RECTIFIER-TYPE THYRISTOR POWER AMPLIFIER (SINGLE AND THREE PHASE)

I. Introduction

This leaflet will discuss basic principles of operation of single and three phase, rectifier-type, thyristor power amplifiers. Additional literature contained within the instruction book will provide specific ratings and installation procedures for the customers particular order.

For brevity, TPA will be used as the abbreviation for thyristor power amplifier throughout the leaflet.

A. Thyristor

The thyristor is a three-terminal, silicon device which exhibits characteristics similar to a thyratron. It is capable of blocking both forward and reverse voltages; and when forward biased (anode positive with respect to the cathode), will switch to the conducting state if the gate is supplied with a positive signal. Once turned on, the cell continues to conduct until the voltage across it reverses or the current through it falls below a minimum value--termed the holding current.

B. Rectifier-Type TPA (General Information)

Rectifier-type TPAs are used to convert a-c line voltage to a controlled d-c output voltage. This is accomplished by replacing half of the diodes in conventional, bridge rectifiers by thyristors and phase controlling the gate pulses supplied to them.

The output voltage and current from a rectifier-type TPA are unidirectional; hence, power inversion is not possible (power flow can only be from line to load).

II. Single-Phase, Rectifier-Type TPA

For the purpose of explanation, the single-phase, rectifier TPA will be divided into functional subassemblies. Only components fundamental to basic circuit operation will be shown, and these will be idealized to simplify the discussion. Components essential for reliable circuit operation and common to both single-phase and three-phase, rectifier-type TPAs will be discussed in the last section of this instruction leaflet.

Figure 1 is a block diagram of the single-phase, rectifier-type TPA. The basic subassemblies to be discussed are outlined by dotted lines, and all inputs to and outputs from the amplifier are shown.

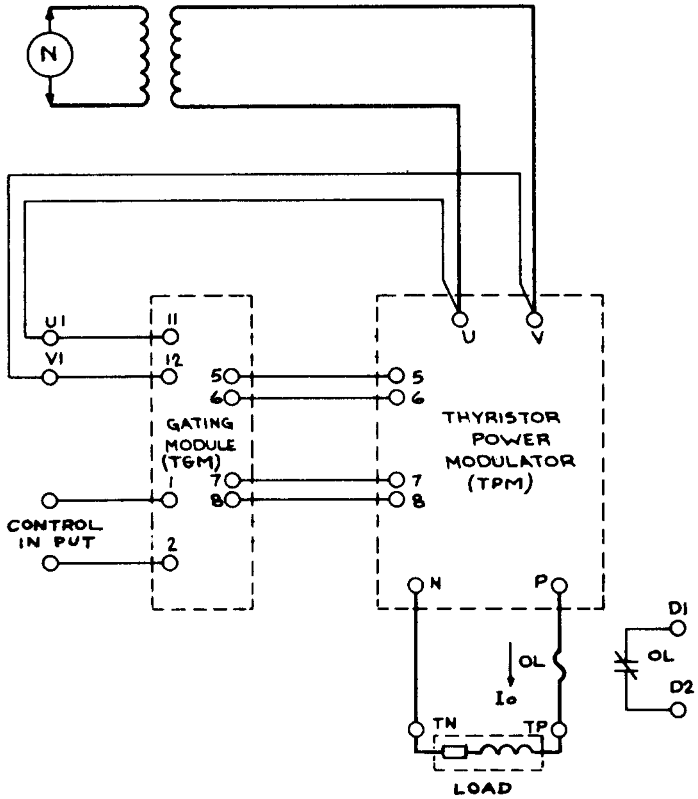

FIGURE 1 - BLOCK DIAGRAM SINGLE PHASE RECTIFIER TYPE TPA

A. Thyristor Gating Module (TGM)

The function of the TGM is to provide gate pulses of sufficient amplitude, width, and proper phase relation to fire the thyristors of the thyristor power modulator (TPM).

Figure 2 shows a typical gate pulse from the TGM in phase relation to the line voltage across the thyristor it is firing. The firing angle is measured from the time the thyristor first becomes forward biased and the leading edge of the gate pulse. This angle may be shifted with respect to the voltage across the thyristor from $\alpha \approx 10^\circ$ to $\alpha = 180^\circ$ by a control signal input to the module.

