科技资料

Conference Record of the 1992 Twentieth Power Modulator Symposium

92CH3180-7

Conference Record of the

1992 Twentieth Power Modulator Symposium

sponsored by
US Army LABCOM, ET&DL

Naval Surface Warfare Center, Dahlgren Laboratory

Air Force Wright Laboratory

Air Force Phillips Laboratory

Strategic Defense Initiative Organization

in cooperation with
The Advisory Group on Electron Devices

and under the management of
Palisades Institute for Research Services, Inc.

Library of Congress Catalog No.: 92-53252

Available from
IEEE Single Copy Sales
445 Hoes Lane
Piscataway, NJ 08854

Printed in USA

IEEE Catalog Number 92CH3180-7
ISBN 0-7803-0718-6 (softbound)
ISBN 0-7803-0733-X (casebound)
ISBN 0-7803-0719-4 (microfiche)
Library of Congress Number 92-53232

Foreword

The Conference Record of the 1992 Twentieth Power Modulator Symposium provides another chapter in the history of the development of pulse power technology. It will provide a ready access to information on pulse power's constantly changing advances for those now practicing and those in the future who enter this very exciting career field. The excellent quality and content of the symposium and its proceedings are due to the Program Chairman, Dr. Glen McDuff and the Technical Program Committee.

The basic underlying theme of this years symposium was devoted to applications. Three keynote speakers dealt with applications. Three keynote speakers dealt with applications of pulse power in the US Army, US Navy and in commercial uses. Dave Singh spoke about "Power Electronics in Army Systems". Guy Grater discussed "Interface Technologies for Shipboard Applications of Pulsed Power Systems" and Steve Levy from Power Electronics Applications Center challenged the audience on the "Commercial Applications for Modulators and Pulse Power". On Wednesday afternoon, in parallel with the Poster Session, a panel discussion was held to further explore means whereby pulse power has useful properties and applications. This was organized by Karl Schoenbach of Old Dominion University and COPPSAT.

At the 1990 Symposium, the Germeshausen Award was introduced. The award is to be given to those individuals making outstanding contributions in the science and technology of power modulators and related pulse power. The award was named for Kenneth J. Germeshausen and it recognizes his seminal work on hydrogen thyratrons and power modulators. This year the Awards Committee selected two individuals whose careers have been almost synonymous with the advances made in pulse power technologies and who have been leaders in their own unique ways. Sol Schneider, formerly of the Army ETDL was recognized for his long history in the development of and support of hydrogen thyratron and related pulse power technology. Sol was also one of the founders of the Hydrogen Thyratron Symposium and served as chairman for many years. The second gentleman honored in this years symposium is Hugh Menown of the United Kingdom who is one of those individuals who is widely recognized for his expertise in high power thyratron technology. His signature is on many of the major advances in thyratron developments. In addition to the Germeshausen Award, individual student awards were presented to John Kenney of Old Dominion University and to Peyman Hadizad of the University of Southern California.

Poster sessions were again a highlight of the Symposium. Approximately fifty-three posters were presented in two sessions, with very active participation by attendees in spite of a tight schedule. Dr. Scott Gilmour presented a one day course on microwave tubes which was derived from a normal five day course.

This year saw a greater international participation which included a total of twenty-two papers presented by attendees from eleven foreign countries. The symposium has become an internationally recognized forum for the exchange of ideas in pulse power technology.

My highest regards are extended to the authors and attendees for contributing to the overall success of the symposium. In addition, my thanks are extended to the Army LABCOM ETDL, Navy NAVSWC, Air Force AFWL and AFPL, SDIO, The Advisory Group on Electron Devices and to the Palisades Institute for Research Services for their support. Mark Goldfarb, Janice Brooks and William Klein are to be commended for a job well done.

The 1994 Twenty-first Power Modulator Symposium will be held on June 28-30, 1994 at the Westin South Coast Plaza, 666 Anton Blvd., Costa Mesa, California.

Bobby Gray
Rome Laboratory
Symposium Chairman

EXECUTIVE COMMITTEE

B. Gray, *Symposium Chairman*
Air Force Rome Laboratory

G. McDuff, *Program Chairman*
Consultant

S. Schneider, *Chairman Emeritus*
Consultant

M. Goldfarb, *Treasurer*
Palisades Institute for Research Services, Inc.

J. Brooks, *Secretary*
Palisades Institute for Research Services, Inc.

L. Luessen, *Chairman Ex-Officio*
Naval Surface Warfare Center, Dahlgren Lab

M. Weiner, *Chairman Designate*
U.S. Army LABCOM

L. Walko, *Sponsor*
Air Force Wright Laboratory

J. O'Loughlin, *Sponsor*
Air Force Phillips Laboratory

P. Rustan, *Sponsor*
Strategic Defense Initiative Organization

D. Singh, *AGED Liaison*
U.S. Army LABCOM

M. Gundersen, *Program Chairman Ex-Officio*
University of Southern California

TECHNICAL PROGRAM COMMITTEE

T. Bekker
NSWSES
M.T. Buttram
Sandia National Labs
J. Creedon
Consultant
R. Dollinger
SUNY at Buffalo
R.A. Gardenghi
Westinghouse
A.S. Gilmour, Jr.
SUNY at Buffalo
R.J. Gripshover
NSWC
H.C. Grunwald
ITT
L. Hatfield
Texas Tech University
R.A. Hill
Engineering Resources
B. Hoeberling
Los Alamos National Lab
M.J. Kushner
University of Illinois
F. Lee
Virginia Tech University
S. Levy
PEAC
R. Limpaecher
AVCO Research Laboratory
H. Mehta
EPRI
H. Menown
EEV
M. Nikolich
W.J. Schafer Associates
W.C. Nunnally
University of Texas at Arlington
M.F. Rose
Auburn University
W.J. Sargeant
SUNY at Buffalo
C. Scheffler
Raytheon Co.
R.J. Temkin
MIT

CONTENTS

PAGE

SESSION 1: KEYNOTE SESSION

SESSION 2: SYSTEMS

CONTENTS (Continued)

PAGE

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

PAGE

POWER ELECTRONICS IN ARMY SYSTEMS

H. SINGH, T. PODLESAK, C. BRAUN
U.S. ARMY LABCOM, ETDL
FORT MONMOUTH, NJ 07703-5000

J. CARTER, J. CREEDON
VITRONICS, INC.
EATONTOWN, NJ

I. REINGOLD
GEO-CENTERS, INC.
EATONTOWN, NJ

Abstract

Pulsed power components are essential elements in the development and operation of Army (and other Service) sensor, electronic warfare/countermeasures, and communication systems. Their development is critical to the realistic achievement of advanced, forward-looking technologies leading to the use of electric guns, high power microwave sources, and all-electric or mostly electric vehicles such as tanks and aircraft.

