A Novel Approach to Implement a Closed Loop Controlled Power Converter in Thermal Vacuum Tubes

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Abstract*— In electronics, vacuum tube or electron tube is a device that controls electric current between electrodes in an evacuated container. Vacuum tubes mostly rely on thermionic emission of electrons from a hot filament or a cathode heated by the filament. One of the critical issues of these vacuum tubes is, maintaining the powered filament tube for a long time. Filament gradually becomes weak due to irregularities in supply voltage and higher heat generation. Weak filament can be easily identified by observing the reduced output power of the tube. Sudden filament supply failures and irregularities in supply cause the filament to be deteriorated. In this approach, we consider a self-controllable switching power supply which produces a ramp voltage output by varying firing angle of thyristors with respect to time. To generate the ramp voltage, the power converter is introduced. The ramp voltage is set as the input power supply to the filament. Such power supply helps minimize possibilities to occur sudden and huge current spikes which are capable to harm filament. Proposed power converter consist of a pulse generator to generate PWM pulse, a pulse amplifier to step up the input voltage, an initiator to create basic ramp signal, a synchronizer to match triggering pulses with ac line input, a supervision circuit to detect faults and a communication unit for dealing with plant's main control unit. Here, a controllable AC output is used for the purpose of pulse generation and supervision. Constant negative ramp voltage generated through the initiator circuit is fed to a differential amplifier to obtain an inverted output which is decreasing with time. The pulse generator is built with a RC circuit of which charging time is proportional to the output voltage of the differential amplifier. The RC circuit fires a PNPN diode to generate a low voltage basic pulse. It is recognized that the generated pulse is not sufficient enough to fire two back to back thyristors configured in the thyristor bank. A pulse transformer and amplifier circuits are occupied to step up the generated pulses. Finally amplified pulses are fed to a gate of the three terminal thyristors to fire up and obtain the desired output voltage of the converter. This approach makes the filament supply voltage a reliable input regardless of the magnitude or a specific application.*

Keywords—Power-Converter, Rectifier, Thermal, Thyristor, Vacuum-Tube

I. INTRODUCTION

Thermal electron vacuum tubes are mainly used in high power radio transmitters, X-ray machines, research laboratories, etc. Most probably those are high expensive devices in many applications such as 250KW short wave radio transmitters. In an electron tube, electric current is controlled between electrodes in an evacuated chamber [2]. Thermionic tube or thermionic valves are commonly recognized as devices which emit thermionic electrons from a hot filament. The simplest vacuum tube, the diode, contains only a heater, a heated electron-emitting cathode (the filament itself acts as the cathode in some diodes), and anode. Current can only flow in one direction through the device between the two electrodes, as electrons emitted by the cathode travel through the tube and are collected by the anode. Adding one or more control grids within the tube allows the current between the cathode and anode to be controlled by the voltage on the grid or grids [4].

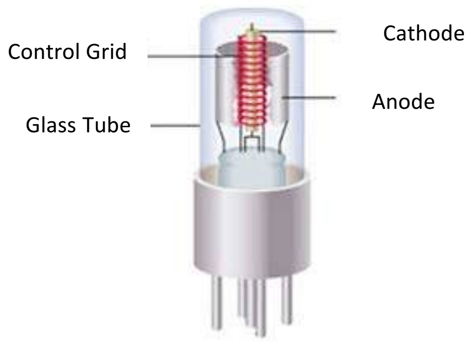

Figure 1. Thermal Electron Vacuum Tube with a Control Grid [4]

These electron tubes are similar to transistors, but employed in high power applications. Internal electron flow from cathode to anode decides the operation and functions of a cathode tube device. The electron flow is crafted by its filament and the life time of the tube is significantly affected by the quality and properties of the filament. In addition to that supply voltage Filament supplier is one of the most critical functional blocks in entire application.

II PROPOSED APPROACH

Figure 2 presents the basic overall picture of the power converter design which include major components,

- Pulse generator to generate PWM pulse
- Pulse amplifier to step up the input voltage
- Initiator to create basic ramp signal
- Synchronizer to match triggering pulses with AC line input
- Supervision circuit for fault detecting
- Communication unit for dealing with plant's main control unit

Primarily, the output of the power converter, i.e. the filament supply voltage should resist load and source fluctuations. Also it must be able to increase gradually in the form of a ramp input. For the control strategy, the output must always be monitored and, fault detection and indication must also be a part of the system. Further proper safety and communication mechanism has to be established for the entire plant. Apart from those, the converter output has to be in lined with the following numerical values.

