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Research Paper

SOFT-SWITCHING BIDIRECTIONAL ISOLATED FULL-BRIDGE CONVERTER WITH ACTIVE SNUBBERS

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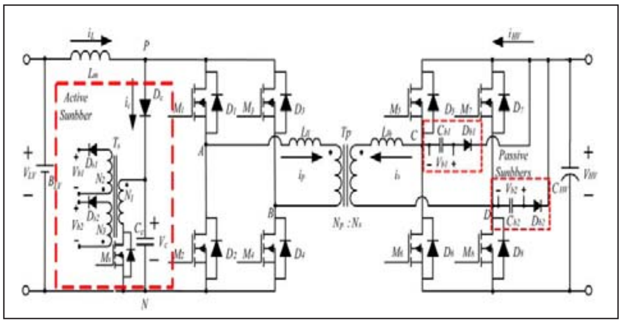
A bidirectional isolated full-bridge dc-dc converter with a conversion ratio around nine times, soft start-up, and soft-switching features for battery charging/discharging is proposed in this project. The converter is equipped with an active flyback snubbers, which can reduce voltage and current spikes and reduce voltage and current stresses, while it can achieve near zero-voltage-switching and zero-current-switching soft-switching features. In this paper, the operational principle of the proposed converter is first described, and its analysis and design are then presented.

Keywords: : Bidirectional dc-dc, Full bridge converter, Active snubbers, Zero voltage switching

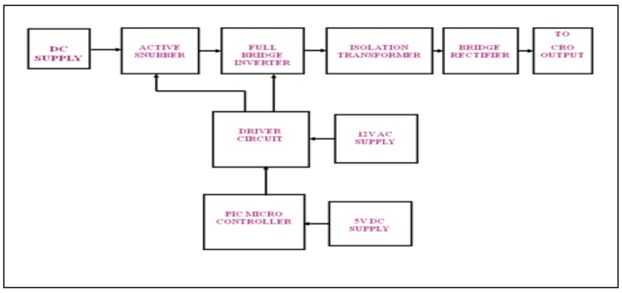
INTRODUCTION

A conventional passive approach is employing a resistor–capacitor–diode snubber to clamp the voltage, and the energy absorbed in the buffer capacitor is dissipated on the resistor, resulting in low efficiency.It is hard switching system. In this system Passive and active clamp circuits were proposed to suppress the voltage spike due to the current difference between the current-fed inductor and leakage inductance currents. It is soft switching system. The proposed converter can reduce the voltage spike caused by the current difference between leakage inductance and current fed inductor currents, the current spike due to diode reverse recovery, and the current and voltage stresses, while it can achieve near ZVS and ZCS soft-switching features.

CIRCUIT DIAGRAM



BLOCK DIAGRAM: HARDWARE



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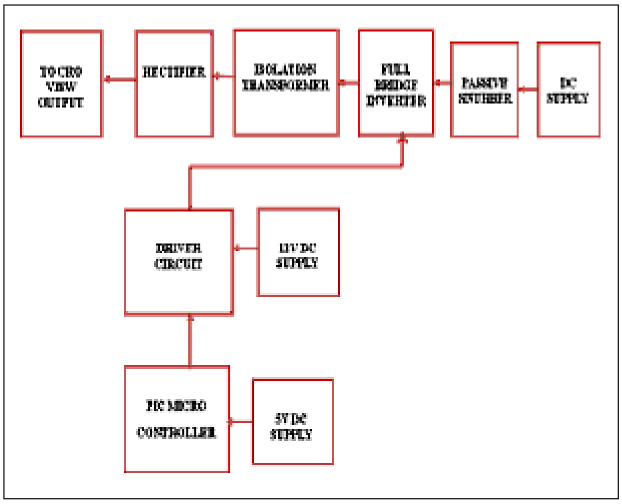
FORWARD DIRECTION



CIRCUIT DIAGRAM

A. Step-Up Conversion

In the step-up conversion, switches *M*1-*M*4 are operated like a boost converter, where switch pairs (M1,M2) and (M3,M4) conduct to store energy in Lm. At the high-voltage side, body diodes D5-D8 of switchesM5-M8 will conduct to transfer power to CHV. When switch pairs (M1,M2) and (M3,M4) are switched to (M1,M4) or (M2,M3), current difference iC (= iL-iP) will charge capacitor CC until iP rises up to iL, and capacitor voltage VC will be clamped to

