT2E/-M MCT271 MCT2200 MCT2201 MCT2202	7	10		V
	(T_A = 0-70°C)		MCT210	6	10		
Collector-Emitter Dark Current	(V_{CE} = 10 V, I_F = 0)	I_{CEO}	ALL		1	50	nA
	(V_{CE} = 5 V, T_A = 0-70°C)					30	µA
Collector-Base Dark Current	(V_{CB} = 10 V, I_F = 0)	I_{CBO}	ALL			20	nA
Capacitance	(V_{CE} = 0 V, f = 1 MHz)	C_{CE}	ALL		8		pF

** Typical values at T_A = 25°C

TRANSFER CHARACTERISTICS (T_A = 25°C Unless otherwise specified.)

DC Characteristic	Test Conditions	Symbol	Device	Min	Typ**	Max	Unit
Output Collector Current	(T_A = 0-70°C)	CTR	MCT210	150			%
	(I_F = 10 mA, V_{CE} = 5 V)		MCT2200	20			
			MCT2201	100			
			MCT2202	63		125	
	(I_F = 10 mA, V_{CE} = 10 V)		MCT2 MCT2-M MCT2E MCT2E-M	20			
			MCT271	45		90	
	(I_F = 3.2 mA to 32 mA, V_{CE} = 0.4 V) (T_A = 0-70°C)		MCT210	50			
Collector-Emitter Saturation Voltage	(I_C = 2 mA, I_F = 16 mA)	$V_{CE\ (SAT)}$	MCT2 MCT2-M MCT2E MCT2E-M MCT271			0.4	V
	(I_C = 16 mA, I_F = 32 mA, T_A = 0-70°C)		MCT210				
	(I_C = 2.5 mA, I_F = 10 mA)		MCT2200 MCT2201 MCT2202				
AC Characteristic Saturated Turn-on Time from 5 V to 0.8 V	(I_F = 15 mA, V_{CC} = 5 V, R_L = 2 kΩ) (R_B = Open) (Fig. 20)	t_{on}	MCT2		1.1		μs
			MCT2E		1.1		
	(I_F = 20 mA, V_{CC} = 5 V, R_L = 2 kΩ) (R_B = 100 kΩ) (Fig. 20)		MCT2		1.3		
			MCT2E		1.3		
Saturated Turn-off Time from SAT to 2.0 V	(I_F = 15 mA, V_{CC} = 5 V, R_L = 2 kΩ) (R_B = Open) (Fig. 20)	t_{off}	MCT2		50		
			MCT2E		50		
	(I_F = 20 mA, V_{CC} = 5 V, R_L = 2 kΩ) (R_B = 100 kΩ) (Fig. 20)		MCT2		20		
			MCT2E		20		
Turn-on Time	(I_F = 10 mA, V_{CC} = 10 V, R_L = 100 Ω)	t_{on}	MCT2-M MCT2E-M		2		
Turn-off Time	(I_F = 10 mA, V_{CC} = 10 V, R_L = 100 Ω)	t_{off}	MCT2-M MCT2E-M		2		
Rise Time	(I_F = 10 mA, V_{CC} = 10 V, R_L = 100 Ω)	t_r	MCT2-M MCT2E-M		2		
Fall Time	(I_F = 10 mA, V_{CC} = 10 V, R_L = 100 Ω)	t_f	MCT2-M MCT2E-M		1.5		

** Typical values at T_A = 25°C

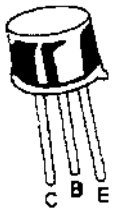
Continental Device India Limited

An IS/ISO 9002 and IECQ Certified Manufacturer

NPN SILICON PLANAR TRANSISTORS

CL 100, A, B
CK 100, A, B

TO-39
Metal Can Package



CL100 And CK 100 Are Medium Power Transistors Suitable For Awide Range Of Medium Voltage And Current Amplifier Applications.

Complementary CK100, A, B

ABSOLUTE MAXIMUM RATINGS (Ta=25°C unless specified otherwise)

DESCRIPTION	SYMBOL	VALUE	UNITS
Collector -Emitter Voltage	V_{CER}	50	V
Collector -Base Voltage	V_{CBO}	60	V
Emitter Base Voltage	V_{EBO}	5	V
Collector Current-Continuous	I_{CM}	1	A
Power Dissipation @ Ta=25°C	P_D	800	mW
Derate above 25°C		5.33	mW /°C
Total device dissipation @ Tc=25°C	P_D	3	W
Derate above 25°C		20	mW /°C
Operating And Storage Junction Temperature Range	T_j, T_{stg}	-55 to +175	°C

ELECTRICAL CHARACTERISTICS (Ta=25°C unless specified otherwise)

DESCRIPTION	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Collector Emitter Breakdown Voltage	BV_{CER} *	I_C =10mA, I_B =0	50			V
Collector Base Breakdown Voltage	BV_{CBO}	I_C =100μA, I_E =0	60			V
Emitter Base Breakdown Voltage	BV_{EBO}	I_E=100μA, I_C=0	5			V
Collector Leakage Current	I_{CBO}	V_{CB}=40V, I_E=0			50	nA
Emitter Leakage Current	I_{EBO}	V_{EB}=4V, I_E=0			1	μA
DC Current Gain	h_{FE} *	I_C=150mA,V_{CE}=10V	40		300	
Base Emitter On Voltage	V_{BE}(on)*	V_{CE}=1V, I_C=150mA,			0.9	V
Collector Emitter (Sat) Voltage	V_{CE}(sat)*	I_C=150mA,I_B=15mA			0.6	V

CLASSIFICATION	A	B
HFE	40-120	100-300

*Pulse Condition : PW ≤300us, Duty Cycle ≤ 2%