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Power Transistors
Application Note
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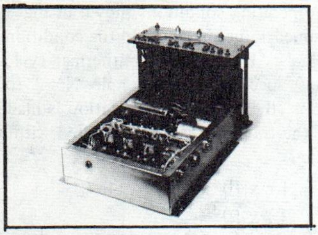


A 750-Watt Three-Phase Frequency Converter

by W. J. Beiswinger

Military equipment frequently uses three-phase 400-Hz power, and industrial plants and laboratories often require power at a variety of low frequencies. Ac-to-ac converters, driven from standard power lines, can be used to meet these requirements. This Note describes a frequency converter with output frequency from 380 Hz to 1250 Hz that delivers up to 750 watts of three-phase power at 120/208 volts rms. The circuit uses a three-phase bridge inverter supplied from a rectified ac line; the input can be single-phase or three-phase, 120 volts or 208 volts, at any frequency from 47 Hz to 1250 Hz. The RCA-2N5805 power transistor used in this converter is especially suited for power-switching circuits.

CIRCUIT DESCRIPTION

As shown in the block diagram of Fig. 1, the converter has four basic components:

- a power supply, which consists of a rectifier and a filter, to change the ac line power to dc power for the three-phase bridge inverter;
- the three-phase bridge inverter;
- three-phase logic and driver circuits to switch the transistors of the inverter in the proper sequence; and
- an output transformer.

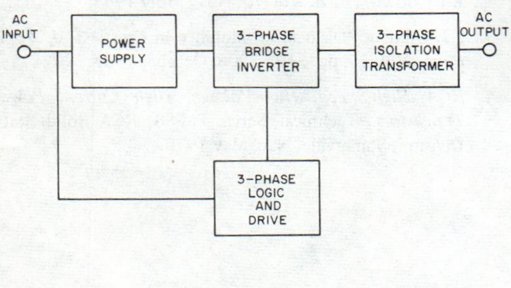


Fig. 1– Block diagram of 750-watt three-phase converter.

Fig. 2 is a schematic diagram that shows the power supply, inverter, and output transformer. The logic and driver circuits are shown in Figs. 3 and 4.

The Power Supply

The bridge rectifier will operate from either a single-phase or three-phase line; the circuit shown in Fig. 2, which uses 1N1204A rectifiers, is designed for either a 120-volt or a 208-volt line. The 11,000-microfarad filter capacitor keeps ripple below 50 millivolts even when a single-phase input line is used.

The Inverter

The three-phase bridge inverter uses pairs of RCA-2N5805 switching transistors that are transformer-driven from the logic circuit. The switching transistors in turn control the flow of current through the delta-connected primary of the output transformer.

The Logic and Driver Circuits

The logic and driver circuits include a low-voltage dc supply, which operates from a single phase of the ac line. A stepdown transformer reduces the line voltage to 12 volts, and provides isolation from the power line. This transformer, T4, has a frequency range from 47 Hz to 1250 Hz; its parameters are shown in Table I. The supply voltage is regulated by a pass transistor and a 12-volt zener diode.

The logic sequence begins with a tunable unijunction oscillator that delivers timing pulses to a six-stage ring counter, as shown in Fig. 3. The timing of these pulses is determined by the oscillator frequency; adjustment of the 75-kilohm potentiometer can set the frequency of the pulse sequence from 380 Hz to 1250 Hz. The output pulses from the ring counter are coupled to a diode matrix, shown in Fig. 4, to activate the inverter drive transistors.

The drive transistors provide drive to the inverter through transformers T1, T2, and T3. The first timing pulse produces a positive voltage across one half of the primary of T1, a negative voltage across one half of the primary of T2, and a

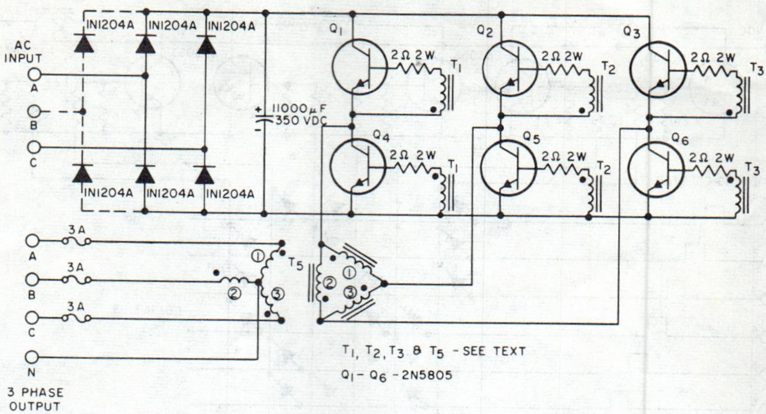


Fig. 2— Schematic diagram of three-phase frequency converter, showing the dc supply, the inverter, and the output transformer.

