Scanning the Issue

Special Issue on Pulsed Power: Technology and Applications

Pulsed power is a technology that refers to the gradual accumulation of energy over a relatively long time scale (seconds), and its compression into very short pulses (hundreds of picoseconds to microseconds) for delivery to a "load." Whereas typical loads over the past 40 years or so have comprised charged particle beam-producing diodes, high-power electromagnetic radiation-producing switches, or imploding plasmas for radiation production and fusion energy research, recent loads have included biological media, water from municipal drinking supplies, and effluents from combustion processes, among other environmental and biomedical applications. In short, pulsed power has evolved to not only continue to play an important role in defense, including the nascent area of threats to the civilian infrastructure, but has evolved to become an important technology in the environmental and biomedical arenas as well.

We are pleased to present this Special Issue of the PROCEEDINGS OF THE IEEE on Pulsed Power: Technology and Applications. The only other time that Pulsed Power was featured in PROCEEDINGS OF THE IEEE was in a Special Section guest edited by Dr. J. P. VanDevender in 1992 [1]. The fact that the 1992 Special Section was dominated by papers featuring large, laboratory-scale pulsed power-driven experiments is representative of the scarcity of pulsed power applications outside of the defense sector at the time. The intervening dozen years has witnessed an ever-increasing list of novel applications for pulsed power technology, and this Special Issue seeks to express the breadth of pulsed power science and technology research that is ongoing internationally. This Special Issue comprises 15 papers, the first one providing background information on pulsed power technology for the nonspecialist, followed by 14 invited papers describing aspects of pulsed power technology or their specific applications. The papers are organized as follows.

A. Scanning the Technology

The introduction to the Special Issue prepared by Schamiloglu *et al.* seeks to place ongoing activities in pulsed power in a broader context. The parameter space of research is mapped out and supplementary material of a tutorial nature is provided. The intent of the supplementary material is to complement the classic paper of J. C. "Charlie" Martin, "Nanosecond Pulse Techniques," which initially appeared in [1]. This paper has been made available by the PROCEEDINGS OF THE IEEE and can be found on the Web.[1]

B. Invited-Paper Descriptions

The remaining 14 papers were invited to appear in this Special Issue. They are organized with the highest power systems and applications appearing initially, with the most compact systems appearing toward the end.

The first four invited papers describe applications where pulsed power is used to generate charged particle beams for a variety of applications. The initial invited paper, "Advances in Pulsed Power-Driven Radiography Systems" by *Maenchen et al.*, is particularly appropriate as the lead paper, since it describes recent advances in radiography source research, a collaborative effort between scientists in the United States and the Atomic Weapons Establishment (AWE) in the United Kingdom. In pulsed power-driven radiography, intense electron beams are focused onto a high atomic number ("high-Z") target to produce intense Bremsstrahlung radiation. It was this very application, after all, that led Charlie Martin to "invent" modern pulsed power at AWE beginning in 1959. The state of the art in pulsed power-driven radiography, including the innovation of the inductive voltage adder, is described in detail.

"Electron Beam Pumped Krypton Fluoride Lasers for Fusion Energy" by Sethian *et al.*presents another application of pulsed power-driven intense electron beams. Here, intense electron beams are used to pump a KrF laser cell, as part of a concept to achieve controlled thermonuclear fusion in the laboratory through the inertial confinement of fuel targets illuminated with intense KrF laser radiation. Whereas the radiography example in the previous paper is a single-shot system, the challenges described in this paper include developing such systems that can operate in a repetitively pulsed manner.

In "Materials Modification Using Intense Ion Beams" by Renk *et al.*, we find a description of pulsed energetic ion beams developed for applications including surface modification and alloying of metals, and thin-film and nanopowder synthesis. Rapid thermal processing with ions is quite promising for large-scale commercial use, due to the

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[1]http://www.ieee.org/organizations/pubs/proceedings/

high specific ion energy deposition without reflection and to the relative efficiency and low cost of the pulsed power ion beam drivers compared to other high-kinetic energy alternatives. This paper presents results of ongoing research in the United States, Russia, and Japan.

"Pulsed Power-Driven High-Power Microwave Sources" by Korovin *et al.* describes how intense electron beams are used to generate very high power sources of coherent microwave radiation, both in single shot and repetitively pulsed systems. Research programs from the Institute of High Current Electronics in Russia and across many universities in the United States are described. Such high-power microwave (HPM) sources find applications in plasma physics, particle acceleration techniques, fusion energy research, high-power radars, and communications, in addition to studies of the effect of intentional electromagnetic interference on electronics.

The next invited paper describes a technology where the pulsed power system is used to directly drive an antenna. "JOLT: A Highly Directive, Very Intensive, Impulse-Like Radiator" by Baum *et al.*describes, for the first time, a system developed at the Air Force Research Laboratory Directed Energy Directorate (AFRL/DE) at Kirtland Air Force Base, NM, in the late 1990s. This repetitively pulsed, hyperband microwave system produces a field range product (rE_{far}) of about 5.3 MV in a 100-ps pulse. Such sources have applications that include target identification, detection of buried targets such as leaky pipes and humanitarian demining, and impulse synthetic aperture radar (ISAR) systems for "seeing through walls."

