A high-power inverter

Gratton, G.

Publisher's version / Version de l'éditeur:
http://doi.org/10.4224/21274243
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB), 1965-03

ERB-697 [redacted]

UNCLASSIFIED

NATIONAL RESEARCH COUNCIL OF CANADA
RADIO AND ELECTRICAL ENGINEERING DIVISION

A HIGH-POWER INVERTER

G. GRATTON

OTTAWA

MARCH 1965

ABSTRACT

A high-power inverter with dual-transformer configuration is described. The output is 700 watts at 115 volts, with 87% efficiency when operating from a 36-volt d-c source. Voltage and frequency regulation are excellent. The design may be extended to provide 2400 volts d-c at 700 watts, with an over-all efficiency of 87%.

CONTENTS

FIGURES

A HIGH-POWER INVERTER

- G. Gratton -

INTRODUCTION

In most cases where a-c mains are not available an inverter can be utilized even if high power is involved. Most electrical equipment will operate satisfactorily with a square-wave input, and in cases where the harmonics are objectionable, a filter network can be added, though filtering 700 watts at 60 c/s is difficult. The simple inverter described below will readily supply 700 watts at high efficiency.

CIRCUITRY

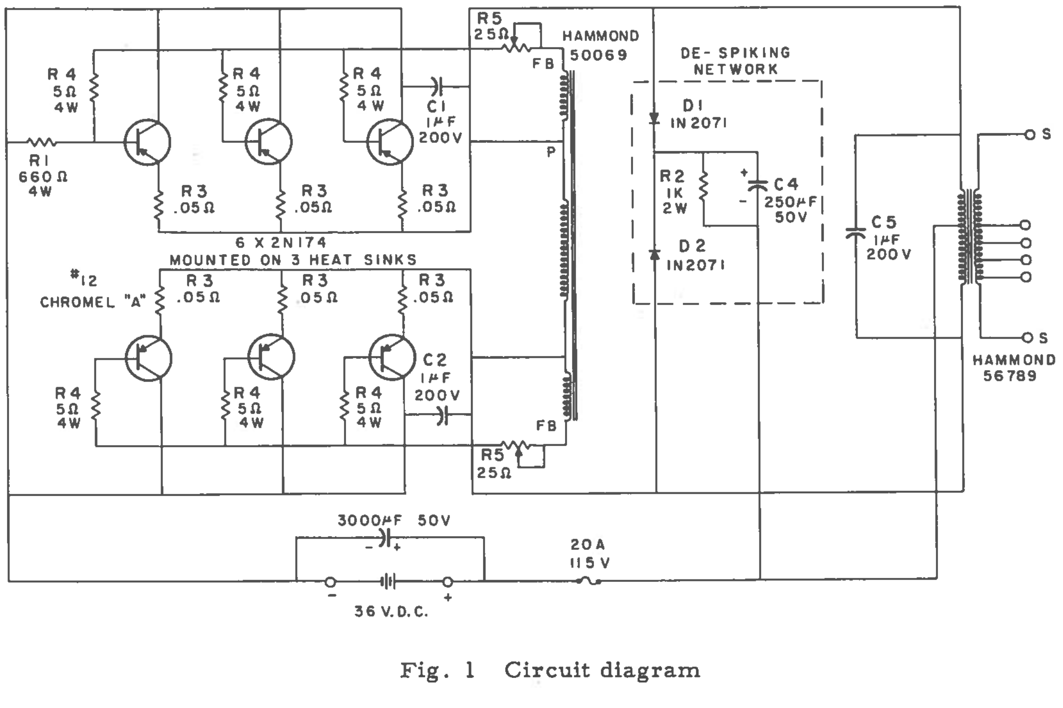

Fig. 1 Circuit diagram

A dual-transformer configuration (Fig. 1) is used because, compared with other inverter circuits, it produces spikes (transients) of considerably lower amplitude (Fig. 2). Since these spikes can cause transistor failure through voltage breakdown, it is imperative they be kept at a minimum.

Also, since the output transformer in the dual-transformer circuit does not become saturated, the magnetizing current is low and the efficiency of the system is thereby increased.

A toroidal core is used for the oscillator transformer because of its low power saturation and its low leakage inductance. The latter is an important factor in minimizing spikes.

The output transformer is chosen simply for voltage ratio, and capacity to supply the power without becoming saturated.