The status of key pulse power components (capacitors, switches, batteries) will be described, along with projected technical milestones that are expected to be achieved during the next decade. Army future systems needs will be discussed emphasizing the role that power electronics plays in meeting these needs by integrating pulse power components into subsystems and systems. Potential spin-offs for commercial applications will also be noted.

Introduction

Pulsed power technology has been selected as one of the Department of Defense critical technologies. Critical technologies are recognized as technologies with great promise for ensuring the long-term superiority of United States electronic oriented systems or weapons systems. However that promise can only be realized when the specific technology is integrated into a balanced science and technology effort along with associated supportive technology.

Pulsed power production and power conditioning is a multi-step process involving energy storage, extraction, pulse generation, and modulation (Figure 1). High power capacity batteries, and high energy density capacitors are required in tandem with the prime power sources to provide additional energy storage, power and pulse generation for a wide variety of applications. Typical power conditioning assembles are shown on Figure 2, and Figure 3 indicates the impact of pulse power technology and components on important subsystems and systems. Figure 4 indicates the pulsed power characteristics that are prerequisite requirements for different classes of potential weapons systems.

Capacitors, voltage converters, pulse forming networks, and switches are key pulse power components critical to the diversity of Army system applications (and other Service and government system applications as well). RF sources, batteries, alternators, and inverters can be considered important peripheral technical areas closely associated with pulse power componentry. Figure 5 is a list of current pulse power technology development under investigation. Figure 6 is a projection of what characteristics may be available if not in production items, at least in prototype developmental products by the time frames shown.

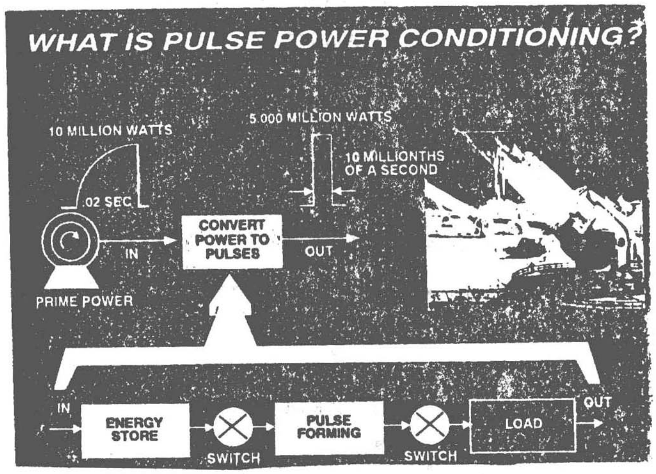

FIGURE 1: DEFINITION OF PULSE POWER AND PULSE POWER CONDITIONING.

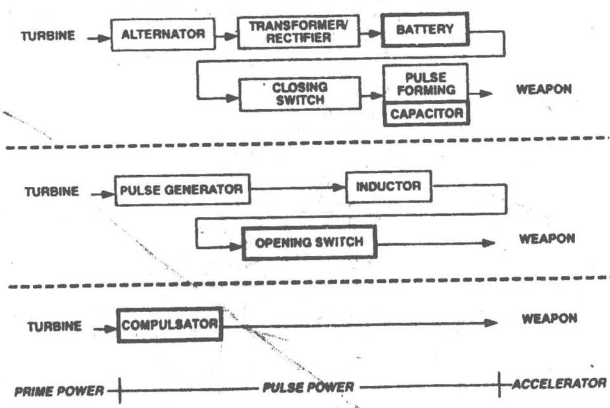

FIGURE 2: TYPICAL PULSE POWER CONDITIONING ASSEMBLIES.

ELECTRIC LAUNCHERS	HIGH POWER MICROWAVES	ACCELERATORS
CAPACITORS BATTERIES INDUCTORS ROTATING MACHINES SWITCHES PULSER INTEGRATION	OPTICAL SWITCHES STORAGE MEDIA SPARK GAPS THYRATRONS	THYRATRONS SOLID STATE SWITCHES
LASERS	**RADAR MODULATORS**	**MOTOR DRIVES/ACTUATORS**
THYRATRONS SOLID STATE SWITCHES CAPACITORS	SPARK GAPS OPTICAL SWITCHES	SOLID STATE SWITCHES HIGH FREQUENCY MAGNETICS

FIGURE 3: THE IMPACT OF PULSE POWER TECHNOLOGY AND COMPONENTS ON IMPORTANT SUBSYSTEMS AND SYSTEMS.

