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Switching Inverter with Sine-Wave Output

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ABSTRACT

A relatively simple method of obtaining a multiple-stepped sine-wave output using semiconductor devices as switches was developed. This circuit employs Triacs as power switches, requiring approximately one-fourth the number of switches normally required by conventional techniques. The shift register used to drive the switches was composed of discrete components, but commercially available integrated circuits could probably be substituted. Since the basic inverter operates at a higher frequency, its size and weight are very greatly reduced compared to that of a conventional inverter for the same rating. Because the output closely approximates a sine wave, the filtering required is considerably less than that for a conventional inverter.

PROBLEM STATUS

A final report on one phase of a continuing problem.

AUTHORIZATION

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SWITCHING INVERTER WITH SINE-WAVE OUTPUT

INTRODUCTION

Semiconductor devices are widely used in dc-to-ac inverters and dc-to-dc converters and are most conveniently and efficiently employed as switches. This method of employment inherently produces square-wave outputs. When used for dc-to-dc converters, this characteristic is desirable, since it produces minimum ripple in the rectified dc output. However, many electrical loads are designed for sine-wave inputs, which can not be efficiently supplied by square-loop magnetic cores and semiconductor switches.

Many attempts have been made to overcome this incompatibility by using multiple switches to approximate a sine-wave output. Invariably, however, such attempts have evolved such complex circuits as to be unacceptable from the standpoint of reliability and cost. This complexity is caused by the need for a reasonably large number of steps (and therefore switches) to produce an acceptable sine wave and, also, since most semiconductor devices are unidirectional, different switches must be used for the positive and negative half-cycles of the sine wave. Such circuits can very quickly become incredibly complex. In any event, all such circuits represent a tradeoff between complexity and quality of the sine wave.

The basis for this report is to promulgate a relatively simple circuit utilizing some novel circuit techniques to produce an inverter with a reasonably good sine-wave output.

METHOD OF SYNTHESIZING A SINE WAVE

The method for producing the stepped sine-wave output is shown by the block diagram in Fig. 1 consisting of three basic functional circuits:

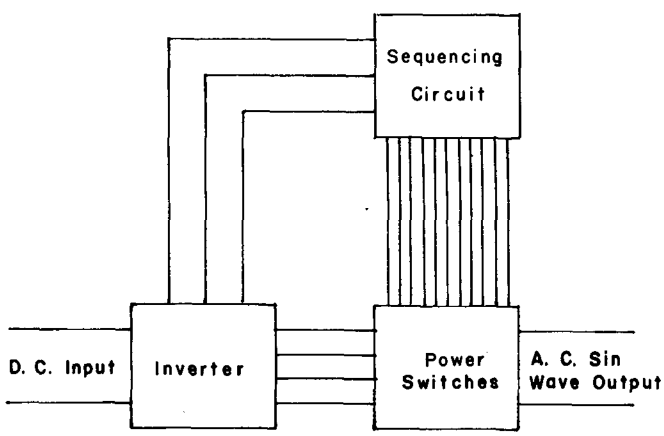


Fig. 1 - Dc-to-ac inverter circuit

1. The basic inverter that provides multiple voltage outputs to the power switching circuits and also the power and timing intervals to the sequencing circuit,

2. The sequencing circuit to activate the output power switches in the proper sequence,

3. The output power switching devices to connect the proper inverter output to the load in the proper sequence.

The demonstration model constructed and tested during this project was designed for a 10-step-per-cycle sine-wave output of approximately 400 Hz. Consequently, the basic inverter was designed for 2000 Hz, since a 10-step wave (using both positive and negative half-cycles) requires five cycles of the basic inverter for each cycle of the sine-wave output. The basic inverter circuit is shown in Fig. 2 and is entirely conventional, except for the multiple output windings. These windings consist of three power secondary output coils having output voltages of approximately 12 V, 9.7 V (12 sine 54°), and 3.7 V (12 sine 18°) plus 1 V on each coil to compensate for an assumed 1-V drop across each Triac. An additional center-tapped secondary winding is included to supply ±4 V for driving the sequencing circuit.

