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Phase-Controlled Converter for Nd:YAG Laser Flashlamp Driver

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Abstract

Phase-controlled technique through thyristors (SCR) is used instead of diodes in order to form a power converter. Output voltage of this power converter can be varied by controlling the firing angle of SCR and is used to charge the capacitor banks. Each firing angles are referred to zero-crossing point of each half of the 50 Hz AC voltage. Adjustable voltage is then used to charge the capacitor bank inside Capacitor Charging Power Supply (CCPS) for Xenon flashlamp driver. Flashlamp produced source of pulsed light that pumped the Nd:YAG laser crystal. The Nd:YAG laser usually operates at various input energies, thus requiring variable values of voltage to charge the capacitor bank. Developed phase-controlled converter can steadily controll the output voltage of CCPS from 500 V to 1000 V.

Keywords: Phase-controlled technique, thyristors (SCR), Nd:YAG laser, Xenon flashlamp driver

Abstrak

Teknik terkawal-fasa melalui rektifier terkawal-silikon (SCR) telah digunakan sebagai menggantikan diod untuk membentuk pengubah kuasa. Voltan keluaran daripada pengubah kuasa ini boleh dipelbagaikan dengan mengawal sudut tembakan pada SCR dan digunakan untuk mengecas bank kapasitor. Setiap sudut tembakan akan dirujuk kepada titik silang-sifar untuk setiap separuh tempoh voltan AC 50 Hz. Voltan boleh ubah ini kemudian digunakan untuk mengecas kapasitor bank di dalam pembekal kuasa pengecas kapasitor (CCPS) untuk pemandu lampu kilat Xenon. Lampu kilat membekalkan sumber cahaya denyut yang akan mengepam kristal laser Nd:YAG. Nd:YAG laser biasanya beroperasi pada pelbagai tenaga input, maka ia memerlukan voltan boleh ubah untuk mengecas bank kapasitor. Pengubah kuasa terkawal-fasa yang dibina boleh mengawal dengan mantap voltan keluaran CCPS dari 500 V ke 1000 V.

Kata kunci: Teknik terkawal-fasa, rektifier terkawal-silikon (SCR), laser Nd:YAG, pemandu lampu kilat Xenon

Introduction

By varying the charging voltage of the capacitor banks, one can supply various level of energies to pump the Nd:YAG rod through the lighting process of the flashlamps. One of the most rugged and cost effective techniques to provide fully controlled voltage for capacitor's charger is by using the phase-controlled rectifier, also known as phase-controlled thyristor. The output voltage is varied by controlling the delay or firing angle of thyristor.

A phase-controlled thyristor is turned on by applying the short pulse to its gate and is turned off due to natural commutation of the AC line (Rashid, 2004; Al-Majali, 1997). Phase-controlled thyristor based power converter provides an efficient means for a control of high DC power circuits (Deuitch and Paz, 1957).

This voltage control circuit contains three main parts; zero crossing detection part, controller circuit and triggering section. The advantage of using phase-controlled thyristor comparing to other voltage control technique is that it can easily handle a high power module by changing the type of thyristor being used; high power thyristor for high power application and vice versa.

This paper describes the design of phase-controlled converter developed for capacitor charging power supply in Nd:YAG Xenon flashlamp driver. This power supply is expected to replace the conventional capacitor charger that used the variable transformer or variac to control the charging voltage of the capacitor banks.

Requirements for Converter

By using a pure DC supply such as a battery, the capacitor will charge up with a time constant that depends on the capacitance value and the impedance through which the current flows into the capacitor. However, the output from a phase-controlled thyristor is not purely DC. This means that the charging process of the capacitor depends on how fast the output current level is changing.