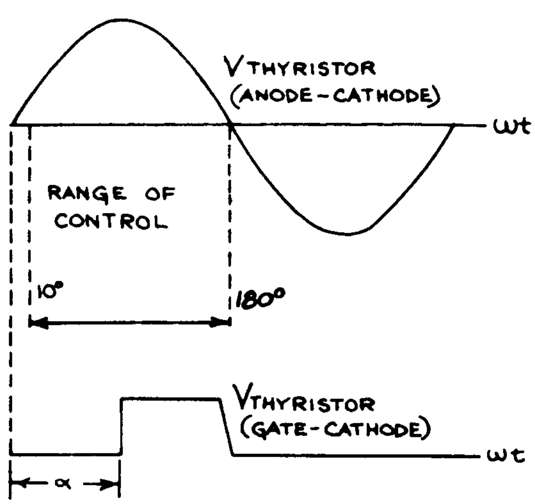

FIGURE 2 - TYPICAL GATE PULSE FROM TGM PHASE RELATED TO LINE VOLTAGE ACROSS THYRISTOR.

Proper polarity of the synchronizing voltage to the TGM ($V_{U1}-V_{V1}$) must be observed; otherwise, the thyristor would receive gate pulses while reverse biased and would not conduct.

The detailed circuitry and description of operation of the TGM is contained in separate instruction leaflets.

