ELECTRICAL CHARACTERIZATION OF A MAPHAM INVERTER USING PULSE TESTING TECHNIQUES

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ABSTRACT

Electric power requirements for aerospace missions have reached megawatt power levels. Within the next few decades, it is anticipated that a manned lunar base, interplanetary travel, and surface exploration of the martian surface will become reality. Several research and development projects aimed at demonstrating megawatt power level converters for space applications are currently underway at the NASA Lewis Research Center. Innovative testing techniques will be required to evaluate the components and converters, when developed, at their rated power in the absence of costly power sources, loads, and cooling systems. Facilities capable of testing these components and systems at full power are available, but their use may be cost prohibitive. This paper proposes the use of a multiple pulse testing technique to determine the electrical characteristics of large megawatt level power systems. Characterization of a Mapham inverter is made using the proposed technique and conclusions are drawn concerning its suitability as an experimental tool to evaluate megawatt level power systems.

INTRODUCTION

Aerospace electrical power needs have been increasing steadily over the past two decades, as shown in Figure 1. Table 1 depicts the increase in the electrical power of space-based applications, which shows that the power levels of large space electrical systems seems to be about doubling every 5 to 8 years. It can also be seen from Table I that the power level for this type of application has gone from about 1 kW in 1970 to a projected power need in the multi-megawatt range by the year 2020.

When power systems are small, in the few hundred watt or kilowatt range, testing of these power systems is relatively easy to do and can often be done in a small laboratory environment. As space electrical systems grow larger, i.e., tens and hundreds of kilowatts and even megawatts in size, the development and testing of these power systems become more challenging and difficult. In addition, the specific weight of the power electronics (kg/kW) becomes more and more critical in the design of

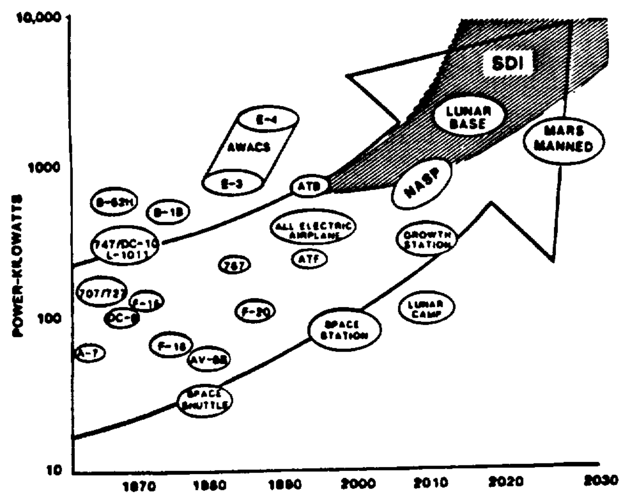

Figure 1. Power level trends for aerospace missions.

TABLE I. SPACE ELECTRICAL POWER NEEDS BY YEAR

Mission	Year	Power Level
Ion Thrusters Space Test	1970	1 KW
Technology Satellite	~1975	0.4 KW
Space Shuttle	1980	20 KW
Space Station	Late 1990's	75 KW
Growth Space Station	2010	250 KW
Lunar Base	2020	1000 KW
SDI Applications	2020 - 2030	10 - 100 MW

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reliable and efficient large space-based systems. The availability of very light weight reactors, solar cells, and storage elements render the power electronics to constitute a much larger fraction of the total electrical power system. Thus, it becomes necessary not to only reduce the size and weight of the power electronics but to thoroughly optimize as well as test the overall power electronic subsystems such as inverters and converters. As was mentioned earlier, testing of these high power systems, when developed, becomes more difficult to perform due to the need for large power sources with associated controls, load, and heat rejection. Full power characterization of these systems in a laboratory environment requires large amounts of floor space, with multi-ton cranes and may cost millions of dollars.

While simulation and optimization of many systems can easily be done with computers; in high power components and circuits, however, this may not be practical. This is due to the fact that critical parasitic inductances, capacitances, and their associated leakages are very critical and are difficult to identify for inclusion in the computer model and, therefore, their effects cannot be predicted by computer analysis.

An intermediate method of evaluating large power hardware, that is more realistic than computer simulation, and yet not requiring large power sources, loads, and thermal management with consequent high costs in materials and workyears, would seem to be desirable for a variety of high power components and systems.