VHV·(NP /NS), achieving near ZCS turnoff for M2 or M4. In the meantime, high-side current iS has the priority flowing through one of the two passive capacitor–diode snubbers, and either Cb1 or Cb2 will be fully discharged before diode D5 or D7 conducts. When switch pair (M1,M4) or (M2,M3) is switched back to (M1,M2) and (M3,M4), switch M2 or M4 can have near ZCS turn-on feature due to leakage inductance Lll limiting the di/dt of high-side diode-reverse-recovery current. The flyback snubber operates simultaneously to discharge snubber capacitor CC and transfer the stored energy to buffer capacitors Cb1 and Cb2. With the flyback snubber, the energy absorbed in CC will not flow through switches *M*1-*M*4, which can reduce their current stresses dramatically when the leakage inductance of the isolation transformer is significant. The key voltage and current waveforms of the converter operated in the step-up conversion are shown in Fig. 5. A detailed description of the converter operation over a half switching cycle is presented as follows.

1) **Mode 1** [$t0 \le t < t1$]: Before *t*0, all of the four switches *M*1-*M*4 are turned on. Inductor *Lm* is charged by *V*LV. At *t*0, *M*1 and *M*4 remain conducting, while *M*2 and *M*3 are turned off. Then, clamping diode *DC* conducts, and snubber capacitor *CC* is charged by the current difference *iC*. In this mode, the flyback snubber still stays in the OFF state. The equivalent circuit is shown in Fig. 6(a).

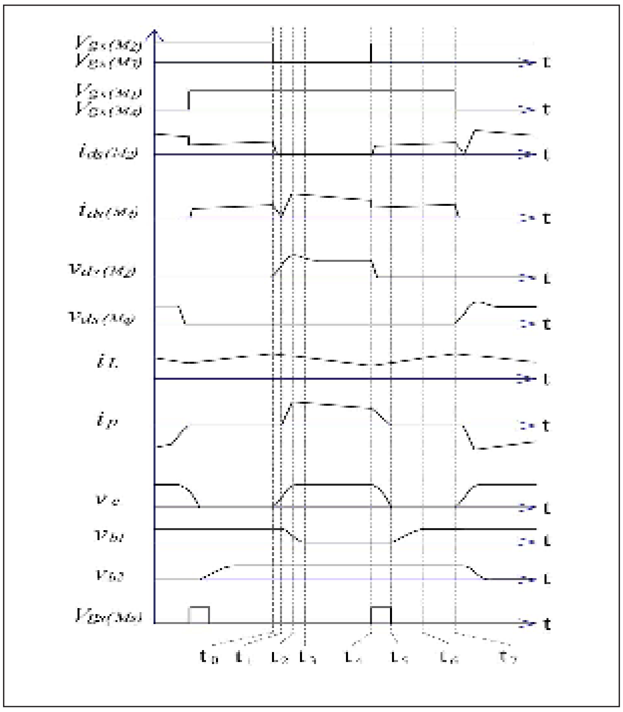
2) **Mode 2** [$t1 \le t < t2$]: In this mode, leakage inductance current *iP* will start to track current *iL*, and buffer capacitor *Cb*1 will start to release energy. At time *t*2, current *iP* is equal to current *iL*, the voltage of switches *M*2 and *M*3 and capacitor *CC* will reach the maximum value simultaneously, and its equivalent circuit is shown in Fig. 6(b). A near ZCS soft switching is therefore attained during *t*0 to *t*2.

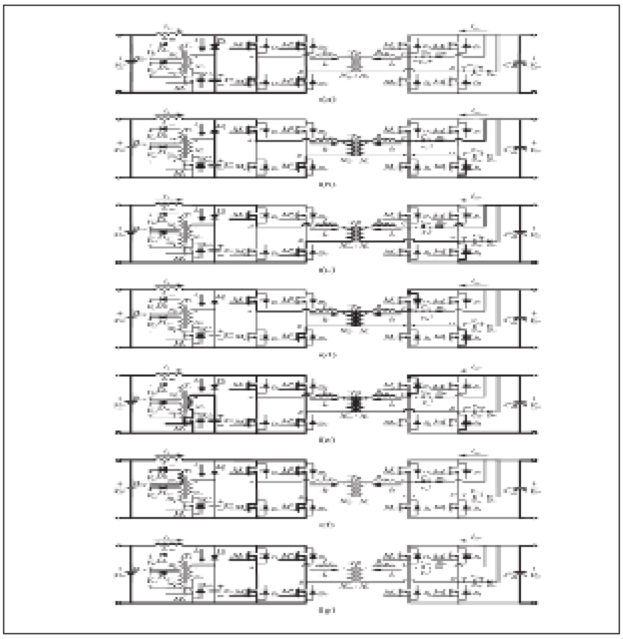
3) **Mode 3** [$t2 \le t < t3$]: Before *t*3, the energy stored in buffer capacitor *Cb*1 is not fully discharged yet. Thus, the capacitor will not stop discharging until *Vb*1 drops to zero. The equivalent circuit is shown in Fig. 6(c).