CH3180-7/92/0000-0001$1.00

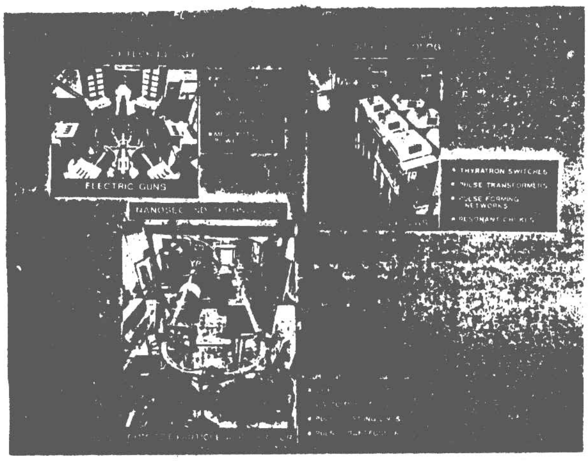

FIGURE 4: PULSE POWER SYSTEM REQUIREMENTS VARY FROM SYSTEM TO SYSTEM. WHAT IS APPROPRIATE FOR COMPONENTS FOR AN ELECTRIC LAUNCHER MAY NOT BE APPROPRIATE FOR A PARTICLE ACCELERATOR. THEREFORE, DIFFERENT TYPES OF COMPONENTS WILL HAVE TO BE DEVELOPED FOR DIFFERENT TYPES OF SYSTEMS.

(a) MULTI-MEGAWATT THYRATRON
(b) OII
(c) MCT
(d) CAPACITORS
(e) BATTERIES
(f) INVERTERS
(g) TURBINE GENERATOR/ALTERNATOR

FIGURE 5: PULSE POWER COMPONENT TECHNOLOGIES CURRENTLY UNDER DEVELOPMENT.

TECHNICAL AREA	BY 1995	BY 2000	BY 2005
HIGH-ENERGY DENSITY CAPACITORS	• 10^4 J/kg AT 1 Hz • 10^4 SHOTS	• 10^4 J/kg AT 10 Hz & 10 SHOTS • 100 J/kg AT 1000 Hz & 10 SHOTS	• 10x IMPROVEMENT IN ENERGY DENSITY & SHOT LIFETIME
SWITCHES • MAGNETIC • SOLID-STATE • PLASMA	• 100 kV AT 10 kHz • 0.3 NSEC RISETIME AT 10 Hz • 10^{14} A/SEC SINGLE SHOT	• 1 MV AT 100 kHz • 0.1 NSEC RISETIME AT 10 kHz (50 MHz BURST) • 10^{14} A/SEC AT 10 Hz	• 10x IMPROVEMENT IN AVERAGE POWER CAPABILITY
HIGH-POWER MICRO-WAVES (1-3 GHz)	• 1000 J AT 1 Hz	• 10 KJ AT 10 Hz	• 10 KJ AT 10 Hz
HIGH-POWER RF DEVICES	• 60 kW	• 500 kW	• 1.5 MW
COMPACT ACCELERATORS	• 20 MeV AT 19 kA, SINGLE SHOT	• 500 MeV AT 10 kA, & 10 Hz	
INVERTERS	• 500 g/kW	• 300 g/kW	• 100 g/kW
ALTERNATORS	• 100 g/kW	• 30 g/kW	• 10 g/kW
FUEL CELLS	• 700 g/kW	• 200 g/kW	
BATTERIES	• 16 WATT-hr/kg	• 100 WATT-hr/kg	
VOLTAGE CONVERTERS	• 1 kW/kg	• 10 kW/kg	• 30 kW/kg

SOURCE: 15 MARCH 1990 DoD CRITICAL TECHNOLOGIES PLAN REPORT TO CONGRESS

FIGURE 6: PROJECTIONS OF MILESTONES FOR PULSE POWER COMPONENTS AND SYSTEMS FOR THE YEARS 1995, 2000 AND 20005. THESE COMPONENTS MAY BE COMMERCIAL UNITS OR DEVELOPMENTAL PROTOTYPES.

Figure 7 shows a breakdown of major pulse power/power electronics elements, and technologies that are part of these elements that are being investigated, or require study. We're working on many, but not all of these. Those specific aspects of important components that need to be improved are shown in Figure 8. We've called them "show stoppers", since those improvements are essential if systems performance are to be enhanced. Figure 9 is an indication of pulse width requirements for the diverse types and classes of systems for specific Army applications, while the next chart Figure 10, is a

ENERGY SOURCES AND STORAGE
FUSED SALT BATTERIES
PULSED CAPACITORS
COMPACT ROTATING GENERATORS
PULSED TRANSFORMERS
EXPLOSIVE GENERATORS
INDUCTORS

CIRCUITRY
PULSER INTEGRATION
PROGRAMMED INDUCTIVE ELEMENT CIRCUIT
NONLINEAR CIRCUITS
DIAGNOSTICS
MARX CIRCUITS

SWITCHES
NEW SOLID-STATE AND OPTICAL SWITCHES
DIODES
BACK LIGHTED THYRATRON/ PSEUDO SPARK
THYRATRONS
MAGNETIC SWITCHES
OPTICALLY TRIGGERED JUNCTION
IGNITRONS
GATE TURNOFF THYRISTORS
CROSSATRONS
EXPLOSIVE SWITCHES
SPARK GAPS
VARISTORS

MATERIALS
DIELECTRICS
DIAMOND
SILICON CARBIDE
FERRITES

FIGURE 7: MAJOR PULSE POWER/POWER ELECTRONICS ELEMENTS AND TECHNOLOGIES EITHER BEING INVESTIGATED OR REQUIRING STUDY, ARRANGED BY MAJOR CATEGORIES.

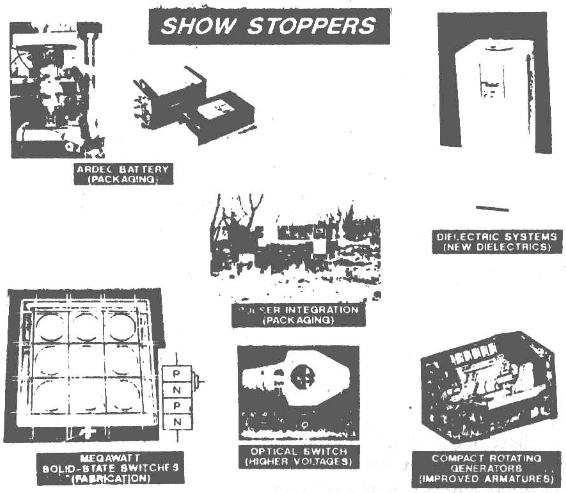

FIGURE 8: THE MOST SIGNIFICANT PULSE POWER COMPONENTS, OR "SHOW STOPPERS", WHICH ARE ESSENTIAL TO THE SIGNIFICANT IMPROVEMENT OF THE PERFORMANCES OF MAJOR SYSTEMS.