The operation of the phase-controlled thyristor may be explained by a gradual variation of the firing angles of the controlled rectifier (Al-Majali, 1997). The output voltage and current from the converter have one polarity. If V_m is the peak input voltage, the average output voltage V_{dc} can be found from Equation (1):

$$V_{dc} = \frac{V_m}{2\pi}(1 + \cos\alpha) \tag{1}$$

And V_{dc} can be varied from $\frac{V_m}{\pi}$ to zero by varying α from 0 to π. The average output voltage become maximum when α = 0 and the maximum output voltage V_{dm} is written as;

$$V_{dm} = \frac{V_m}{\pi} \qquad (2)$$

The output voltage can be normalized with respect to V_{dm}. Normalized output voltage is given by:

$$V_n = \frac{V_{dc}}{V_{dm}} \qquad (3)$$

Normally, there will be the gating sequences when triggering the thyristors. The gating sequences for the thyristors switch is generating a pulse-signal at a positive zero crossing of the supply voltage V_S first, then pulse is delayed by the desired angle α, and is applied between the gate and cathode terminals of the thyristors through a gate isolating circuit (Rashid, 2004).

Control Technique

Figure 1 shows the functional block diagram of the phase-controlled converter. It comprises of five main circuit blocks namely the zero-crossing detectors, microcontroller, triggering, isolation and phase-controlled thyristor itself. Single phase AC voltage is supplied to the converter through zero crossing detector blocks.

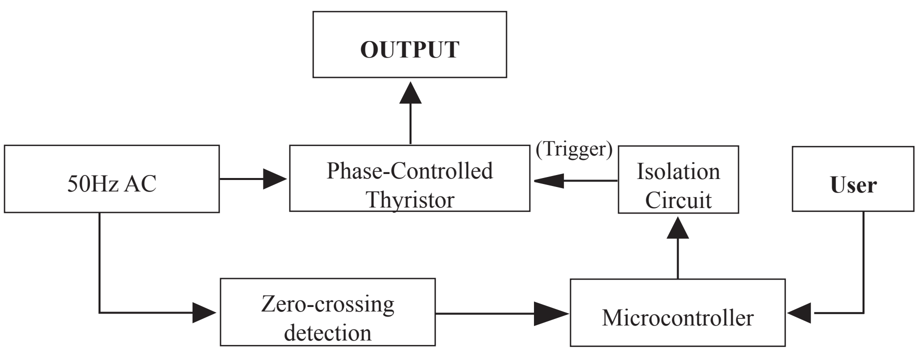

Figure 1 Functional block diagram for the Phase-Controlled Converter

In order to fire the triggering pulses precisely, it should be referred to the instant where the input supply crossing the zero line (Scholand and Jung, 2003). A pulse is generated at the zero crossing instant of each half cycle. The duration of half cycle for the 50 Hz AC voltage is 10 ms corresponding to 180 degree of traverse time. All delayed of the triggering pulse will be referred to this zero crossing point.

The output pulses corresponding to zero crossing points of both the positive and negative half cycles of 50 Hz supply from the zero crossing detector blocks are fed to the microcontroller. The microcontroller acts as the brain for the whole system to provide the triggering pulses at multiple value of firing angles. The delayed triggering pulses then, being fed to the thyristors via the isolation blocks. Microcontroller can provide additional information relating to trigger delay for displaying purposes or any higher function orders.

The lines carrying trigger pulses from the microcontroller to the converter section must be isolated to avoid high voltages reaching the controller in the event of thyristor's failure. Opto-SCR driver is used which output can drive the thyristors directly. Two such isolators are used for the two triggering signals; one for each thyristor.

The developed phase-controlled converter was characterized by using the standard oscilloscope and high-voltage probe. The control unit was supplied by a 50 Hz AC voltage. The firing angle was verified within the range of 0 to 360 degree which corresponding to delay trigger pulse of 0 to 20 ms.

Experimental Result

In performing the calibration, the output signal was measured by delaying the trigger pulses within 0 to 20 ms. The typical output signal obtained from this experiment is shown in Figure 2. Signal a (the top line) shows the output signal from 50 Hz voltage supply. Signal b (the center line) indicates the output signal produced when trigger pulse delayed at 10 ms. Finally, signal c (the bottom line) shows the shape of output voltage corresponding to delay time of 5 ms.