4) **Mode 4** [$t3 \le t < t4$]:When the energy stored in *Cb*1 has been completely released to the output at *t*3, diode *D*5 will conduct. The circuit operation over this time interval is identical to a regular turnoff state of a conventional current-

fed full-bridge converter. The equivalent circuit is shown in Fig. 6(d).

5) **Mode 5** [$t4 \leq t < t5$]: At $t4$, all of the four switches $M1$-$M4$ are turned on again, and switch *MS* of the flyback snubber is turned on synchronously. Switches$M2$ and$M3$ achieve a ZCS turn-on soft-switching feature due to *Lll*, and current *iP* drops to zero gradually. In the flyback snubber, the energy stored in capacitor *CC* will be delivered to the magnetizing inductance of transformer *TS*. The equivalent circuit is shown in Fig. 6(e).





6) **Mode 6** [$t5 \leq t < t6$]: When switch *MS* is turned off at $t5$, capacitor voltage *VC* drops to zero, and the energy stored in the magnetizing inductance will be transferred to buffer capacitor $Cb1$. In this mode, the time interval of driving signal *Vgs*(*Ms*) is slightly longer than the discharging time of capacitor *CC*. The purpose is to ensure that the energy stored in capacitor *CC* can be completely released, creating a ZCS operational opportunity for switch $M2$ or $M4$ at the next turnoff transition. The equivalent circuit is shown in Fig. 6(f).

7) **Mode 7** [$t6 \leq t < t7$]: At $t6$, the energy stored in the magnetizing inductance of transformer *TS* was completely transferred to buffer capacitor $Cb1$, and the circuit operation is identical to a regular turn-on state of a conventional current-fed converter. Its equivalent circuit is shown in Fig. 6(g). The circuit operation stops at $t7$ and completes a half-switching cycle.

B. STEP-DOWN CONVERSION

In the analysis, the leakage inductance of the transformer at the low-voltage side is reflected to the high-voltage side, in which equivalent inductance L-.

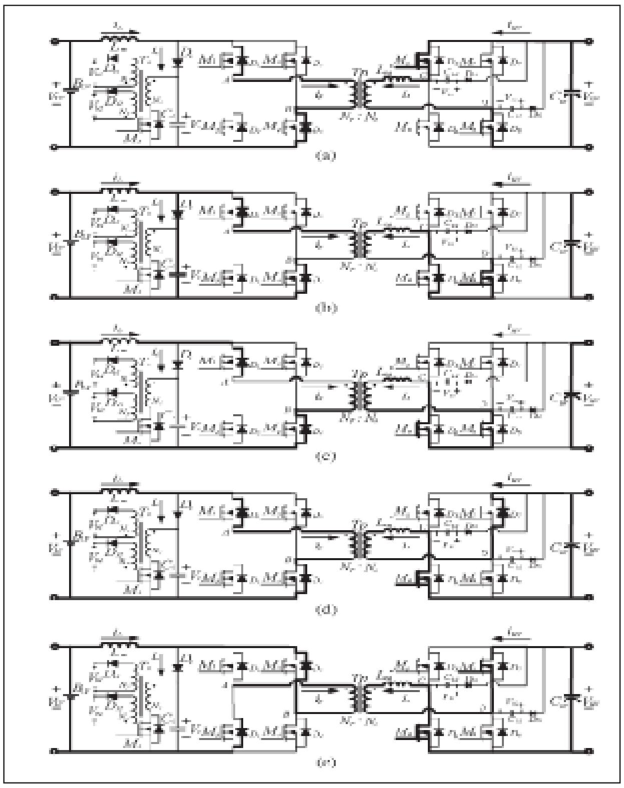
eq equals ($Llh + Lll \cdot N2\, s / N2\, p$).

In the step-down conversion, switches $M5$ <“ $M8$ are operated like a buck converter in which switch pairs (M5,M8) and (M6,M7) take turns conducting to transfer power from capacitor CHV to battery BLV. For alleviating leakage inductance effect on voltage spike, switches M5-M8 are operated with phase-shift control, achieving ZVS turn-on features. Although there is no need to absorb the current difference between iL and iP , capacitor CC can help clamp the voltage ringing due to L-eq and the parasitic capacitance of M1 <“ M4. With the two passive capacitor–diode snubbers, switches M6 and M8 can achieve near ZCS turnoff.

