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Design of a Microcontroller-Based Push-Pull Inverter with Automatic Voltage Regulator

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Abstract:
This research work explores the possibility of designing and constructing a microcontroller-based circuit that functions as an inverter and automatic voltage regulator. The circuit was developed with proteus® software and its firmware was developed using Mikrobasic® software. The circuit, which has two modes, namely the inverter mode and the automatic voltage regulator mode, was built around a PIC16F877 microcontroller. In the automatic voltage regulator mode, the constructed circuit maintained the output voltage between 215V and 235 volts for input mains voltage variation between 160 and 265 volts. In the inverter mode, the circuit produced a modified sine wave whose root mean square value varies between 210 and 225 volts when it was loaded up to 1kW maximum output power.

Keywords: *Proteus, micro basic, inverter, automatic voltage regulator, microcontroller*

1. Introduction

With the widespread use of computers and other electronic devices, electrical power issues such as sags, harmonics and outages have become increasingly important. Of these issues, power outages and under voltages have the greatest potential to disrupt the operation of sensitive electronic equipment. For example, frequent power outages can result in a latent failure of computer components such as hard-drives which can cause the outright failure of the entire computer system. Thus, during outage periods, critical equipments are usually powered using power generating sets or battery-powered inverters, which are preferred because they operate noiselessly and do not pollute the environment.

It is common in developing countries, such as Nigeria, for the mains voltage to deviate significantly from the specified standard range. Such deviations are usually corrected with electronic equipment known as Automatic voltage regulators (AVRs). AVRs maintain their output voltage within a narrow range over a much larger range of input mains voltage. Combinations of power inverters and automatic voltage regulators can be used to solve problems of power outages, undervoltage and overvoltage.

In this work, a microcontroller based circuit that performs the functions of an inverter and an automatic voltage regulator was developed. When power outages occur, the circuit behaves as a modified squarewave inverter by generating electrical power at its output terminal from a 24 volts battery. When the utility supply is restored, the circuit compensates for deviations in the utility voltage levels from the standard 220-240V range. It achieved this by changing the taps of a multi-tap transformer in response to changes in the input mains voltage. When the input voltage exceeds 265 volts, the circuit simply isolates the load from the utility supply to prevent damaging the load.

2. Review of Previous Work

2.1. Inverter Topologies

The design of a dc to ac voltage source inverters can be done using several energy conversion topologies. Push-pull, half-bridge and full bridge converters have been successfully employed in inverter circuit designs (Suryawanshi et al., 2006; Abolarinwa and Gana, 2010; Sekar and Baladhandapani, 2013). Push-pull converters are restricted to low d.c supply voltage applications because of their tendency to develop magnetic flux walking problems that can lead to failure. They are however commonly employed because of their rather simple structure compared to that of full-bridge converter circuits. Full-bridge converters are used in high power applications where their higher component count and the associated cost are of secondary importance (Wuidart, L, 1999).

Voltage source inverter systems can also be classified based on their output waveform type. The earliest power inverters produce square wave output waveforms. Square waveforms are easily and efficiently produced at high power levels. However, the high harmonic content implies that they cannot be used to power harmonic sensitive loads. A version of square wave inverters is the modified sinewave inverters. Inspite of the term, a 'modified sinewave' inverter produces a waveform that looks more like a square wave than a sinewave. Pure sinewave inverters are by far the best, because their output waveforms have very little harmonic content, though they are somewhat more complex to design compared to square wave and modified squarewave inverters. Consequently, they are much more costly. Kolla et *al*. (2013) provides a detailed explanation on the performances and characteristics of the various inverter types. Figure1 shows the output waveforms of the various inverter types.