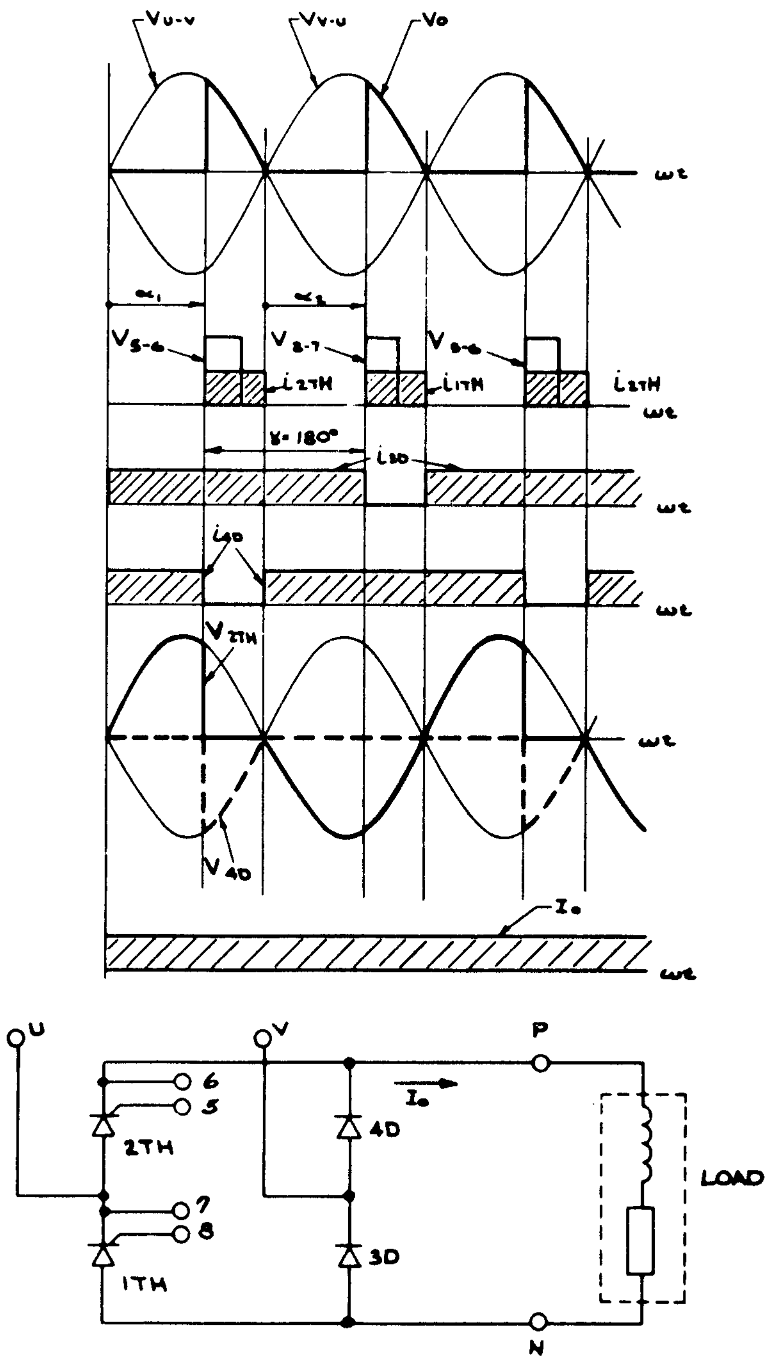

FIGURE 3 - SINGLE-PHASE RECTIFIER TYPE TPM

B. Single-Phase Thyristor Power Modulator (TPM)

The single-phase, rectifier-type TPM is essentially a single-phase bridge rectifier with thyristors in two legs of the bridge and silicon diodes in the other two legs. Figure 3 shows a simplified schematic of a single-phase rectifier TPM along with time-related waveshapes for an assumed firing angle ($\alpha = 120^{\circ}$).

Referring to Figure 3, the terminals U and V are connected to a feeding AC source and the terminals P and N to the load. Some of the typical waveforms are displayed for a firing angle, $\alpha = 120^{\circ}$, inductive load. A steady-state condition is assumed at $\omega t = 0$, with the load current I_o flowing through the diodes 3D and 4D. At $\omega t = \alpha_1$, a gate pulse is applied to thyristor 2TH, which then will switch to a low impedance state. The current will now commulate from 4D to 2TH, and output voltage V_o will follow the trace of the line voltage V_{u-v}. However, at $\omega t = 180^{\circ}$, the latter reverses its polarity and the load current will commutate back to 4D. At $\omega t = 180^{\circ} + \alpha_2$, the thyristor 1TH is fired which will carry the load current until $\omega t = 360^{\circ}$, etc. It is apparent from the oscillograms, that the output V_o is a function of the firing angle α. It is zero for $\alpha = 180^{\circ}$, and reaches a maximum at $\alpha = 0$.

A typical transfer curve and regulation curve of the single-phase, rectifier-type, TPA is shown in Figure 6.