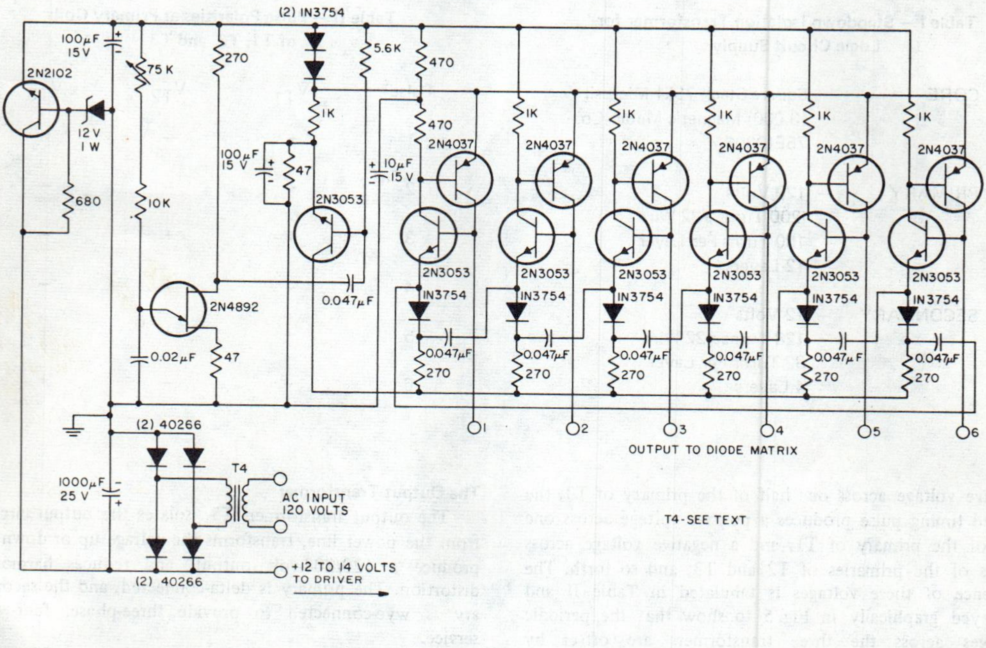


Fig. 3— Oscillator and six-stage ring counter for the logic circuit of the three-phase frequency converter.

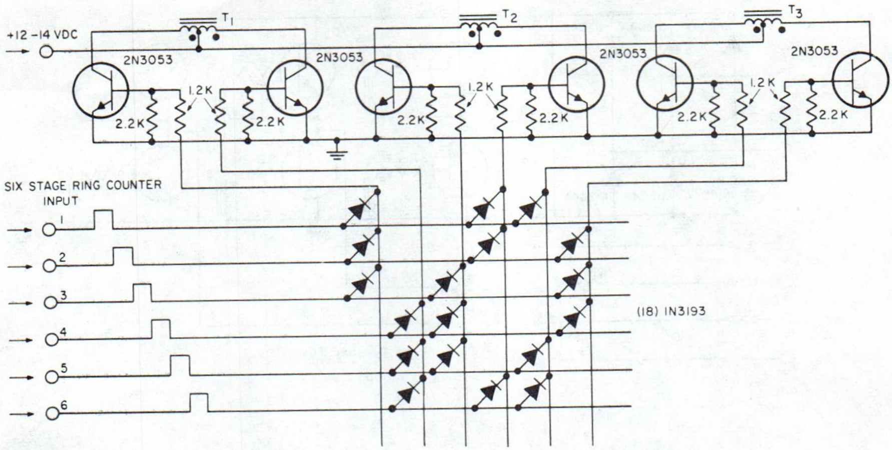


Fig. 4— Diode matrix and driver for output devices of three-phase frequency converter.