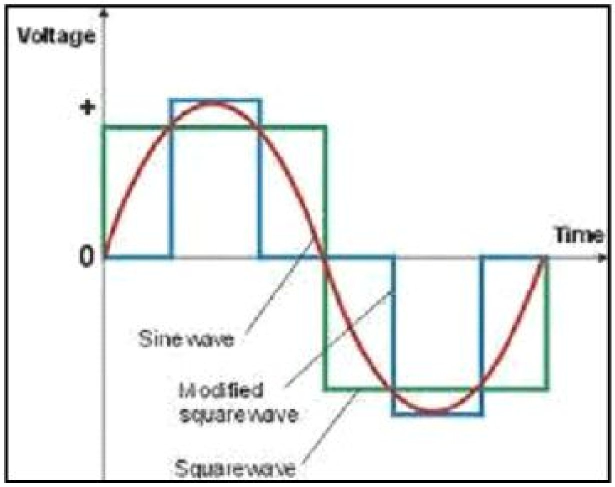

Figure 1: The output waveforms of pure sinewave, modified squarewave and squarewave inverters (Kolla et. al., 2013)

In low frequency inverters, a step-up transformer is usually employed to step up the chopped battery voltage to the required output voltage levels (Abolarinwa and Gana, 2010). In moderately powered inverters, the cost of such transformer is significant compared to the cost of other electronic devices employed.

2.2. Automatic Voltage Regulators

Automatic voltage regulators are used to maintain load voltages within specified tolerance ranges. They compensate for changes in the supply voltages which can cause electrical devices to malfunction. A type of AVR is the static automatic voltage regulator. In pulse-width modulation (PWM) based static AVRs, the output of an inverter is connected in series with the mains supply. The output voltage of the inverter is then varied using pulse width modulation techniques to compensate for deviations in the mains voltage from the desired value (Pratik et al, 2014). Another type of AVR is based on transformer tap changing techniques. The taps of an autotransformer are changed to compensate for changes in the mains voltage (Abolarinwa and Gana, 2010).

In AVRs employing auto-transformers, the transformer is usually the bulkiest and heaviest component in the equipment. In this work, a single 50 Hz power transformer is used as part of a combined microcontroller-based inverter and automatic voltage regulator circuit. This approach results in a circuit that is cheaper compared to the combined cost of equivalent inverter and AVR units.

3. Methodology

The developed microcontroller-based inverter /AVR hardware essentially consists of a PIC 16F877A microcontroller based circuit, an SG 3524 based modified sine-wave inverter driver circuit, a step-up transformer with various taps on its high voltage winding, a stabilizer circuit which consists of groups of relays for tap-changing and changeover purposes, and a simple switching power supply unit.

The AVR and inverter hardware circuits were developed and modelled with Proteus® software. The microcontroller firmware, developed with MikroBasic software, controls the operation of the entire circuit. The circuit is then built from electronic components that are soldered on a Veroboard. The firmware was written into the microcontroller's program memory with a USB programmer unit. The microcontroller software, inverter circuit, microcontroller circuit, stabilizer circuit and the power supply unit are described below.

3.1. Microcontroller Software

The circuit firmware was developed using MicroBasic software and its operation was verified by running it on a Proteus model of the microcontroller circuit.

The software is a simple finite state machine illustrated in Fig 2. The finite state machine has three distinct states, namely off state, mains state and inverter state. In the off state, the circuit does not produce any output power. In this mode, the microcontroller continually samples the mains voltage. When the mains r.m.s voltage exceeds 100 volts, the state machine goes to mains state.

In the inverter mode, the circuit produces a 220V r.m.s modified sine wave output waveform. On entering this mode, the state machine isolates the mains supply from the load and then enables the inverter circuit. The battery voltage is sampled continuously, and if it falls below 18 volts, the state machine goes to off state. The minimum battery voltage required for the state machine to enter the inverter mode is 22 volts.

In the mains mode, the circuit regulates the mains voltage by changing the taps on the mains transformer. When the mains voltage falls below 100 volts or rises above 265 volts, the state machine changes state from mains state to off state. The stabilizer routine is run when the state machine is in mains mode. This routine measures the mains voltage and then activates the appropriate transformer tap-changing relay as necessary to maintain the output voltage within the acceptable tolerance range.

