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Circuit Implementation of Trapezoidal Uninterruptible Power Supply System based on Fluctuating Input Voltage Method

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Abstract

Circuit configuration which leads to the realization of trapezoidal uninterruptible power supply system based on fluctuating input voltage method is primary focus of this paper. Trapezoidal shaped alternating current (ac) voltage load waveform is a critical requirement in the implementation of hybrid fiber/coax (HFC) distribution networks used in the conversing CABLE TV (CATV) and telecommunication industry. This network type allows for efficient distribution of multimedia services to the consumer. The efficient conversion, control, and conditioning by static means of electrical power from its available input form into a trapezoidal form are highly possible and require very stringent control strategy. This paper presents the circuit structures which take advantage of the remarkable feature of voltage feed-forward Pulse-width Modulation (PWM) control to accommodate the change in the input voltage to a converter to generate trapezoidal voltage waveform which, is the expected output waveform of trapezoidal uninterruptible power supply (TUPS) system. A high-performance single-stage TUPS system for single-phase trapezoidal ac supply that is synchronized with the ac mains supply is considered in this study. This is in view of the fact that the theoretical analysis that leads to a small-signal model of the system allows the voltage-load transient to represent the UPS system performance. The integral classical controller and voltage mode control as an output feedback are used for the implementation of saw- tooth carrier-based pulse-width modulation (PWM) for the TUPS system.

Keywords: *Harmonics, hybrid-fiber/coax, inverter, modulation index, pulse-width modulation, switching frequency, trapezoidal waveform.*

1. Introduction

The infrastructures, known as "information superhighway," namely: CABLE TV (CATV), consumer electronics, and telecommunication industries are capable of providing a platform for a wide range of broad-band, multimedia entertainment, communication, and information services [1]. Information superhighway is increasingly becoming complex. In recent years, hybrid fiber/coax (HFC) distribution networks have emerged as one of the preferred approaches for distributing multimedia services to the customer [2], particularly by the cable TV industry. This hybrid dramatically network connects optical fiber to the neighborhood with coax cable to the residence. Compared with all-fiber or all-coaxial networks, this network allows for segmentation of services and high reliability, distribution efficiency, and low cost. The need for qualitative and reliability in power supplies used in the telecommunication

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industry has obviously been with us for many years. With the increased use of electrical power and our dependency on an electrical supply, reliability has become an increasing concern. With the rapid advance in hardware, it is highly possible to build power supply system with artificial intelligence capability. Power electronics which, mainly deals with the efficient conversion, control and conditioning of electrical power by static means from its available input form into a desired electrical output form can do just that [3].

Based on the capability of power electronics, TUPS, an acronym for trapezoidal uninterruptible power supply has the ability to serve as an interface, provide clean, appropriate, and reliable power for hybrid fiber/coaxial systems. In the particular case of power outage, TUPS can supply power for up to 20min, to allow a back-up supply from diesel generating sets to be brought on-line or, if the generators fail to start, a controlled shut down of the computers, telecommunication equipments, etc, to be completed [4].

The voltage waveform, level, and frequency of the network power distribution are still evolving. However, in order to transfer a larger power to the network devices at a given peak voltage and to keep low electromagnetic interference (EMI), the PN (power node) delivers a trapezoidal- shaped voltage waveform rather than a sinusoidal waveform [1]. Based on the information obtained from Bellcore and cable TV operators, 90V/50 Hz is chosen since it provides a good compromise between safety, loading capability, corrosion, and distribution losses.

The design of circuits which can generate 90V/50Hz trapezoidal load voltage waveform even when the mains sinusoidal 220V/50Hz input voltage fluctuates is what this work aims to achieve. In this particular case, the circuit design approach ensures that the correctness of the system is dependent on both the logical result of computation and the time at which the load voltage waveforms are produced.

2. Overview of Uninterruptible Power supply System (UPS) Structure

Ideally, a UPS should be able to deliver: 1) a regulated trapezoidal output voltage with low total harmonic distortion (THD) during normal or backup modes, and voltage regulation, even when feeding nonlinear loads; 2) seamless transition from charging to backup mode during power failure and vice versa; 3) low THD Trapezoidal input currents with unity power factor while in normal mode irrespective of the load nonlinearities or power factor [5]. The best system in this regard is the off-line UPS.

The electrical power conversion can be realized by power converters built on power semiconductor switching devices and the converters are controlled by control electronics. This kind of power converter is usually known as switching-mode converter. Figure 1 shows a power electronic system block diagram. Fig. 1 is further shown in a different format in Fig. 2. A detailed control diagram of the power topology is shown in Fig. 3 and is based on the derived model of the trapezoidal UPS system.

The major component parts are: diode rectifier and input filter, supply voltage sensor, synchronization and reference generator, output voltage modulator, inverter voltage detector, carrier generator, and output filter. The configuration of Figure 3 will operate in two different modes, namely, normal/charging and backup modes. In the normal/charging mode, the battery on/off switch is opened. Hence, the alternating current (ac) mains supply the load power through the PWM inverter and charge the battery at constant current as well. In the backup mode, the ac mains is not available and the battery on/off switch is closed. Thus, the battery supplies the load power.

