A Simple Gate-Pulse Generating Circuit for Single-Phase Line-Commutated Thyristor Converter

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***Abstract*—The design and implementation of a simple gate-pulse generating circuit for single-phase controlled rectifier under variable input voltage and variable frequency conditions is presented in this paper. The control scheme is consisting of voltage sensor, uncontrolled rectifier, comparator, differentiator, monostable multivibrator, amplifier and pulse transformer. The triggering pulses for the thyristors are generated by comparing the voltage sensor output with the reference dc voltage derived from the uncontrolled rectifier. It is found that the firing angle can be controlled satisfactorily from 0° to 90° by changing the reference voltage. The firing angle, once adjusted, remains constant irrespective of the changes in ac supply voltage and frequency.**

***Index Terms*—constant firing angle, converter, natural commutation, thyristor, varable voltage and frequency**

I. Introduction

Thyristors or Silicon Controlled Rectifiers (SCRs) are widely used as a power semiconductor solid state switching device [1]-[5]. It is mainly used in devices where the control of high power, possibly coupled with high voltage, is demanded. The operation makes them suitable for use in medium to high-voltge AC power control applications. Bipolar Junction Transistors (BJTs) and Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) although have very fast switching characteristics compared to SCRs, their uses are limited to medium power levels at few hundred volts [1]. Moreover, Insulated Gate Bipolar Transistors (IGBTs) are switching devices which exhibits better characteristics over the MOSFETs and thyristors [2]. However, their higher cost and inability to work at very high voltages makes SCR a better choice even today. The turn on process of SCR is known as triggering which initiates it from Forward-Blocking state to Forward-Conduction state [3]. The SCR is triggered into conduction at a firing angle. There are various control schemes used to generate gating pulse or firing pulse which are supplied between the gate and cathode of SCR. The output of thyristor rectifiers provides a dc voltage with variable average value. The average voltage can be controlled and adjusted electronically by delaying the current pulse to the thyristor gates in synchronism with input ac supply voltage.

Thyristor single-phase bridge, shown in Fig. 1, operates on the same principle as the diode single-phase bridge rectifier, except that each thyristor begins to conduct only when a current pulse is injected into the gate when the thyristor is forward biased. Once a thyristor begins to conduct, it continues to conduct until the current flowing through it becomes zero [4], [5].

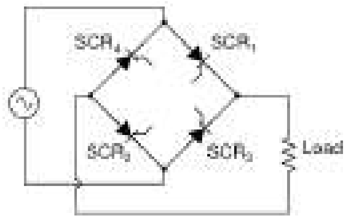

Figure 1. Controlled bridge rectifier.

With a resistive load, the current becomes zero at the instant the ac source voltage passes through zero volts. Therefore, the output is a full-wave rectified voltage which is always positive. When the load is inductive, the output voltage can be negative for part of the cycle [5]. This is because an inductor stores energy in its magnetic field which is later released. Current continues to flow, and the same thyristors continue to conduct, until all the stored energy is released.

There are few popular methods of generating firing pulses [6]-[12]. In one scheme [6] a ramp signal is generated in synchronism with input ac supply voltage by using two comparators and an approximate ramp generator circuit using a transistor and capacitors. In another scheme the supply voltage is first integrated to obtain a cosine wave and is compared with a reference dc voltage. The advantage of this method is that the output voltage is proportional to the control voltage i.e., the

Manuscript received May 11, 2015; revised January 31, 2016.

doi: 10.18178/ijeee.4.5.403-407

output voltage is independent of variation in input voltage. Peter Geno *et al.* [7] presented cosine wave crossing control for firing circuit. The scheme includes various protections like short circuit, under voltage and over voltage etc. Shaikh A. B. *et al.* [8] designed, simulated and fabricated a triggering circuit for converters used in DC drives applications. Subramanian K. *et al.* [9] eliminated the Phase Locked-Loop (PLL) control using a linear ramp signal based synchronization technique that has been proposed and implemented successfully, for the capacitor switching operation of a simple power system [10]. Rafique M. U. *et al.* [11] presented a method which is fully isolated and provides full and stable control over the firing angle of the SCR from 0 to π. This method removes the pulse transformer that is not only expensive but also provides the means of magnetic coupling that is harmful for the circuit.