- Output current: 300A (rms),
- Maximum capacity: 3KW,
- Full filament voltage ramp: 10V,
- Confirmation signal is issued to main control system of plant at 5s.

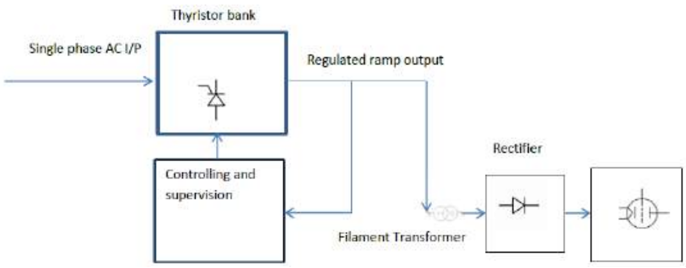

Figure 2. Overview of the power converter with major components

III. FUNCTIONAL DESCRIPTION

Figure 5 (next page) presents overall block diagram for the Thermal Stabilizer. In the diagram UA is the controllable AC output. UA is fed to T1 and T3 for the purpose of pulse generation and supervision respectively. Output of the T1 is reduced by voltage divider configured through resistors and it is fed to a RMS to DC converter (AD532) which the output is directed to non-inverting input of a differential amplifier. Inverting input of the differential amplifier is set to a constant negative ramp voltage generated through the initiator circuit. Differential amplifier gives an output which is decreasing with time due to constant negative ramp voltage input. Pulse generator is built with a RC circuit of which charging time is proportional to the output voltage of the differential amplifier. The RC circuit fires a PNPN diode (two pin) to generate a low voltage basic pulse. It is recognized that the generated pulse is not sufficient enough to fire the back to back thyristors configured in the thyrister bank. A pulse transformer and amplifier circuits are occupied to step up the generated pulses. Finally amplified pulses are fed to a gate of the three terminal thyristors to fire up to obtain the desired output voltage of the converter.

A. Power System Overview

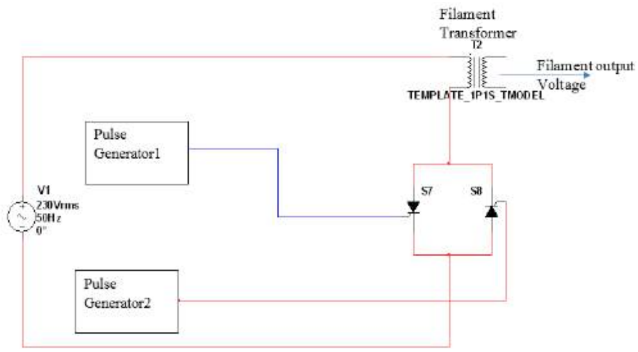

Figure 3. Back to back controllable thyristor rectifier

Figure 3 is a simple format of the block diagram shown in Figure 5 which presents the overview of the Thyristor Rectifier as a circuit diagram. Voltage drop across or current through the primary of filament transformer is controlled by pulse generators which generate firing pulses for S7 and S8 thyristors. A phase shift of 180° is maintained between two pulse generators to ensure the equal firing of positive and negative cycles to the line supply.

B. Pulse Generators

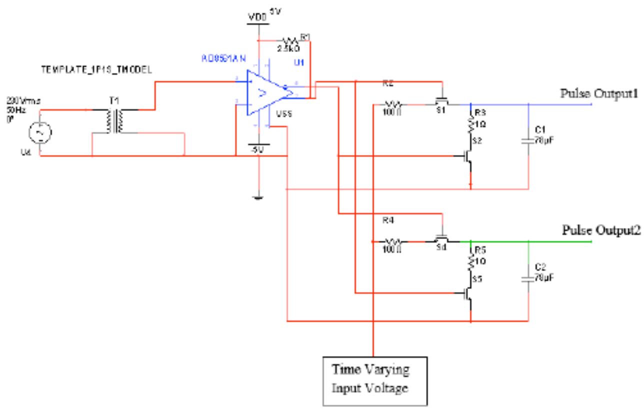

Figure 4. Pulse generators

Figure 4 shows the proposed pulse generator circuit. Here, AD8561; a high fast dual output analog comparator is used. Stepped down line voltage from the T1 transformer is compared with zero reference voltage to produce switching pulses for S1, S2, S4 and S5 MOSFET switching transistors. Pin7 and Pin8 of the comparator are set for complementary outputs. Input voltage for Pulse Output1 and Pulse Output2 is common. It is a time varying supply voltage to ensure the time gap between generated pulses gradually reduces so that firing angle gradually increases with the time being until the stable pre-set value is reached.