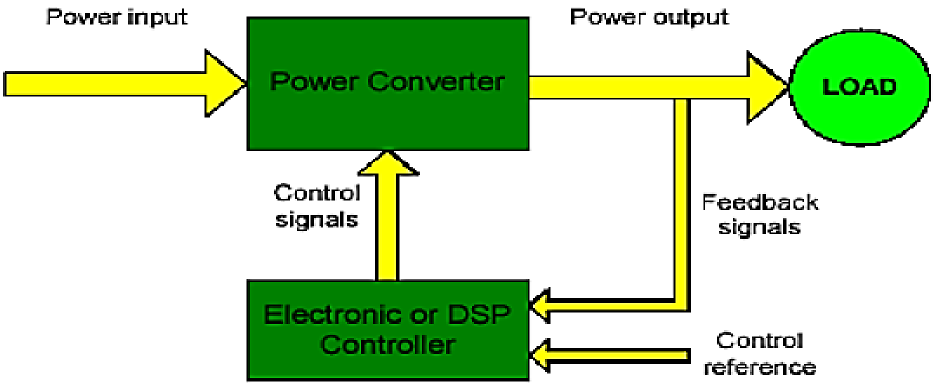

Figure 1: Block diagram of power electronics system

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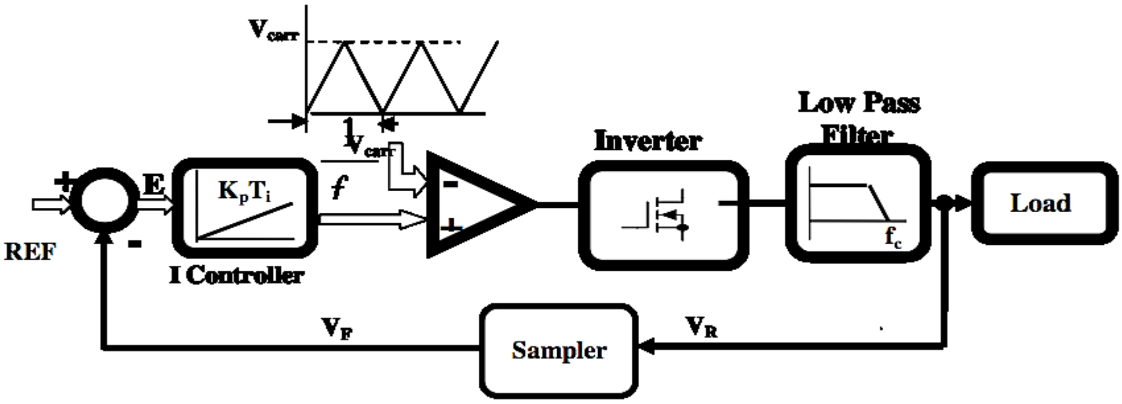

