ABSTRACTS OF
DAE BRNS National Symposium on High Voltage-Energy Storage Capacitors & Applications

HV – ESCA 2023

Pulse Capacitor Development Facility

Plasma Focus

Marx Generator

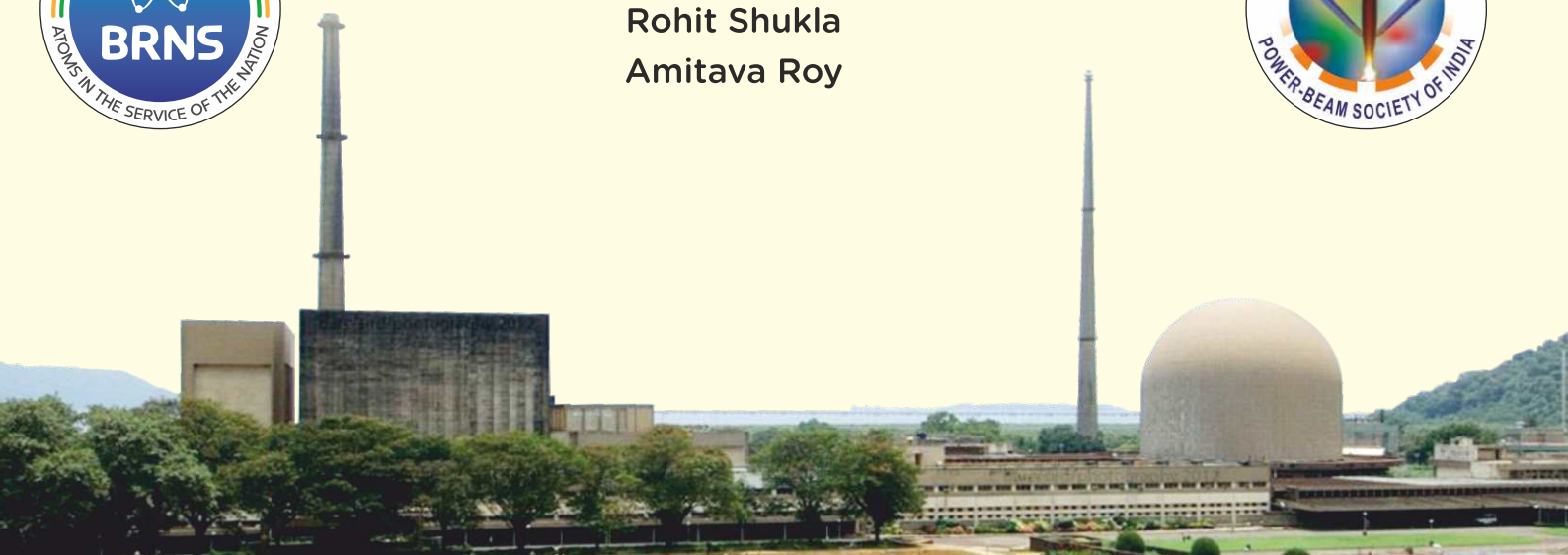
IEC Setup

Editors

R. K. Sharma

Rohit Shukla

Amitava Roy



ABSTRACTS OF

DAE BRNS National Symposium

on

High Voltage-Energy Storage Capacitors & Applications

HV – ESCA 2023

June 22-24, 2023

DAE Convention Centre
Anushaktinagar, Mumbai - 400094

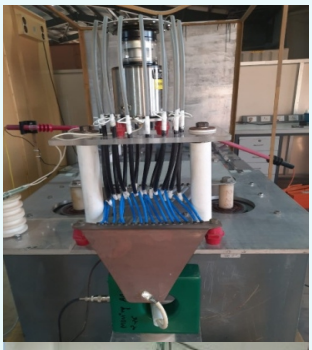
Editorial Committee

DAE-BRNS
National Symposium on High Voltage- Energy Storage Capacitors and Applications

(HV-ESCA-2023)

22nd to 24th June 2023

Venue: DAE Convention Centre, Anushakti Nagar, Mumbai.