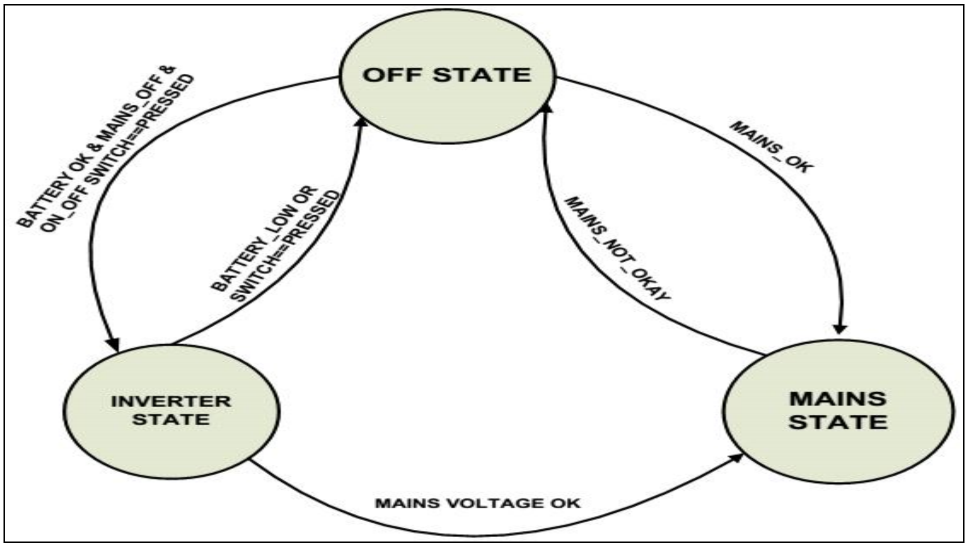

Figure 2: Inverter/AVR Finite State Machine

3.2. The Inverter Circuit

The inverter circuit is built around a SG3524 pulse width modulator (PWM) integrated circuit, as shown in Figure 3. This PWM chip generates two out of phase logic level output waveforms with variable duty cycle. The internal oscillation frequency of the SG3524 pwm chip, determined by the values of resistor R10 and Capacitor C2, was set at 100Hz, according to the procedure outlined in the SG3524 datasheet. With this, the frequency of the a.c waveform produced by the inverter can be adjusted to exactly 50Hz by simply varying the resistance of potentiometer RV2. The class B output stages formed by Q1-Q4 generate a low impedance sources from the output voltages produced by the pwm chip.

Negative feedback is applied to the inverter circuit to ensure good regulation of the inverter output voltage. The feedback network components are D1, D2, D3, R7, R12, C1 and RV1. The voltage induced in the secondary windings of the transformer is riding on the 24 volts d.c battery voltage. This d.c bias voltage is removed by the 24 volts zener diode D1. The resulting d.c voltage is then filtered and attenuated by the network formed by R7, RV1 and C1.

The inverter circuitry was interfaced to the PIC16F877A microcontroller circuit. The microcontroller monitors the output voltage of the class B driver circuit. If for any reason, the two voltages are simultaneously high, the microcontroller turns off the pwm chip to prevent failure of the switching mosfets. To achieve this, the microcontroller simply sends a logic 1 (5V) signal to the shut-down pin of the SG3524 pwm chip.