Figure 2: Controlled block diagram of a trapezoidal UPS system

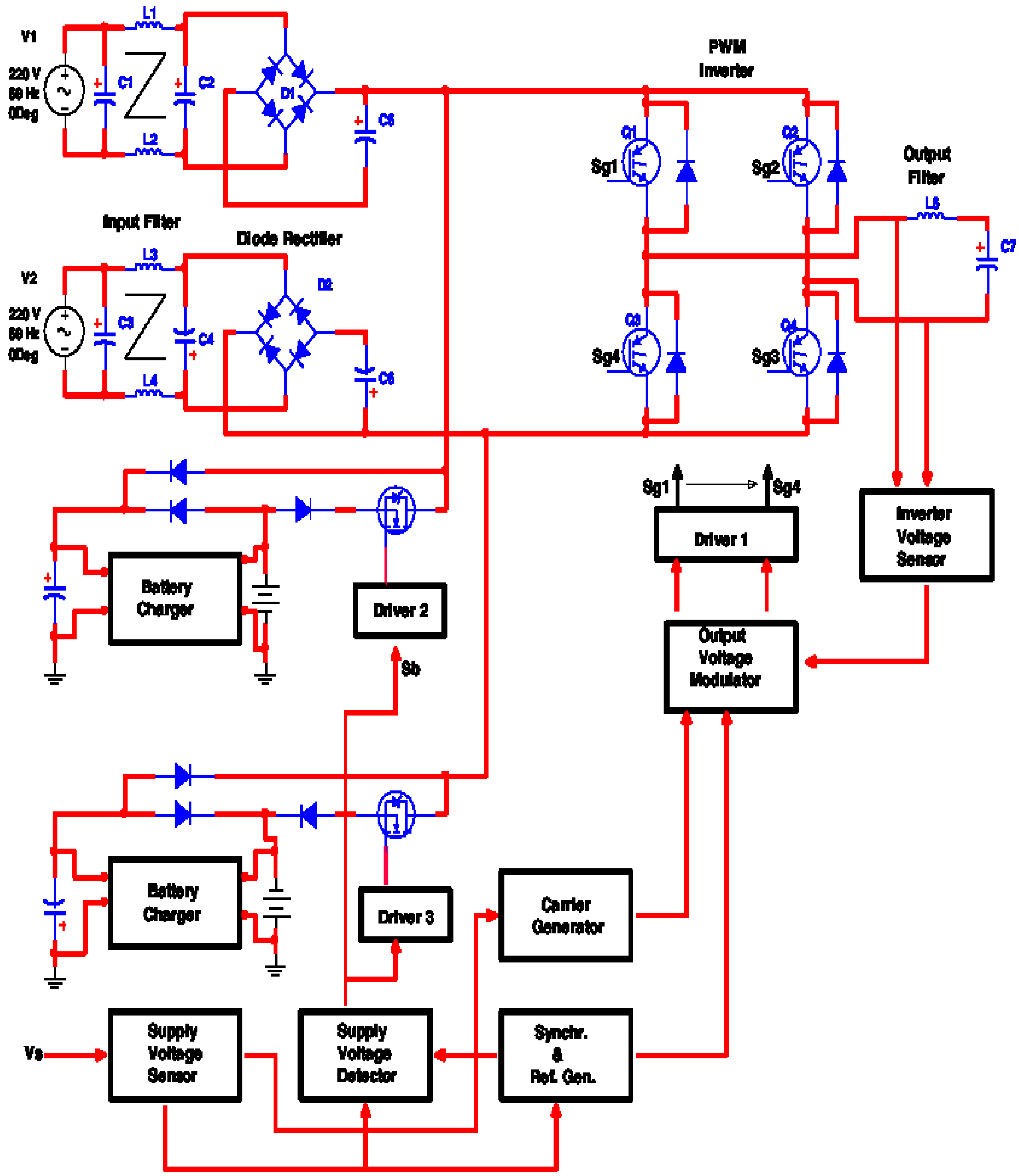

Figure 3: UPS power circuit configurations and control strategy.

A brief description of the components of the power configuration is as follows. The power supply consists of two single-phase full-wave rectifiers and provides dual dc voltage supply. The synchronization and reference unit allows for the generation of a trapezoidal reference signal and its synchronization to the mains voltage. The carrier generator in conjunction with the synchronization and reference unit generates a 51.2 KHz saw-tooth carrier signal (feed-forward control). The comparison between saw-tooth carrier and the reference signal is carried out in the output voltage modulator unit. The inverter voltage sensor senses the inverter output and provides the necessary sampled output to be compared with the trapezoidal reference signal, so that an error signal is generated. The input filter (L1, L2, C1, C2) is basically an EMI) filter and, thereby, it does not affect the 50-Hz current component. The output filter (Lo, Co) filters out the high-frequency-voltage components

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generated by the PWM operation of the inverter and defines the trapezoidal-shaped load voltage across Co. The supply-voltage detector basically provides the signal SB to the battery on/off switch to enable the battery provides load current in the event of mains power failure. The detailed circuit diagrams of each of the blocks in Figure 3 are presented in Figure 4 through 10. These circuits are put together and drawn using Circuitmaker schematic and simulation software. The final circuit is then simulated and the results obtained have been documented in another published paper.

3. Design Guidelines

A. Power Stage Transfer Function

The transfer function Tp(s) of the power stage (inverter) and the output filter is expressed as

$$T_s(s) = \frac{\tilde{v}_o(s)}{\tilde{d}(s)} = 2V_{CC}\frac{\omega_r^2}{\omega_Z}\frac{s+\omega_Z}{s^2+2\xi\omega_r s+\omega_r^2} \tag{1}$$

where V_{CC} is the positive power supply dc voltage. $\omega_r = \frac{1}{\sqrt{L_o C_o}}$ is the resonance frequency of the output filter made of L_o and C_o. Two poles are introduced at this angular frequency. The damping factor ξ is given as

$$\xi = \frac{1/CR+(r_C+r_L)/L}{2\omega_r} \tag{2}$$

Where R is load resistance. A zero is introduced due to the equivalent series resistance r_C of the output filter capacitor C_O, at the frequency.

B. Power Supply Capacitor (C_5 and C_6)

Small values of C_5 and C_6 lead to reduced input-current distortion and high-input power factor, [6]. However, power supply capacitor has to be large enough to filter out the high-frequency current harmonics generated by the PWM operation of the inverter. Hence, limiting the maximum capacitor peak-to-peak voltage ripple in one switching period to a given value $\Delta\upsilon_{dc}$ is a good consideration. Therefore, the maximum capacitor impedance, $X_{C_{dc},\max}$, for a given maximum normalized voltage ripple, $\frac{\Delta v_{dc}}{v_{dc}}$ = 0.2 pu [2] is expressed as

$$X_{C_{dc},\max} = \frac{f_C}{\pi}\left(\frac{\Delta v_{dc}}{v_{dc}}\right)_{\max} \tag{3}$$

Where f_C,, is the switching frequency.

C. Integrator

Conclusion section is mandatory and contains advantages, disadvantages, review the main part of research paper and use of research work. If author want to acknowledge someone, then acknowledgement section may include in research paper after conclusion. Appendix section (if required) appears before acknowledgement section.

