Development of a Microcontroller-Based 6/12/18/24V Power Inverter Circuit

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***Abstract*— A power inverter circuits is normally designed to meet its design specifications when the applied input DC voltage is within specified tolerance limits. Thus, single input inverters are usually specified to work from a DC source having a fixed nominal voltage. This limits the usefulness of the inverter circuit when a DC source having the specified nominal voltage is not available. In this work, a modified square wave inverter system that is specified to work properly from batteries with nominal voltages of 6, 12, 18 and 24 V was designed. A model of the microcontroller-based circuit was developed with Proteus® software and its firmware was written in C language using the MicroC® development tool. A prototype of the circuit was constructed and then tested. The constructed circuit was found to work properly by producing a 50 Hz modified square waveform when it was powered from batteries having nominal voltages of 6 V, 12 V, 18 V and 24 V.**

Keywords— Microcontroller, Inverter, Proteus®, modified square wave, multi-tap transformer

I. Introduction

Power inverters are important components in most renewable energy conversion schemes. They effectively allow electrical and electronics appliances that can only be operated from AC sources to be powered from DC energy sources. Usually, power inverters are rated to work at a fixed nominal DC voltage; for example, a 12 V inverter will not work efficiently or not at all when it is powered from a 6 V source. Usually, if a DC voltage that is above the specified voltage is applied, the inverter circuit may be damaged.

This operating voltage restriction is not of much importance in most power conversion schemes because these systems are usually designed to operate at a fixed nominal voltage. However, it is sometimes desirable to have an inverter system that can work over a wide range of input DC voltage values. This may be important in cases where it is required to change the nominal operating voltage of the renewable energy installation. For example, if we desire to increase the nominal operating voltage of the renewable energy system by increasing the number of the series connected batteries, or reduce the voltage by removing one of the batteries, maybe due to a fault condition, it will be necessary to replace the inverter with one that has an operating voltage rating that matches that of the modified installation. This is an expensive option; what is required in this case is an inverter system that can work properly over a range of nominal DC voltages.

This work seeks to develop such a power inverter system that will work when it is powered from a DC source whose nominal voltage varies from 6 V to 24 V. Since most heavy duty batteries suitable for powering energy backup systems have a terminal voltage of either 6 V or 12 V, we can power the proposed circuit from any combination of 6 V or 12 V batteries, provided that the maximum nominal voltage does not exceed 24 V.

The developed circuit, based on a microcontroller, automatically detects the nominal voltage of the input DC source and generates a 240 V r.m.s ,50 Hz modified square waveform at its output terminal. The circuit is basically a simple push – pull inverter that was modified to have different voltage transformation ratios for different nominal battery voltages, such that the peak value, and hence, the r.m.s value of the output waveform remains constant.

This paper is organized as follows: Section II gives a description of inverter circuit classifications; section III describes the working principles and the design of the inverter circuit; section IV shows the results obtained from the simulated and constructed circuit; and in section V, a brief summary of this work is given.

II Power Inverters

Inverter circuits can be classified into single input inverters and multi-input inverters. Single input inverters are designed to have only one DC input port, and for such inverters to work properly, the value of the DC voltage applied must be at a fixed nominal value [1], [2]. In renewable applications where there are two or more sources of DC energy, a number of these single input inverters can be used to generate an AC output voltage from the DC sources. In these applications, all the single input inverters are connected together to generate power at the load end [3]. This requires as many single input inverters as the number of available DC energy sources, and if we have more than a few sources, the total cost of acquiring the required number of inverters can be prohibitive. To reduce this cost, a class of inverters, known as multi-input inverters, which have the ability to generate AC power from a number of separate DC sources have been developed [4]. These multi-input inverters typically consist of cascades of multi-input DC to DC converters and full bridge inverter circuit [3], [5], [6].