Tirtharaj Sen *et al.* [12] designed, simulated and fabricated a triggering circuit using cosine control scheme. This circuit is not able to generate a triggering pulse of constant delay angle during supply voltage and frequency fluctuation due to the fact that the reference voltage is taken from a separate source.

In this paper, this limitation is avoided by generating the reference voltage from the output of step-down transformer. The reference voltage is proportional to any supply voltage fluctuation and the firing angle remains constant irrespective of system frequency.

II. Circuit and System Description

A. *Block Diagram of Firing Control Scheme*

The block diagram of the scheme is shown in Fig. 2. It is a single line diagram which shows that the main supply is given to the converter and the logic circuit for generating pulse for the synchronization. The relevant waveforms at different points of firing circuit are shown in Fig. 3. The scheme consists of step down transformer, comparator, differentiator, monostable multivibrator, AND gate, pulse amplifier and pulse transformer. The circuit diagram of firing circuit is shown in Fig. 4.

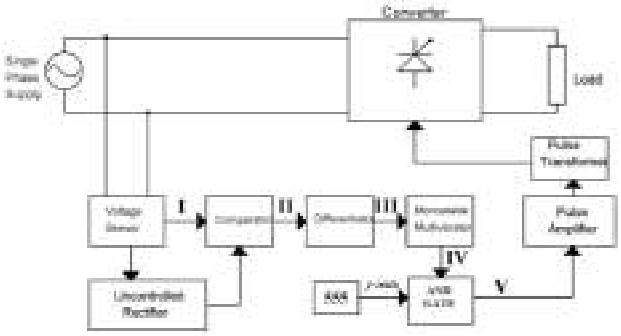

Figure 2. Block diagram of firing control circuit.

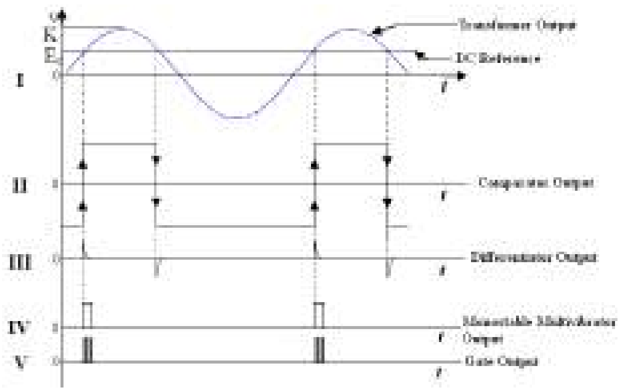

Figure 3. Theoretical voltage wave shapes at different points of the firing circuit.