This paper describes a method for testing large electrical power systems such as converters or inverters by operating them at full power, but only for short periods of time. This would eliminate the large input power requirements for running the test as well as the large heat rejection systems needed for both the load and for the system under test. The testing method is to turn on the system to be evaluated, a converter for example, for only a few cycles of the internal operating frequency. At first, it may only be for one cycle or even for a half cycle for a 20 kHz chopping rate (this corresponds to an "on" time of 50 or 25 microseconds). After examining the results, additional cycles can be used, until full electrical equilibrium is reached. Such a technique would allow the characterization of the circuit at full scale electrical operating conditions with little heat generated. That is because electrical equilibrium is reached far more quickly than its thermal counterpart. This method of testing also has the highly desirable result of preventing circuit or component thermal burnout during testing. The subsystem or system can be fully examined using the single and multiple pulse method and, in many cases, the causes of a potential failure can be determined without the failure actually occurring. This non-destructive testing of components or circuits prevents schedule slippage and extra cost that may be incurred.

In some cases, the single and multiple pulse testing approach may eliminate the need for long term full power measurements, with consequent major savings in schedule time, workyears, and money. If long term full thermal equilibrium measurements are needed, the single and multiple pulse techniques can be used as a conservative, non-destructive intermediate step. Also, the single and multiple pulse circuitry can possibly be used to control faults in long term full power measurements.

Characterization of a 2 kW Mapham inverter is demonstrated using the pulse testing technique. The minimum number of cycles required for the inverter to reach electrical equilibrium, which is taken as 99% of steady-state power, is determined. The experimental procedure and the results obtained are presented in this paper.

EXPERIMENTAL APPARATUS

A block diagram of the test setup is shown in Figure 2. The main constituents include the inverter and its control circuitry, the main input power sources, and a resistive load bank.

The inverter tested is generally known as a Mapham inverter capable of providing 3 kW with a 125 VDC input in an overloaded condition. It uses a resonant tank circuit in an H-bridge configuration to develop a sinusoidal voltage across the resonant capacitor from which the output is taken with no isolation transformer. The inverter is triggered subresonantly at a 20 kHz rate in order to provide commutation time for the thyristor switches and thus results in a fundamental output frequency of 20 kHz. An extensive operational and analytical studies of the Mapham inverter is provided in references [1-3].

The control circuitry basically consists of a free running oscillator that drives a programmable pulser which controls the pulse gating network. The programmable pulser is capable of producing a precisely controlled number of gating pulses. The number of pulses produced is switch selectable in a range from one to 127 pulses or it can be set to provide pulses continuously. The upper limit can be easily extended by increasing the upper boundary of the pulse counter in the programmable pulser. An explanation of the operation of the programmable pulser along with a schematic is given elsewhere [4].

Evaluation of the inverter was performed with the DC input power being provided by either a Hewlett Packard Model 6483C DC power supply or by a custom-made capacitor bank. The HP 6483C is capable of providing sufficient current to operate the inverter in a continuous mode and was used to establish the steady-state operating characteristics of the inverter. The capacitor bank consisted of ten electrolytic capacitors connected in parallel with a rating of 10,000 microfarads at 250 VDC each. The basic schematic of the capacitor bank is given in Figure 3 with various safety circuits included. The resistor, R_{ch}, in series with the input is used to limit the capacitor charging current. It also serves to limit the current available to the inverter from the charging power supply, i.e. the HP 6483C.

Initial pulse testing was performed by monitoring the inverter output voltage and tank current with the input power being provided by the HP DC supply. These measurements were repeated using the capacitor bank as the input power source to the inverter. For each case, these tests were performed with and without resistive loading of the inverter for a selected number of cycles of operation.

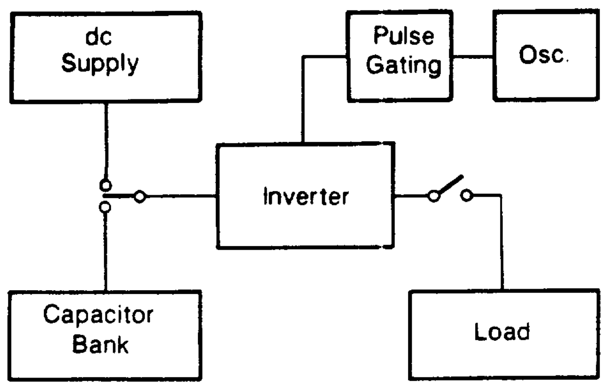

Figure 2. Experimental test setup.