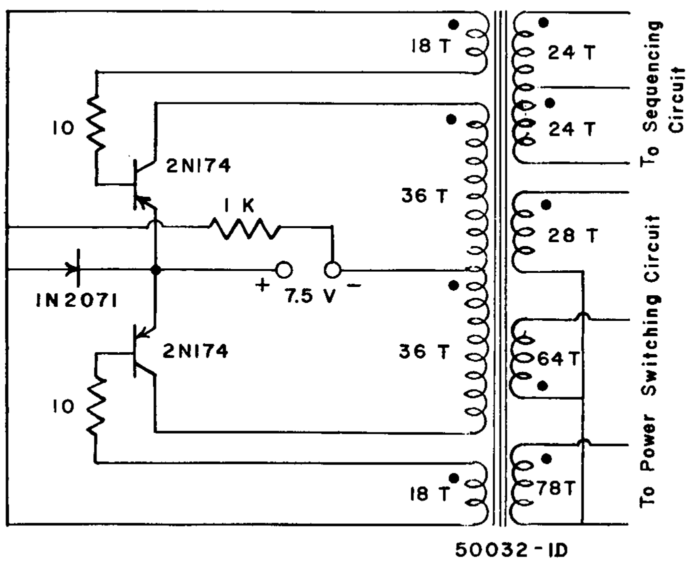
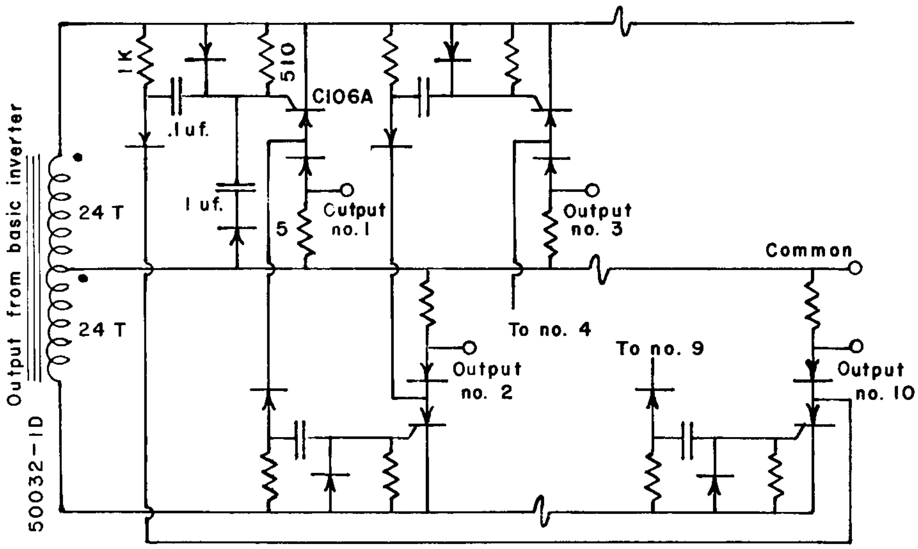


Fig. 2 - Basic inverter circuit

The sequencing circuit, shown in Fig. 3, consists of 10 SCR circuits (only four stages are shown in Fig. 3). As each circuit fires, it provides a signal to trigger the appropriate output switch "on" and also charges the condenser for triggering the next succeeding stage. Since the sequencing circuit is driven by the 4-V, square-wave, 2000-Hz output from the basic inverter, when the first stage is triggered "on," it remains conducting for the first half-cycle. On the next half-cycle the polarity is reversed, thus turning off stage number one. The polarity is now correct for stage number two and the triggering signal is supplied by the discharge of the condenser in its gate circuit, which had been charged during the first half-cycle. This procedure is repeated for each half-cycle, so that each stage fires in sequence, supplying triggering pulses to the power output switches in order. The tenth stage is connected to the first stage, and the sequence is repeated. The completion of the tenth-stage firing corresponds to the completion of one cycle of the power output circuit. The 1-μF capacitor and series diode connected to the trigger circuit of the first



All components same as stage no. 1
All rectifiers IN2071

Fig. 3 - Sequencing circuit

stage supply the signal to turn on the first stage, when the circuit is initially turned on, and then has no further effect on the circuit.