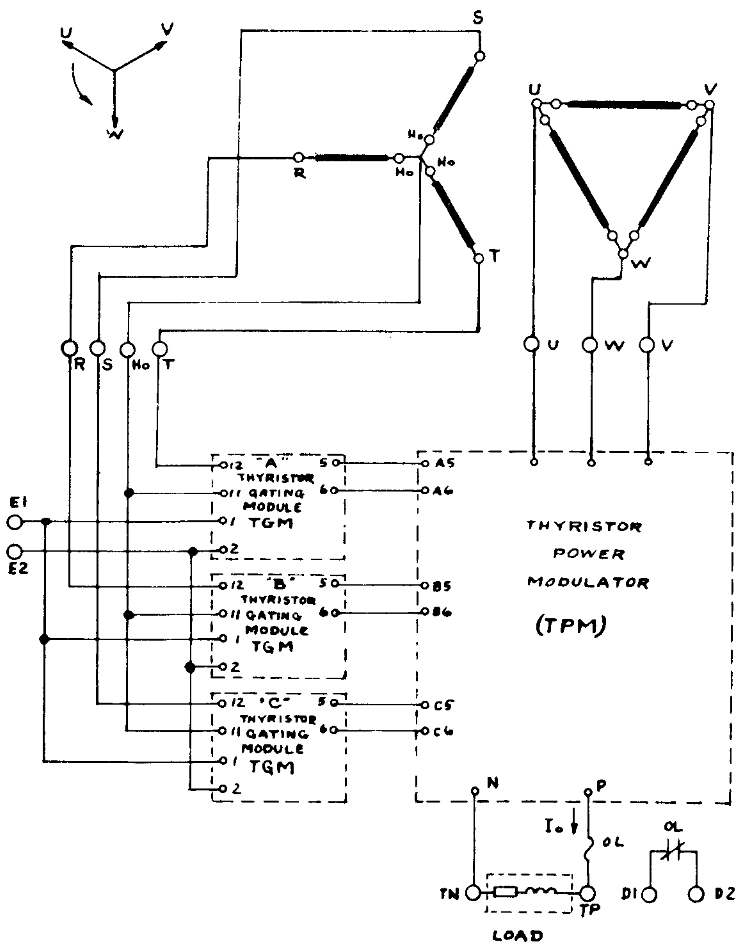

FIGURE 4 - BLOCK DIAGRAM THREE PHASE RECTIFIER TYPE TPM

III. Three-Phase, Rectifier-Type TPA

The general information in Section I of this leaflet is basic to both single and three-phase, rectifier-type, thyristor TPAs.

Figure 4 is a block diagram of the three-phase, rectifier-type TPA. Basic subassemblies to be discussed are outlined by dotted lines, and all inputs to and outputs from the amplifier are shown.

A. Thyristor Gating Modules (TGM)

A single TGM can provide gate pulses, phase related to only one line voltage. The three-phase system thus requires three gating modules to supply phase-controlled gate pulses, one synchronized by each of the three line voltages.

The general description of each TGM in the three-phase system is identical to that discussed in Section II of this instruction leaflet.

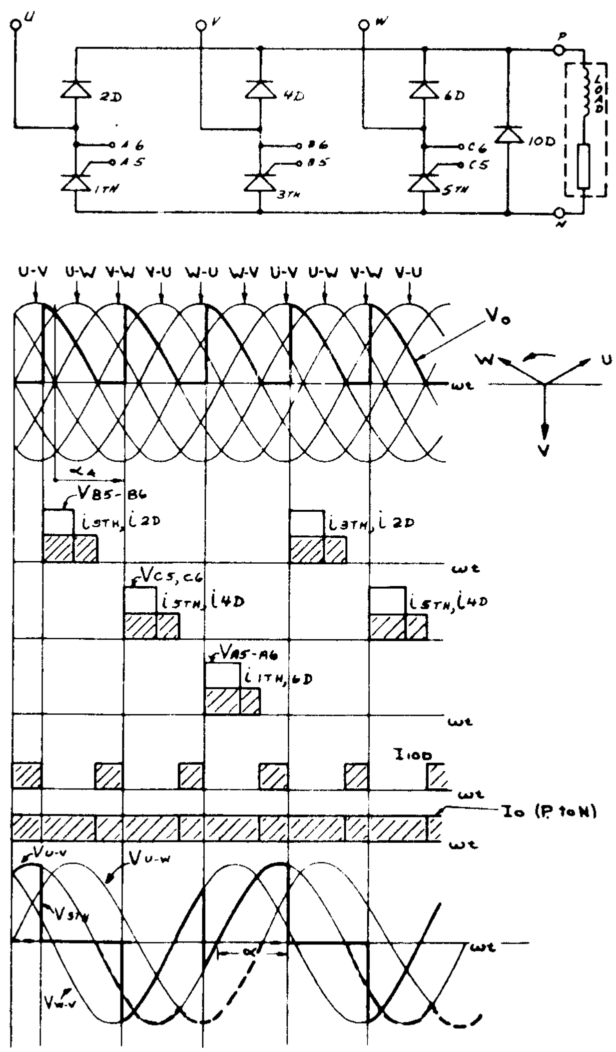

FIGURE 5 - THREE-PHASE, RECTIFIER-TYPE TPM

B. Three-Phase Thyristor Power Modulator (TPM)

The thyristor power modulator is basically a bridge-rectifier configuration of thyristors and diodes. Figure 5 is the simplified schematic of a three-phase, rectifier-type TPM with time-related waveshapes for an assumed firing angle ($\alpha \approx 100^o$) and an inductive load.