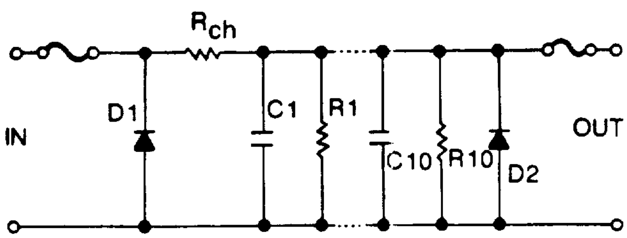

Figure 3. Basic capacitor bank configuration.

EXPERIMENTAL RESULTS

The steady state of the inverter output voltage and tank current using the HP source as the input power to the inverter is shown in Figures 4a and 4b, without and with a 12-ohm load, respectively. These tests were also performed under the same conditions with the inverter operation limited to eight cycles. It appears that while the inverter reaches electrical equilibrium in four cycles under no load, it requires only one cycle when loaded, as shown in Figures 5a and 5b, respectively. Similar results were obtained when the capacitor bank replaced the HP source as the input power to the inverter. These results are shown in Figures 5c-d. It is important to note that the near-sinusoidal waveform given in Figures 4 and 5 represent that of the inverter output voltage while the other waveform with some discontinuities represents the tank current. These discontinuities are attributed to the switching occurring in the inverter bridge.

The inverter input voltage was also obtained with the inverter being operated for eight cycles without and with the 12-ohm load. This was performed in order to determine the degree of the input voltage droop. The results of these tests are shown in Figures 6a-b and 6c-d when the inverter is driven by the HP source and the capacitor bank, respectively. It can be clearly seen that when not loaded, the inverter input voltage displays very little droop regardless of the driving source. When loaded, the inverter input voltage droop is seen to increase as expected. This increase, however, is more severe when the inverter is driven by the HP supply, as shown in Figure 6b. This can be attributed to the limited energy that can be furnished by the HP source within its response time capability as compared to that of the capacitor bank.

It is important to note that the custom-built capacitor bank was designed to exhibit no more than 1% droop at 50 cycles of inverter operation. To validate the design, the inverter was operated for 50 cycles with a 12-ohm load connected to its output. The result of this test is depicted in Figure 7 where it can be seen that the droop amounts to only about 0.5%. The main factors that led to lower input voltage droop include smaller connected load, larger capacitors used, and better inverter efficiency than the design called for.

CONCLUSIONS

The currently emerging demand for space-based power systems and components is toward higher energy densities and larger power levels. For instance, future plans for many space exploration missions call for tremendous increases in the power capability to a magnitude in the order of megawatts. Facilities capable of testing these components and systems at full power are available, but their use may be cost prohibitive.

In this work, an innovative test method based on a multiple pulse technique was demonstrated on a 2 kW Mapham inverter. The concept of this technique shows that characterization of large power systems under electrical equilibrium at rated power can be accomplished without large costly power supplies. Also, the heat generation that occurs in systems when tested in a continuous mode is eliminated.

The results of this work indicate that there is a good agreement between this testing technique and that of steady state testing, as presented in this paper. Although it was proved to be viable for characterization of a medium power inverter, it is strongly believed that this technique is applicable to the evaluation of much larger power systems. Efforts are currently underway to apply this pulse testing technique on a 1 MW converter.

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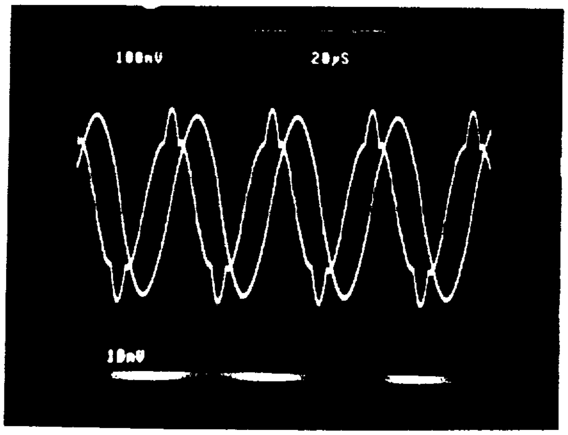