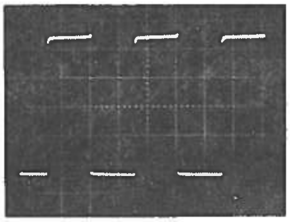

Fig. 2(a)

Collector-emitter waveform
70 volts (peak-to-peak)

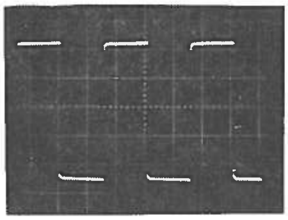

Fig. 2(b)

Waveform across primary (P-P)
of oscillator transformer
132 volts (peak-to-peak)

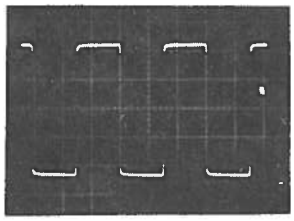

Fig. 2(c)

Waveform across secondary
of output transformer
115 volts (peak-to-peak)

1 division = 5 milliseconds

The voltage across the "off" transistors is twice the supply (battery) voltage plus any spikes present. Therefore, the transistors should be chosen for a BV_{cbs} (voltage breakdown with base effectively short-circuited) of the sum of those voltages (supply + spikes) plus a safety factor of approximately 20%.

Other qualifications are as follows:

1) high H_{fe} at rated current (current gain of 20-30)
2) low saturation resistance (power dissipation of transistor rises with saturation resistance)
3) adequate I_e (emitter current) rating, which will be

$$I_e = \frac{\text{watts out}}{\text{input voltage} \times \text{efficiency}} .$$

Germanium transistors 2N3146 and 2N3147 with 150-180 volt BV_{cbs}, 15 ampere I_e, and 150 watt power rating would be ideal, but even 2N174's whose BV_{cbs} rating is somewhat low (80 volts) can be substituted for them.

With 2N174 transistors as switches to achieve 700-watt performance, the following observations were made.

1) With two paralleled transistors on each side of the the switch, the base current drive had to be at such a high level as to be unsafe for the transistors.

2) With three paralleled transistors, the base drive could be lowered sufficiently to safeguard them, and incidentally to keep the transistors operating at a low temperature.

3) Individual emitter resistors (R3) should be used to reduce the effect of a wide variation in transistor gain, thus insuring that they share the current.

4) Bases could be connected to a common resistor, but under extremely nonlinear lamp loads, individual base resistors (R4) tend to protect the transistors.

Capacitors C1, C2, C5, C6, and the de-spiking network, comprising D1, D2, C4, and R2, reduce the spikes on the switching waveform to a negligible level. Resistor R1 is part of a voltage divider network that slightly forward-biases the bases of one side of the switch to insure initial oscillation.

Potentiometer R5 sets the maximum base drive, which limits power output to a pre-set value (variable from 200 to 800 watts).

RESULTS

The no-load current drain of the system, with a battery voltage of 38 volts, is 1.4 amperes. The efficiency with a 700-watt load is 87% (Fig. 3). Even with a voltage drop of 4% across the battery terminals when the load is increased from 300 watts to

800 watts, the output voltage regulation is 13%. With constant battery voltage, the expected regulation would be approximately 3% for a change in load from 300 to 800 watts.

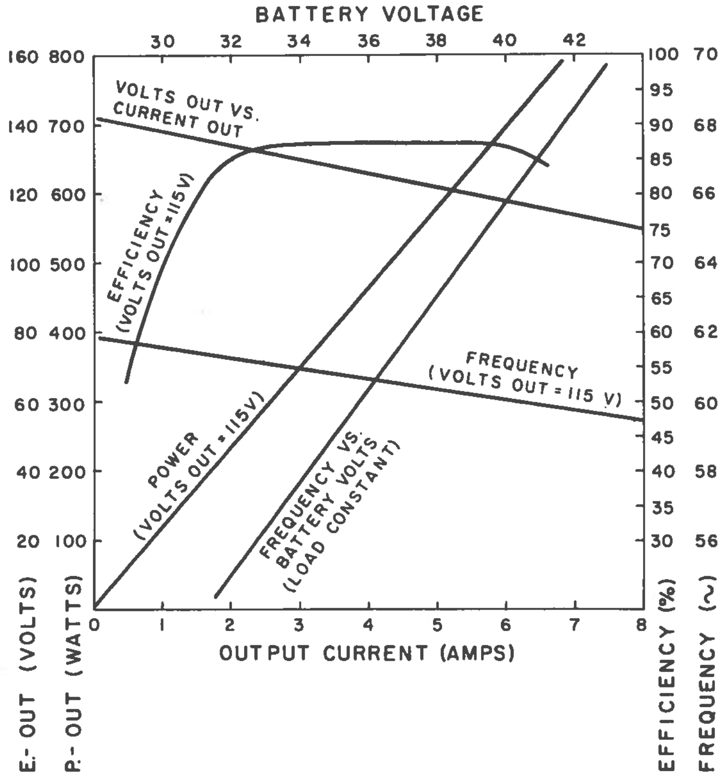

Fig. 3 Performance curves

Switching frequency is lowered when battery voltage falls or when the load is increased. A 10% change in battery voltage induces an 8.5% change in frequency, and a 10% change in load at the 650-watt level causes a 0.05% change in frequency. Varying the load current from zero to 7 amperes causes only a 3% change in frequency.