Referring to figure 5, terminals U, V, and W are connected to the AC supply source and terminals P and N to the load. At $\omega t = 0$, the load current I_o flows through the commutating diode 10D. At $\omega t = 40^o$, a gate pulse is applied to thyristor 3TH which then switches to a low-impedance state. As the voltage U-V is greater than zero, the current will commutate from the commutating diode 10D to thyristor 3TH. The output voltage will follow the trace of U-V until it reaches zero. Then it follows the zero line until thyristor 5TH fires at which time it will start to follow the V-W trace. While the output voltage follows the zero line, the load current passes through the commutating diode 10D. No current flows through 10D if $\alpha \leq 60^o$. It is apparent from the oscillograms that the average value of the output voltage V_o is a function of the firing angle α. It will be maximum for $\alpha = 0^o$ and minimum for $\alpha = 180^o$. A typical transfer curve of the three-phase, rectifier type is shown in Figures 6 and 7.

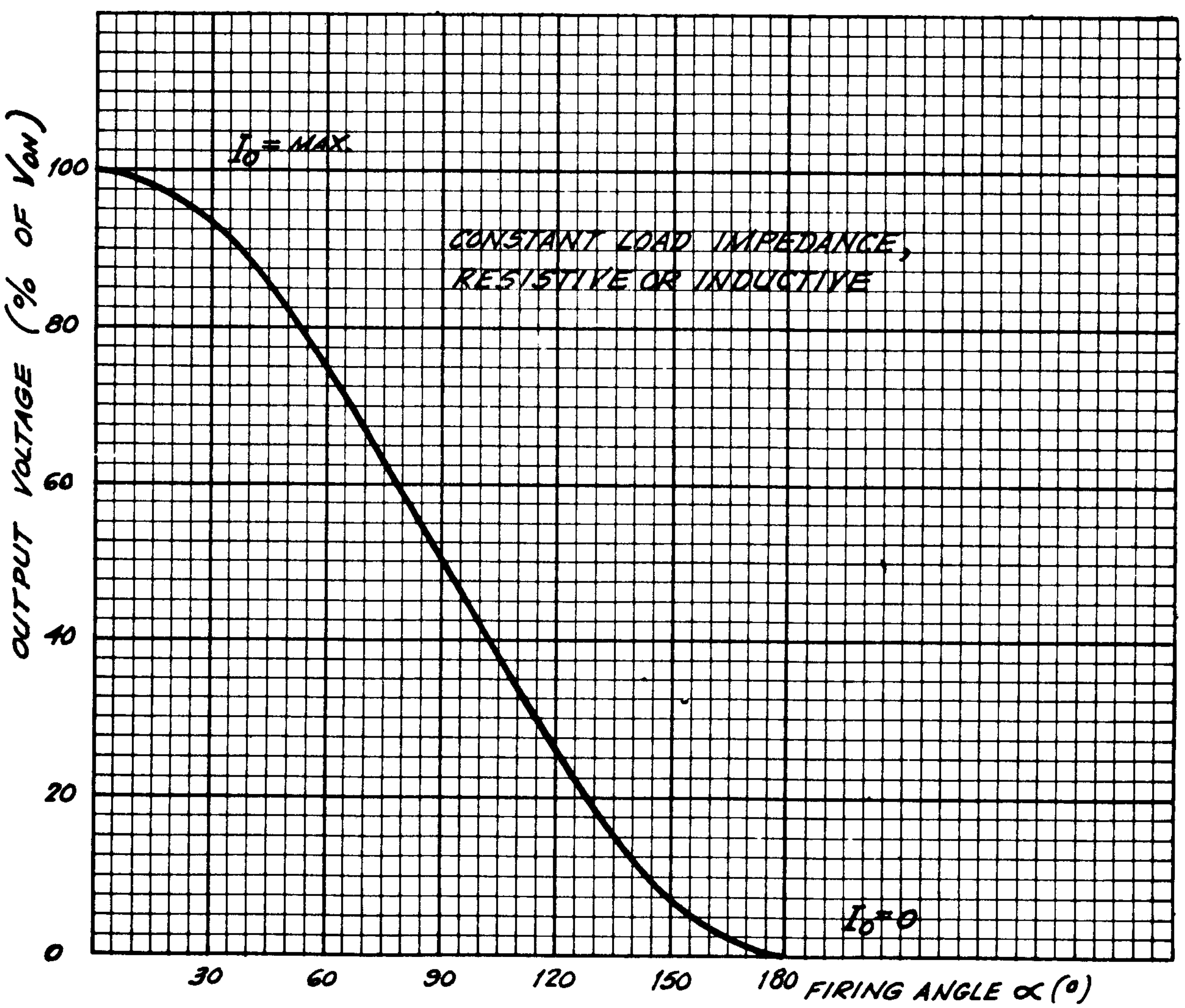

FIGURE 6 - TYPICAL TRANSFER CURVE APPLIES TO BOTH SINGLE-PHASE AND THREE-PHASE TPM

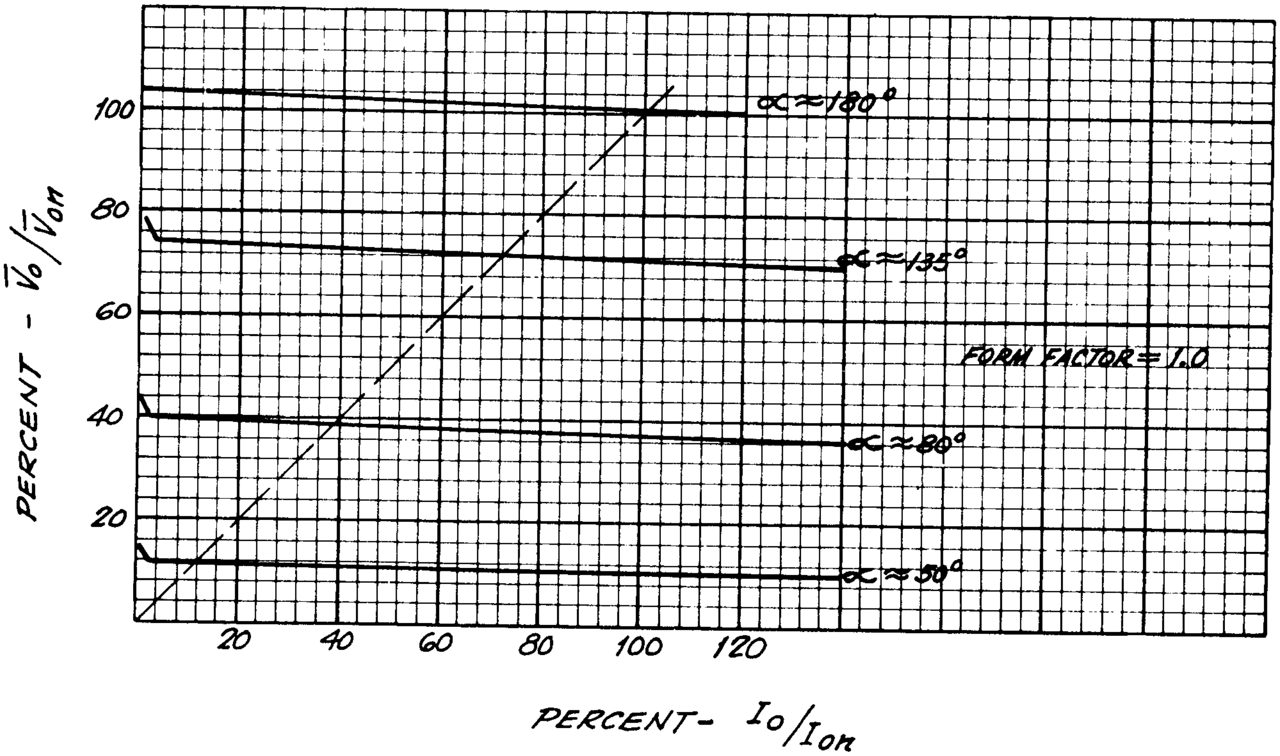

FIGURE 7 - TYPICAL TRANSFER CURVES AND REGULATION CURVES SINGLE-PHASE AND THREE-PHASE RECTIFIER-TYPE TPM

IV. Protection Networks

In preceding sections, we were concerned with the basic operating principles of single and three-phase, converter-type TPAs. This section is devoted to circuit elements not considered before but essential to reliable circuit operation.

A. Line Transformers

All thyristor power amplifiers are equipped with line transformers to provide the following features:

1. isolation from the power system
2. change of voltage levels
3. commutating reactance.