Inverter circuits are generally based on two topologies. In the first topology, a high voltage DC source is generated from a low voltage DC energy supply, such as a battery, with a DC to DC converter unit. The average value of the generated high voltage DC source is designed to be equal to the peak value of the inverter output waveform. Electronic switches are then used to convert the high voltage DC source to the desired SC output waveform [7], [8]. This topology generally avoids the use of low frequency magnetic components, resulting in a compact circuit. In the second topology, the output AC waveform is generated directly from the DC source with the use of a low frequency transformer and a number of electronic switches [9]. This results in a bulky design caused by the weight and size of the low frequency magnetic components. Fig. 1 shows the schematic diagram of a single-input, transformer based push pull inverter circuit.

Single input inverters can be applied to a wider range of applications if they can be designed to work at different values of the nominal DC input voltage. For example, an inverter circuit that can work properly with, say 12 V and 24 V DC input voltages will be more useful than one that is rated to work at a single voltage, say 24 V. The work of Ogunseye and Ogunseye in [10] discussed such a single input inverter circuit that can work from either 12 V or 24 V DC sources. However, the circuit developed in [10] cannot be used to generate an AC waveform from a 6 V battery or cascades of batteries having 18 V nominal voltage. This work seeks to fill this gap: an inverter circuit that can work properly with 6 V, 12 V, 18 V and 24 V batteries was developed. The intention of the authors is to develop a circuit that can work with any combination of 6 V and 12 V batteries, provided that the maximum nominal voltage of the battery combination does not exceed 24 V.

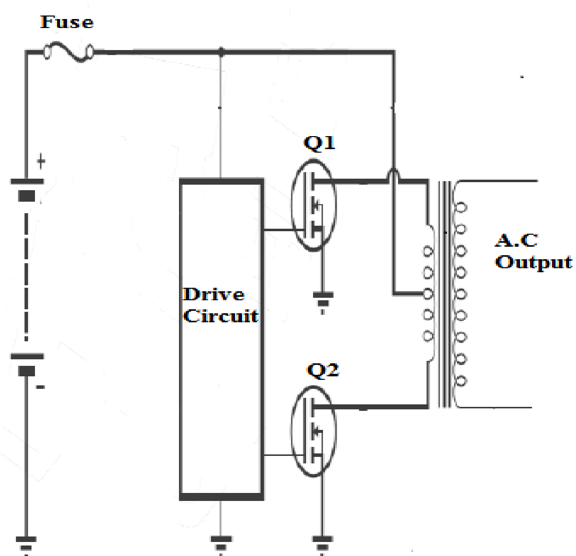


Fig. 1. Push-Pull Inverter Circuit.

III. METHODOLOGY

The developed circuit is based on a simple modification of a standard single input push-pull power inverter circuit shown in Fig. 1. In simple transformer based push-pull inverters, the nominal battery voltage and the voltage transformation ratio of the step-up transformer are fixed to ensure that the peak output voltage of the inverter does not exceed the rated value. If losses in the transformer and the MOSFET switches in Fig. 1 are ignored, the peak value of the output voltage of the step-up output transformer, V_p is given as

$$V_P = N_2/N_1 \times V_{Bat} \qquad (1)$$

Where

N_2 = Number of turns of the secondary (high voltage) winding of the step-up transformer;

N_1 = Number of turns of the primary (low voltage) winding of the step – up transformer;

V_{Bat} = The battery voltage

For a fixed value of turns ratio, the peak output voltage Vp ideally depends only on the nominal battery voltage. In standard inverters, the turn ratio is carefully selected such that the peak output voltage, never exceeds the rated value as the battery voltage changes around its fixed nominal value [2]. If the ratio V_{Bat}/N_2 is kept constant for different nominal battery voltages, the inverter circuit will keep the value of Vp unchanged, according to Eq. (1).

In the developed circuit, the effective voltage transformation ratio (N_2/N_1) is adjusted by creating taps on the low voltage windings of the step-up transformer. The circuit generates the correct peak output voltage for all the valid values of nominal input DC voltages by selecting the appropriate taps on the primary winding of the step-up transformer. This is equivalent to keeping the ratio V_{Bat}/N_2 unchanged. The transformer taps are selected by steering drive pulse signals generated by the microcontroller unit to the gates of the switching devices (MOSFETs) that are connected to the taps, with all other switching MOSFETs switched off.