The key voltage and current waveforms of the converter operated in the step-down conversion are shown in Fig. 7. A detailed description of its operation over a half-switching cycle is presented as follows.

1) **Mode 1** [*t*0 *d” t* < *t*1]: In this mode, switches*M*5 and*M*8 are turned on, while*M*6 and*M*7 are in the OFF state. The high-side voltage *V*HV is crossing the transformer, and it is, in fact, crossing the equivalent inductance *L* eq and drives current *iS* to rise with the slope of *V*HV/ *L”* eq. With the transformer current increasing toward the load-current level at *t*1, the body diodes (*D*1 and *D*4) are conducting to transfer power, and the voltage across the transformer terminals on the low-voltage side changes immediately to reflect the voltage from the high-voltage side. The equivalent circuit is shown in Fig. 8(a).

2) **Mode 2** [*t*1 *d” t* < *t*2]: At *t*1, switch*M*8 remains conducting, while *M*5 is turned off. The body diode of *M*6 then starts conducting the freewheeling leakage current. The transformer current *iS* reaches the load-current level at *t*1, and *VAB* rises to the reflected voltage (*V*HV · *NP* /*NS*). Clamping diode *DC* starts conducting the resonant current of *L”* eq and the parasitic capacitance of*M*1 <“ *M*4. At the same time, switch*MS* of the flyback snubber is turned on and starts transferring the energy stored in capacitor *CC* to buffer capacitors *Cb*1 and *Cb*2.



The process ends at *t*2 when the resonance goes through a half resonant cycle and is blocked by clamping diode *DC*. With the flyback snubber, the voltage of capacitor *CC* will be clamped to a desired level just slightly higher than the voltage of *Vds*(*M*4). The equivalent circuit is shown in Fig. 8(b).

3) **Mode 3** [*t*2 ≤ *t* < *t*3]: At *t*2, the body diode of switch*M*6 is conducting, and switch*M*6 can be turned on with ZVS. The equivalent circuit is shown in Fig. 8(c).

4) **Mode 4** [*t*3 ≤ *t* < *t*4]: At *t*3, switch *M*6 remains conducting, while *M*8 is turned off. Buffer capacitor *Cb*2 is discharging by the freewheeling current. When *Cb*2 is fully discharged, a near ZCS turnoff condition is therefore attained, and the body diode of*M*7

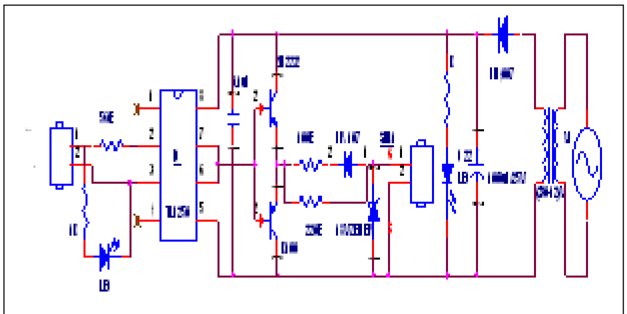
then starts conducting the freewheeling current. The equivalent circuit is shown in Fig. 8(d).

5) **Mode 5** [$t4 \le t < t5$]: At $t4$, with the body diode of switch *M7* conducting, *M7* can be turned on with ZVS. Over this time interval, the active switches change to the other pair of switches, and the voltage across the transformer reverses its polarity. The circuit operation stops at $t5$ and completes a half-switching cycle. The equivalent circuit is shown in Fig. 8(e).

HARDWARE DETAILS

Driver Circuit

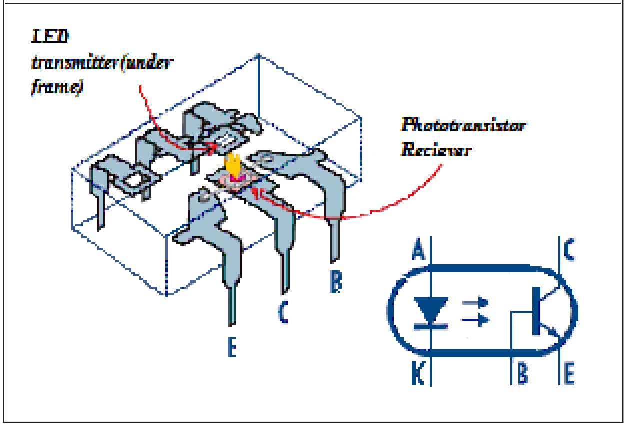
It is used to provide 5 to 12 volts to switch the MOSFET Switches of the inverter. Driver amplifies the voltage from microcontroller which is 5volts. Also it has an optocoupler for isolating purpose. So damage to MOSFET is prevented.