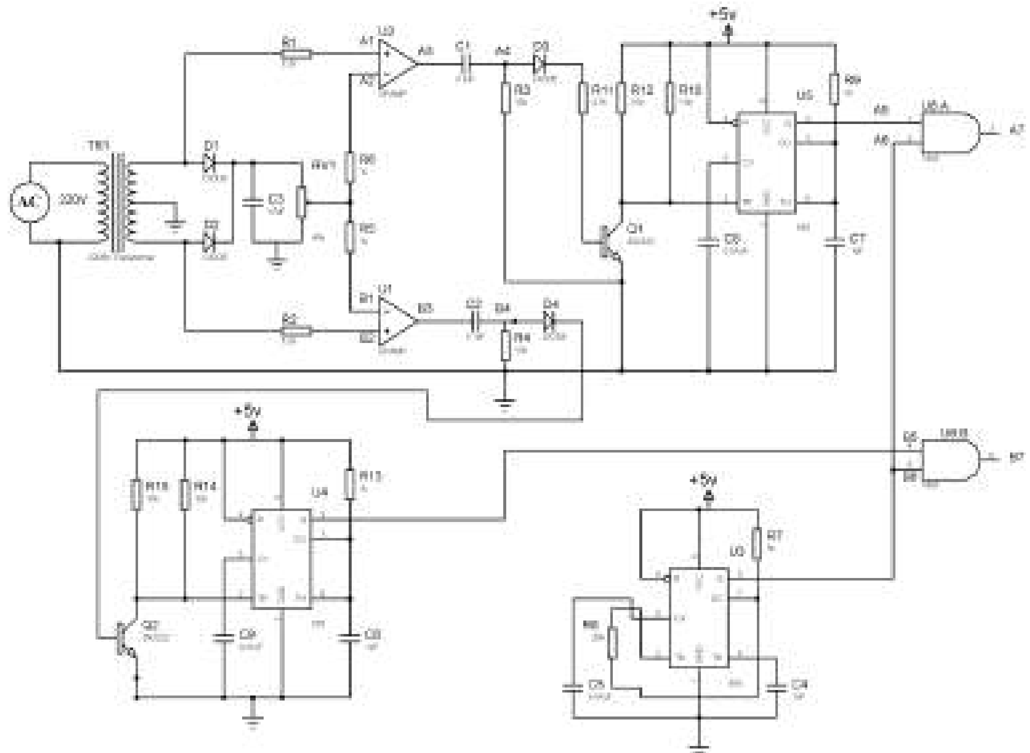

Figure 4. Circuit diagram of the firing circuit.

A brief description of each block along with design features is given below.

Step-down transformer: A single-phase transformer with center tapped secondary windings has been used. The main purpose of this transformer is to step down 50Hz, 220V to 6-0-6V.

Comparator: The secondary voltage of the transformer is compared with a dc reference signal using a 741C op-amp comparator to produce an alternating rectangular waveform of a variable pulse width. The output of the comparator ideally swings between +5 and -5V at every crossing of transformer output voltage and dc reference voltage. Using a variable resistor, the dc reference voltage can be altered and hence the rectangular waveform of variable pulse width is obtained at output terminal.

Differentiator: A simple R-C differentiator is used to differentiate the rectangular voltage waveform. The elements *R* and *C* are selected as 10KΩ and 0.01μF, respectively.

Monostable multivibrator: Monostable multivibrator often called a one shot multivibrator is a pulse generating circuit in which the duration of this pulse is determined by the *RC* network connected externally to the 555 timer.

A 555 timer produces an output pulse using a positive going edge trigger to produce a delay angle between 0° and 90° for the conversion mode of operation. The negative spike of the differentiator is blocked by a connected diode. The values of *R*9 & *C*7 for the monostable are chosen so that the pulse width is approximately 0.5ms. Once triggered, the circuit's output will remain in the high state until the set time elapses.

Oscillator: IC 555 timer is used for oscillator. The oscillator produces square wave output waveform of 20kHz by connecting suitable resistor and capacitor. Pulse gating of thyristor is not suitable for RL loads and this difficulty can be overcome by using continuous gating. However, continuous gating may lead to increased thyristor losses and distortion of output pulse. So, a pulse train generated by modulating the gate pulse at high frequency is used to trigger the thyristor.

AND gate: The outputs of monostable multivibrator and oscillator are applied to the AND gate. IC7408 two input AND gate is used for this purpose. A long duration pulse may saturate the pulse transformer and the firing pulse may be distorted so high frequency modulation is necessary. The duty cycle is kept less than 50 percent, so that the magnetic flux in the transformer can be reset. The modulation pulse also reduces the gate dissipation.

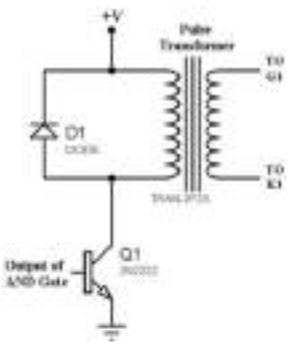

Figure 5. Pulse amplification and isolation circuit.