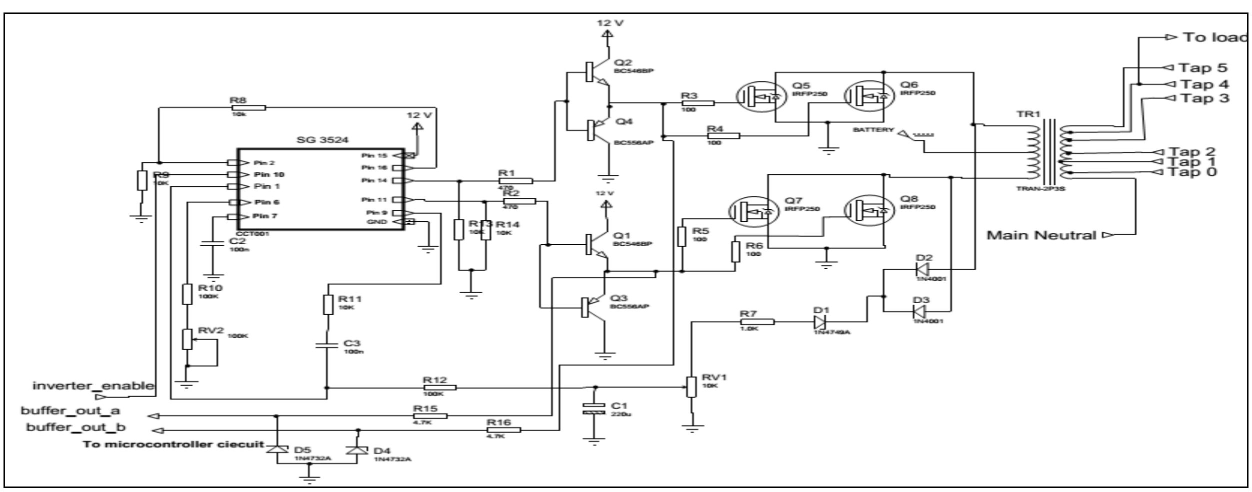

Figure 3: The push-pull inverter circuit

3.3. Microcontroller Circuit

The microcontroller circuit is responsible for the control of the entire inverter- stabilizer circuit. It runs the stabilizer control algorithm when the mains voltage is available and also controls the inverter circuit.

The microcontroller circuit is shown in Figure 4. Transformer TR1, a low power transformer, steps down the mains input voltage and provides isolation between the microcontroller and mains supply. The secondary voltage of the transformer is then full-wave rectified and attenuated by the voltage divider network formed by R4, R5 and R6. The microcontroller, using its internal analogue-to-digital (ADC) converter, measures this voltage to determine the appropriate transformer tap to select, as needed to maintain the output voltage within acceptable limits.

The core temperature of the inverter/stabilizer transformer was measured using LM 35, a temperature sensor integrated circuit. This IC generates an analogue output voltage that is proportional to the measured temperature. This voltage is sampled by the microcontroller through one of its analogue channels.

The microcontroller runs a simple state machine that switches on or off a 12 volts d.c fan in response to the measured transformer core temperature. This state machine maintains the transformer core temperature between 35 and 60 degrees.

Pushbutton P1 is a simple switch allows the user to turn on or turn off the inverter circuit.

