THYRISTOR CONVERTERS (SINGLE AND THREE PHASE)

I. Introduction

This leaflet will discuss basic principles of operation of single and three phase converter-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. Converter-Type TPA (General Information)

The converter-type TPA is used to convert a-c line voltage to a controlled d-c output voltage. This is accomplished by replacing all of the diodes in a conventional bridge rectifier by thyristors and phase controlling the gate pulses supplied to them.

Unlike the rectifier-type TPM, the converter-type TPM can invert---i.e. with a generating load, power flow can be from the load to the line. This implies a bidirectional output voltage since the current output from any rectifier supply is always unidirectional.

In the majority of industrial applications, converter-type TPAs supply highly inductive loads; and the discussion to follow assumes such a load.

II. Single-Phase, Converter-Type TPA

For the purpose of explanation, the single-phase converter 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 converter-type TPAs will be discussed in the last section of this Instruction Leaflet.

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

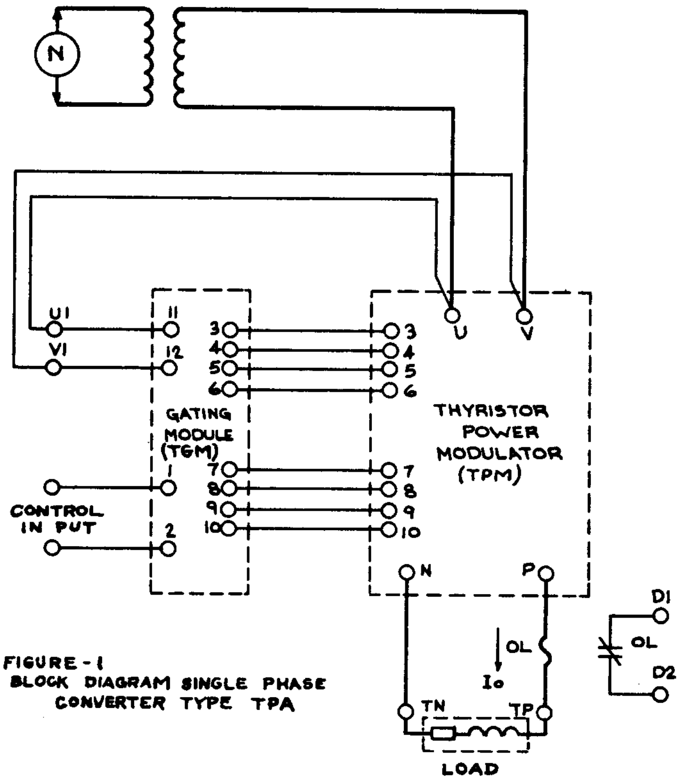


FIGURE-1
BLOCK DIAGRAM SINGLE PHASE CONVERTER TYPE TPA

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 $\alpha \approx 10$ to $\alpha \approx 160^{\circ}$ by a control signal input to the module. The pulse retardation limit of 160° insures a gate pulse to the thyristor each cycle. As we will see later, this is required during inverter operation; hence, it is a built in feature of all TGMs used in converter-type TPAs.

Proper polarity of the synchronizing voltage to the TGM (V_{U1-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.

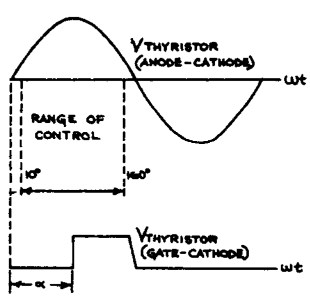


FIG.2 ··· TYPICAL GATE PULSE FROM TGM PHASE RELATED TO LINE VOLTAGE ACROSS THYRISTOR.

B. Thyristor Power Modulator (TPM)

The thyristor power modulator (TPM) is basically the bridge-rectifier configuration of thyristors. Figure 3 shows a simplified schematic of a single-phase, converter-type TPM and time-related waveshapes for an assumed firing angle ($\alpha \approx 60^o$).