Optocoupler

Optocoupler is also termed as optoisolator. Optoisolator a device which contains a optical emitter, such as an LED, neon bulb, or incandescent bulb, and an optical receiving element, such as a resistor that changes resistance with variations in light intensity, or a transistor, diode, or other device that conducts differently when in the presence of light. These devices are used to isolate the control voltage from the controlled circuit.

Figure 1: Construction of Optocoupler and Usual Circuit Diagram



HOW THEY'RE USED

Basically the simplest way to visualize an optocoupler is in terms of its two main components: the input LED and the output transistor or diac. As the two are electrically isolated, this gives a fair amount of flexibility when it comes to connecting them into circuit. All we really have to do is work out a convenient way of turning the input LED on and off, and using the resulting switching of the phototransistor/ diac to generate an output waveform or logic signal that is compatible with our output circuitry.

For example: just like a discrete LED, you can drive an optocoupler's input LED from a transistor or logic gate/buffer. All that's needed is a series resistor to set the current level when the LED is turned on. And regardless of whether you use a transistor or logic buffer to drive the LED, you still have the option of driving it in pull down or pull up mode. This means you can arrange for the LED, and hence the optocoupler, to be either on or off, for a logic high (or low) in the driving circuitry. In some circuits, there may be a chance that at times the driving voltage fed to the input LED could have reversed polarity (due to a swapped cable connection, for example). This can cause damage to the device, because optocoupler LED's tend to have quite a low reverse voltage rating: typically only 3 - 5V. So if this is a possibility, a reversed polarity diode should be connected directly across the LED as shown in Fig.3. On the output side, there are again a number of possible connections even with a typical optocoupler of the type having a single phototransistor receiver (such as the 4N25 or 4N28). In most cases the transistor is simply connected as a light-operated switch, in series with a load resistor RL (see Fig.4). The base of the transistor is left unconnected, and the choice is between having the transistor at the top of the load resistor (Fig.4A) or at the bottom (Fig.4B). i.e., in either pull-up or pull-down mode. This again gives plenty of flexibility for driving either logic gates or transistors, as shown in Fig.5. If higher bandwidth is needed, it can be achieved by using only the collector and base connections, and by using the transistor as a photodiode (Fig.6A). This lowers the optocoupler's CTR and transfer gain considerably, but can increase the bandwidth to 30MHz or so.

An alternative approach is still to use the output device as a phototransistor, but tie the base down to ground (or the emitter) via a resistor R_b, to assist in removal of stored charge (Fig.6B). This can extend the opto's bandwidth usefully (although not dramatically), without lowering the CTR and transfer gain any more than is necessary. Typically you'd start with a resistor value of 1MW, and reduce it gradually down to about 47kW to see if the desired bandwidth can be reached.

Triggering Unit

PIC 16F877A Microcontroller

INTRODUCTION

We are using PIC 16F877A for producing switching pulses to multilevel inverter. so as to use those vectors which do not generate any common mode voltage at the inverter poles. .This eliminates common mode voltage Also it is used to eliminate capacitor voltage unbalancing. The microcontroller are driven via the driver circuit so as to boost the voltage triggering signal to 9V.To avoid any damage to micro controller due to direct passing of 230V supply to it we provide an isolator in the form of optocoupler in the same driver circuit.

FEATURES OF PIC MICROCONTROLLER

The microcontroller has the following features:

1. High-Performance RISC CPU

- Only 35 single- word instructions to learn. Hence it is user friendly.easy to use
- All single - cycle instructions except for program branches, which are two-cycle
- Operating speed: DC – 20 MHz clock input DC – 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory, Up to 368 x 8 bytes of Data Memory(RAM), Up to 256 x 8 bytes of EEPROM Data Memory. It is huge one

2. Peripheral Features

- Timer0: 8-bit timer/counter with 8 – bit prescaler. It is used for synchronisation
- Timer1: 16-bit timer/counter with prescaler, can be incremented during Sleep

- Timer2:8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture , Compare and some PWM modules, having following features
- Capture is 16-bit, max. resolution is 12.5 ns
- Compare is 16-bit, max . resolution is 200 ns
- PWM maximum resolution that is 10-bit

3. Synchronous Serial Port (SSP) with SPI (Master mode) and I²C(Master/Slave)

- Universal Synchronous Asynchronous Receiver Transmitter with 9 bit address
- Parallel Slave Port (PSP) 8 bits wide with external RD, WR and CS controls

4. Analog features

It has an analog Comparator module with:

- Two analog comparators
- Programmable on-chip voltage reference (VREF) module (3)Programmable input multiplexing from device inputs and internal voltage reference thus 3 parts.

