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Advantage of Resonant Power Conversion in Aerospace Applications

Irving G. Hansen
Lewis Research Center
Cleveland, Ohio

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AUTH: A/HANSEN, I. G.

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ADVANTAGE OF RESONANT POWER CONVERSION IN AEROSPACE APPLICATIONS

Irving G. Hansen
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

An ultrasonic, sinusoidal aerospace power distribution system is shown to have many advantages over other candidate power systems. These advantages include light weight, ease of fault clearing, versatility in handling many loads including motors, and the capability of production within the limits of present technology. Rererences are cited that demonstrate the state of resonant converter technology and support these conclusions.

INTRODUCTION

A resonant power converter may be defined as a switching type of converter in which energy is simultaneously delivered to the load and stored in a resonant inductor-capacitor (LC) circuit. A simplified switched resonant circuit is shown in figure 1(b). If the Q of this circuit is greater than unity, the current will be sinusoidal and pass through zero. Because the switch remains in saturation until the current is near or at zero, minimum turnoff energy will be dissipated. Significant advantages are to be gained through this low-loss (self-commutated) switching. For example, if transistors are used as power switches, the self-commutating collector current avoids second breakdown and thus removes the requirement for complex, lossy snubbing systems. Once second breakdown is avoided, transistors can be operated at substantially higher power levels. Low loss per switch cycle permits a high operating frequency for a given efficiency and thus reduces system mass. As an example, multikilowatt systems can be built today with specific power densities of 2 kW/kg. And finally, operating a resonant converter at high frequency minimizes the energy available to a load fault; this in turn eases the switching and protection problems inevitable in large power systems.

PRESENT CIRCUIT STATUS

Series-resonant power converters can be broken into two classes: one in which the load is placed across the capacitor, and another in which the load is taken in series with the resonant elements. The first class of converter is typified by Mapham's original work (ref. 1) in which a load resistor is placed directly across the resonant capacitor (fig. 1(a)). This creates a voltage source having low distortion because the capacitor tends to integrate any switching discontinuity. Schwarz (ref. 2) describes the second class of inverter, wherein the series elements not only provide a current source, but also preclude a dc path and thus insure positive commutation (fig.1(b)). More recent work with the voltage class of inverter has been performed by Hewlett Packard. In this circuit, field-effect transistors are operated at 200 kHz, resulting in an extremely lightweight computer power supply. In the design of this inverter, voltage control is achieved by varying the chopping frequency and operating the reactive elements as low-pass underdamped filters. The rationale for the selection of a resonant converter for this application centered on the minimal RFI problems presented by a sinusoidal high frequency (ref. 3). Yet another example of a voltage-configured converter using high-speed Darlington switches and including some design equations is provided by S. R. Babu of General Electric (ref. 4). The second class of converter, with its current source characteristics, has been used in applications wherein the load was subjected to intermittent shorting. In this converter, silicon-controlled rectifier switches were used in a high-frequency, full-bridge configuration with the control scheme configured in a manner to prevent "latch up" of the dc source (refs. 5 and 6).

A transistorized resonant converter has recently been operated in the multikilowatt region by Hughes Research Laboratory (ref. 7). And finally the versatility of a resonant power system was demonstrated by its adaptation to a bidirectional power converter capable of operation in all four quadrants (ref. 8) as a universal link between ac and dc sources.

All of these recent resonant converters display high efficiency, high operating frequency, and light weight. Typically at multikilowatt power levels and at operating frequencies above 20 kHz, efficiencies are in the 90 to 96 percent range and, when advanced components are used, packaged system masses of 2 kg/kW are realistic.

PRESENT POWER COMPONENT STATUS

The Lewis Research Center has for many years maintained a program of power component development. Among these components are

(1) Transformers delivering 2.5 kW at 20 kHz and weighing less than 7 lb (0.126 kg/kW).

(2) Capacitors having current capabilities of 100 A at 40 kHz (75 kVA) that have completed full-power vacuum life testing. Even though an eventual weight reduction by a factor of 2 is anticipated, the present power density of these capacitors is about 0.12 kg/kVAR.

(3) Transistors with ratings of 500 V and 150 A and fall times of 0.75 μsec. With suitable derating these transistors will switch in excess of 25 kW/device at rates of over 20 kHz. As an example, these transistors would be capable of controlling a six-phase aircraft starter motor with a rating of over 100 kW (125 hp).

(4) Diodes rated at 1000 V reverse and 1.5 V forward at 50 A with a reverse recovery time of 100 nsec.

These components represent the basic building blocks of a multikilowatt power processor and are candidates for further development.