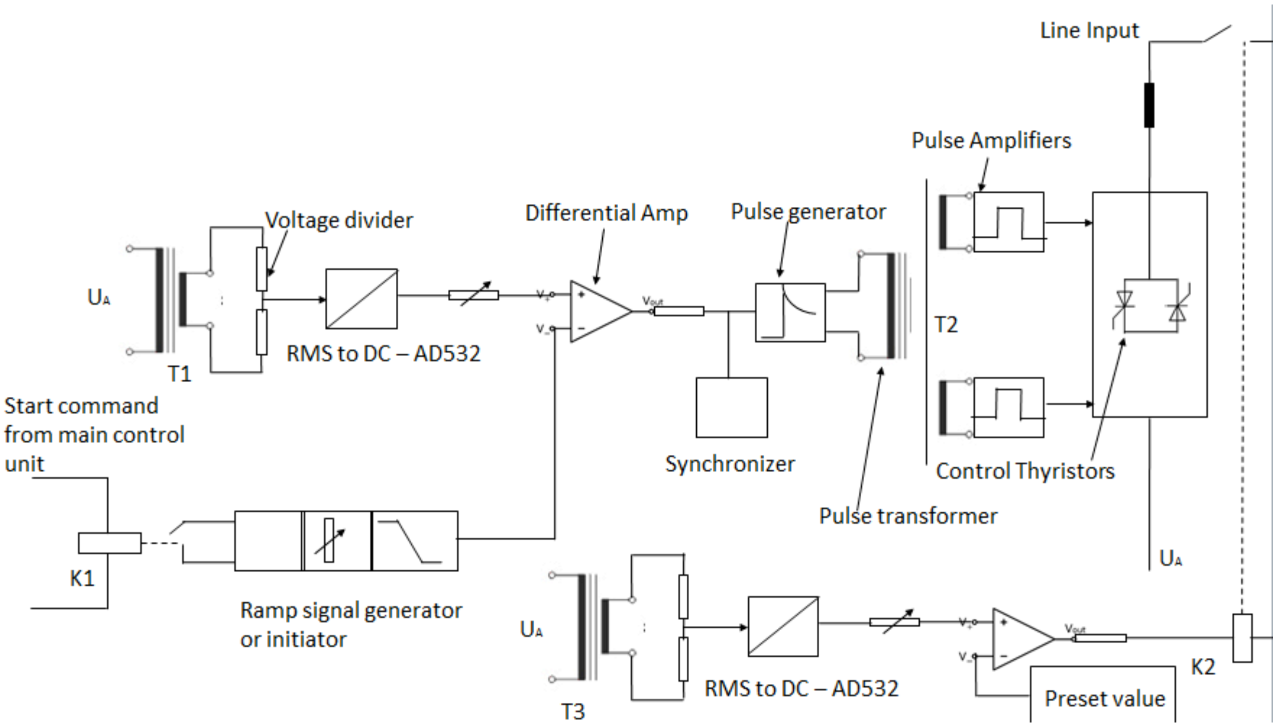

Figure 5. Complete block diagram of the proposed thermal stablizer

IV RESULTS AND DISCUSSION

Figure 6 shows the pulse generator and ramp generator output waveforms with respect to circuit diagrams shown in Figure 4 and Figure 8, respectively. In Figure 4, during the positive half cycle, the input voltage is fed to non-inverting input (pin 2) of the comparator. This voltage is compared with zero reference voltage given at the inverting input (pin 3). Consequently, pin7 gives a positive 5V pulse output and at the same time pin8 stands with a 0V output due to the complementary property. Therefore, S1 and S5 attain switched-on state, while S2 and S4 attain switched-off state. When S1 is switched-on, C1 capacitor starts charging. After for a while, C1 will reach triggering voltage of S7 thyristor [Figure 4].

The time duration to reach triggering voltage directly depends on the nature of the time varying input voltage. In another view, during the positive half cycle only S7 thyristor is fired. Concurrently, S5 MOSFET is switched on and pre-charged C2 is discharged instantly due to low resistor value of R5. Same procedure is applied in negative half cycle except status of switching devices.