Since the open-loop transfer function of the UPS system is type 0, there is the need to make it type 1 so as to reduce the steady-state error of the system. By so doing the integrator is the compensator. The transfer function $T_c(s)$ of the I controller is given as

$$T_C(s) = \frac{K_I}{s} \tag{4}$$

Where K_I is the gain of the integrator.

The output voltage υ_C, (control voltage or modulating signal), of the integrator is defined as

$$v_C = \frac{1}{R_i C_i}\int v_{in} dt \tag{5}$$

[7]. R_i = 1.35Meg and C_i = 22nF are the time constant components.

D. Load Second-Order Filter (C_O and L_O)

The load filter should be small enough to minimize the phase shift between the load current (i_l) and the inverter ac voltage (υ_O). This is as a result of the fact that any phase shift will be reflected back as an input displacement power factor, which, in turn, will deteriorate the overall input power factor. However, the load filter should be large enough to define a trapezoidal-shaped load-voltage waveform with reduced harmonic components. Therefore, the maximum normalized capacitor impedance, $X_{C_O,\max}$, and inductor impedance, X_{L_O}, are related as

$$X_{C_O,,\max} = X_{L_O} \frac{8 f_C^2}{\pi^2}\left(\frac{\Delta v_{C_O}}{v_{C_O}}\right)_{\max} \tag{6}$$

Where $\left(\frac{\Delta v_{C_O}}{v_{C_O}}\right)_{\max}$ = 0.01 pu, [2] is the maximum normalized peak-to-peak capacitor voltage ripple. f_C is the switching frequency (51.2KHz). Consequently, C_O = 23uF and L_O = 27mH.

The transfer function $T_m(s)$ of the modulator is expressed as

$$T_m(s) = \frac{\tilde{d}(s)}{\tilde{v}(s)} = \frac{1}{\tilde{V}_r} \tag{7}$$

$\tilde{V}_r$ is the peak voltage of the modulating signal.

4. Circuit Realisation

The implemented circuits are presented in this section

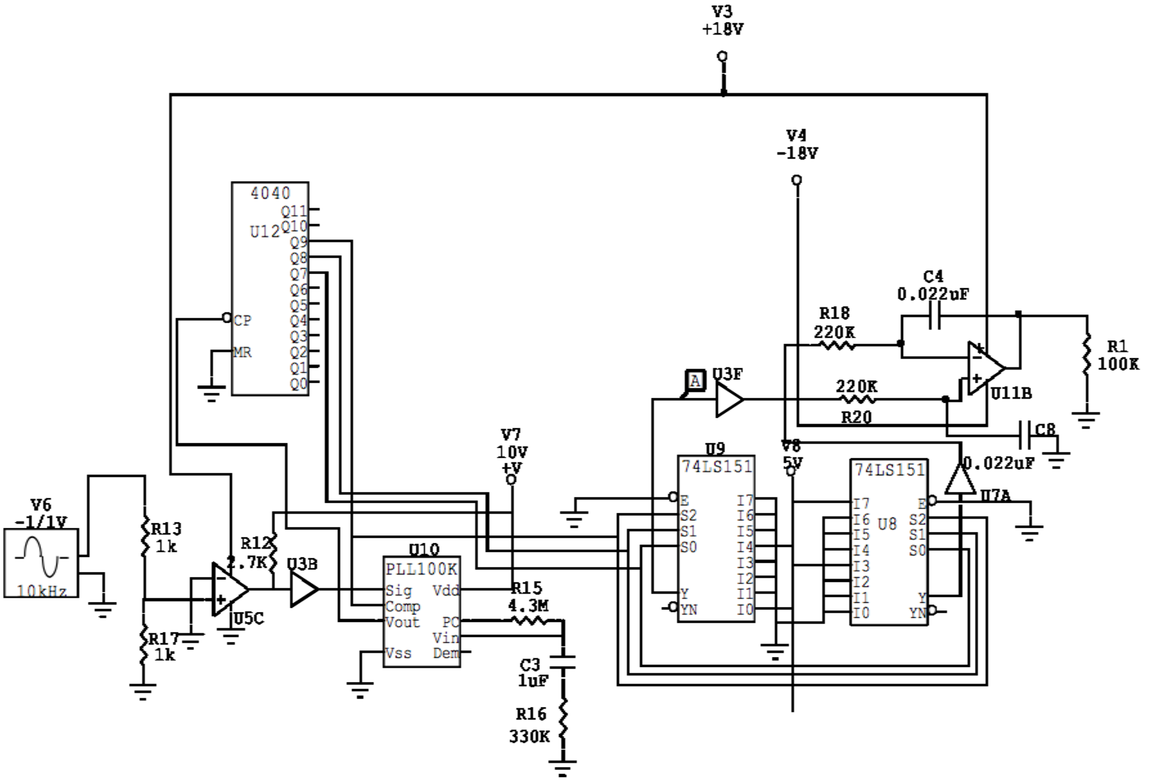

Figure 4: Reference and synchronization units.