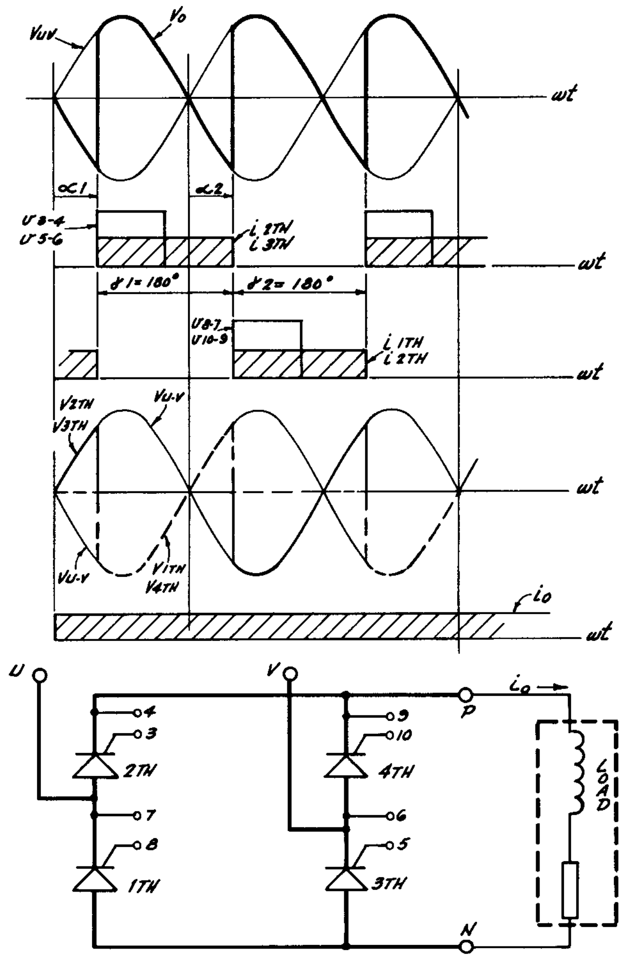


FIG. 3 SINGLE PHASE CONVERTER TYPE TPM

When the line voltage V_{U-V} is positive, thyristors 2TH and 3TH are forward biased; and on receiving gate pulses at α_1, turn on completing a current path to the load. As a highly inductive load was assumed, they continue to conduct for 180^o even though the line voltage reverses (forward bias being maintained by the generating load). At the instant of line voltage reversal, thyristors 1TH and 4TH become forward biased---but remain in the forward blocking state until receiving gate pulses at α_2. Once turned on, the current commutates to 1TH and 4TH; and a reverse voltage is applied to the previously conducting cells forcing them to turn off. Thyristors 1TH and 4TH conduct for 180^o or until gate pulses are again supplied to 2TH and 3TH and the cycle is repeated.

It is apparent from the waveforms in Figure 3 that the average value of the output voltage V_o is a function of the firing angle α . It will be positive for $0 < \alpha < 90^o$ and assume negative values for $90^o < \alpha <$ approximately 160^o. Operation in the first range with the power flowing from the a-c source to the load is called rectifying. Inverter operation is obtained in the second range with the power flowing from the load back to the line. This second mode of operation is, therefore, only possible when the load is generative.

As the load current cannot reverse, operation in two quadrants only of the V_O-I_O plot is possible. Inverter operation has to be limited to a maximum firing angle α of approximately 160^o. This is necessary because the current will only commutate to the fired thyristor if the anode of this cell is positive at this time. Furthermore, the load current has to diminish completely in the previously conducting cell before its anode becomes positive again. If this is not the case, the current will commutate back to this cell, resulting in an inverter fault. The pulse retardation limit, previously mentioned, insures gate pulses occur at $\alpha \approx 160^o$ each cycle; thus, preventing this type of fault.

A general transfer curve of V_O V_S α showing the two-quadrant operation of the single-phase, converter-type TPA is shown in Figure 6.

III. Three-Phase, Converter-Type TPA

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

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

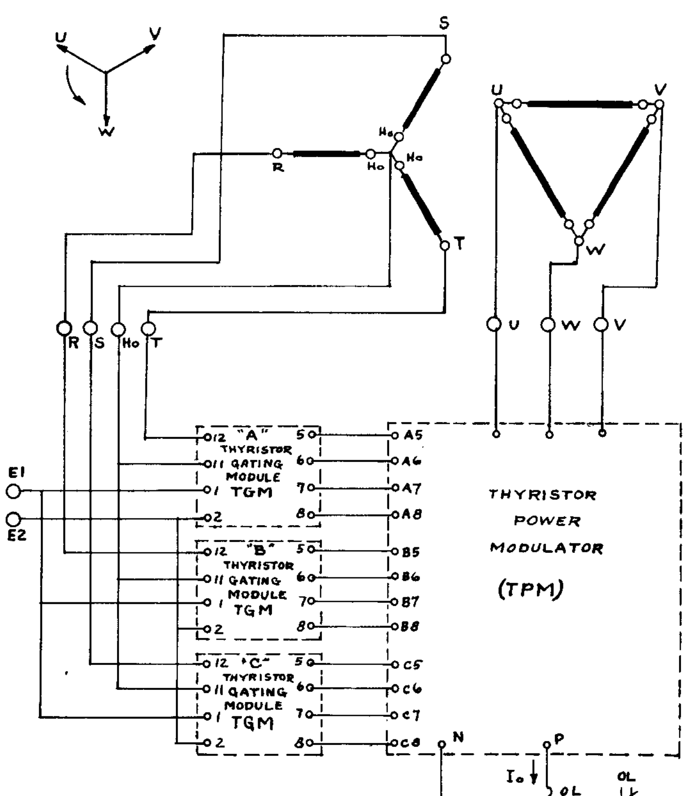


FIGURE-4
BLOCK DIAGRAM THREE PHASE CONVERTOR TYPE TPM

A. Thyristor Gating Modules (TGMs)

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.