Energy storage capacitors are widely popular among modern R&D and industries for both microsecond and millisecond discharged pulsed power applications. Design, development and utilization of these capacitor/ capacitor banks along with a high voltage switch is very challenging to meet the application specific requirements. The technology of high voltage, low-inductance capacitors has numerous applications in domains such as pulse x-ray and neutron sources, lasers, electromagnetic pulse generators, electron beam accelerators, plasma generation and electromagnetic welding in materials, industry, medical, scientific R&D, space, nuclear energy and defense sectors.

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- Pulsed power generators
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- High current and high energy capacitor banks
- Upcoming topologies & control schemes in power modules
- Neutron and X-ray generators
- Electron beam accelerators and applications
- Rail and coil gun technology
- Electromagnetic welding
- New developments in high voltage switches
- Trending applications of pulsed power
- High voltage safety and standards
- EMI & EMC

Symposium Format

- Invited Talks, Oral & Poster Presentation
- Panel Discussions
- Technical Visits to BARC HV facilities
- HV-ESCA-2023 Best Paper Award (Oral & Poster)

Important Dates:

1. Abstract Submission : 25 May 2023
2. Intimation of acceptance : 29 May 2023
3. Submission of paper : 9 June 2023

Abstracts & Papers may be sent to
hvesca2023@gmail.com

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1. Students (apply for 3-tier AC fare*) : Rs. 1,500/-
2. Government Departments : Rs. 2,500/-
3. Industries/Public Sectors : Rs. 10,000/-

Bank details for payment of Registration Fees:
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Account Name: HV-ESCA 2023; Acc No.: 41896082579
IFSC Code: SBIN0001268

Jointly organised by
Beam Technology Development Group (BTDG) and Electronics & Instrumentation Group (E&IG), BARC
Sponsored by
Board of Research in Nuclear Sciences (DAE)
In association with
Power Beam Society of India

डॉ. अजित कुमार मोहान्ती
Dr. Ajit Kumar Mohanty

भारत सरकार
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अध्यक्ष, परमाणु ऊर्जा आयोग
व
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Chairman, Atomic Energy Commission
&
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MESSAGE

High voltage energy storage capacitors have been one of the most valued technologies since last century for its immense importance in strategic & industrial applications. Decades of persistence endeavour to inculcate indigenous competency in development of High voltage energy storage capacitors has not only made our nation self reliant in this field but also opened up new opportunities in this arena. The technology of high voltage, low-inductance energy storage capacitors are indispensable in domains of particle accelerators, LASERs, electromagnetic welding, flash x-ray, pulsed neutron generators etc. and thus extremely important for modern day fundamental & applied researches. This symposium has huge potential to bring all such diverse fields of synergy on to a single platform and grow further.

The theme of this national Symposium augurs well with our DAE mandate to achieve & share technical excellence gained in the field of High Voltage Energy Storage Capacitors and their applications in multiple areas of research.

The topic of this symposium is of interest to researchers in fundamental as well as applied science. Several Strategic, Medical and Industrial developments are directly linked to the growth of High Voltage Energy Storage Capacitors. I wish all the participants fruitful and astonishing interaction during this symposium and best wishes to the organizers.

Ajit Kumar Mohanty

19.06.2023

(Dr Ajit Kumar Mohanty)

राष्ट्र की सेवा में परमाणु
प ऊ वि
DAE
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Dr. (Smt.) Archana Sharma
Director, BTDG

FOREWORD
From Director BTDG

It is indeed my pleasure to see a conference on "DAE-BRNS National Symposium on High Voltage-Energy Storage Capacitors and Applications (HV-ESCA)" is being realised by the conference organizers. As the Director- Beam Technology Development Group, I welcome and thank all the patrons and attendee of conference from Academia and Industry. Our group has been involved rigorously in the design and development of pulse power systems for various applications like intense relativistic electron beam (IREB) generation, magnetic pulse welding (MPW), pulsed neutron generation and wire explosion experiments. Among all the applications mentioned above high energy storage capacitors are the heart of complete pulsed power systems.