The developed circuit decides on the correct transformer tap to select by sampling the battery voltage during its power on initialization sequence. If the voltage of the battery lies within the valid range of battery voltages, the pulses generated by the inverter circuit will be directed to the appropriate output pins on the microcontroller. In this way, the appropriate set of switching MOSFETs that are connected to the taps on the transformer will be switched on and off continuously to generate the desired AC output waveform.

The firmware of the circuit was written in C programming language using the MicroC suite from Mikroelektronika®. A model of the circuit, developed with Proteus® software by Labcenter Electronics, was used to verify the functionality of the circuit, after which a prototype was constructed.

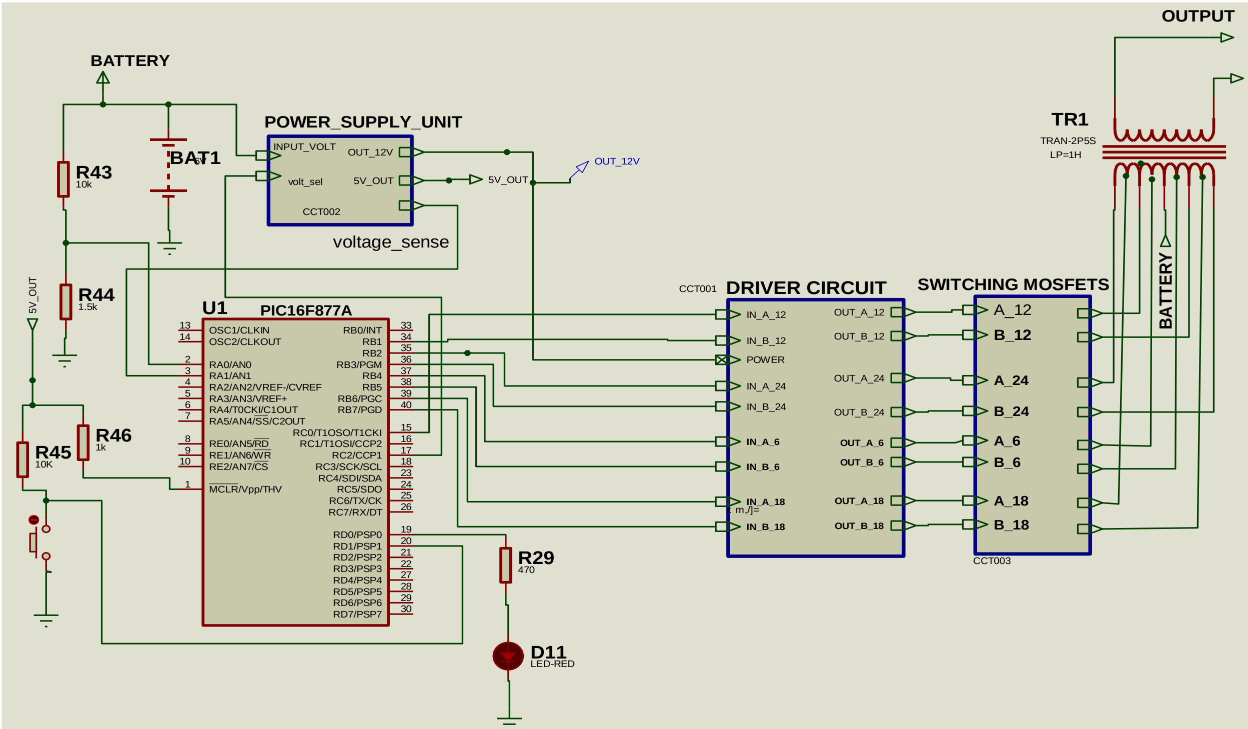


Fig. 2. The Overall Schematic Diagram of the Power Inverter System.