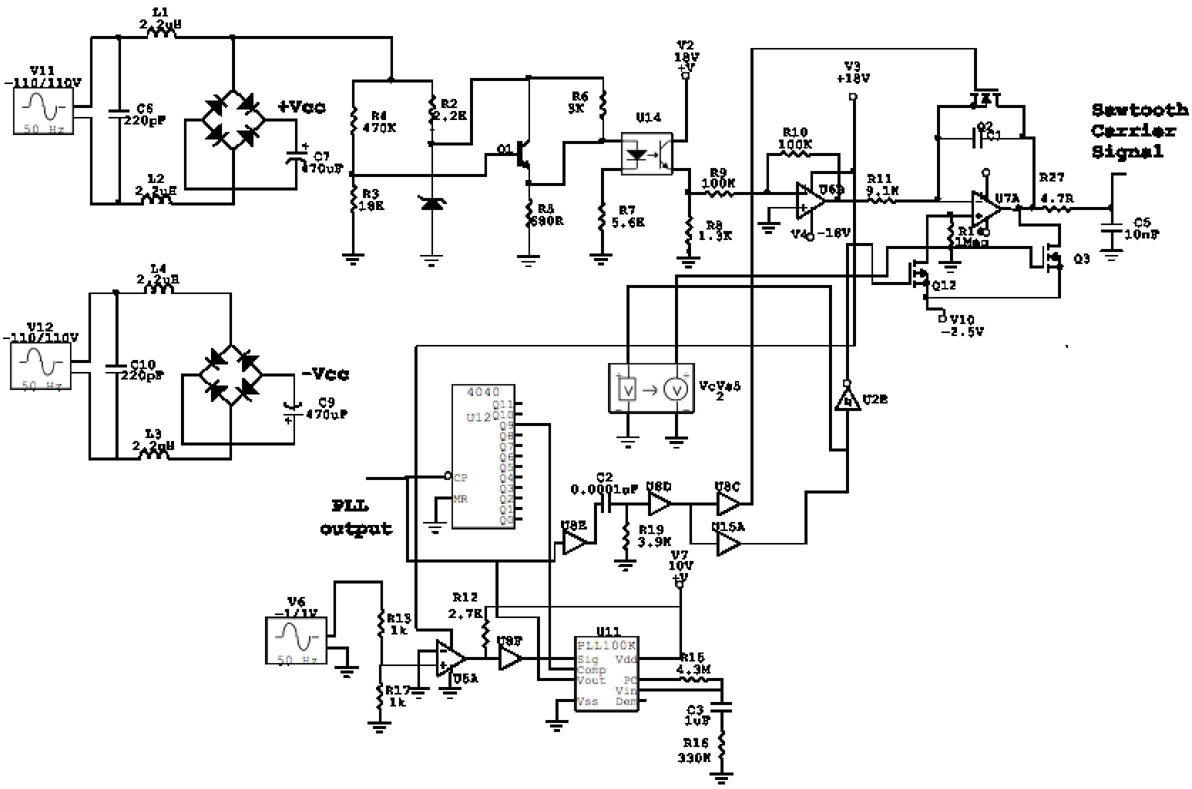

Figure 5: Carrier wave generator.