The three day conference on "DAE-BRNS National Symposium on High Voltage-Energy Storage Capacitors and Applications (HV-ESCA)" will cover vast technical areas starting from capacitors manufacturing to fundamental issues like dielectric breakdown and so on. A lab visit for all the conference participants will ensure their exposure to actual scientific and commercial systems.

In the end I wish this conference a grand success and thank the conference organizers for spreading awareness and educate Scientific & Technical personnel across the country on energy storage capacitors technology.

Archana

(Dr. Archana Sharma)

Government of India
Bhabha Atomic Research Centre
Electronics and Instrumentation Group

RCnD building
Trombay- 800 085

Dr Siddhartha Mukhopadhyay
OS & Director, E&I Group, BARC

FOREWORD
Director, E&I Group, BARC

It gives me immense pleasure in welcoming the esteemed delegates and participants to this first ever National Symposium on High Voltage- Energy Storage Capacitors and Applications (HV-ESCA 2023). This symposium is an amalgamated effort of Electronics & Instrumentation Group (E&IG), Beam Technology Development Group (BTDG), BARC, Board of Research in Nuclear Sciences (BRNS) and Power Beam Society of India (PSI).

This meet is organized to bring out the latest development and applications of high voltage energy storage capacitors and related technologies in the field of particle accelerators, pulse x-ray and neutron sources, lasers, electromagnetic pulse generators, plasma generation, electron beam accelerators andelectromagnetic welding for materials, industry, medical appliances, scientific R&D, nuclear energy, space and defense sectors.

I am quite sure that this national symposium will definitely evolve new research problems, applications and collaborations. Every participant will gain a deeper insight and understanding after attending this three-day symposium.

Best wishes to all the participants of HV-ESCA 2023 on behalf of E&I Group, BARC, Mumbai.

Siddhartha Mukhopadhyay

Government of India
Bhabha Atomic Research Centre
Control Instrumentation Division

RCnD building
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Smt. Anuradha Mayya
OS & Head, CnID, BARC

FOREWORD
Chairperson, HV-ESCA 2023

As Chairperson Organizing committee, HV-ESCA-2023, I extend a warm welcome to all the participants of this National Symposium on High Voltage-Energy Storage Capacitors and Applications.

Energy storage capacitors are widely used in R&D and industries for microsecond and millisecond discharged pulsed power applications. High voltage, low-inductance capacitors have numerous applications in domains such as particle accelerators, pulse x-ray and neutron sources, lasers, electromagnetic pulse generators, electron beam accelerators, plasma generation and electromagnetic welding of materials. Design, development and utilization of these capacitors/ capacitor banks along with high voltage switches pose very many challenges.

Areas of research interest encompass capacitor technology, fast rising voltage pulse generators, topologies & control schemes for power modules, pulsed nuclear radiation generators, electromagnetic welding, accelerators, EMI & EMC, high speed projectiles, plasmas, high voltage safety and standards. This symposium will provide a platform for researchers to interact and exchange domain expertise.

I wish all the participants of HV-ESCA-2023 a wonderful and stimulating interaction during the Symposium.

(Anuradha Mayya)

R.I. Bakhtsingh
Head, APPD

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FOREWORD

From Convenor- HV-ESCA 2023

I express my heartfelt pleasure on the announcement of conference on "DAE-BRNS National Symposium on High Voltage-Energy Storage Capacitors and Applications (HV-ESCA)". In the capacity of Convener-HV-ESCA 2023, I welcome and thank all the patrons and attendee of conference from Academia and Industry. Our division has been involved rigorously in the design and development of pulse power systems for intense relativistic electron beam (IREB) generation, magnetic pulse welding (MPW), pulse neutron generation and wire explosion experiments. Various kinds of capacitors, like film storage capacitors, ceramic capacitors will be covered in this conference.