Pulse amplification and isolation: The gate pulses obtained from AND operation may not be able to turn on the thyristor. It is therefore common to feed these gate pulses to a pulse amplification and isolation circuitry to meet the two objectives of strengthening these pulses and providing proper electrical isolation as shown in Fig. 5.

III. Results and Discussions

Fig. 6 to Fig. 9 shows the simulation results obtained using Proteus Professional 8.1 software. The comparator inputs are taken from step down transformer TR1 and uncontrolled rectifier as shown in Fig. 4. The dc reference voltage can be altered by adjusting the variable resistor RV1 in Fig. 6 and hence the pulse width of the rectangular waveform obtained at A3 of comparator U2 can be varied. The differentiator output is obtained at A4. Fig. 7 shows a similar result obtained from the comparator U1.

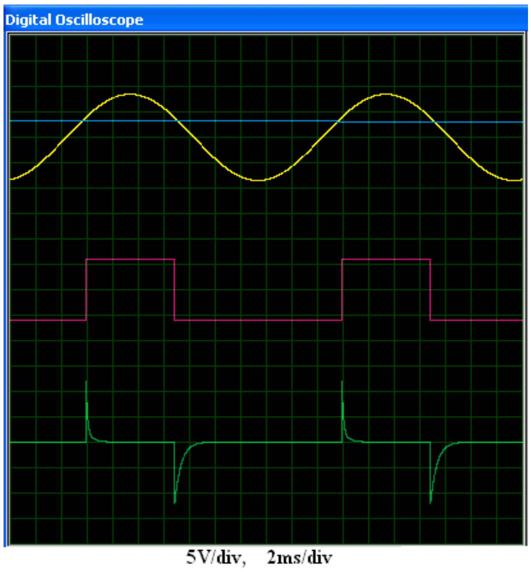

Figure 6. Simulation results at A1 and A2, comparator U2 output at A3 and differentiator output at A4.

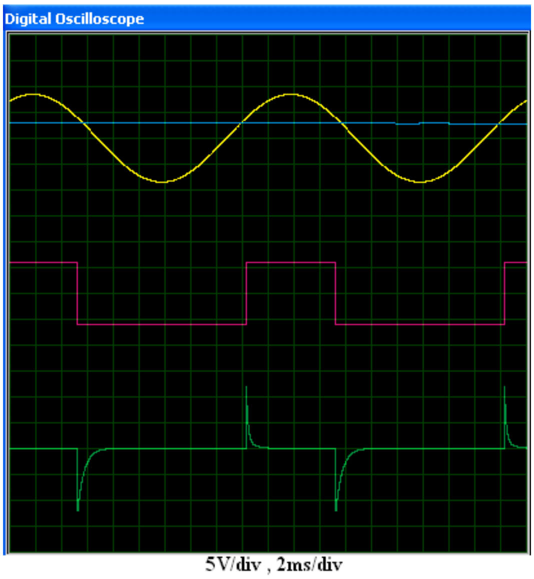

Figure 7. Simulation results at B1 and B2, comparator U1 output at B3 and differentiator output at B4.

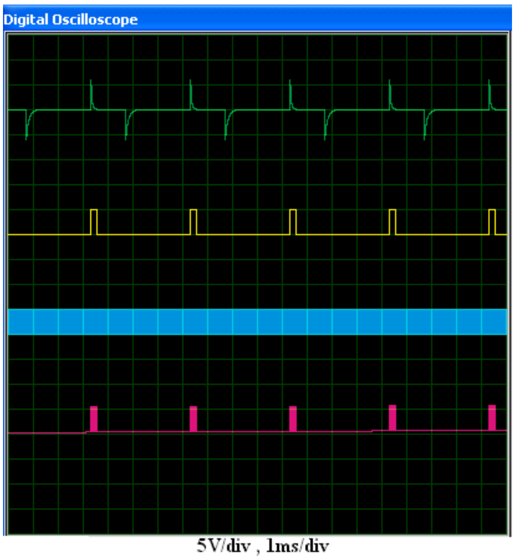

Figure 8. Simulation results for differentiator output at A4, monostable multivibrator U5 output, oscillator U3 output and AND gate output.