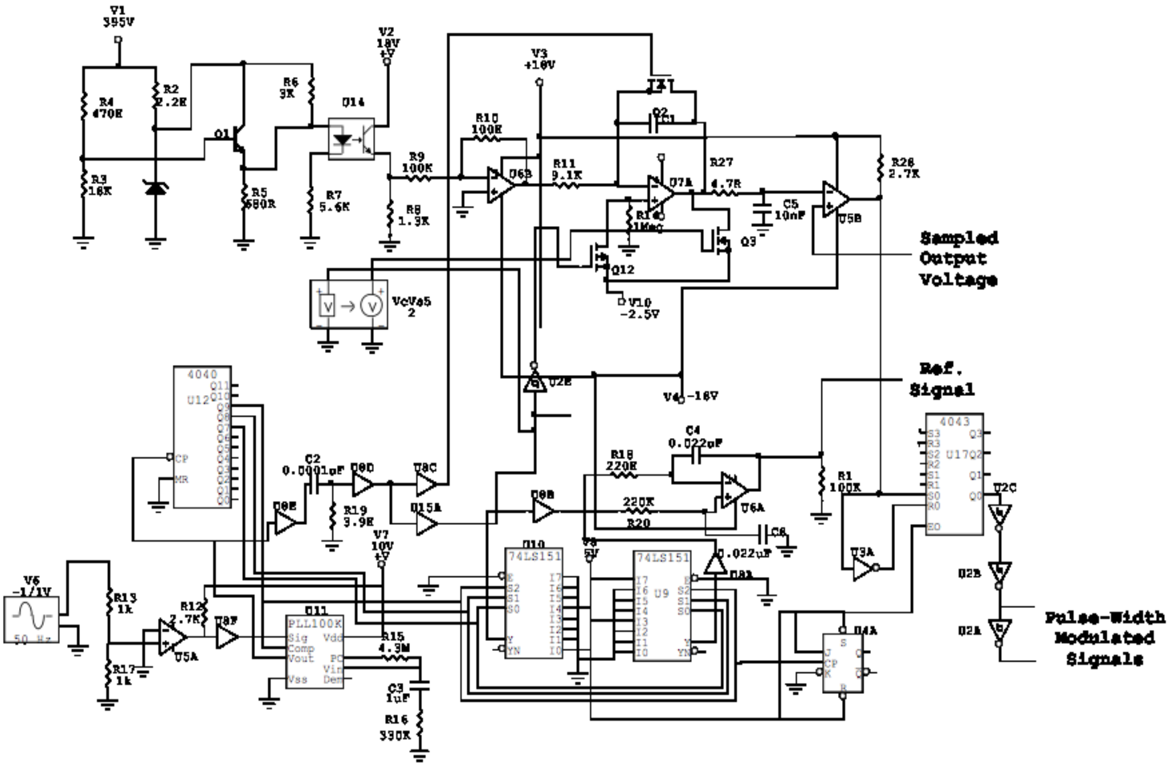

Figure 6: Output voltage modulator.

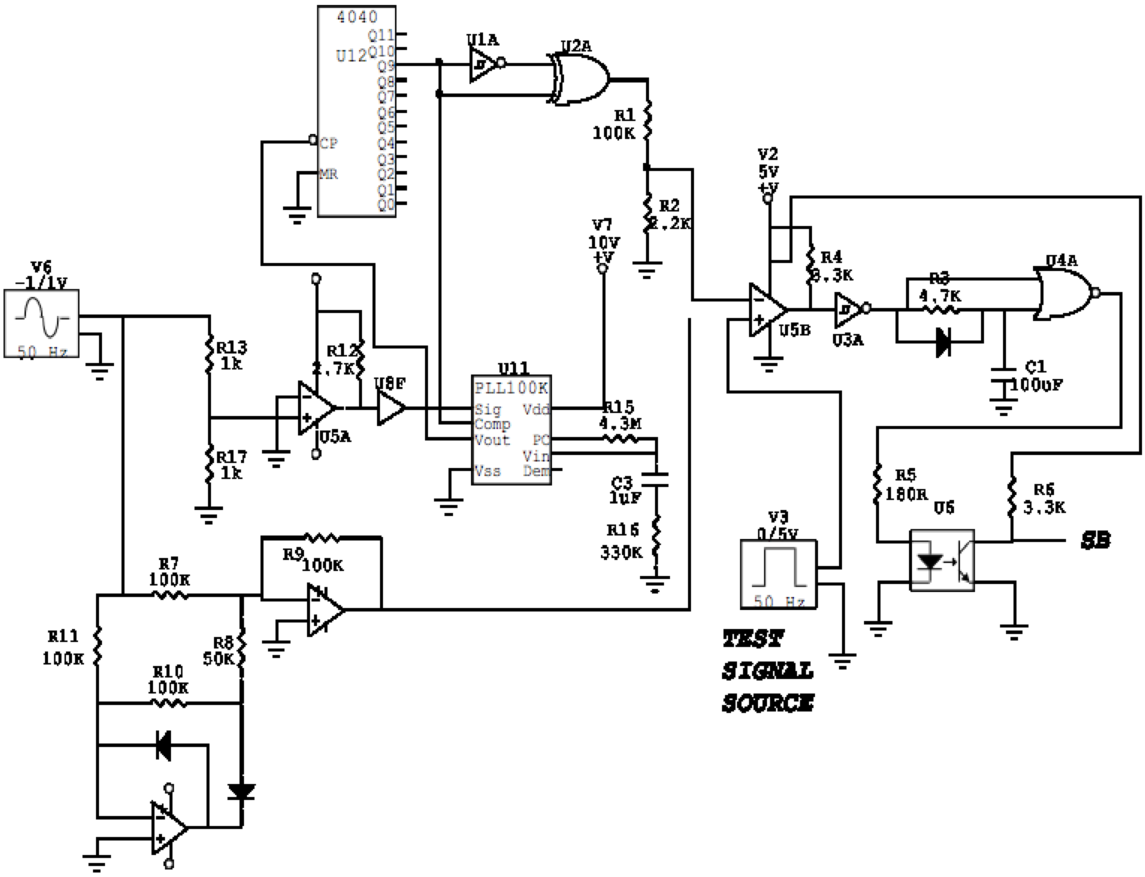

Figure 7: Supply voltage detector.

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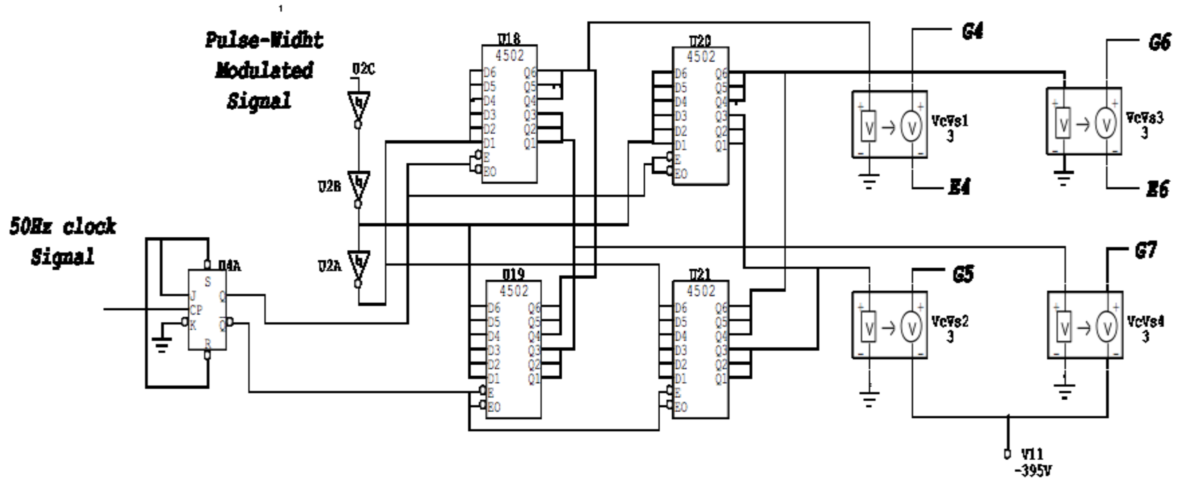