A. Hardware

The schematic diagram of the inverter circuit is shown in Fig. 2. The circuit is designed around a PIC16F877A microcontroller unit that has number of peripheral devices, such as analogue to digital converter (ADC) unit and timers/counter units which are required in developing this circuit. The developed inverter circuit consists of the microcontroller unit that controls the operation of the circuit; the driver units that interfaces the semiconductor switches in the output stage of the circuit with the microcontroller; the DC to DC converter unit that generates regulated 5 V and 12 V supplies from the input batteries; and the output stage which consists of the switching MOSFETs and a step-up transformer having multiple taps on its low voltage winding.

The microcontroller unit has an internal ADC unit which is used to sample the battery voltage and the output voltage of the DC to DC converter unit through two of its analogue channels. The 8 bits timer0 module of the microcontroller was configured to generate periodic interrupts every 5 ms This periodic interrupt was used as a simple scheduler to schedule the running of software tasks. The capture/compare/pulse width modulation (CCP) module of the microcontroller was used to generate pulses width modulation (PWM) pulse that was used in controlling the operation of the DC to DC converter unit. The microcontroller unit was also programmed to generate pulses of precise duration at designated port pins for the generation of the desired modified square wave form.

In this circuit, the MOSFET type (IRFP 150N) used as semiconductor switches in the output stage requires a gate source voltage of 10 V before it is switched on fully. Thus, it becomes necessary to generate this voltage from the battery voltage that can have any value from 6 V to 24 V. A DC to DC converter circuit, shown in Fig. 3, was used to achieve this. When batteries having nominal voltages of 6 V or 12 V are used, the circuit operates as a PWM -controlled step up boost converter. If 18 V or 24 V batteries are used, the PWM pulse is turned off. In this case, transistor Q15 in Fig. 3 is switched off, causing the battery voltage to be applied to the 7812 linear voltage regulator through inductor L1 and diode D10.The repetitive frequency of the pulse width modulation pulses was set at 10 kHz. A simple integrating control action was used in software to achieve regulation of the output voltage.

The output stage of the circuit consists of the switching MOSFET and the multi-tap step up transformer. The circuit is actually a modification of the standard push-pull power converter topology, with the traditional center-tapped transformer replaced with one having multiple taps on its low voltage winding. The multiple taps on the transformer allows for the selection of the right transformer turns ratio to generate the rated output voltage from batteries having a nominal voltage that varies between 6 V and 24 V. The transformer has four pairs of taps on the low voltage winding, with each pair of taps used for achieving voltage step up ratios for operation from 6 V, 12 V, 18 V and 24 V batteries. Associated with the MOSFET switches are the driver circuits that generate well-buffered 15 V pulses from the 5 V logic output pulses of the microcontroller. The driver circuit was designed along the lines of the driver circuit described in [10].