With a resistive load, the system can be switched on or off at the supply or load side, with or without full load, without ill effects.

If the load is inductive, care must be taken when switching off. When an inductive circuit is suddenly interrupted, a back e.m.f. is produced. If no path is provided to dissipate this energy at the output of the inverter, the back e.m.f. will cause a high-voltage transient to be reflected in the primary. This might very well bring about voltage breakdown of the transistors. On the other hand, if the inverter circuit is interrupted at the primary side, the problem is obviated.

If the load is nonlinear, as with lamps, where the cold and operating temperature resistance can vary over a range ratio of 30:1, care must be taken when switching on. When a lamp load is switched in the circuit, the initial resistance may be of the order of 2 ohms, thereby imposing a 7-kilowatt load on the inverter. Obviously, the system cannot supply that much power. What happens instead is that the transformer comes out of saturation owing to a lack of base drive at the switching transistors. This, in turn, causes the transistor switches to oscillate at a much higher frequency (2 kc/s) and the waveform to look like a sine wave rather than a square wave. The end result, if the condition is sustained for more than a few seconds, is usually burnt-out transistors.

If the transistors have withstood the ordeal, the lamp, meanwhile, is quickly approaching operating temperature and therefore nearing its quoted wattage. The whole process may take a second or less, depending on the magnitude of the load. The hazards to the transistors and recovery time of the system are proportional to the size of the load, therefore increasing the possibility of transistor failure with increasing loads. The same problem occurs, of course, if the output is short-circuited.

A capacitive filter on the output can also be disastrous. This is especially true if the electrolytic capacitor has not been "formed" (unused for a long time). In such cases, the capacitor acts, initially, like a short circuit until it is formed, which may take seconds. Even formed electrolytic capacitors have low impedance initially. A small resistance (4 ohms) in series with the electrolytic capacitor will suffice to protect the inverter, provided the capacitor has been formed.

If a Variac, or its equivalent, is used to bring the nonlinear load to power slowly, most of the problems mentioned in the preceding paragraphs are eliminated.

The inverter was also tried with a special transformer composed of four 400-volt center-tapped windings connected in series, giving a total of 2400 volts d-c output after rectification and filtering. With proper care for the problems listed in the preceding paragraph on electrolytic capacitors, there was no trouble in attaining 800 watts output at 87% efficiency.

The battery terminals are relatively free of reflected transients (Fig. 4). Even under full load, these are limited to spikes of 40 microseconds duration at the oscillating frequency, with an amplitude of 2 volts. The secondary waveform is free of spikes.

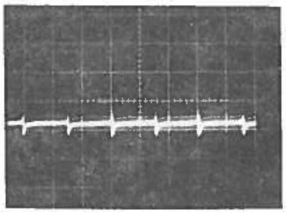

Fig. 4 Waveform across battery terminals
with 700-watt load
2 volts (peak-to-peak)
1 division = 5 milliseconds

The inverter was operated with battery voltages of 32 to 42 volts without deleterious effects.

The only heat problem encountered involved the saturating core transformer. After a half-hour operation under "no load" condition, it grew uncomfortably hot. This is due to a higher voltage across its primary winding and an increase in base current as a result of lower voltage drop across the emitter resistors.* Under normal working conditions, with a load, the problem is non-existent. After one hour of operation with a 600-watt load, there was no sign of overheating.

---

*If the inverter has to operate under "no-load" conditions for more than 15 minutes, it would be advisable to have a bleeder across the output.

CONSTRUCTION

The six transistors are mounted on three Delco heat sinks, forming a package measuring 5" × 5" × 3". The emitter resistors, R3, are made of 6-inch lengths of No. 12 chromel-A wire. It is suggested that a mechanical or silver-solder contact be used with this wire. Hook-up wire throughout the primary circuit is No.12. A 30-ampere fuse should be installed in the battery circuit to protect the transformers in case of transistor failure. The whole unit can be built in a volume of one cubic foot.

ACKNOWLEDGMENT

The author is indebted to Dr. D.W.R. McKinley and Mr. J. Humphries for technical advice.