Figure 8: Gating and driver stage.

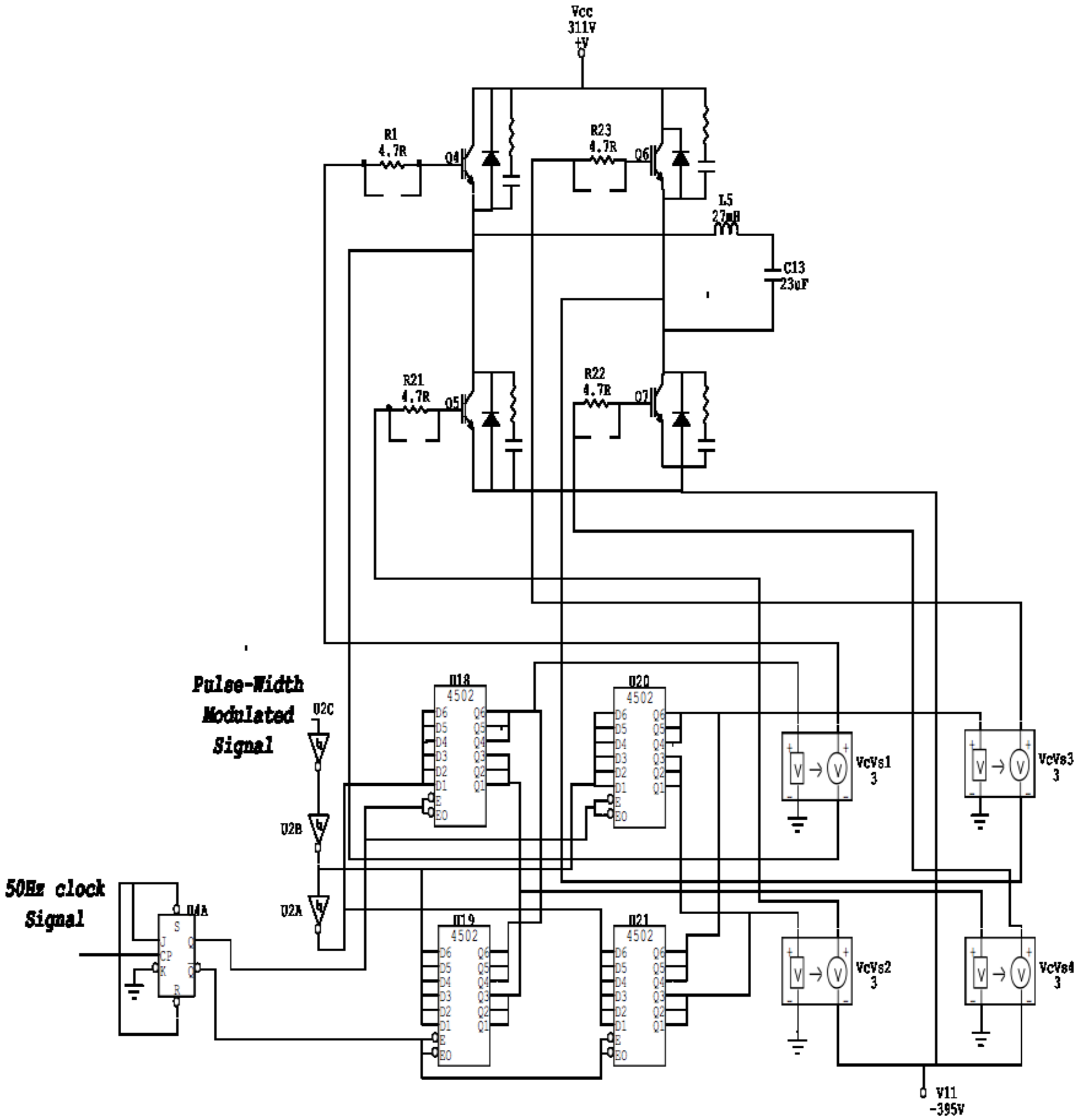

Figure 9: Inverter stage.