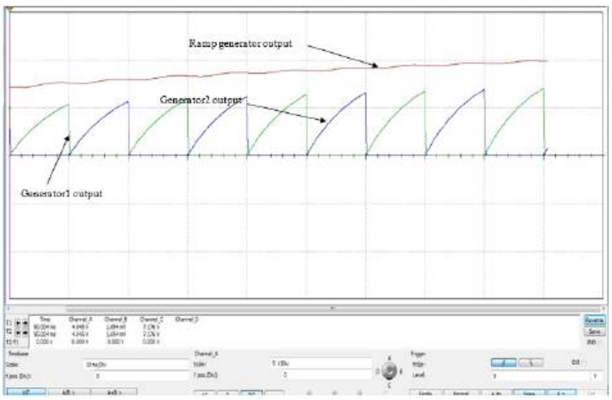

Figure 6. Pulse generator output and ramp voltage input

Figure 7 illustrates outputs of both initiator and ramp generators presented in the proposed circuit in the Figure 8.

At the beginning output voltage is set to zero. Output feedback voltage is compared by AD8561 of which pin2 is set for output feedback voltage. Voltage at pin3 is pre-set to 3.4V in this circuit (According to our application). At the beginning, voltage at pin2 of the comparator is set to low value than that of at the pin3 by implementing the circuit configuration. Therefore output pin7 stands with a 0V output and pin8 stands with a 5V output which is capable to switch on S3 and S6 switching MOSFETs. Thereafter, V1; -4.5V supply is connected to inverting input of 741 Op-Amp and non-inverting input has a zero voltage as S3 is in switched-on state.