5. CMOS Technology

It has following features:

- Low-power, high-speed Flash/EEPROM technology
- Fully static design
- Wide operating voltage range (2.0V to 5.5V)
- Commercial and Industrial temperature ranges
- Low-power consumption

Overview of PIC 16F877

PIC 16F877 is one of the most advanced microcontroller from Microchip. This controller is widely used for experimental and modern applications because of its low price, wide range of applications, high quality, and ease of availability. It is ideal for applications such as machine control applications, measurement devices, study purpose, and so on. The PIC 16F877 features all the components which modern microcontrollers normally have. The figure of a PIC16F877 chip is shown below.

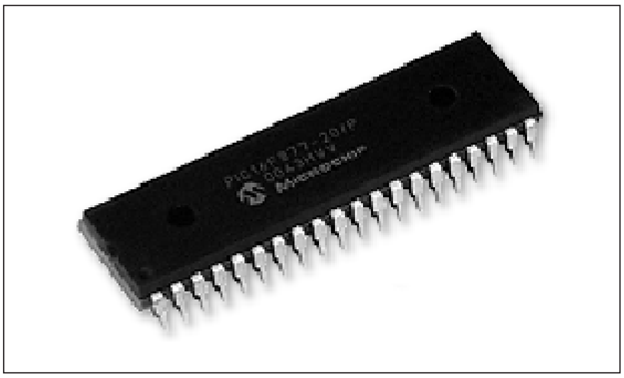


Image Taken From

Features of PIC16F877

The PIC16FXX series has more advanced and developed features when compared to its previous series. The important features of PIC16F877 series is given below.

General Features

1. High performance RISC CPU.
2. ONLY 35 simple word instructions.
3. All single cycle instructions except for program branches which are two cycles.
4. Operating speed: clock input (200MHz), instruction cycle (200nS).
5. Up to 368×8bit of RAM (data memory), 256×8 of EEPROM (data memory), 8k×14 of flash memory.
6. Pin out compatible to PIC 16C74B, PIC 16C76, PIC 16C77.

7. Eight level deep hardware stack.
8. Interrupt capability (up to 14 sources)
9. Different types of addressing modes (direct, Indirect, relative addressing modes).
10. Power on Reset (POR).
11. Power-Up Timer (PWRT) and oscillator start-up timer.
12. Low power- high speed CMOS flash/ EEPROM.
13. Fully static design.
14. Wide operating voltage range (2.0 – 5.56)volts.

Peripheral Features

1. Timer 0: 8 bit timer/counter with pre-scalar.
2. Timer 1:16 bit timer/counter with pre-scalar.
3. Timer 2: 8 bit timer/counter with 8 bit period registers with pre-scalar and post-scalar.
4. Two Capture (16bit/12.5nS), Compare (16 bit/200nS), Pulse Width Modules (10bit).
5. 10bit multi-channel A/D converter
6. Synchronous Serial Port (SSP) with SPI (master code) and I2C (master/slave).
7. Universal Synchronous Asynchronous Receiver Transmitter (USART) with 9 bit address detection.
8. Parallel Slave Port (PSP) 8 bit wide with external RD, WR and CS controls (40/ 46pin).
9. Brown Out circuitry for Brown-Out Reset (BOR).

Key Features

1. Maximum operating frequency is 20MHz.
2. Flash program memory (14 bit words), 8KB.
3 Data memory (bytes) is 368.
4. EEPROM data memory (bytes) is 256.
5. 5 input/output ports.-
6. 3 timers.
7. 2 CCP modules.
8. 2 serial communication ports (MSSP, USART).
9. PSP parallel communication port
10. 10bit A/D module (8 channels)

Analog Features

1. 10bit, up to 8 channel A/D converter.
2. Brown Out Reset function.
3. Analog comparator module.