The three day conference on "DAE-BRNS National Symposium on High Voltage-Energy Storage Capacitors and Applications (HV-ESCA)" lasting for twelve involved technical sessions will cover vast technical areas starting from capacitors to end applications like pulsed power and dissimilar metal welding and so on. A lab visit for all the conference participants will ensure their exposure to actual scientific and commercial systems.

At the end I wish this conference a grand success and request all the conference attendees to actively participate in the conference and interact with the experts of respective field of interests.

R. I. Bakhtsingh

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A Glimpse into a Life of 40 Years in High Voltage and Pulsed Power Technology

Pralhad Ron, Ex. Head: *Accelerator & Pulsed Power Technology Division (APPD)*, BARC, Mumbai

ABSTRACT:

The Talk covers the birth and evolution of *High Voltage and Pulsed Power* programs at BARC starting from 1960. Salient features of a few selected developments and their applications to programs of national importance carried out during 1960 to 2001 are enumerated. The programs are classified into: (1) Research & Development in *Exploding Wire Phenomenon (EWP)* and its fallout, (2) Development of *Industrial Electron Accelerators* at Electron Beam Centre at Kharghar, (3) *Pulsed High Magnetic Fields* and their applications to Nuclear Power Plants at Narora and Kakrapar, (4) *Pulsed High Power Microwaves* and applications to intense EMI/EMC in Defense in battle field scenario, (5) *Intense Flash X-rays* and applications in Defense in Terminal Ballistics, (6) *Conversion of Van-de-Graff into a Folded Tandem Ion Accelerator* for nuclear research. The impactful programs developed at the APPD, BARC form a major content of a book [1] *'Foundations of Pulsed Power Technology',* Jane Lehr & Pralhad Ron, Publ. John Wiley, US,2017.

*****INVITED TALK*****

ELECTROMAGNETIC RAILGUN: TECHNOLOGY AND CHALLENGES

Ankathi Raju

Outstanding Scientist & Director, Armament R&D Establishment (ARDE), Pashan, Pune 411021, INDIA

Hypervelocity weapons and hypersonic projectiles are the critical armament systems on which immense technological development is taking place for the futuristic war scenario. Electromagnetic Railgun technology is one of the unique and practical method for accelerating projectile to muzzle velocity beyond 2000 m/s. A railgun consists of two parallel current-carrying rails and a current-carrying armature placed in sliding contact between the rails with an interference. On application of the high current pulse, the armature is accelerated by the Lorentz force and ejected with hypervelocity at high enough current. The acceleration in electromagnetic railguns of projectiles with a mass of several hundreds of grams up to the velocities ranging between 2000 and 3000 m/s require current as high as several mega-amperes.

Substantial technological development on Railgun technology was taken place across the globe. Remarkable development from a laboratory system to field worthy system was held with US Navy. Various options of power systems for Railguns were experimented, however all practical railguns are working on High Energy Capacitor bank based pulsed power system. US has developed 100 MJ compact capacitor bank, however Turkey, Japan and European Union are working on 10 MJ Capacitor Banks.

ARDE has designed and developed a 10 MJ Capacitor Bank to drive a 45 mm bore railgun and successfully demonstrated the launching of projectile above 500g at hypervelocity. The pulsed power system used capacitors with energy density of 1 J/cc and high current switching systems based on Ignitrons and semiconductor switches. Bitter coil-based pulse shaping inductors, high current cables, interconnecting bus bar assembly, high current connectors and HV relays are developed in house and integrated. The technology is further getting upgraded for compact pulsed power system for mobility, multi-shot firing and design up-gradation towards a field worthy system. Indigenization of high energy density capacitors, semiconductor switches and capacitor charging power supply are initiated. Further to these, the pulsed power system will be enhanced to 100 MJ to cover multiple application and extended weight of projectiles and enhanced range requirements.

