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RESEARCH ON SPACECRAFT ELECTRICAL POWER CONVERSION

Final Report
Research Grant Number NGL-34-001-001
Supplement No. 17

Prepared for
National Aeronautics and Space Administration
Goddard Space Flight Center

Thomas G. Wilson, P.I. January 31, 1983
RESEARCH ON SPACECRAFT ELECTRICAL POWER CONVERSION

Final Report on Research Grant Number NGL-34-001-001 Supplement No. 17

Prepared For National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland

Center for Solid-State Power Conditioning and Control School of Engineering Duke University Durham, NC 27706

Thomas G. Wilson, P.I. January 31, 1983
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1. BACKGROUND

Research on this project began in the Department of Electrical Engineering at Duke University in May 1961. During the first years of the grant it was funded under Grant Number NSG 152-61. On June 19, 1968 the project was put on the three-year step-funding program of NASA, and the grant number was changed to Grant NGL 34-001-001. The final funding for the grant was Supplement No. 17 which spanned the period March 1, 1976 to February 28, 1979.

2. OVERVIEW

Over the almost eighteen-year period covered by this grant, the U.S. space program came of age. It was an exciting period as technology raced forward on many fronts. For those of us on the faculty at Duke University and our graduate students, it was a real pleasure and honor to have the opportunity to participate in and contribute to the shaping of events in the area of electrical power conversion. To see the design techniques, analyses, and understanding developed during this era being used today to power virtually every computer that is manufactured and every new communications installation is a continuing source of excitement and satisfaction. Much research and development still remains to be done to meet new applications calling for higher power, improved dynamic response, greater reliability and lower costs; but it is clear that acceptance of the new switching-mode approach to electronic power conditioning has firmly caught hold and that all products requiring almost any type of power supply will be the better for it.

Of lasting gratification to all at Duke who participated in the program is the remembrance of the many regular trips we made to Goddard Space Flight Center where we were always warmly welcomed, our results and ideas were critically examined in a constructive environment, meaningful suggestions
were made, clear goals and objectives were set, and we all returned to Duke with enthusiasm to meet the new challenge. Of particular significance and lasting impact on the lives of the graduate students who worked on this program is the high standards of professional performance set and the personal attention given by two of the technical monitors of our project, Mr. Fred Yagerhofer in the early years of the program and in more recent times by Mr. G. Ernest Rodriguez. Both gentlemen were exemplary in all respects.

In this final report, we undertake to summarize the project activities by briefly reviewing in Section 3 the personnel who have been associated in a significant way with the work of the grant. In Section 4, we list in chronological order all publications that were an outgrowth of this grant with the exception of Special Reports to NASA which are listed separately in Section 5. Invention disclosures submitted to NASA as a part of this project are listed in Section 6. Section 7 lists patents that were issued and Section 8 is the concluding section of the report.

3. PERSONNEL

Throughout the course of the grant Professor Thomas G. Wilson served as principal investigator. Bruce A. Wells, Associate Professor in the Department of Electrical Engineering, participated on a part-time basis during the years 1966 to 1970. In 1971, Professor Harry A. Owen, Jr. joined the project as Associate Investigator and continued to serve in that capacity until the end. Drs. Wilson and Owen are both full-time members of the faculty of the Department of Electrical Engineering.

Numerous students, graduate and undergraduate, were associated with the project in many different capacities over the lifetime of the grant. Table I lists the names of those graduate students who had a serious commitment to the project for a period of time greater than one year and contributed in a
meaningful way to one or more of the research publications. Also noted are
the years covering their involvement and an indication if a M.S. thesis or
Ph.D. dissertation resulted that was based on work related to the project.
Some continued to serve for a period of time after completing their
dissertations as Post Doctoral Research Associates. An interesting statistic
is that eleven of the sixteen persons continue to work professionally in the
area of power electronics in industry and in other universities.

**TABLE I. GRADUATE STUDENTS WITH MAJOR COMMITMENT TO RESEARCH PROJECT**

<table>
<thead>
<tr>
<th>Student</th>
<th>Years</th>
<th>Degree Type</th>
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<tbody>
<tr>
<td>William E. Hammond</td>
<td>1964-65</td>
<td></td>
</tr>
<tr>
<td>Yuan Yu</td>
<td>1964-68</td>
<td>Ph.D. Dissertation (1967)</td>
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<tr>
<td>Sam Y-M Feng</td>
<td>1966-72</td>
<td>Ph.D. Dissertation (1972)</td>
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<tr>
<td>George Dakermanji</td>
<td>1970-73</td>
<td></td>
</tr>
<tr>
<td>Dan De Yu Chen</td>
<td>1972-75</td>
<td>Ph.D. Dissertation (1975)</td>
</tr>
<tr>
<td>1972-77</td>
<td></td>
<td>Ph.D. Dissertation (1977)</td>
</tr>
<tr>
<td>Anil K. Ohri</td>
<td>1972-77</td>
<td>Ph.D. Dissertation (1977)</td>
</tr>
<tr>
<td>Stephen D. Huffman</td>
<td>1975-77</td>
<td></td>
</tr>
<tr>
<td>David D. Bahler</td>
<td>1977-78</td>
<td>M.S. Thesis (1978)</td>
</tr>
<tr>
<td>Ronald C. Wong</td>
<td>1978-79</td>
<td></td>
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</table>
4. PUBLICATIONS