B. Thyristor Power Modulator (TPM)

The thyristor power modulator is basically a bridge rectifier configuration of thyristors. Figure 5 is the simplified schematic of a three-phase, converter-type TPM with time related waveshapes for an assumed firing angle ($\alpha \approx 40^{o}$).

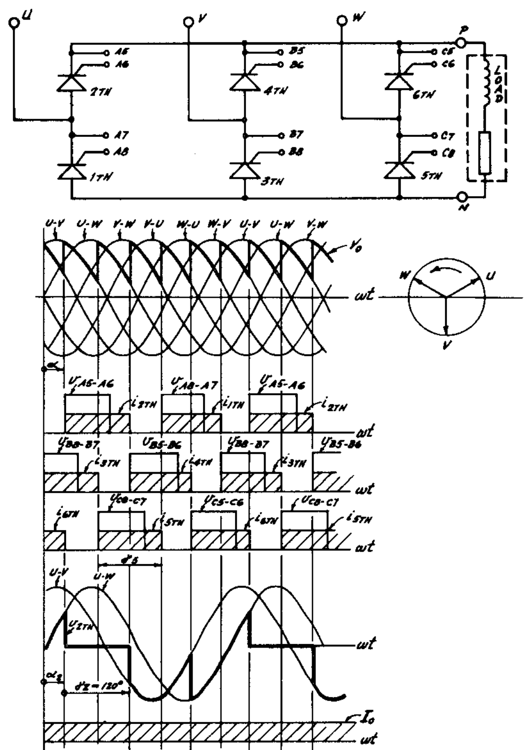


FIG. 5 THREE PHASE CONVERTER TYPE TPM

For the three-phase system to function properly, a specific relationship must exist between the gate pulses and the line voltage applied to the thyristors. For the phase rotation and cell configuration shown in Figure 5, thyristor 2TH first becomes forward biased at wt=o. To obtain full voltage output from the amplifier, we must be capable of generating a gate pulse for the cell at this time. The TGM providing the gate pulse should be full phase advanced; hence, the synchronizing voltage to the gating module supplying thyristor 2 is the line voltage V_{U-W}. Similarly, the TGM feeding 4TH is synchronized from V_{V-U}---etc.

For the operating condition shown, 2TH remains in the forward blocking state until it receives a gate pulse at $\alpha \approx 40^{o}$. From wt=o until time α , load current I_o flows through 6TH and 3TH. At wt= α , 2TH receives a gate pulse and switches to a low impedance state. As V_{U-V}

is greater than V_{W-V}, the load current commutates from 6TH to 2TH and the output voltage now follows the voltage V_{U-V} until 60° later 5TH is fired, etc.

It is apparent from the waveshapes of Figure 5 that the average value of the output voltage V_o is a function of the firing angle α. It will be positive for $0 < \alpha < 90°$ and assume negative values for $90° < \alpha <$ approximately 160°. Operation in the first range, with the power flowing from the a-c source to the load is called rectifying. Inverter operation is obtained in the second range, with the power flowing from the load back to the line. This second mode of operation is therefore only possible when the load is generative. As the load current cannot reverse, operation in two quadrants only of the V_o-I_o plot is possible. Inverter operation has to be limited to a maximum firing angle α of approximately 160°. This is necessary because the current will only commutate to the fired thyristor if the anode of this cell is positive at this time. Furthermore, the load current has to diminish completely in the previously conducting cell before its anode becomes positive again. If this is not the case, the current will commutate back to this cell resulting in an inverter fault.

A general transfer curve of V_oV_s α for the three-phase, converter-type TPA is shown in Figure 6.