EXAMPLE OF HIGH-FREQUENCY SYSTEM APPLIED TO AN AIRCRAFT

The proposed system is an ac (sinusoidal), high-frequency (multi-kilohertz) power distribution and control system. The central concept of this system is based on a self-commutated resonant power conversion stage, a distributed high-frequency power bus, and bidirectional power conversion where appropriate. The advantage of a high-frequency sinusoidal power system for this application lies in its low mass and great versatility. The versatility of such a system is not limited merely to the ease by which voltage levels can be altered; it opens new degrees of design freedom to exploitation. Lower frequency waveforms, including dc, can be synthesized from this high-frequency carrier, as required, to satisfy user demands. A basic circuitry connection to allow this is shown in figure 2(a). In this circuit, switch pairs 1,1' and 2,2' are operated in such a manner as to perform synchronous rectification of the carrier and thus synthesize a lower frequency output. In this respect the circuit operates somewhat as a conventional cycloconverter with a high stroke count. Actual photographs of a high-frequency (25 kHz) carrier and a synthesized 400-Hz waveform are shown in figure 2(b). Proper sequence of the switch pairs will also allow reverse power flow by chopping a lower frequency (including dc) into a higher carrier frequency. This inherent symmetry of the high-frequency inversion system is illustrated in the bidirectional implementation shown in figure 3. The remarkable system versatility is exploited by this configuration, which transforms either ac or dc into either ac or dc while allowing power flow in either direction.

In particular the bidirectional converter can be considered as a universal interface between storage, generation, transmission, and user. It will allow frequency and power waveforms to be tailored to the load requirements. This enables variable-speed induction motor operation with relatively simple circuitry (basically only a synchronous rectifier). Induction motors with this simple circuitry can be substituted in many applications for samarium-cobalt motors and their massive associated electronics. One configuration of a bidirectional conversion system is shown in figure 4. In this system the rapid response of the various high-frequency sources creates an essentially uninterruptible power system. As an example, if 10 sequential cycles of a 20-kHz power system were lost, during switchover or failure, only 500 μsec of energy storage would be required at the load.

Once a basic circuit control philosophy is established, the control and protection circuitry will be common for a large percentage of converters in any one system. Under these conditions hybridization of the control and protection circuitry becomes practical. This system would allow starting or auxiliary powering of the airplane from 60-Hz ground service or powering of ground service from an airplane. The latter connection would allow one airplane (or helicopter) to start another at remote locations.

When fault protection and load switching are considered, an ac distribution system displays additional merit. The same self-commutating characteristics that minimize switching losses greatly simplify current interruption. Also in a resonant power converter the energy available to circuit faults is limited only to that energy stored in the reactive elements. Because of the high operating frequency the available fault energy is minimized. Regarding electromagnetic interference, a sinusoidal power system operating at high frequency represents a much "cleaner" source of interference than any equivalent power "square wave" chopper system. Therefore much less filtering will be required for an ac system than for alternative systems.

CONCLUSIONS

Resonant power converter technology has demonstrated significant advantages over other circuit topologies for multikilowatt power levels. These advantages include light weight, high efficiency, high output power capability, and minimum electrical interference. Advanced control techniques that allow waveform synthesis together with bidirectional energy transfer represent an enabling technology for many aerospace applications. As an example the present electronics required to operate variable-speed motors from dc sources are much larger and heavier than the motor itself. However, by synthesizing a variable-frequency multiphase drive from a high-frequency carrier, the electronics can be greatly reduced.

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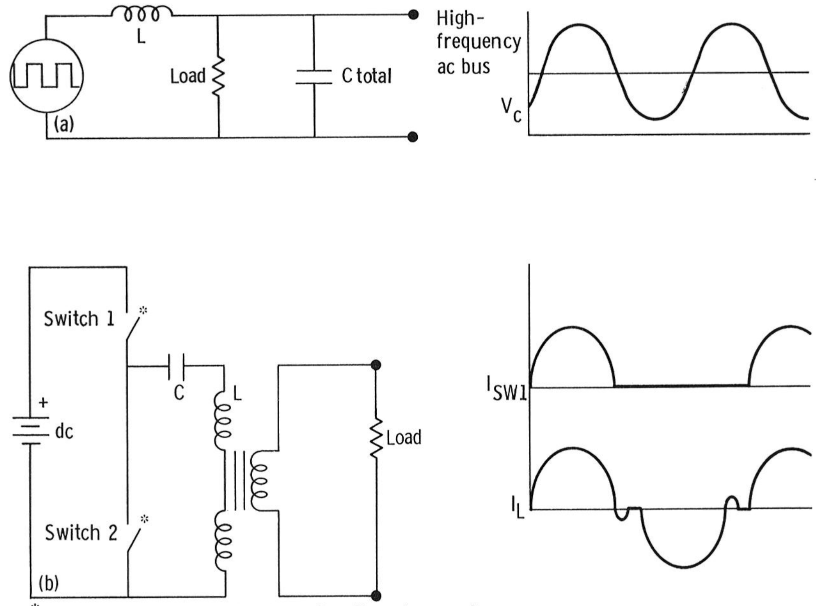
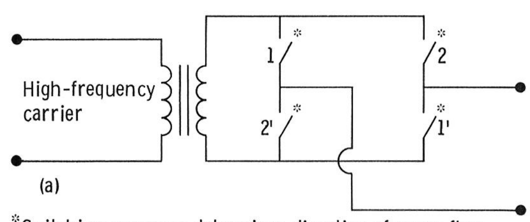