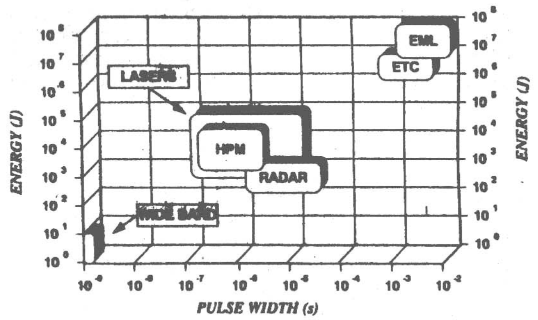

FIGURE 9: THE ENERGY AND PULSE WIDTH REQUIREMENTS OF DIVERSE ARMY PULSE POWER SYSTEMS.

schematic of the impact of our technology on different types of systems. Figure 11 summarizes those Army needs.

Our Electronics Technology and Devices Laboratory Pulse Power Center at Fort Monmouth is in the forefront in investigations leading to advanced state-of-the-art pulse power components. Many of you have visited the Center. Figure 12 is a montage of the Pulse Power Center and some of its features for those who are not familiar with that facility.

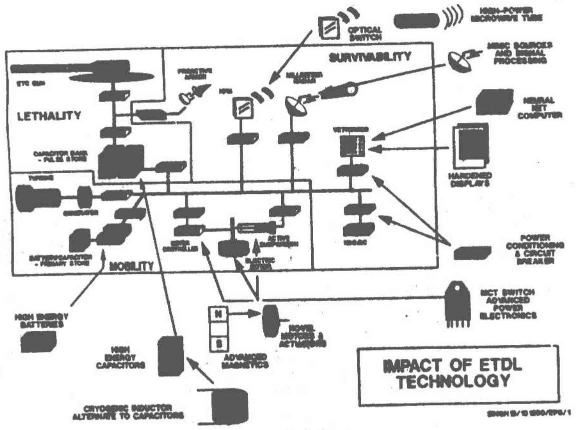

FIGURE 10: THE IMPACT OF PULSE POWER TECHNOLOGY ON DIFFERENT TYPES OF SYSTEMS FOUND ON FUTURE ARMY VEHICLES.

ELECTRIC GUNS:
ELECTROTHERMAL CHEMICAL GUN FOR COMBAT VEHICLES, GROUND OR AIR

HIGH POWER MICROWAVE:
ELECTRONIC WARFARE, ACTIVE PROTECTION, RADAR, MINE DETECTION AND NEUTRALIZATION

LASERS:
ELECTRONIC WARFARE, TARGET ACQUISITION, COUNTERMEASURES

ACCELERATORS:
STRATEGIC DEFENSE, EXPLOSIVE DETECTION

FIGURE 11: THE NEEDS OF THE ARMY WITH REGARD TO PULSE POWER.

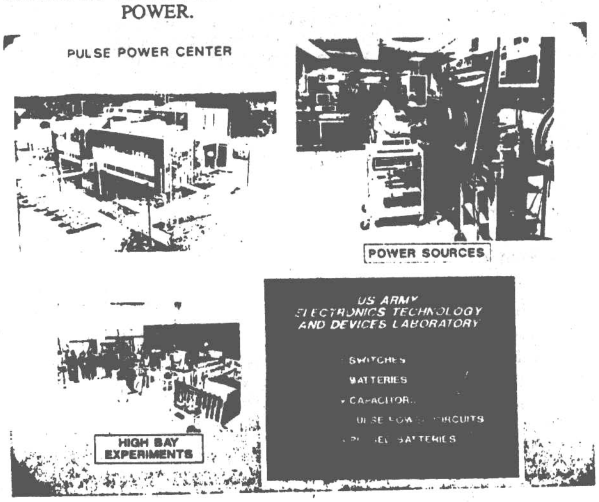

FIGURE 12: THE U.S. ARMY PULSE POWER CENTER, AND ASSOCIATED FACILITIES OF THE ELECTRONICS TECHNOLOGY AND DEVICES LABORATORY, LOCATED AT FORT MONMOUTH, NJ. THE PULSE POWER CENTER FEATURES 30 MVA CONTINOUS INSTALLED POWER, 10 MW LIQUID COOLING, AND TWO HIGH BAY AND ASSOCIATED SMALLER LABORATORIES, ALL LOCATED IN A FACILITY SHIELDED TO TEMPEST STANDARDS.

The former Soviet Union (now the Commonwealth of Independent States) has done outstanding work in developing many pulse power components. They are further along than we are in what has been achieved in much of pulse power component technology. We in the United States now have an opportunity to obtain and evaluate Russian prototypes, and we're trying hard to avail ourselves of that opportunity. Possibly some of you can help us in that regard.

All-electric vehicles are the wave of the future. While the primary importance for the development of electric propulsion systems for cars and trucks is to reduce pollution, the Army is interested in an all-electric tank because of its great potential for vastly improved performance. The all-electric tank will have an electric gun as well as an electric propulsion system. It is worthwhile noting that the Air Force is interested in developing a "more-electric aircraft". That program will replace hydraulic, mechanical, pneumatic and accessary gearbox systems with electrical systems that will be more reliable. The power electronics breakthrough that makes this approach attractive is the development of the metal oxide semiconductor controlled thyristor (MCT), a miniaturized solid-state switch that allows fine, highly reliable electrical control.