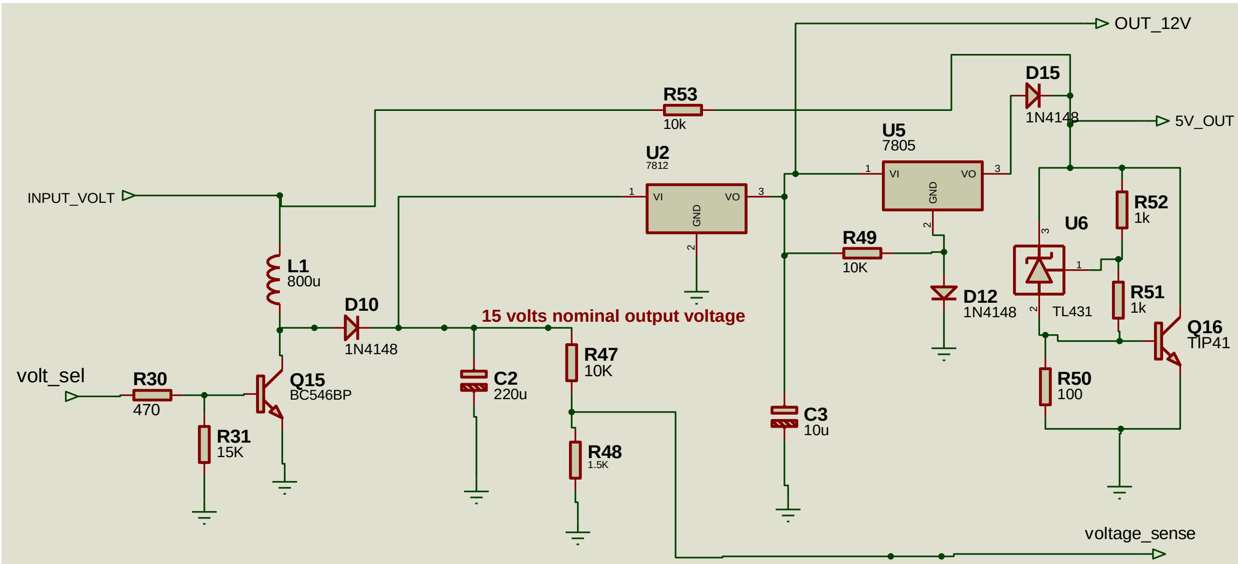
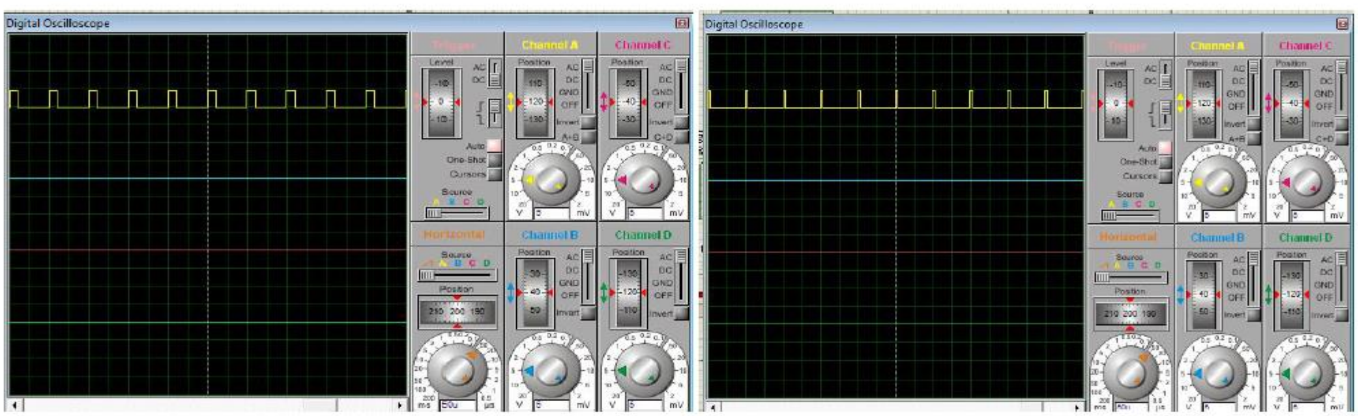


Fig. 3. Schematic Diagram of the Power Schematic diagram of the DC to DC converter circuit.



(a) (b)

Fig. 4. The Dc to Dc Converter pwm Control Signal for Battery voltages of (a) 6 V and (b) 12 V.

B. Software

The firmware of the inverter circuit is driven by periodic interrupts that are generated by timer0 module of the PIC microcontroller. The timer0 interrupt is scheduled to occur every 5 ms The firmware is divided into distinct software tasks that are scheduled to run in the main software loop when the timer0 module interrupts a number of set times. These tasks include software routines that sample the battery and the DC to DC converter output voltages, regulate the output voltage of the converter using pwm, determine the nominal battery voltage and debounce the on/off push button.