Table I – Stepdown Isolation Transformer for Logic Circuit Supply

CORE	–	Square Stack 75EI Microsil (0.006) Magnetic Metals Co. 75EI3306
PRIMARY	–	120 Volts 1200 Turns #32 Wire 100 Turns Per Layer 12 Layers
SECONDARY	–	12 Volts 128 Turns #22 Wire 32 Turns Per Layer 4 Layers

Table II – Pulse Polarities at Primary Coils of T1, T2, and T3

Pulse	V_{T1}	V_{T2}	V_{T3}
1	+	–	+
2	+	–	–
3	+	+	–
4	–	+	–
5	–	+	+
6	–	–	+

positive voltage across one half of the primary of T3; the second timing pulse produces a positive voltage across one half of the primary of T1, and a negative voltage across halves of the primaries of T2 and T3; and so forth. The sequence of these voltages is tabulated in Table II and displayed graphically in Fig. 5 to show that the periodic voltages across the three transformers are offset by 120-degree intervals.

Design information on transformers T1, T2, and T3 is shown in Table III.

The Output Transformer

The output transformer, T5, isolates the output circuit from the power line, transforms the voltage up or down to produce a 120/208-volt output, and reduces harmonic distortion. The primary is delta-connected, and the secondary is wye-connected to provide three-phase, four-wire service.

The primary coils carry the full supply voltage. The waveshapes in the primary and secondary coils are the same, and are shown in Fig. 6; the polarities of these pulses are

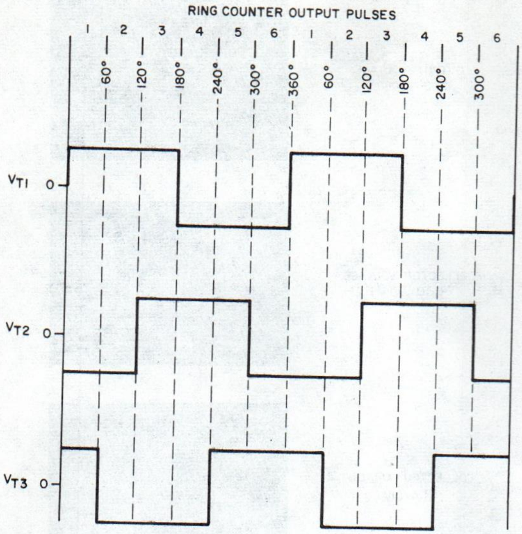
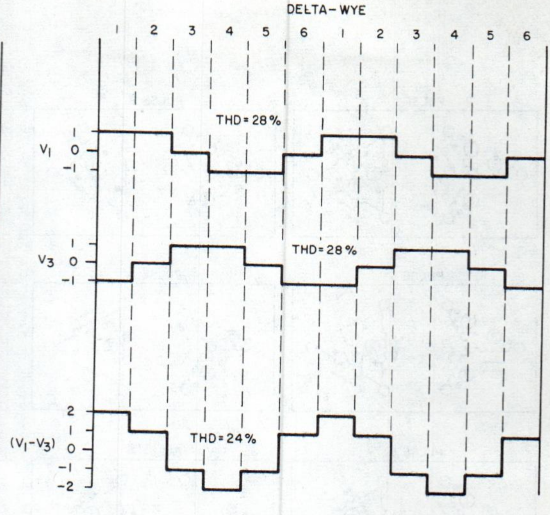


Fig. 5— Sequence of voltages across drive transformers T1, 'T2, and T3.



1	$V_1 - V_3 = 1-(-1) = 2$
2	$V_1 - V_3 = 1-0 = 1$
3	$V_1 - V_3 = 0-(1) = -1$
4	$V_1 - V_3 = -1-(1) = -2$
5	$V_1 - V_3 = -1-0 = -1$
6	$V_1 - V_3 = 0-(-1) = 1$

Fig. 6— Phase-to-neutral and phase-to-phase voltages in the delta-wye output transformer.

shown in Fig. 7. The manner in which the secondary coil voltages add to reduce distortion is also shown in Fig. 6. The voltage across secondary terminals A and C is equal to the difference of the voltages in secondary coils 1 and 3. Subtraction of waveform V3 from waveform V1 results in the output waveform (V1 - V3), which is more sinusoidal than V1 or V3. The measured value of total harmonic distortion (THD) in each coil is 28 per cent; the THD across the output terminals is 24 per cent.