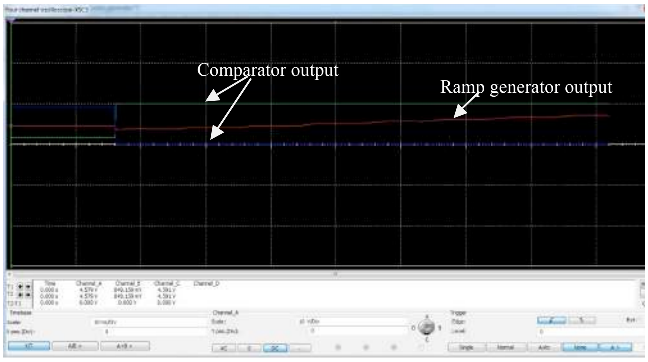

Figure 7. Output waveforms; ramp and comparator

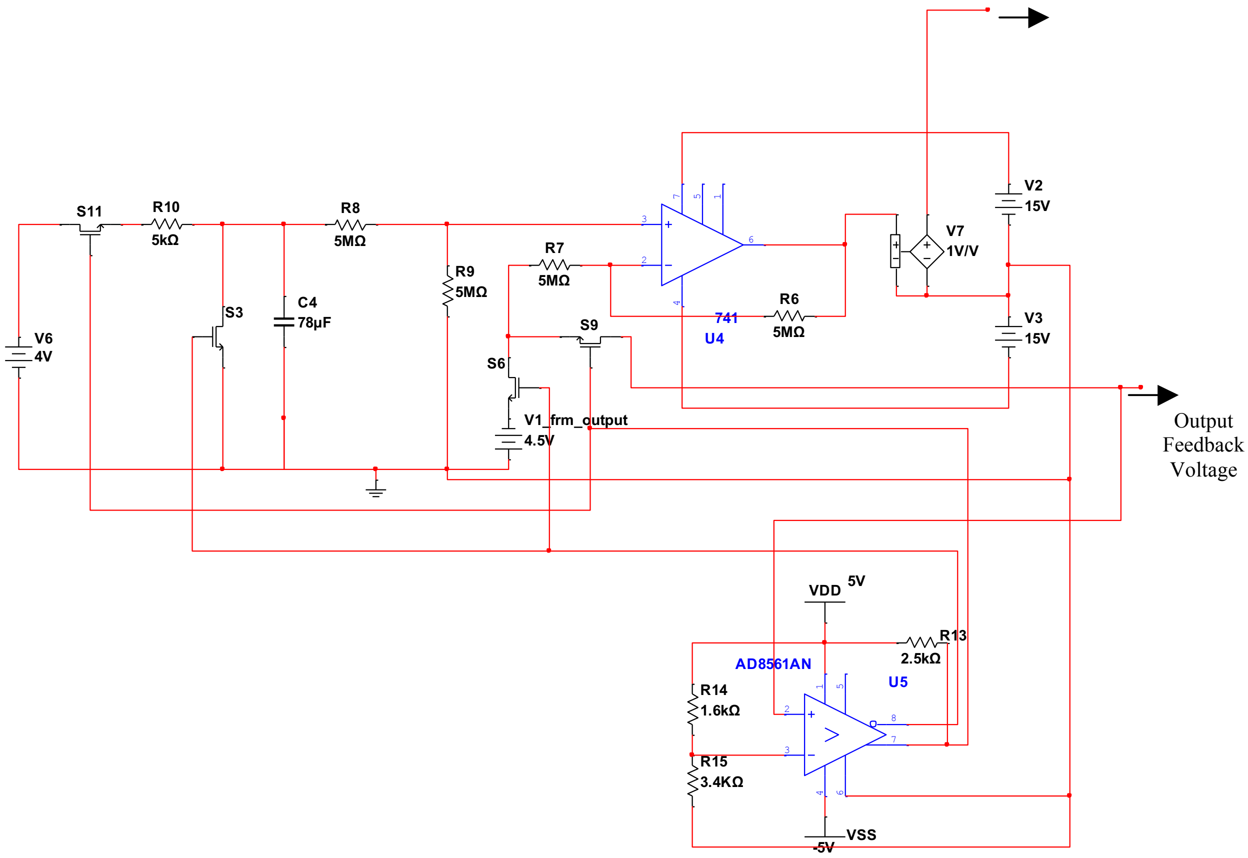

Figure 8. Circuit diagram for initiator and ramp generator

The voltage difference of these input pins is amplified by factor one and supplied to pulse generators. It is clear that at the initial stage, the voltage difference is 0-(-4.5V) =4.5V. This voltage is capable of creating pulses to fire-up back to back thyristors successfully. At the end of this initial time period, output feedback voltage has increased to a higher value than pre-set 3.4V at the pin3 of the comparator. Subsequently 5V and 0V outputs are generated at pin7 and pin8 respectively. As a consequent, MOSFET S9 and S11 are switched on, S3 and S6 (Previously on) are switched off instantly. Now, 741 OP-Amp is set with a negative output feedback voltage at pin2 and non-inverting input is set with an exponentially ramp signal. The difference voltage will be amplified by the amplifier. Difference of input voltage is increased with time, i.e. the output voltage of OP-AMP is also increased with time. This ramp voltage is supplied to input of the pulse generator. The time gap of the pulses reduces so that firing angle of the thyristor increases. R10 and C4 generate exponentially increasing voltage which is to set at pin3. By changing the values of the components we can adjust the settling time of the whole system comfortably. This exponentially increasing voltage is stabilized at a certain time according to capacitor charging equation. Subsequently, the output voltage of 741 OP-AMP becomes stable.

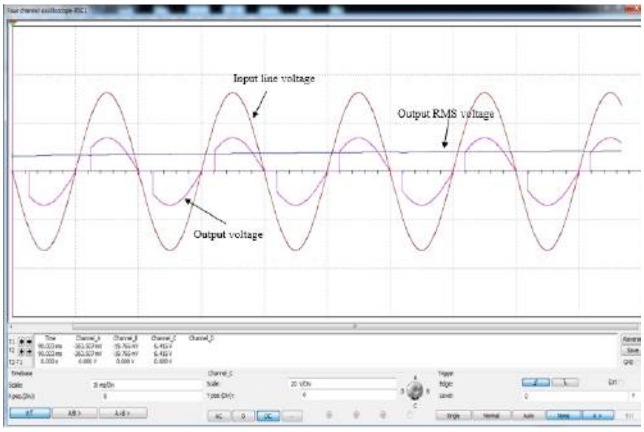

Figure 9. Input and output voltage wave forms of the power converter

Finally, the input voltage for pulse generators will also reach to a stable value by ensuring the stabilized final output. Waveforms shown in the Figure 9 witness that the supply voltage to thermal vacuum tube is in the form of AC input (standard power input) and the desired output voltage is formed in a way that, back to back thyristors are fired by varying the firing angles. Hence proposed converter technique has introduced a non-irregular closed loop controlled regulated power supply to the filament of the thermal vacuum tube.

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