Mega-ampere currents and high magnetic stress coupled with high firing rates and barrel life requirements impose stringent constraints on barrel materials and structures. High current primary supply and capacitors with advanced technologies are required for sustained and reliable operation of multi-shot firing. Also new materials and coating techniques are under evaluation to reduce barrel wear and erosion to have sustained multi-shot capability. These technological challenges are identified and addressed to develop field worthy system.

*****INVITED TALK*****

HPM Beam Positioner Servo system: Concept to Realization

Vivek Sanadhya[1], Geetha Andrew[2], V K Goyal[2], Hari Balakrishna[2], Ankit Agrawal[2]
1. Head, Automation Control Section.
2. Scientific Officer, ACS
Control Instrumentation Division, BARC, Mumbai 400094

Abstract

HPM weapons cause electromagnetic interference (EMI) to produce effects on small UAVs ranging from upset to system damage. Once impractical to field due to significant power requirements and size. With advances in enabling technologies, HPM weapons are now rapidly advancing in range, power, and deployability, with marked decreases in size and energy efficiency. These advancements will enable them to be used to degrade offensive operations.

A Controllable Antenna Platform (HPM beam director) is required for HPM devices to focus the EMI in the required direction for maximum efficiency and to reduce the potential collateral damage. A proper design of such platform is absolute necessity for HPM weapon to be effective against agile airborne platforms with minimal response time.

*****INVITED TALK*****

Inertial Electrostatic Confinement Device: An Excellent Neutron and X-ray Generator

S.R. Mohanty[1,2], L. Saikia[1], N. Bharali[1], S. Kalita[1]
1Centre of Plasma Physics-Institute for Plasma Research, Nazirakhat, Assam-782402, India
2Homi Bhabha National Institute, Anushaktinagar, Mumbai, Maharashtra, 400094, India

Abstract

Inertial electrostatic confinement (IEC) is a significant approach for producing fusion neutrons. The devices which are operated in accordance with the IEC approach, can efficiently confine ions in converging electrostatic fields for fusion purposes in a cylindrical/spherical geometry. These devices can produce a neutron yield typically of the order of 10^8-10^{10} neutrons/sec (n/s) from deuterium–deuterium (DD) reactions in both continuous and pulsed modes of operation. Visualizing it's importance, the compact cylindrical and spherical IECF devices have been designed and installed at the Centre of Plasma Physics-Institute for Plasma Research. These are mainly comprised of a cylindrical or spherical grid assembly housed inside a cylindrical or spherical vacuum chamber along with vacuum pumping system, a gas injection system, a high voltage feedthrough, and a high voltage negative polarity power supply. Plasma parameters such as the electron temperature (T_e), plasma potential (V_p) and plasma density (n_i) are evaluated. The DD neutron production rate of the order of 10^7 n/s is measured in this device by applying 90 kV to the cathode grid in continuous mode of operation. Proof-of-principle studies are made to detect explosives using DD neutrons emitted from the device. Further x-ray production, imaging, and radiography have been carried out at different voltages. This paper will give an overview of various developments in IEC research at our institute.