The power switching circuits, shown in Fig. 4, consist of three Triacs which are selectively triggered to sequentially connect the proper output from the basic inverter to the load. Only one of the inverter outputs is connected to the load at any one time, but each stays on for the duration of the basic inverter half-cycle. The simplicity of this circuit is derived from the characteristic of the Triac. This device is unique among semiconductor devices in that it conducts current in either direction and can be triggered in either direction by gate pulses of either polarity. Thus it greatly simplifies the switching in an ac curcuit. There is, however, one characteristic that must be taken into consideration. In square-wave circuits, the switching interval is characterized by a very rapid rise in voltage across the Triac. If this dv/dt is large enough, the Triac will fire spontaneously, without a trigger signal, and obviously the circuit would not operate properly. For this reason, large output voltages are probably not practical. However, as better Triacs are manufactured, capable of withstanding higher dv/dt or if circuit modifications can be devised to limit this effect, this restriction may be removed. The added coil in series with each Triac was inserted to limit the rate of voltage rise across the Triac at the instant of switching, but the core was designed to saturate quickly and thus would not limit the current flow through the remainder of the half-cycle. Apparently this technique was quite successful. These windings may not be necessary if the load is inductive.

The manner in which the sine wave is obtained can best be understood by referring to Fig. 5. The outputs of the three power output circuits from the basic inverter are shown in 5a, b, and c showing their relative timing and magnitude. These three outputs are shown in the power switching circuit (Fig. 4) and are each connected to the output bus through a Triac, but only one Triac is activated at any given time. Note also that the polarity of the medium-voltage coil in Fig. 4 is reversed. Therefore, the output shown in Fig. 5b has been reversed from those shown in Fig. 5a and c. Thus by taking pulses successively from a, b, c, b, a, a, b, c, b, a, the synthesized curve shown in Fig. 5d is obtained. This selection is accomplished by selectively triggering the proper Triac to