"Plasma Imaging and Spectroscopy Diagnostics Developed on 100–500 kA Pulsed Power Devices" by Sinars *et al.* describes the development in the United States and Israel of high-resolution plasma imaging and spectroscopy diagnostics in the X-ray and ultraviolet energy range for use on 100–500-kA pulsed power facilities. This modest infrastructure investment, which requires just a few people to operate, consists of facilities that are used to develop new ideas and technologies with application to larger systems used to study high energy density plasmas. The development of diagnostic techniques in pulsed power systems is particularly challenging because of the harsh electromagnetic environment, limited access, and very fast temporal and short spatial scales of the phenomena being investigated.

The next two invited papers describe research in a field that has recently emerged, the application of pulsed electric fields to biological systems, also referred to as bioelectrics. In "Ultrashort Electrical Pulses Open a New Gateway Into Biological Cells," Schoenbach *et al.* describe their research activities using pulsed power to generate large electric fields to affect change at the cellular level. Possible applications of the intracellular electroeffect include enhancing gene delivery to the nucleus, controlling cell functions that depend on calcium release (causing cell immobilization), and treating tumors.

"Pulsed Electric Field Inactivation of Spoilage Microorganisms in Alcoholic Beverages" by *Beveridge et al.* describes a program at the University of Strathclyde, Glasgow, U.K., that studies the generation of electric fields of the order of 30 kV/cm across liquids contaminated with microorganisms. The pulsed electric field induces a relatively large transmembrane potential that can lead to irreversible electroporation and, consequently, cell lysis. Results are presented that describe the effect of a monopolar pulsed electric field to alcoholic beverages containing known spoilage microorganisms.

The next four invited papers present the results of research programs that are seeking to develop more compact pulsed power systems for various applications. "Research Issues in Developing Compact Pulsed Power for High Peak Power Applications on Mobile Platforms" by Gaudet *et al.* describes the efforts of two university consortia in the United States that are performing basic research whose results can lead to more compact systems in the future. Particular interest to the researchers are pulsed breakdown phenomena in liquid and solid dielectrics, the design of compact pulse forming lines through changes in their topology, and novel approaches to thermal management, since compact systems will ultimately have to deal with more efficient heat dissipation techniques than are commonly used today. This research program is driven by the push to "all-electric" and "more electric" mobile platforms in the U.S. Department of Defense.

In "The RADAN Series of Compact Pulsed Power Generators and Their Applications," Mesyats *et al.* present a review of the achievements of researchers from the Institute of Electrophysics (Ekaterinburg, Russia) and the Institute of High Current Electronics (Tomsk, Russia) over the past decade in the development of repetitively pulsed, nanosecond high-voltage generators. The basic high-voltage units of the RADAN instruments are built around coaxial pulsed forming lines and efficient charging devices based on Tesla transformer technology. The wide-ranging applications of these instruments in science and engineering include the formation of nanosecond and subnanosecond voltage and hyperband RF pulses, narrowband high power microwave generation, X-ray radiography, radiation physics, chemistry, and biology.

In "Compact Solid State-Switched Pulsed Power and Its Applications," Jiang *et al.* report on recent advances across several groups in Japan and Russia that are using commercial power semiconductor devices (Japan) and proprietary switches (Russia) to develop compact pulsed power systems with high repetition rate and long lifetime. The novel applications they report developing such compact systems for include accelerators, systems for flue-gas treatment, and gas lasers.

The last invited paper that discusses research programs seeking to develop more compact pulsed power systems is "Ultracompact Pulsed Power," by Fazio and Kirbie. The approach followed by these researchers at Los Alamos National Laboratory, Los Alamos, NM, is to identify the state of the art in critical components in terms of energy density, and then use them in conjunction with other state-of-the-art components to produce examples of pulsed power systems with the greatest overall performance in terms of having the highest output parameters for a given-sized system. The authors also describe advances in components used for prime power that could then be integrated with the ultracompact pulsed power units for compact mobile systems.

The final invited paper in this Special Issue is "Magnetic Flux Compression Generators," by Neuber and Dickens. The concept of using the mechanical energy generated by chemical explosives to generate very high current electrical pulses arose independently in Russia by the late Nobel Laureate A. Sakharov and in the United States by M. Fowler of Los Alamos National Laboratory in the 1950s. Neuber and Dickens describe recent efforts at Texas Tech University where they have been studying aspects of magnetic flux compression generators (MFCGs). These pulsed power generators are extremely efficient, on par with the ultracompact systems described by Fazio and Kirbie. However, whereas the ultracompact systems have output powers as large as hundreds of megawatts, the MFCGs have produced powers in the tens of terawatts.

The papers in this Special Issue give a sampling of the wide range of activities in pulsed power technology. We hope that the readers of the PROCEEDINGS OF THE IEEE will find this Special Issue both intriguing and informative.

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REFERENCES

[1] J. P. VanDevender, *Proc. IEEE, special section on pulsed power technology*, vol. 80, pp. 931–1018, June 1992.

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Dr. Barker is a member of the American Physical Society. He was elected Fellow of the Air Force Research Laboratory in 1998. He has served in various capacities on the organizing committees of numerous international conferences, including cochairing the IEEE Joint Pulsed Power Plasma Science (PPPS) Conference in 2001.