Some two years ago our people approached the Tank Automotive Command (TACOM) with a series of concepts for an All-Electric Tank. These concepts took advantage of advances and projected advances of power electronics components technology. TACOM was extremely interested in these concepts and commissioned a study of "Power Components for the All-Electric Tank". The guidelines were for a 30 ton vehicle, with different sets of subsystems, including drive, main weapon, protection and actuation of turret and suspension. The primary goal was to reduce the size and weight of the tank as a whole, by reducing the size and weight of the subsystems. We believe that by 1996 an electric drive mechanism and electrical actuation of the turret and suspension may be available for transition to an advanced transition demonstration. By 1999 more advanced electric drive and actuators are expected to be available.

In the next decade, further advances in high frequency power distribution and superconductivity will produce even smaller and lighter power handling components, and possibly making a purely electromagnetic or electrothermal gun a reality with regard to a tank's main armament.

An electric main weapon presents the most difficult research problem. Large amounts of electrical energy must be stored for each shot of the electric gun. The first type of electric gun to be applicable will be the electrothermal chemical gun, which derives most of its energy from chemical propellant and only used the electrical energy to produce a more efficient chemical reaction. The first systems will most probably use compulsators, which are alternators compensated to produce the type of electrical pulse necessary for the gun. The energy is stored as rotational kinetic energy. The vast bulk of this energy is not extractable, due to extreme stresses imparted to the machine during discharge. Future system will use capacitors and inductors. These will have more energy available for discharge, will not have gyroscopic moments associated with them and should be more compact. Current capacitors do not have sufficiently high energy density to be practical; and inductors require opening switches with high current ratings and substantial structural support. These components are currently not available in a small size. The situation grows by orders of magnitude with electromagnetic guns, which impart all energy to the weapon's projectile electrically. Superconducting inductors or very advanced capacitors, requiring breakthroughs in material science, would be necessary for the implementation of this technology.

Electric drive is, in many ways, the easiest system to implement. The study found substantial savings in size and weight if current mechanical transmissions were replaced with a generator and two drive motors, one on each tread. Such an arrangement would make it possible to operate the tank's engine at a constant speed, reducing engine size, reducing heat and making it easier to control noise emission, due to operation at a constant or near constant speed. Better fuel efficiency is yet another advantage of such a system. It should be noted that there will indeed be an engine in the "All-Electric Tank"; it is the power transmission that is all-electric. In any event, an internal combustion engine and generator converts chemical energy into electrical energy, as does a battery, but the engine-generator adds an extra mechanical conversion. The drive motors themselves can be reduced in size and weight by operating at a higher frequency, a technique used extensively in aircraft. Such components are available for use in the tank, at this time or in the near future. This would be at a frequency of 400 Hz. There is an extensive effort to develop drive motors at even higher frequencies, such as 20 kHz. Concurrent with the development of high frequency machines would be high frequency power semiconductor switches, to manage and control the power, which would then control the drive motors. ETDL conducts extensive research in advanced power semiconductor switches, and drew on its experience in this area for this study. As mentioned previously, the AF, in their program to develop "more-electric aircraft", is developing actuators that can readily be adapted to the tank, particularly with regard to an active suspension, in which actuators would absorb the shock and vibration of a vehicle by converting it into useful electrical energy. Electric actuation of the turret and suspension would eliminate the fire hazard of hydraulic oil, which tends to leak, and eliminate the need for a great deal of tank maintenance, resulting in the possible reduction of the tank crew from four men to three, by eliminating the loader position, whose major function is hydraulic maintenance, and whose loading function could also be done electromechanically.

A large number of individual cases for different configurations and scenarios of the tank were derived and analyzed from computer simulations, based on volumetric and gravemetric densities of each of the components for best, worst, and nominal case projections for each component technology. Figure 13 shows a representative power distribution for a schematic all-electric tank with a electrothermal gun. A reasonable conclusion is that the technology to implement the all-electric tank concepts is definitely possible. It just will take time and money.

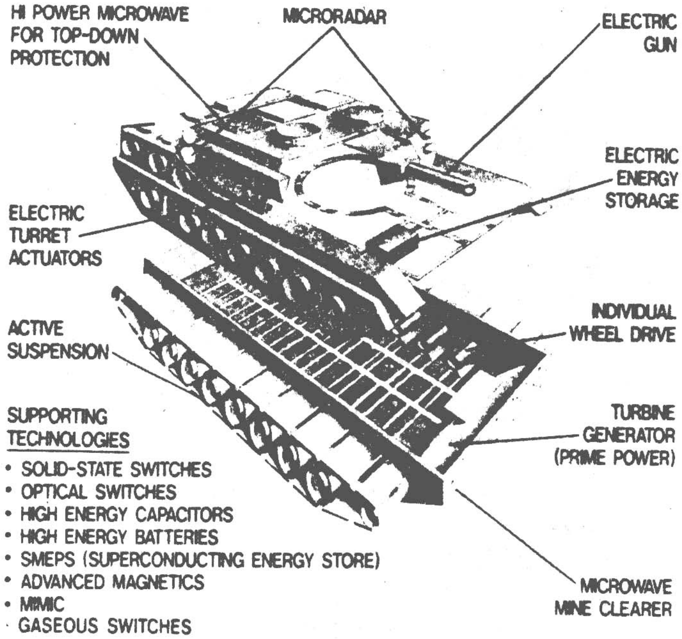

FIGURE 14: ARTIST'S CONCEPTION OF AN ALL-ELECTRIC TANK, WITH SUBSYSTEMS AND SUPPORTING PULSE POWER COMPONENT TECHNOLOGIES IDENTIFIED.

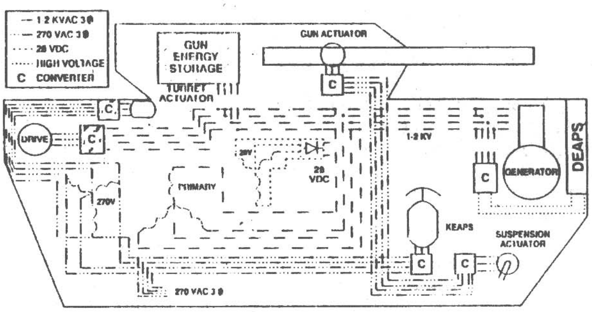

FIGURE 13: POWER DISTRIBUTION SCHEMATIC FOR ELECTRIC DRIVE VEHICLE WITH ELECTRIC GUN AND DIRECTED AND KINETIC ENERGY ACTIVE PROTECTION SYSTEMS (DEAPS AND KEAPS).