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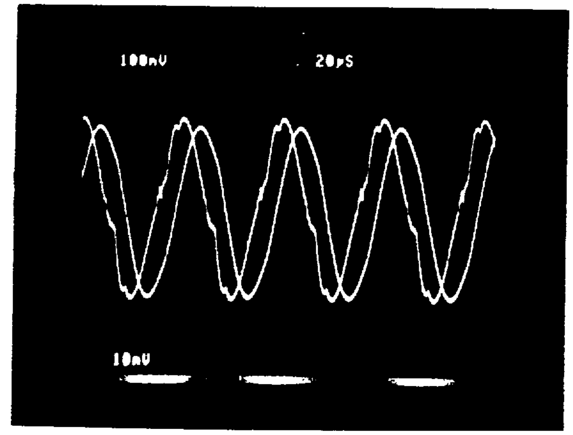
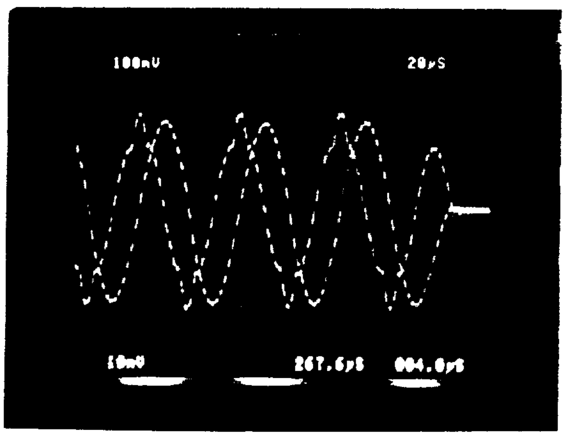


(b)

Figure 4. Steady state inverter output voltage and tank current. a) no-load; b) 12-ohm load.



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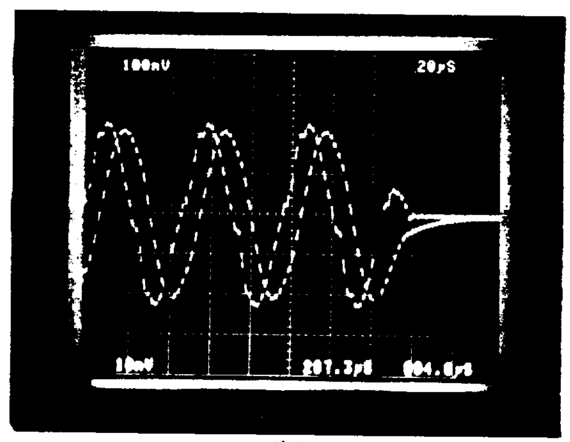

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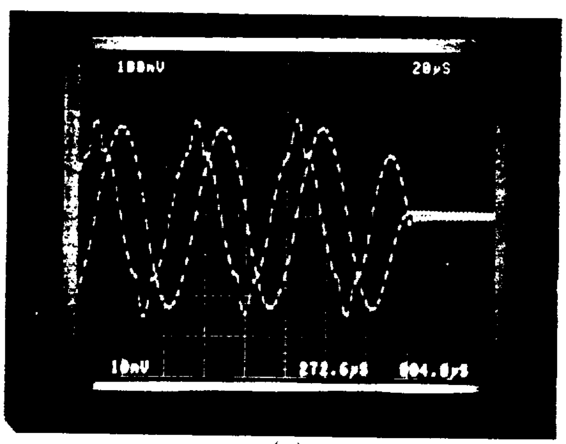

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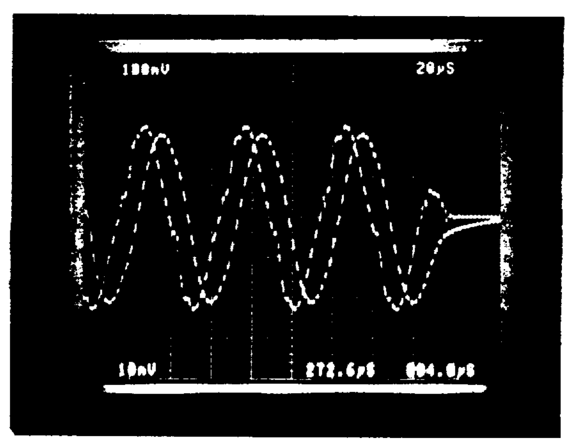
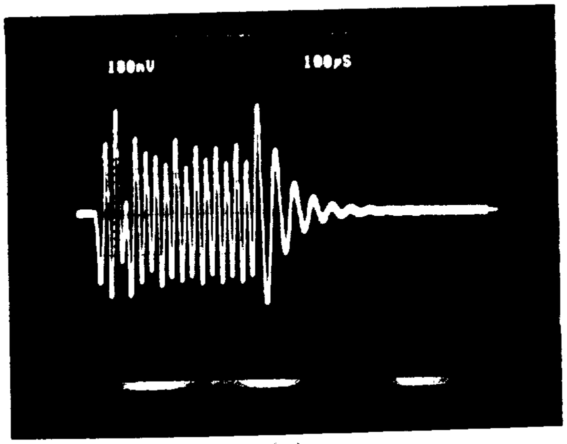