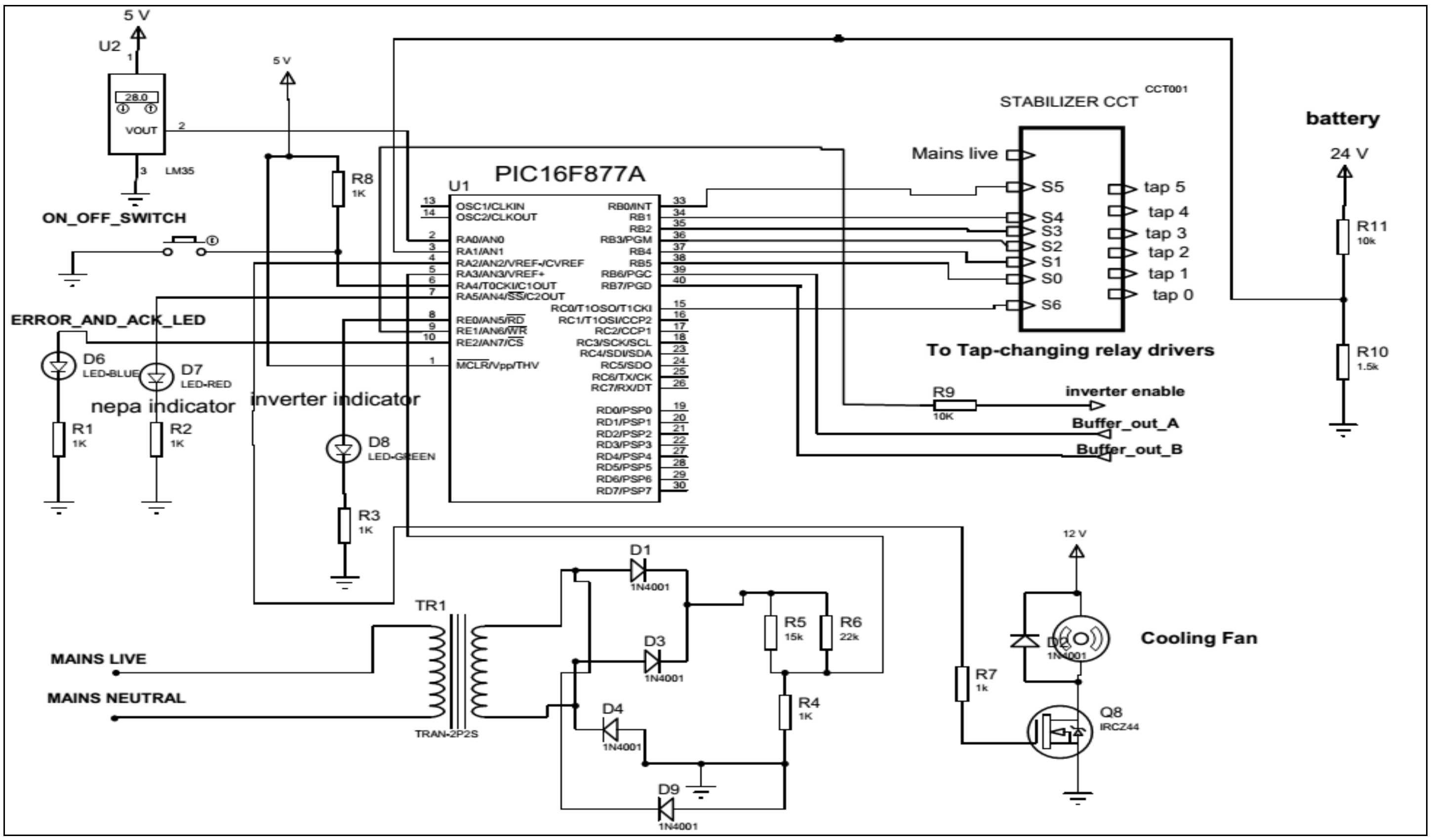

Figure 4: The Microcontroller Circuit

3.4. Stabilizer Circuit

Relays RL1-RL6, shown in Figure 5, are used to select the appropriate taps of the transformer in response to control signals from the microprocessor. The relays are configured as one of six multiplexer; only one of the relays is active at a time. Relay RL7 functions as a changeover switch. It cuts off the mains supply to the load and the microcontroller circuit when the circuit is in inverter mode.