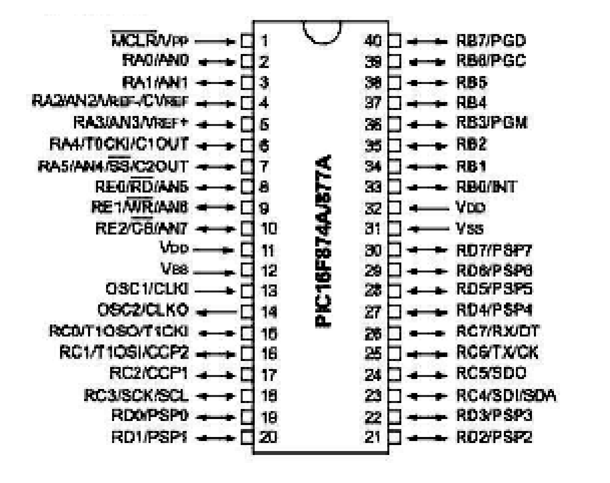
Special Features

1. 100000 times erase/write cycle enhanced memory.
2. 1000000 times erase/write cycle data EEPROM memory.
3. Self programmable under software control.
4. In-circuit serial programming and in-circuit debugging capability.
5. Single 5V,DC supply for circuit serial programming
6. WDT with its own RC oscillator for reliable operation.
7. Programmable code protection.
8. Power saving sleep modes.
9. Selectable oscillator options.

PIN DIAGRAMS

PIC16F877 chip is available in different types of packages. According to the type of applications and usage, these packages are differentiated. The pin diagrams of a PIC16F877 chip in different packages is shown in the figure below.

Figure: PIC Microcontroller Pin Diagram



CCP1 Module

Capture/Compare/PWM Register 1 (CCPR1) is a 16 bit register comprised of two 8-bit registers: CCPR1L (low byte) and CCPR1H (high byte). The CCP1CON register controls the operation of CCP1. The special event trigger is generated by a compare match and will reset Timer1.

CCP2 Module

Capture/Compare/PWM Register 2 (CCPR2) is comprised of two 8-bit registers: CCPR2L (low byte) and CCPR2H (high byte). The CCP2CON register controls the operation of CCP2. The special event trigger is generated by a compare match and will reset Timer1 and start an A/D conversion (if the A/D module is enabled).

Capture Mode

In Capture mode, CCPR1H:CCPR1L captures the 16-bit value of the TMR1 register when an event occurs on pin RC2/CCP1.

An event is defined as one of the following:

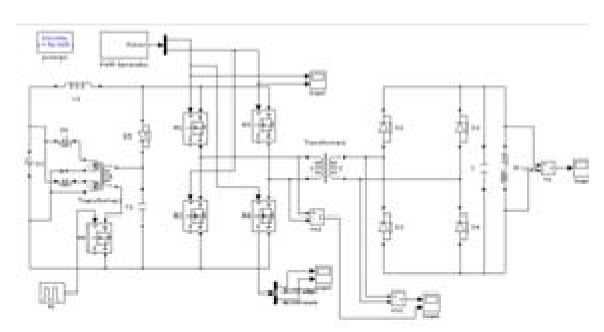
- Every falling edge
- Every rising edge
- Every 4th rising edge
- Every 16th rising edge

The type of event is configured by control bits, CCP1M3:CCP1M0 (CCPxCON<3:0>). When a capture is made, the interrupt request flag bit, CCP1IF (PIR1<2>), is set. The interrupt flag must be cleared in software. If another capture occurs before the value in register CCPR1 is read, the old captured value is overwritten by the new value. The block diagram of