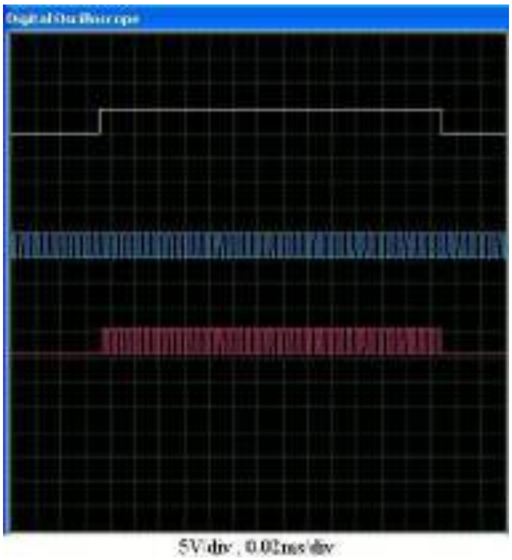

Figure 9. Simulation results for monostable multivibrator U5 output, oscillator U3 output and AND gate output.

Fig. 10 to Fig. 14 shows the experimental results obtained at various points in the circuit. The experimental results are found to be almost similar to the simulation results. However, the voltage wave shape of the experimental sinusoidal voltage obtained from transformer output was not perfectly sinusoidal. This may be due to the manufacturing defects of locally produced transformer.

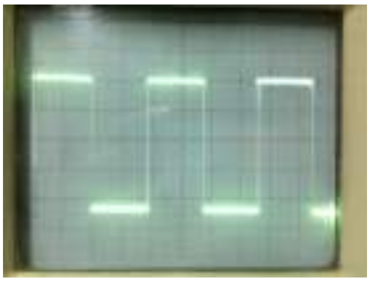

Figure 10. Experimental result of comparator U2 output at A3 [2v/div, 1ms/div].

Figure 11. Experimental results of comparator U2 output at A3 and transformer output signal at A1 [2v/div, 1ms/div].

Figure 12. Experimental results of transformer output at A1 and differentiator output at A4 [2v/div, 1ms/div].

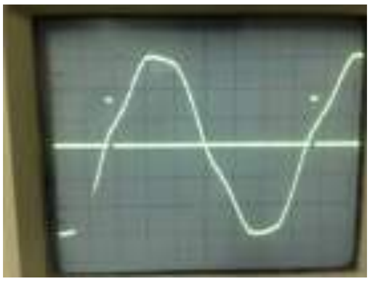

Figure 13. Experimental results of transformer output at A1 and monostable multivibrator U5 output at pin 3 [2v/div, 1ms/div].

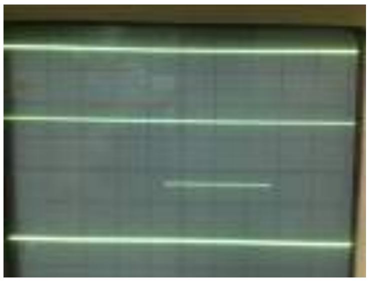

Figure 14. Experimental results of Oscillator U3 output at pin 3 and AND gate output [2v/div, 0.2ms/div].

IV. Conclusions

In this paper a firing circuit for a single-phase controlled rectifier has been implemented and experimentally tested. The present control scheme provides gating pulse where the firing angle is proportional to the dc control voltage and does not change with any variation in input voltage and frequency. The firing circuit was also simulated using Proteus Professional software. It is found that the experimental results are almost similar to the simulation results. Thus, present control scheme can be successfully utilized to get the controlled dc voltage for industrial applications.

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