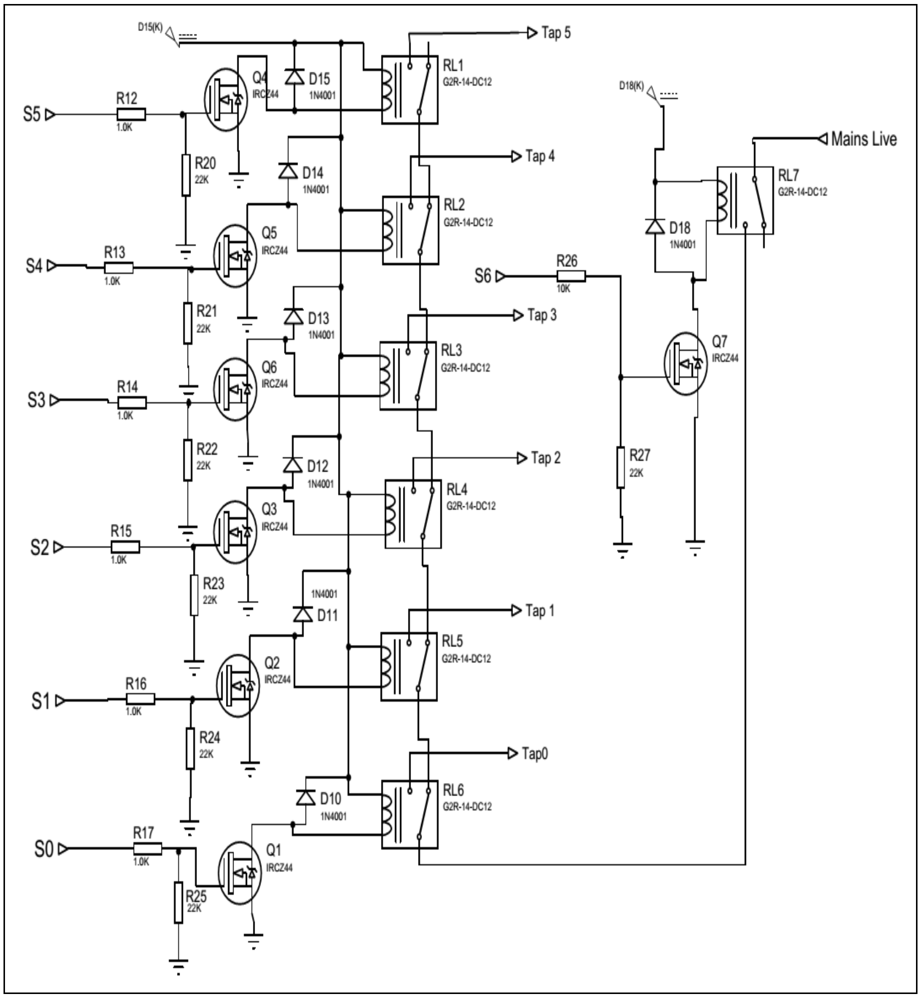

Figure 5: The stabilizer circuit

3.5. Power Supply Unit

The microcontroller circuit requires 5V d.c for its operation. A 12 volts d.c supply is also needed to power the relay circuit and the inverter driver circuit. To maximize efficiency, the 12V supply is generated from the 24 volts battery voltage using a switch-mode power supply unit. The circuit, shown in Figure 6, uses an LM 317 linear voltage regulator as self oscillating switching voltage regulator. The circuit is modified from an application circuit published in the National Instruments LM 317 datasheet. The 5v supply is derived from the 12v output of the switching regulator with a simple LM 7805 linear regulator.

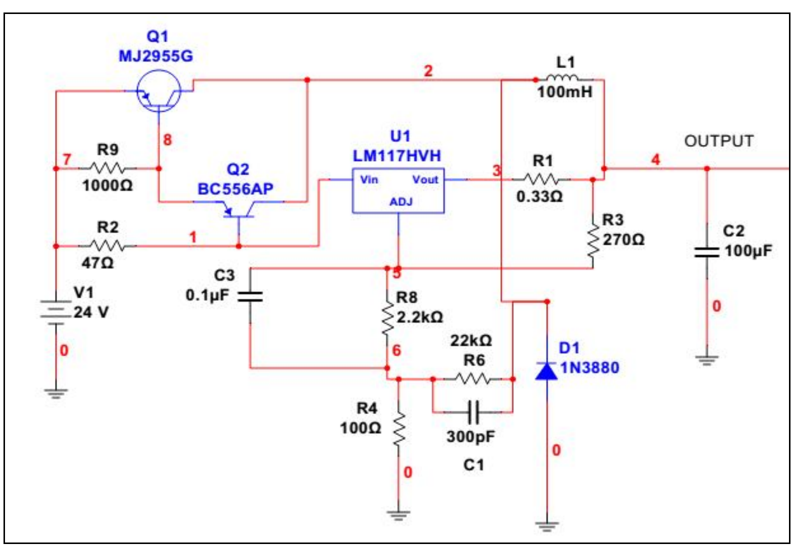

Figure 6: 12 V Power Supply Unit

4. Result
The constructed circuit is shown in Figure 7.

Figure 7: The constructed inverter-AVR circuit boards

The inverter produced a 50Hz modified square wave signal at its output. The inverter was able to maintain the r.m.s output voltage between 210 and 225 volts when it was loaded up to 1 k W (the maximum power ratings of the inverter).
The circuit produces an output voltage whose range varies between 215V and 232 V when the utility supply voltage ranges between 160 and 265 volts. When the input voltage drops below 160 volts, the circuit was not able to maintain the output voltage within 215 and 235V. With an abnormally high input voltage that exceeded 265 volts, the circuit simply isolated the load from the mains supply.

5. Conclusion
In this work, the possibility of designing a circuit that functions as an inverter and a stabilizer to solve the problem of epileptic power supply was investigated. A microcontroller based system that exhibits the functions of an AVR and an inverter was designed. In achieving this goal, some design steps were followed and the implementation of the system was carried out. The system is validated through testing and is found to work well.
The performance of the developed circuit can be enhanced by increasing the range of mains voltage within which the output voltage is well regulated. To achieve this, more taps will be required on the high voltage winding of the mains transformer. Also, a more informative user interface can be incorporated into the circuit to display key parameters such as the battery voltage and current.

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