Dr. Tom Podlesak and Dr. Chris Braun are the two people in our Laboratory who were primarily responsible for the all-electric tank analysis, and for the preparation of a very detailed report that was presented to the U.S. Army Tank Automotive Command. Figure 14 is an artist's rendition of what the all-electric tank may look like.

A major new initiative for the Army is participation in programs leading to high-speed magnetically levitated transportation. The Department of Transportation is supporting the National Maglev Initiative (NMI) in assessing the role of magnetic levitation in the nation's transportation future. NMI, an interagency partnership led by the Federal Railroad Administration and the Army Corps of Engineers, has awarded 27 contracts totaling $4.3M to define opportunities for technological improvements in key aspects of maglev transportation. High-speed rail transportation is an active area of both investigation and implementation in Japan, Germany, and France. Japan has designed a system to operate at over 300 km/hr (200 mph), and Germany has inaugurated high-speed service on a line linking Hamburg, Frankfurt, Stuttgart, and Munich with trains capable of speeds up to 250 km/hr (175 mph). A German consortium, Transrapid International, had developed a prototype maglev train which reaches speeds of 500 km/hr (300 mph).

Progress has been slower in the United States. However the Intermodal Surface Transportation Act signed into law in December 1991 now calls upon federal agencies to help develop a prototype maglev system by 1999. High temperature superconducting magnets often are the core elements in generating the required magnetic fields. Other critical components are switches, control devices, and sensors.

Our Laboratory has a unique capability for evaluating components and materials that are essential elements of maglev systems. Our Pulse Power Center high power facility is exceptionally well suited for testing components and subsystems applicable to maglev. Switches (including high-power, solid-state devices) and magnetic components and subsystems in particular, can be evaluated and assessed by means of experiments done at high power and megamperes of current. An extensive network exists for computer and instrumentation interfacing. Long-term, life-testing of components and subsystems can be planned and implemented on a round-the-clock basis. A Memorandum of Understanding is in effect between the Laboratory Command and the Corps of Engineers that tasked the Command to provide assistance to the Corps of Engineers in transitioning technology. That MOU may well provide the mechanism whereby the Electronics Technology and Devices Laboratory can play a significant supporting role to NMI in the development of maglev transportation. We expect to play such a role.

INTERFACE TECHNOLOGIES FOR SHIPBOARD APPLICATIONS OF PULSED POWER SYSTEMS

Mr. Guy Grater and Dr. Scott Fish

Naval Surface Warfare Center, Annapolis Detachment, Annapolis, MD

Abstract

Navy ships appear to be most attractive platforms for fielding pulsed power weapons systems. Naval Surface Warfare Center, Annapolis (NSWC/A) is participating in a 60 mm Electro-Thermal Chemical (ETC) gun demonstration program for anti-ship missile defense funded by the Balanced Technology Initiative. In support of this program, NSWC/A is conducting shipboard integration studies for the pulsed power system to expose and find solutions to the interface issues of adapting the pulsed power system from the laboratory to the fleet. The gun, platform and loaders are being developed for compatible replacement of existing gun hardware. This minimizes shipboard impact caused by the gun system. The choice of technologies and architectures used to supply power to the weapon system will have an impact on ship design and arrangement. This paper examines the ship integration issues associated with power extraction from the propulsion engines, conditioning that power and delivering it to the pulsed power weapon.

Introduction

Advanced weapons systems utilizing "pulsed" electrical power sources have been proposed for military use in many forms over the past years. The term "pulsed" is used here to describe the high peak power delivered over a short period of time. A review of various pulsed power loads depicted in Fig. 1 shows a wide range of power requirements varying from delivery of megawatts (MW) for seconds to terawatts (TW) for microseconds[1]. The power requirements for the projected near term electric guns fall midway between these extremes, demanding several gigawatts (GW) over a few milliseconds. Although these peak power levels initially appear to be beyond the capability of existing naval platforms, the average power requirements are in the tens of MWs. The modern Navy destroyer propulsion system is capable of developing nearly 80 MW of power. The application of pulsed power weapons to most naval ships is therefore not limited by available shipboard power, but by the conversion capability to produce the electrical characteristics required by the loads. Some form of energy storage and pulse formation will also be required during this power conversion process.

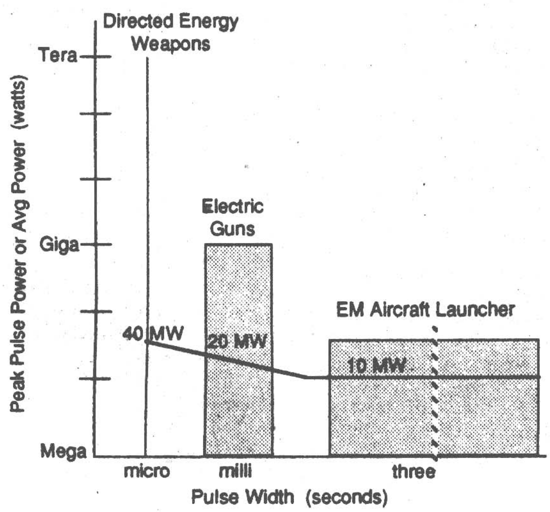

Fig. 1. Pulsed power weapons power ranges and pulse widths.

Electro-Thermal Chemical (ETC) and Electro-Magnetic (EM) guns are the most mature of the electric gun technologies under consideration for naval applications and are presently in hardware development and testing stages. Ship operations will be impacted by these electric guns in the areas of power extraction, conditioning and transmission; energy storage and pulse forming; grounding and shielding; thermal management and ship arrangements. This paper therefore focuses on these aspects of the overall pulsed power weapons system as it pertains to these gun technologies.