(d)

Figure 5. Pulse mode inverter output voltage and tank current at equilibrium. a) HP supply, no load; b) HP supply, w/ load; c) capacitor bank, no load; d) capacitor bank, w/ load.



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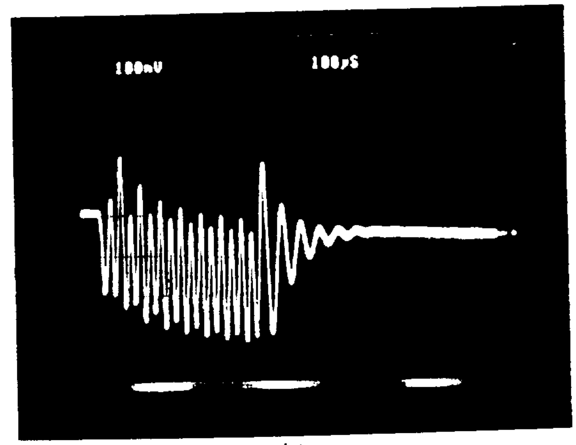

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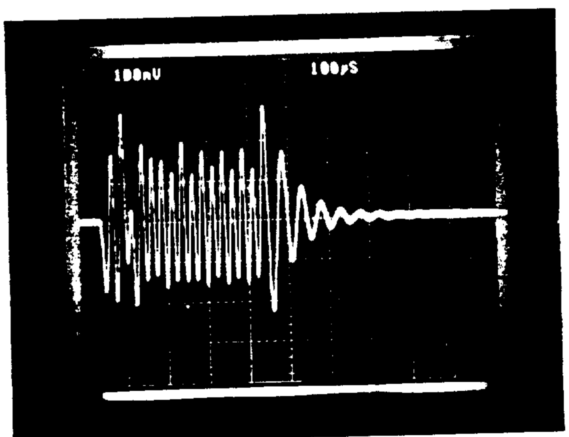

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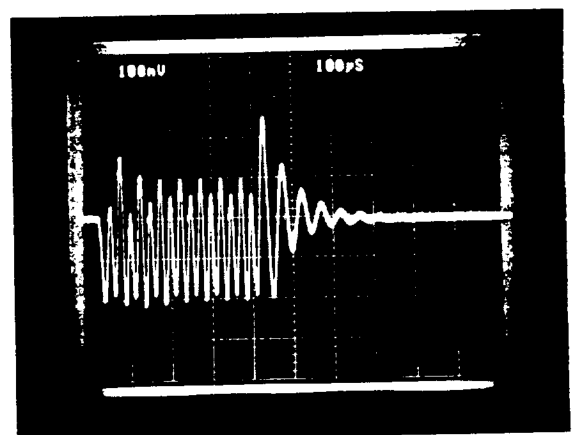

(d)

Figure 6. Input voltage droop. a) HP supply, no load; b) HP supply, with load; c) capacitor bank, no load; d) capacitor bank, with load.

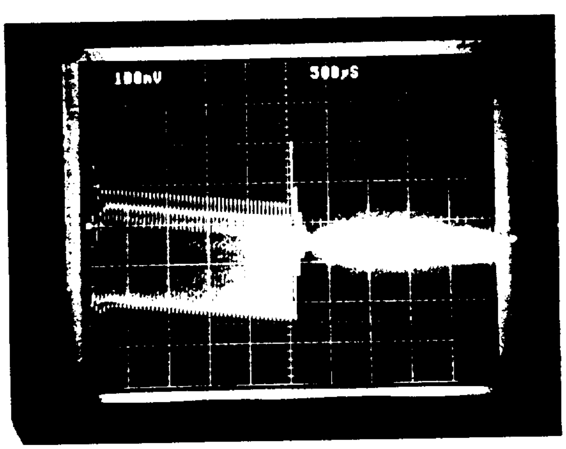

Figure 7. Droop at 50 cycles with load.

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16. Abstract

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