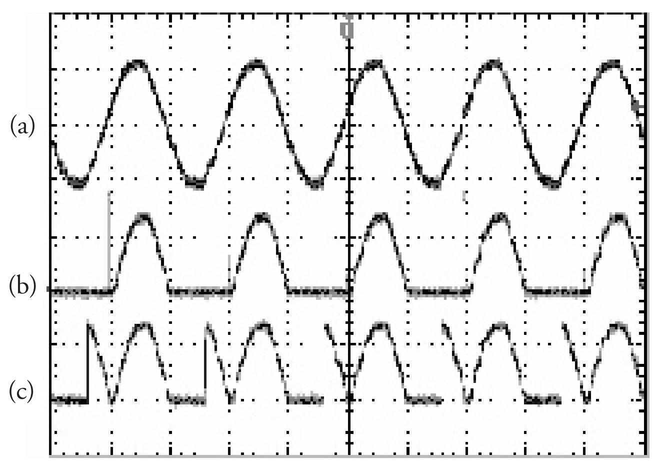

Figure 2 Comparison of output signal from voltage control unit at variable trigger pulse. (a) no trigger pulse (b) 10 ms delay (c) 5 ms delay

The average output voltage V_{dc} , the maximum output voltage V_{dm} and finally the normalized output voltage were computed using Equation (1) – (3). The computed data are used to plot the graph of normalized output against delay time of trigger pulse. The graph is shown in Figure 3. The normalized output was found inversely proportional to the delay time of trigger pulse.

The experiment result was compared with the theoretical value. The dark line represents the theoretical and the dash line is experimental result. The comparison shows that at low firing angle, the experimental output signal is similar to theoretical value showing that the developed voltage control unit was capable to verify precisely the output voltage within 50 % to 100 %. In case of a power transformer having output voltage of 1 kV, this voltage control unit would be able to vary the output within 500 V to 1000 V precisely by delaying the trigger pulse from 1 ms to 10 ms.

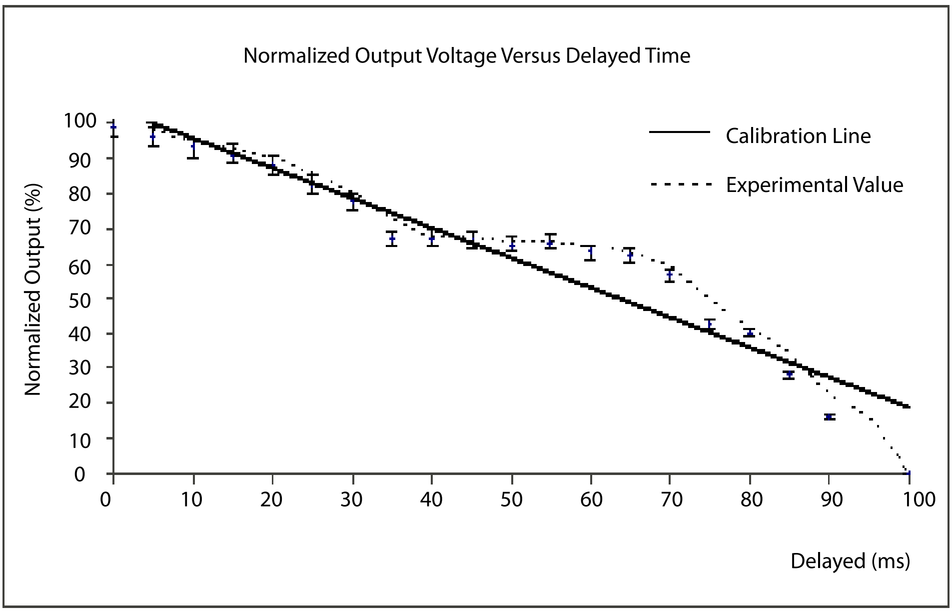

Figure 3 Normalized output voltage versus time delay of trigger pulse

At higher range of firing angle, the experimental output was found slightly unstable. Since the system was build to control the high power charging modules, the error at the high-end of firing angles will be less significance. This is because the minimum charging voltage of the capacitor banks in simmer-mode flashlamp driver, should not less than the simmer voltage being supplied across the flashlamps (Elwell et al., 1995). The rectified output voltage then will be used directly to charge the capacitor banks.

Conclusion

The output voltage of the AC-DC converter is controllable using the phase-controlled thyristors to replace a variable transformer. The charging voltage to charge the capacitor banks can be varied by changing the firing angles of the thyristors. By using the microcontroller, the control technique can be fully digitized and thus increasing the system's reliability.

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