*Switching sequence determines direction of power flow

(a) Equivalent circuit (first class).
(b) Basic ac circuit (second class).

Figure 1. - Resonant half-bridge converter (dc-ac case).



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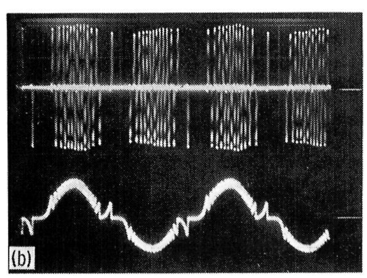

(a) Basic circuitry.
(b) Hughes Research Laboratory synthesized waveform.

Figure 2. - High-frequency waveforms synthesis.

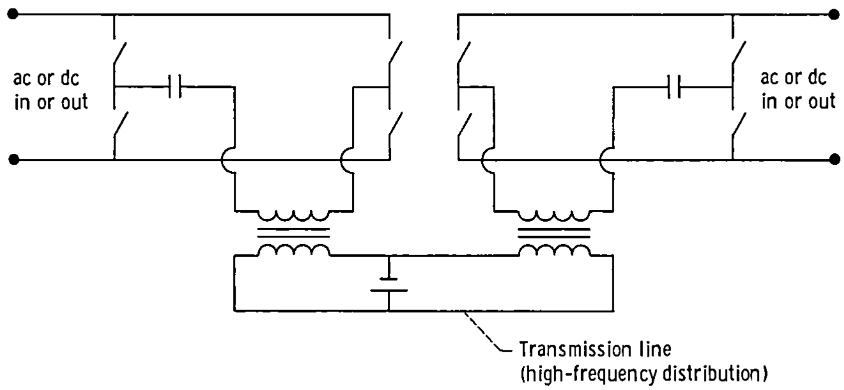

Figure 3. - Bidirectional "universal" power conversion.

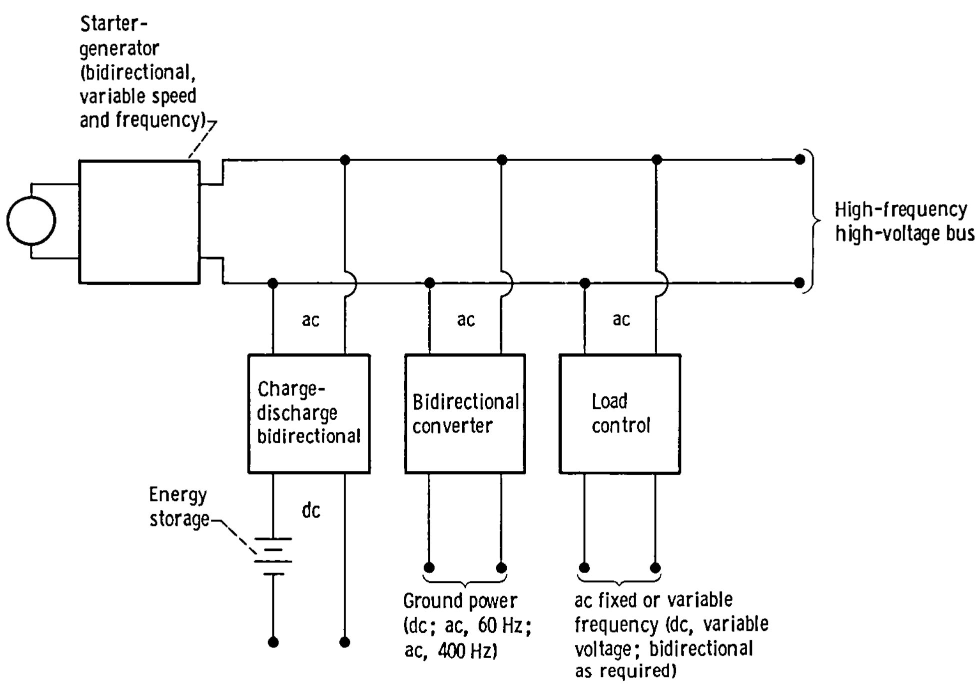

Figure 4. - Bidirectional conversion system configuration.

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16. Abstract

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