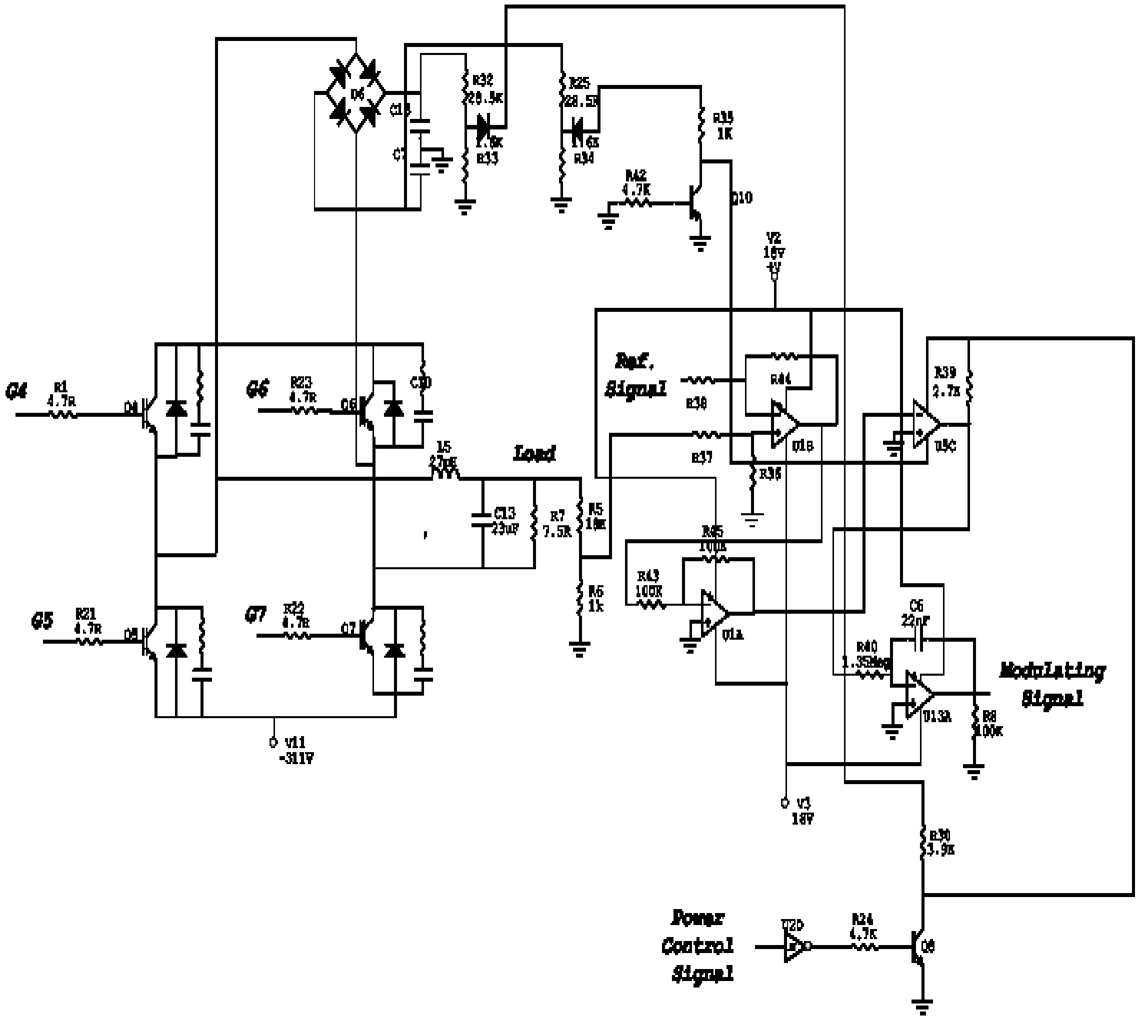

Figure 10: Inverter voltage sensor.

5. Discussion

A 50Hz mains voltage is sampled and fed across the synchronization and reference unit. This is specifically fed into a zero-level comparator which produces a square wave at the same frequency. This signal serve as an input to a phase-locked loop (PLL) configured as a multiplier. This yields a square wave of 51.2 KHz. This is then passed through an edge detector. The signal from this section feeds the switch (operational amplifier) which is positioned parallel with the capacitor of the integrator which constitutes the carrier generator. A 12-stage counter (4040) is positioned along the feedback path of the PLL and its output represents the address signals for the 74LS151 multiplexers. Consequently the multiplexers generate the signals which in turn control the integrator which generates the trapezoidal reference signal. The interconnection of circuits shown in Figure 4 through 10 with respect to the reference signal generate the final trapezoidal load voltage waveform of 90V 50Hz.

Conclusion

The circuit strategy of a TUPS system has been presented. The circuit realization is sufficiently representative of the system performance. The adoption of feed-forward control has allowed main ac voltage fluctuation to be factored into the amplitude of the saw-tooth carrier signal. The waveform result is impressive and lead to the conclusion that carrier-based pulse-width modulation based on the method of fluctuating inverter input voltage can very accurately be used to improve the efficiency and performance of a TUPS system. Also, the desired peak to peak voltage of 90V, 50Hz has be achieved without the use of a low frequency step-up transformer which has always characterized the conventional triangulation method based uninterruptible power supply system.

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