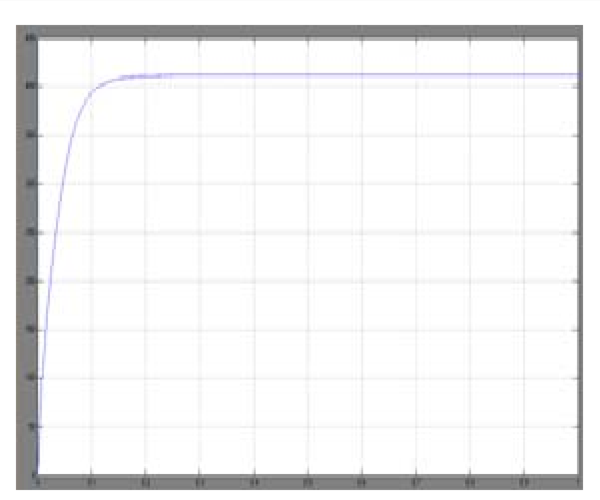
MATLAB

Circuit Diagram

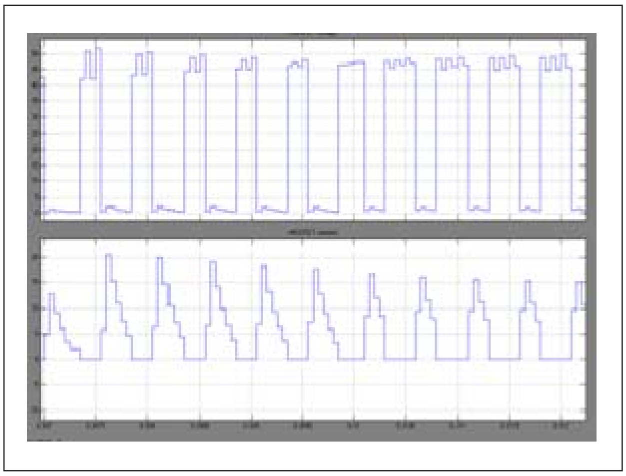
Forward Control



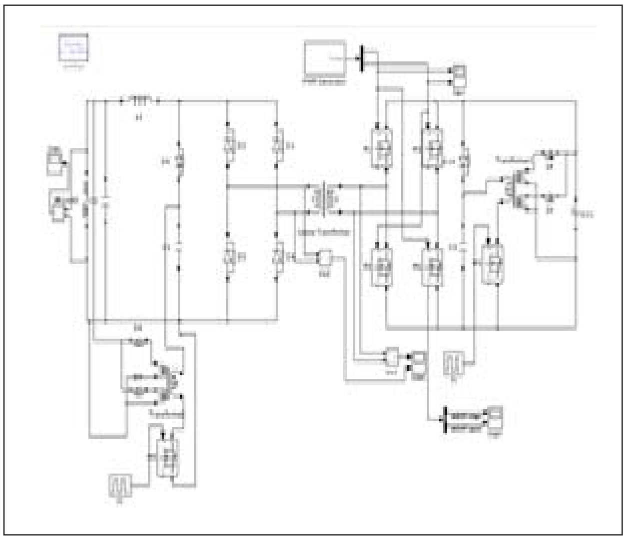
Output Waveform



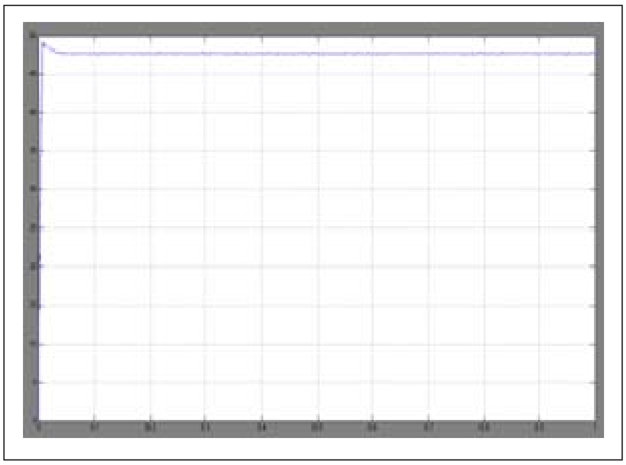
Switching Current and Voltage



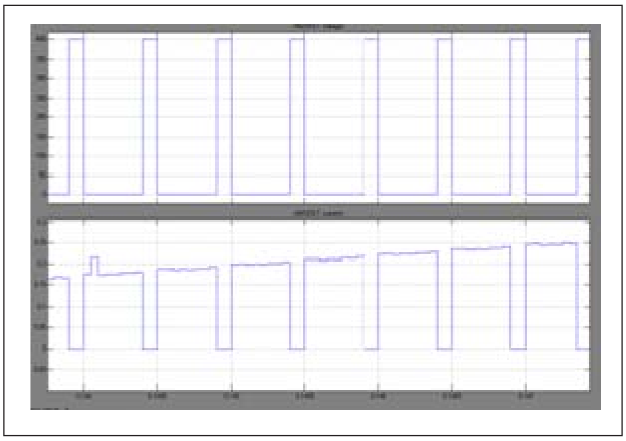
Reverse Control



Output Waveform



Switching Voltage and Current



HARDWARE REQUIREMENT

PIC MICROCONTROLLER

SOFTWARE REQUIREMENT

MATLAB-SIMULINK

ADVANTAGES

- Reduced switching loss
- High efficiency
- Reduced voltage and current stresses

APPLICATIONS

- Battery charging & discharging applications
- Electric vehicle
- Photovoltaic power system applications.

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