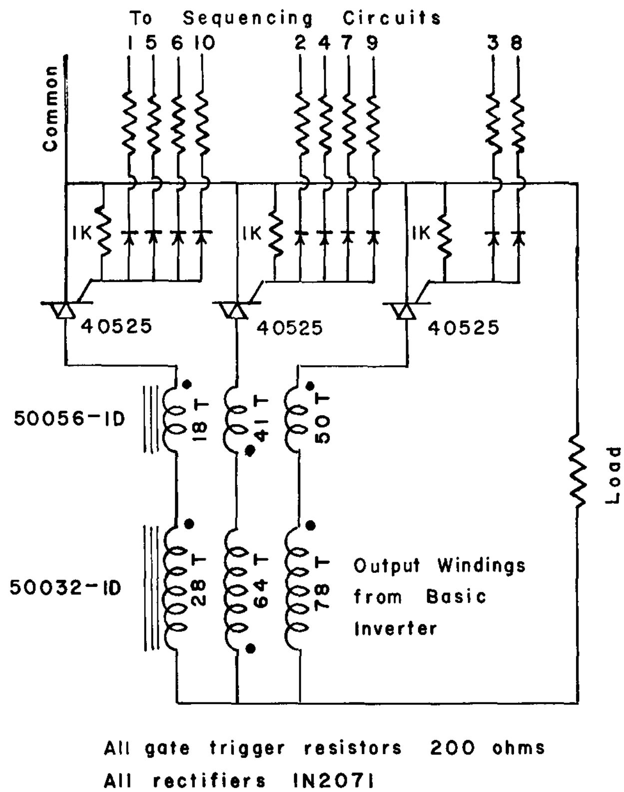


Fig. 4 - Power switching circuits

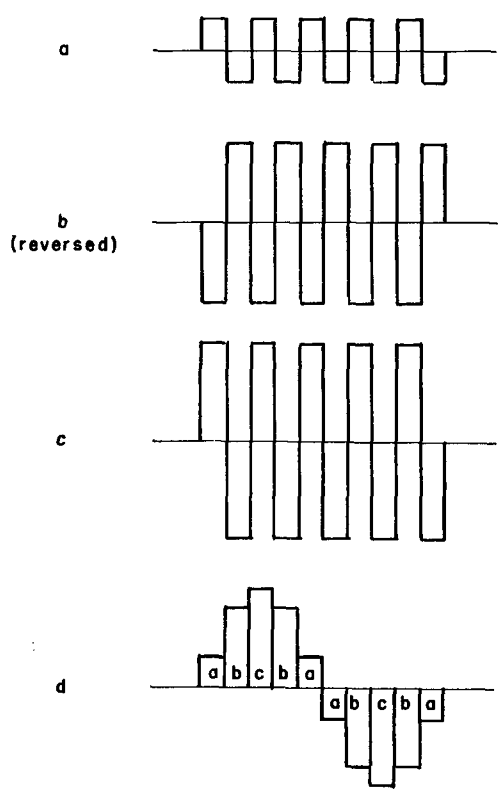


Fig. 5 - Sine-wave synthesis

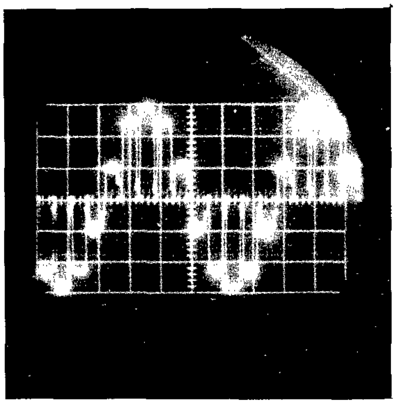


Fig. 6 - Output waveform (0.5 msec/cm, 5V/cm, load 100 Ω)

conduct during each half-cycle. The resulting waveform obtained in actual operation is shown on the oscilloscope picture in Fig. 6.

DISCUSSION

An improved sine-wave simulation can be made by using a larger number of steps without much increase in complexity. The number of steps N is given by the expression 4a + 2, where a is any desired positive integer. The corresponding number of outputs required from the basic inverter (and also the number of Triacs) is given by the expression (N + 2)/4, where N is the number of steps. The basic inverter frequency equals N/2 times the frequency of the desired sine-wave output. All even-numbered outputs are connected in the reverse polarity in the power switching circuit.

The use of a larger number of steps may be quite practical. With the Triacs simplifying the power switching functions because they are bidirectional and also make simpler trigger circuits possible, the chief complexity lies in the sequencing circuit. The circuit shown in Fig. 3 was constructed of discrete components. It is really only a 10-stage shift register to supply triggering signals to the Triacs. With the advent of integrated circuits in the logic field, such devices are probably already available commercially as complete units. Therefore, it should be a relatively simple matter to utilize them directly in lieu of the sequencing circuit explained above. If such devices are available, it is possible to increase the number of steps to produce a much higher quality sine wave without materially adding to the complexity.

The circuits used in these tests were intended as a laboratory study of the feasibility of the techniques involved. A practical device will require the incorporation of voltage and frequency regulation with varying loads, filtering, suppression of transients, starting methods, etc. The results to date have been sufficiently encouraging to warrant the publication of this report and to indicate that further engineering development would be desirable.

ADVANTAGES

The technique outlined above is a relatively simple method of producing a sine-wave output from a solid-state inverter using semiconductor devices in the most efficient manner (as switches). The power switching technique using Triacs requires only (N + 2)/4 switches, as compared to N switches in conventional circuits.

If integrated circuits are employed for the shift-register sequencing circuit, it is entirely practical to produce a reliable many-step sine-wave output of high quality, using approximately one-fourth the power switches normally required.

Also, as an added bonus, since the basic inverter for a sine-wave output with a large number of steps would be operating at a relatively high frequency, the size and weight of the inverter would be very greatly reduced because smaller cores would be required.

Since the output wave closely approximates a sine wave in form, the amount of filtering required to produce an excellent sine-wave output would be a minimum, thus further reducing size, weight, and filtering losses over those of more conventional inverters.

DISADVANTAGES

Laboratory tests indicated that care must be exercised in this circuit to assure that the dv/dt ratings of the Triacs are not exceeded, to prevent spontaneous conduction of the Triacs, when operation is not desired. This is not a problem at low voltages, but at higher voltages it could be a limiting factor. The development of Triacs with higher dv/dt ratings or added circuit techniques could solve this problem.

Provision must also be made to protect the switching circuits from transients in the load circuit, disrupting the proper sequencing in the switching circuits.

CONCLUSIONS

The techniques outlined in this report provide a relatively simple method of obtaining a sine-wave output from an inverter using semiconductor devices in their most efficient manner (as switches). If integrated circuits are used for the shift register, the simplicity of the circuit makes feasible a large number of steps with a minimum number of power output switches to obtain a high-quality sine-wave output.

Better Triacs or improved circuit techniques will be required for high-voltage outputs. Also, additional engineering development refinements will be required to cope with practical load and environmental factors.

The use of integrated circuit switching and a large number of steps in the output waveform will reduce the size and weight considerably over that of a conventional inverter of the same rating.

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