Table II lists in chronological order eighty-one publications in the open literature which were supported in part by this research grant. To provide a complete and comprehensive record of this aspect of the project's activities, this list cites not only complete papers that were published but also abstracts and digests of paper of two or more pages in length that were published separately in the literature. In a number of instances, the same or a very similar manuscript was published in more than one location. These are noted by cross references.

Although financial support under this grant terminated February 28, 1979, additional effort has been expended on the part of faculty members and some former graduate students associated with the project to further develop some of the concepts and ideas that were started during the tenure of the project. These efforts have resulted in seven additional publications over the past three years. These are listed as Items 75 through 81 in the list of publications.

Of particular note should be the fact that two of the papers reporting research results on this grant were singled out by the Aerospace and Electronics Society of the Institute of Electrical and Electronics Engineers to receive special IEEE awards. Paper No. 43, "Computer-Aided Design and Graphics Applied to the Study of Inductor-Energy-Storage DC-to-DC Electronic Power Converters," received the M. Barry Carlton Honorable Mention Award for 1974. It was authored by D.Y. Chen, H.A. Owen, Jr. and T.G. Wilson. Five years later, Paper No. 74, "A State-Trajectory Control Law for DC-to-DC Converters" by W. W. Burns, III and T.G. Wilson, was selected to receive the M. Barry Carlton Award for 1979 "for the best paper published in the Society Transactions in the previous calendar year".
TABLE II. CHRONOLOGICAL LISTING OF PUBLICATIONS


TABLE II. CHRONOLOGICAL LISTING OF PUBLICATIONS (Cont.)


TABLE II. CHRONOLOGICAL LISTING OF PUBLICATIONS (Cont.)


TABLE II. CHRONOLOGICAL LISTING OF PUBLICATIONS (cont.)


### TABLE II. CHRONOLOGICAL LISTING OF PUBLICATIONS (Cont.)


### TABLE II. CHRONOLOGICAL LISTING OF PUBLICATIONS (Cont.)


TABLE II. CHRONOLOGICAL LISTING OF PUBLICATIONS (Cont.)


5. SPECIAL REPORTS

In addition to articles in the open literature which served as the principal means of reporting significant research results accomplished during the course of the project, fourteen special reports were prepared and submitted. These reports, which are listed in Table III, often constitute longer documents with greater detail of information than could be accommodated in a paper in some journal. Some of these special reports are M.S. theses or Ph.D. dissertations prepared by graduate students working on this grant.

6. INVENTION DISCLOSURES

During the course of the grant some twenty-one invention disclosures were submitted to NASA. The titles and dates of these disclosures are given in Table IV.

7. PATENTS

Of the twenty-one invention disclosures, four resulted in the issuance of U.S. Patents. These are enumerated in Table V. In the case of items 1, 2 and 4, waivers were requested by the University and/or the inventors and the costs of obtaining a patent were borne by them. In the case of item 3, the patent was obtained by NASA-engaged attorneys.

8. CONCLUSION

To the best of the Principal Investigator's knowledge, this final report represents an accurate and complete summary of all technical aspects of the research carried out under this grant.
TABLE III. SPECIAL REPORTS


9. STATIC DC TO DC POWER CONDITIONING-ACTIVE RIPPLE FILTER, 1 MHZ DC TO DC CONVERSION, AND NONLINEAR ANALYSIS, William August Sander, III (March 23, 1973).

10. ANALYSIS OF TRANSIENT CHARACTERISTICS AND STARTING OF A FAMILY OF POWER CONDITIONING CIRCUITS: TWO-TRANSISTOR SATURABLE-CORE PARALLEL INVERTERS, Fred Chai Yan Lee (April 16, 1974).

11. DESIGN OF ENERGY STORAGE REACTORS FOR DC-TO-DC CONVERTERS, De Yu Chen (August 18, 1975).


13. AIR-GAPPED STRUCTURES AS MAGNETIC ELEMENTS FOR USE IN POWER PROCESSING SYSTEMS, Anil Kumar Ohri (July 6, 1977).

TABLE IV. INVENTION DISCLOSURES SUBMITTED TO NASA


TABLE V. U.S. PATENTS