Table III – Driver Transformer Design Information

CORE	– Square Stack 21EI Microsil (0.006) Magnetic Metals Co. 21EI3306
PRIMARY	– 14 Volts 140 Turns Bifilar #29 Wire (in Series) 20 Turns Per Layer 7 Layers
SECONDARY	– 4 Volts 52 Turns Bifilar #29 Wire 13 Turns Per Layer 4 Layers

Design information for the output transformer to operate from a 120-volt line or a 208-volt line is given in Table IV.

Table IV – Output Transformer Design Information

CORE	– Square Stack 1.2EI3ϕ Microsil (0.006) Magnetic Metals Co. 1.2EI3ϕ3306
PRIMARY (DELTA)	– 120 Volts 188 Turns #17 Wire 47 Turns Per Layer 4 Layers
	OR
	– 208 Volts 325 Turns #19 Wire 55 Turns Per Layer 6 Layers
SECONDARY (WYE)	– 120/208 Volts 200 Turns #17 Wire 50 Turns Per Layer 4 Layers

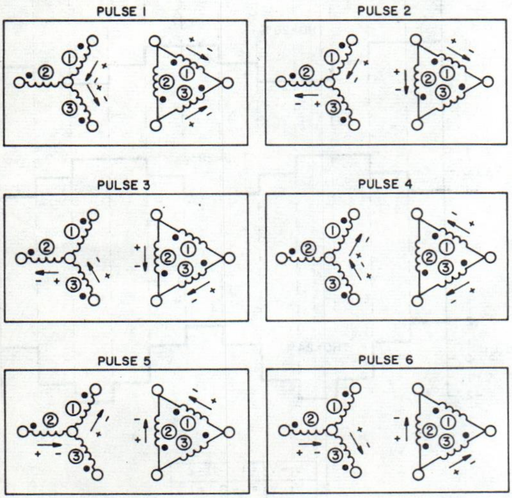


Fig. 7— Pulse polarities in output transformer T5.

CONVERTER PERFORMANCE

A photograph of the output waveform from the 400-Hz converter is shown in Fig. 8. Waveforms of the collector voltage and current in one of the switching transistors (Q1) are also shown in Fig. 8.

Fig. 9 shows the output performance of the converter. Both the efficiency and the regulation are good. Efficiency rises from 50 per cent at low load current to 75 per cent at the rated load current of 2.1 amperes. The rms output voltage varies by only 10 volts between low- and high-current loading.

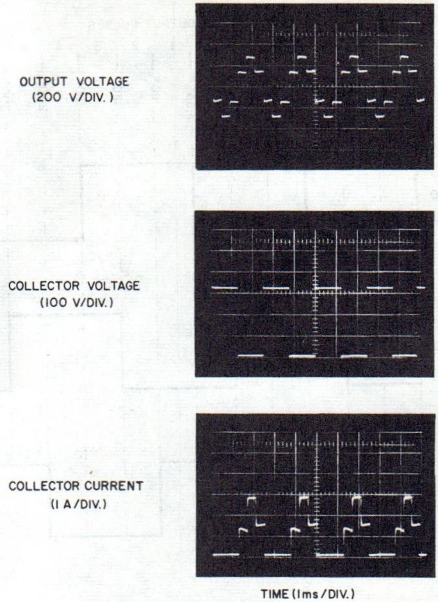


Fig. 8— Waveforms of transformer output voltage, collector voltage, and collector current.

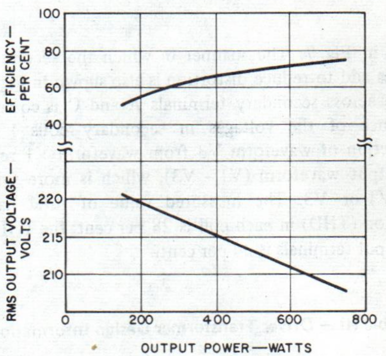


Fig. 9— Performance characteristics of the three-phase converter.