Because of the strict timing required to generate the output pulses needed for AC waveform synthesis, the inverter pulses are generated inside the timer0 interrupt service routine with a finite state machine sequencer. These pulses are only generated if the battery voltage is within the acceptable voltage range of the particular detected battery voltage and if the on/off pushbutton is pressed.

IV. RESULTS

Fig. 4a and 4b show the PWM signal that was used in controlling the operation of the DC to DC converter when the Proteus® model of the inverter is powered by a 6 V and 12 V DC sources respectively. It is seen that the waveform has a higher duty cycle when the circuit is powered from a 6 V source; the duty cycle is 6.8% in the case of the 12 V source and 28.2% for the 6 V DC source. This is consistent with the behavior of voltage boost converter circuits: they reduce their duty cycle when the input DC voltage is increased and the output voltage is kept constant. A sample of the output pulses of the microcontroller that is used in driving the output

MOSFET switches is shown in Fig. 5. In the developed circuit, only two of the eight output pins of the microcontroller that are used for pulse generation are active per time, all the other inactive pins are simply set to logic zero.

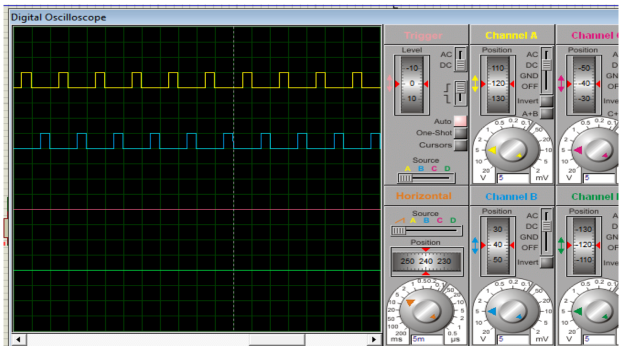


Fig. 5. The A Sample of the Inverter Drive Signal at the i/o pin of the Microcontrollers.

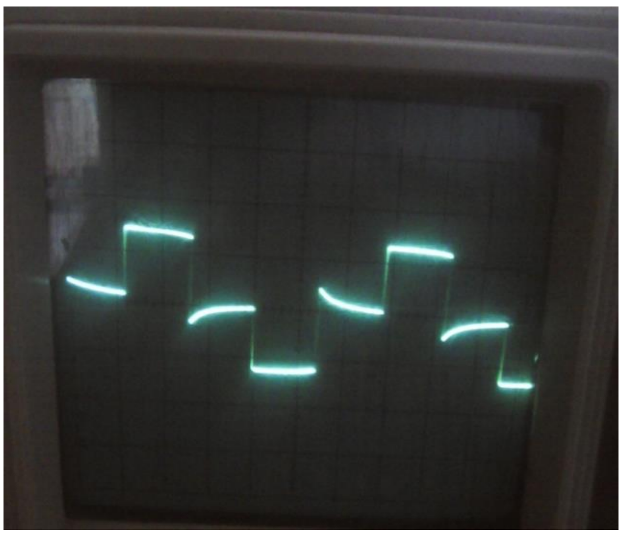


Fig. 6. Sample Output Waveform of the Inverter Circuit.

Fig. 6 shows a sample of the output waveforms of the constructed microcontroller circuit when it is powered from batteries having nominal voltages between 6 and 24 V. In this test, a 60 Watt incandescent lamp load was connected to the output of the inverter. The shape of the output waveform of the inverter remained the same for input voltages over the same range.

V. CONCLUSION

In this work, a microcontroller based inverter circuit that can be powered from batteries with nominal voltages in the range of 6 to 24 V was designed, constructed and tested. This approach effectively removes the single nominal battery voltage restrictions that are generally assumed in inverter circuit design.

The inverter circuit was designed to produce a modified square wave output waveform. This restricts the application of the inverter to applications that can tolerate high harmonic distortions in the output waveform. In future works, the inverter can be designed to generate waveforms with lower level of distortion.

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