Power Extraction, Conditioning and Transmission

A first level architecture trade-off study performed by NSWC/A concluded that "dedicated auxiliary generators driven from the propulsion gas turbine engines is the preferred method of powering shipboard electric guns"[2]. This configuration is equally attractive with both electric or mechanical drivetrains and demonstrates retrofit potential into the present fleet. Therefore, the ability to extract prime power from the existing propulsion gas turbines is vital to the implementation of this class of weapons systems aboard Navy surface combatants.

The coupling of the pulsed power system to the propulsion drivetrain can have a significant impact on the response characteristics of the gun as well as the turbine control system. The dynamic performance of each system while sharing power between the propeller and the pulsed power system or while in dedicated operation must be taken into account.

The conversion of mechanical propulsion power (in the form of a rotating shaft) into usable electrical power requires a generator that is linked to the propulsion system. The present maximum voltage and frequency generated for shipboard distribution is 4160 Volts, 60 Hz; projected pulsed power conditioning systems have input voltages that will exceed this limit. In the case of ETC guns, the input voltage to the PFN is 15 kV DC. In order to minimize the equipment necessary to meet this voltage requirement, the choice of a high voltage (13.8 kV), high frequency (up to 800 Hz) generator was made. These parameters also allow for other pulsed power loads with various voltage levels to be supplied. The transient loading characteristics and resultant stresses and torques imposed on the generator from charging the pulsed power system are of primary concern in the generator design process. Navy shock and vibration standards must additionally be met, as well as managing the thermal loads generated by the machine inefficiencies.

The non-compatibility of the power characteristics between available prime power donors and projected pulsed power loads necessitates an intermediate stage of power conditioning. In some applications, a generator may provide the majority of this power conditioning. However, the AC must still be converted to DC and in some cases transformed to higher voltages. While technologies such as SCRs, IGBTs and

CH3180-7/92/0000-0005$1.00 © 1992 IEEE

MCTs are well defined or under investigation, incorporating these components into a power conditioning system such as solid state frequency converters, rectifiers and transformers of multi-MW power levels is only done by the utility industry. Packaging these systems to minimize ship impact, EMI/EMC and thermal management requirements aboard a Navy ship is no small challenge. The effects of temperature rise on component performance and acceptable levels of degraded operation must be defined. If these challenges are not difficult enough, the components must also be able to operate in a shock and vibration environment.

High voltage AC and DC transmission systems are an integral piece of the power system architecture. By utilizing the propulsion turbines, which are located in the machinery spaces of the ship, as a prime power source, it is necessary to transmit the electrical energy from this location to the topside weapons location. The decision to transmit this energy using high voltage DC was based upon the need to minimize the amount of equipment required at the weapons system location and to reduce the EMI radiated from the cables[2]. There are wide varieties of commercial, high voltage coaxial cables upon which the design for a Navy cable can be based.

Energy Storage and Pulse Forming

The need for intermediate energy storage devices is dependent upon a combination of pulsed power load requirements, platform prime power availability and battlefield operational architectures. The shipboard impacts of high power density batteries, advanced flywheels and other possible energy storage devices will determine their applicability in the naval environment.

The decision to derive the prime power system architecture from the propulsion drivetrain provides the pulsed power system with significant inertial energy. The prime power requirements for most of the ETC gun application scenarios can be met without incorporating additional energy storage devices. However, flywheel energy storage is an attractive option when dedicated, non-propulsion turbines are the prime mover. The flywheel acts as a mechanical "buffer" between the transient torques generated by the PFN charging cycles and the turbine, preventing potentially destructive pulsating torques from affecting turbine operation. The major ship integration issues associated with flywheel systems are: foundation and containment; gyroscopic effects; and shock and vibration sensitivity.

The use of battery-based energy storage systems for shipboard electric gun applications has not been addressed in significant detail to date. However, based upon battery developments in the Army program, the following issues appear to have the highest priority for a naval application: battery chemistry and interaction with the marine environment; space, weight and location requirements; additional power conditioning equipment unique to battery system; and system safety under fault conditions.

Capacitor-based Pulse Forming Networks (PFNs) are considered the most mature of the pulse forming architectures. However, nearly all of the existing capacitor-based PFNs are effectively single shot laboratory systems. Near term Navy ETC gun applications may require up to a 4 Hz repetition rate for certain engagement scenarios. The effects of this rep rate on PFN component performance, pulse-to-pulse repeatability and lifetime under these stressing thermal conditions must be clearly understood before militarization and weaponization can occur. This data can only be achieved through experimental testing.

Grounding and Shielding

The proper grounding of AC generation, power conditioning and DC transmission equipment can be greatly influenced by the operating conditions and use of the pulsed power loads. Conversely, Navy shipboard equipment grounding regulations and accepted commercial grounding practices will dictate the type and configuration of the grounding schemes available to the pulsed power loads. The chosen grounding system architecture will affect the basic circuit designs of each system component and is one of the key issues in shipboard integration. In most pulsed power systems, the operating voltage is above the 4160V, 60 Hz upper limit presently utilized aboard ship.

Commercial distribution systems which operate at the higher 2.4 kV to 15 kV range must either have a high impedance or solid connection to ground. The Navy has adopted this standard practice for its high voltage systems. Systems which operate above 15 kV must be solidly grounded. The advantage of a high impedance to ground system over a solidly grounded system is the ability to selectively trip loads for fault isolation while maintaining continuity of power to other loads. This selective fault isolation option must be evaluated against the requirements of the pulsed power system operational characteristics and protection philosophy.

In the case of an ETC gun system requiring a 15 kV DC charge for its capacitor-based PFN, the 15 kV DC transmission system between the rectifier and the PFN should be "center grounded" as opposed to "one side grounded." This architecture is best for preventing the passage of large currents through the hull structure. In this case, the development of a fault to ground from either side of the circuit can be detected by measuring the voltage of each with respect to ground and appropriate action can be taken to clear the fault or shut down the system before large hull-borne currents develop.