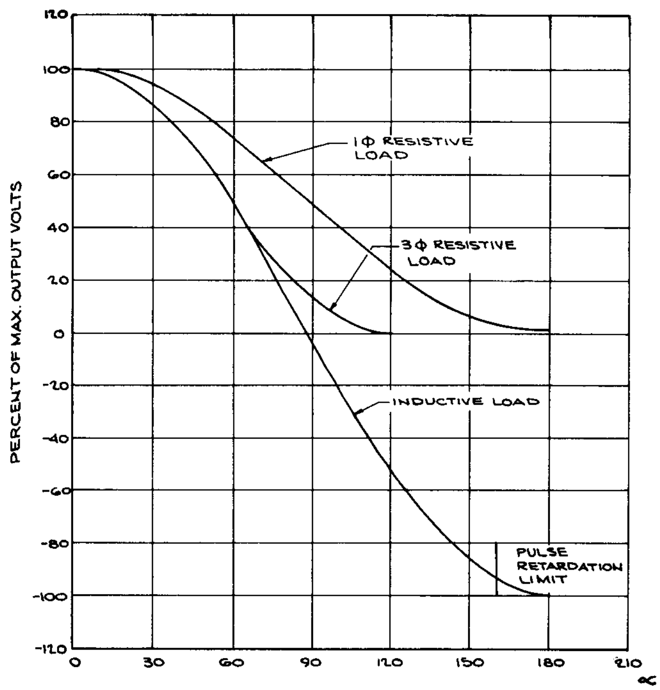
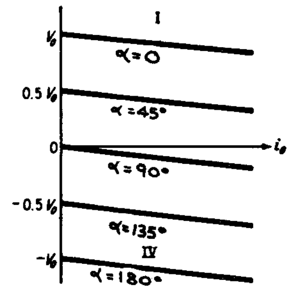


FIG. 6 V_o vs α - CONVERTER TYPE TPM's

IV. Advantage of Converter-Type TPAs

The principle advantage of the converter-type TPAs discussed in Sections II and III is their ability to down-force load current, thereby speeding up the system response.

Figure 7 is a general load regulation curve for the converter-type TPA. Quadrant I represents the rectification mode of operation (power flow from the a-c source) and Quadrant II represents the inverting mode of operation (power flow from the load to the line).



—Converter Output Characteristics

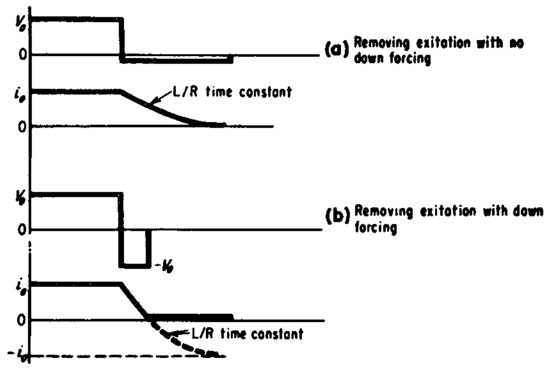


FIG. 7 —Converter Transients With and Without Down Forcing

Figure 7a and 7b represent the transient output current response for the system with no down forcing and with full down forcing. In each case, the amplifier was assumed operating in the rectification mode with full output voltage V_o and current i_o ($\propto = o$). In figure 7a, the phase angle was retarded at t_o to a phase angle $\propto = 90^o$ --- $V_o = 0$ and the output current decayed to zero at a rate dependent entirely on the load time constant. In Figure 7c, at t_o the phase angle was retarded to $\propto = 180^o$; i.e., $V_o = -V_o$ and although the load time constant is unchanged, the load is forced to discharge its stored energy at a much faster rate.

V. 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 a or b are not required in all cases, c 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.

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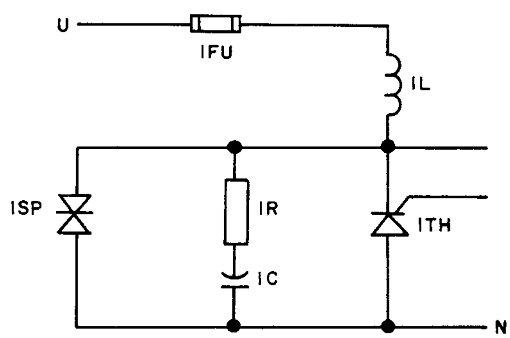

FIG.8 THYRISTOR PROTECTION, CONVERTER TYPE. TPM.

Figure 8 shows one leg of either the single or three phase, converter-type TPM, with its associated protective network.

1. Overcurrent Protection - Special fast blowing fuses (like Amptrap) are used to protect the thyristor against fault current surges exceeding the semiconductor rating. In the three-phase converter, each leg is fused; while in the single-phase converters, the a-c lines are fused.

   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.--- Figures 2 and 4) are used to protect the cell in this region.

2. Voltage Protection - The thyristor can be damaged by excessive voltage transients and excessive rates of forward or reverse voltage application.

A selenium surge suppressor, 1SP, is connected in parallel with each thyristor to clamp high energy voltage transients to a safe value. Thypical of this type of transient is the one produced when the primary of the feeding transformer is switched.

Capacitor 1C decreases the rate of reverse voltage applied to the cell after commutation. The resistor 1R is necessary to limit the discharge of 1C through the thyristor when turned on and also to damp the ringing of the R-C-L network present due to the leakage reactance of the line transformer.

The air core inductor 1L is required only in the three-phase converter circuits to limit the rate of forward voltage seen by the thyristor.

VI. 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^{o}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.

Specific ratings of power amplifiers are not contained in this instruction leaflet, but individual leaflets are available and may be found elsewhere in your instruction book.