Whereas 1 or 2 are not required in all cases, 3 is important in all applications. Commutating reactance alone could be supplied by air reactors, but the applications with no need for isolation and voltage transformation are too limited to justify consideration.

B. Voltage and Current Transients

Thyristors are easily damaged by excessive voltage or current transients. Unlike the selenium-type rectifiers, the thyristor has little inherent protection (capacitance, leakage); hence, for reliable circuit operation, must be protected by external means.

C. The portion of the single-phase schematic in figure 8, shown in heavy lines, represents the components and circuitry provided to protect the thyristors from voltage and current transients. The filter 3C-3R is provided to suppress line transients, such as occuring when disconnecting the primary winding of the feeding transformer. The capacitor 4C has the function of limiting the rate of rise of reverse voltage across the diodes when the thyristors fire. The current limiting fuses 1FU and 2FU are provided for short-time overload and short-circuit protection of the semiconductor cells.

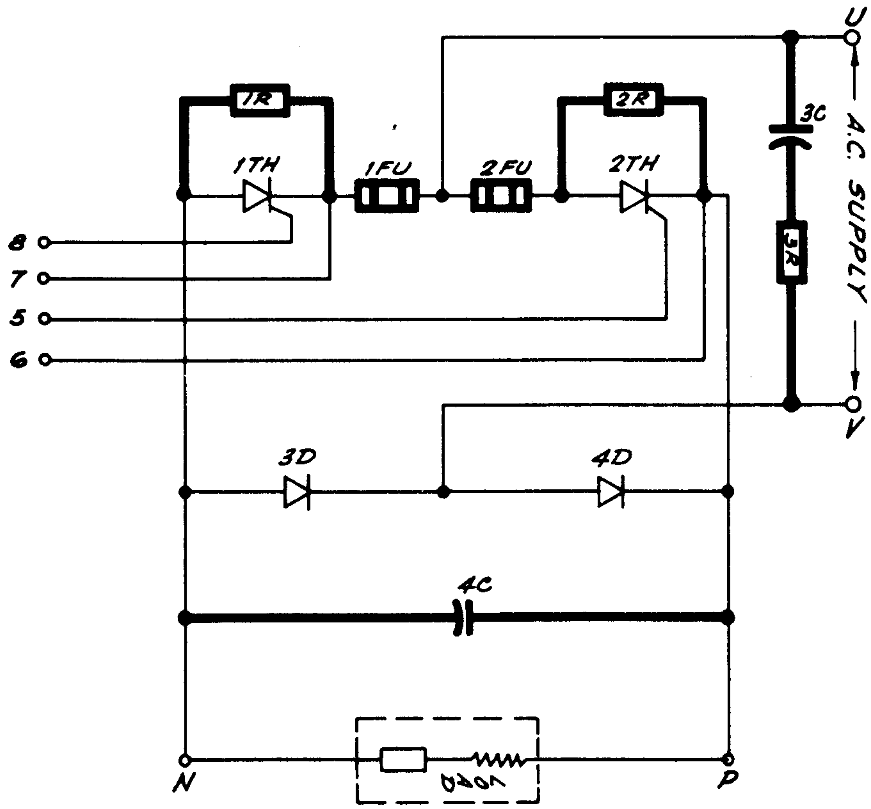

FIGURE 8 - SINGLE-PHASE RECTIFIER-TYPE TPA WITH PROTECTIVE DEVICES

Although fuses afford protection for high-current, short duration overloads, their current-time curves offer little protection for low-current overloads (200% current). Thermal overloads (O.L.---) are used to protect the cell in this region. The position of the O.L. relay is shown in the block diagram, Figure 1.

Resistors 1R and 2R assure that the reverse voltage across the two thyristors divides evenly.

D. Figure 9 shows the protective devices for a three-phase, rectifier-type TPA.

The line filter 11C-11R, 12C-12R, and 13C-13R is provided to suppress line transients such as occur when disconnecting the primary windings of the supply transformer, etc. The output filter 14C-14R has the function to limit the rate of rise of reverse voltage across the diodes when the thyristors fire. The current limiting fuses 1FU, 2FU, and 3FU are provided for short-circuit protection and short-time overload protection of the semiconductor cells.