However, the output of the PFN to the ETC gun must be "one side grounded" because the breach and gun barrel are part of the electrical circuit. The breach and barrel must be at the same potential as the gun mount to prevent any voltage build up across the gun mount bearings. The transition between center-grounded and one side grounded system occurs across the PFN. This ground architecture requires the PFN to be charged while center grounded, then isolated on both positive and negative sides from the charging system, and finally one side grounded during pulse discharge into the gun. The charging system and PFN designers must take this type of scenario into account during the early phases of system design.

Thermal Management

Shipboard integration of any new system requires consideration of its impact on the cooling capacity of the ship. The preferred architectures of various pulsed power systems required that equipment be located in diverse areas of the ship. Therefore, different forms of thermal management were considered for each component. Until detailed dynamic thermal analysis has been conducted on each component, estimates of cooling system requirements are based on steady state operation. This method of estimation significantly increases the capacity of the thermal management system required. Some form of limited duty cycle rating must be incorporated into the estimate for the design of practical cooling systems. This means that the power system components and their associated cooling systems must be designed with sufficient thermal mass and operating temperature limits capable of absorbing the transient thermal loads during gun operations. This stored heat can then be removed over the much longer time period between gun firing missions. Heat rejection and temperature sensitivity characteristics of individual components must therefore become major factors in component designs for shipboard use.

Location of individual components is a key factor. Equipment located below decks in machinery spaces are more likely to use fresh water/seawater heat exchangers because of the proximity and availability of such systems. Other spaces, such as topside location of a PFN and gun, are more likely to utilize available forced air and/or chilled water cooling. It must be noted that cooling methods of this type are typically more expensive than the fresh water/seawater systems. The thermal design and operational requirements of each component is a major factor in the ability to install a pulsed power system shipboard.

Ship Integration/Arrangements

In comparison to a tank or an aircraft, a Navy ship appears to have an abundance of volume and mass margin for the installation of pulsed power classes of weapons systems; however, simple comparisons can be misleading. Modern naval combatants have been designed with ever decreasing growth margins in both weight and volume. This trend has, of course, been driven by requirements for reduced acquisition cost. An additional trait found on surface combatants is the increased cost of weight and volume as a function of height in the ship. Several factors play a role in this increased cost. Weight placed high in the ship reduces the stability of the ship and may require additional ballast to be carried in the bilges to maintain safe operations. Several ship classes are currently undergoing programs to reduce topside weight by component replacement with lightweight material alternatives. Reductions in topside volume are being motivated by desired reductions in radar cross section, and the associated weight problem just mentioned.

In the case of the Navy's newest surface combatant, the Arleigh Burke class of destroyers (DDG-51), the baseline interior outfitting of the ship is sufficiently tight as to be classified as having negligible volumetric margin for growth. While this initially suggests that no new equipment may be retrofitted to the ship without an equivalent removal of existing equipment, there are two possible alternatives: The first option is to increase space by enlarging the hull or superstructure; however, the resultant time and cost of this type of major ship alteration makes this option undesirable. A second alternative is for more efficient utilization of selected existing spaces. Repositioning existing equipment and stringent volume and weight limitations on new equipment must be addressed with this alternative. The impact of this option is tighter size limitations on the power system components, which must fit into spaces which were not originally sized for them[3]. Figure 2 depicts the preferred architecture for a DDG-51 class ship equipped with ETC guns.

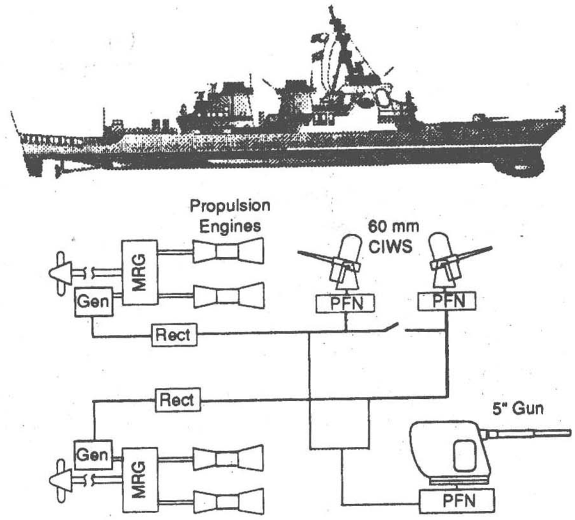

Fig. 2. Pulsed power system architecture for Navy surface combatant.

Conclusions

In the present constrained environment, it is clear that increased cooperation and synergism between designers of advanced weapons systems and ship hull, mechanical and electrical systems will be necessary in order to ensure timely, cost-effective implementation of new systems. Introduction of some of the critical interface technologies and requirements issues associated with implementation of pulsed power weapons aboard Navy ships will facilitate the technical interaction between these two groups.

Electric gun technology, specifically ETC technology, is at a critical stage of development. Carefully focused engineering studies are necessary to sort reality from fiction in the critical area of power system sizing and the associated ship integration issues. On the basis of continuing research at NSWC, Annapolis, it has become clear that the application of pulsed power weapons on naval combatants is not limited by available shipboard prime power but by (a) the ability to properly condition the power for appropriate weapon load characteristics, (b) strategically locate equipment within the ship, and (c) operate within the design limits imposed by the ship. This suggests that current trends in power component research and development will facilitate future ship integration and deployment of pulsed power systems to the extent that the Navy can influence the direction of this research.

References

1. "Propulsion Derived Electrical Energy Applications," Workshop Proceedings, DTRC, Annapolis, MD, Code 2720 (August 1989).

2. Doyle, T. J. and G. F. Grater, "Propulsion Powered Electric Guns - A Comparison of Power System Architectures," DTRC/PAS-91-31 (July 1991).

3. Fish, Scott, et al., "Initial Impact Assessment of Electro-Thermal Chemical Gun Outfit Aboard DDG-51 with Mechanical Drive," DTRC/PAS-91-53 (February 1992).