As for single-phase units, thermal overloads are used for lower current, long-duration, overload conditions. Figure 4 shows the thermal O.L. in a three-phase TPA.

Resistors 1R to 6R are provided to assure that the reverse voltage appearing across each series thyristor-diode leg (1TH and 2D, for example) divides evenly.

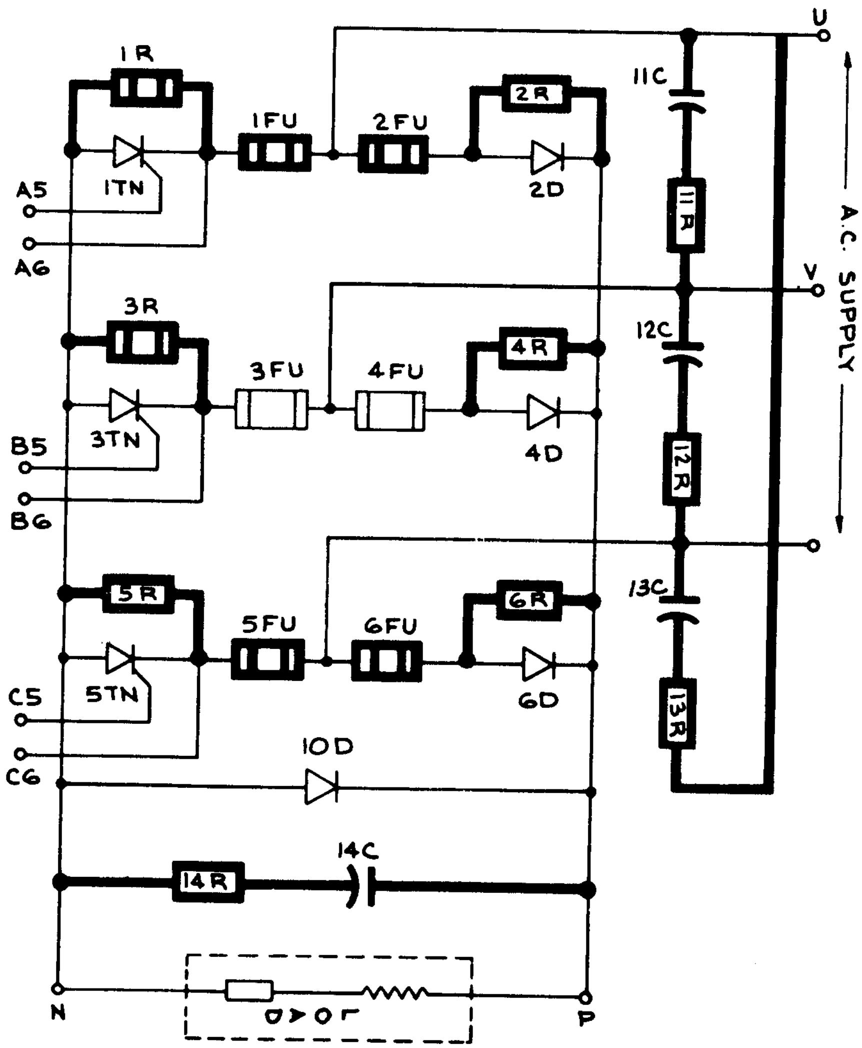

FIGURE 9 - THREE-PHASE RECTIFIER-TYPE TPA WITH PROTECTIVE DEVICES

V. Power Ratings of TPAs

The following factors determine the power rating of the TPA:

A. Thyristor Blocking Voltage (V_{BO})

The V_{BO} rating determines the maximum line voltage (50-60 cycle) which can be blocked, hence, the maximum d-c output voltage from the amplifier.

B. Thyristor Current Rating

The device manufacturer specifies both an average and rms maximum current rating for the thyristor, neither of which can be exceeded during circuit operation.

The current ratings are valid only if the cell junction temperature is kept below 125°C, which requires the thyristor be mounted on heat sinks. Convection-cooled heat sinks are adequate for the smaller cell sizes, however, force cooling is required for the larger devices. Formfactor of the load current, altitude, and ambient temperature also influence the rating of the amplifier.