*****INVITED TALK*****

From Voltage to brilliance: Understanding the role of laser power supplies

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Abstract: Laser technology finds its application in a wide range of fields, including scientific research, medicine, industries, and the military. The efficiency, stability, size, and lifespan of a laser greatly depend on the laser power supply. Generally, laser power supplies are designed to be stable, lightweight, compact, and reliable. However, specific laser applications may require specialized power supplies that not only meet the basic requirements but also provide additional functionalities like adjustable voltage or current, frequency control, computer interfaces, remote control, and electromagnetic compatibility. Capacitors play a significant role in laser power supplies as they store and deliver electrical energy to the pumping mechanism, such as flash lamps or diode lasers, which excite the gain medium. This discussion explores different technologies and emerging trends related to efficient charging methods for energy storage capacitors. Gas lasers have been extensively used in various forms for many years. Pumping mechanism of a gas laser involves adding energy to the gas atoms or molecules to excite them to a higher energy level. Gas laser driver circuits employ fast high-voltage pulse power technology, including spark gaps, thyratron, semiconductor switches, and magnetic pulse compression. Laser diodes have gained popularity in a wide range of applications, from communication to powering high-power pulsed lasers. The discussion also focuses on the current trends in diode driver technology that enable high-speed switching and maintain a stable injection current level..

*****INVITED TALK*****

NANODIELECTRICS FOR ENERGY STORAGE

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Abstract

There is a substantial and growing need for efficient and eco-friendly energy storage devices. Dielectric capacitors are reliable, lightweight, and scalable, but their design is complicated by the simultaneous requirement of high dielectric constant and high dielectric breakdown strength. The incorporation of nanometric fillers, even in small quantities, into conventional polymers was found to improve dielectric properties significantly and gave rise to a class of novel materials christened nano dielectrics. Nanodielectrics hold promise because of the possibility of tailoring their constituents according to need. In this paper, I shall discuss the state of the art and various issues related to the application of nanodielectrics to high-energy capacitors, briefly discussing in the process some of the relevant work done on nanodielectrics, in the HV Laboratory at IIT Kanpur.

*****INVITED TALK*****

Fast-ramped Power Converters with Energy Storage and Grid Power Control

Mangesh Borage[1,2], Abhishek Srivastava[1] and Alok Singh[1]
[1]Raja Ramanna Centre for Advanced Technology, Indore 452013, India
[2]Homi Bhabha National Institute, Training School Complex, Anushaktinagar, Mumbai 400094, India

Abstract

Fast-ramped power converters (FRPCs) are used in particle accelerators, particularly in booster synchrotron, to energize electromagnets at a fast rate in synchronism with the energy of charged particles. In Indus Accelerator Complex, a 12-pulse controlled rectifier scheme is used in booster synchrotron to ramp the output current at 2000 A/s with repletion rate of 1 Hz. This power converter is in operation, meeting the designed performance parameters, for many years and is due for up gradation in the near future. The power converter schemes based on controlled rectifiers, though are suitable for high power application, have comparatively slower response and low input power factor. The large power fluctuation at the input is frequently a cause of voltage flicker on ac mains, which is expected to become more severe if the repetition rate is increased or more number of magnets are connected in series, as envisaged in future accelerator projects. Further, the performance specifications of FRPCs for the next-generation synchrotron radiation source are expected to be tighter than in the present system. Therefore, development of technology for FRPCs using multi-stage high-power switch-mode power converter scheme with capacitive energy storage in the intermediate dc link to relieve the grid of large power fluctuations has been initiated at Raja Ramanna Centre for Advanced Technology, Indore. The paper describes power converter scheme, energy storage capacitors, principle of grid power control, reports design details and test results of 100 A prototype and discusses high power design issues.

*****INVITED TALK*****

Explosive Driven Pulse Power Capability at TBRL, Chandigarh

Harish Kumar Gupta, Phool Chandra Gautam*, Radhesh Dewett, Prateek Kishore, Madhvi Narula. Pankaj Soni, Pragati Angra, Ajay Kumar
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Pulse Power Regime of 10 kJ to several MJ energy is a field of interest for scientists involved in various applications such as Nuclear Fusion, High Power Microwaves, Pulse Electron Beam Studies, EMP and X-ray etc. The high energy capacitor bank is required to carried out repeated experiments up to few 100 kJ. However, to fulfill very high energy requirement and single shot operation, Flux Compression Generator (FCG) is potential source for pulse power application, has high energy density in MJ/kg and compact also. TBRL has been working particularly in this field since past several years and has developed capability to design, and test electrical sub-systems experimentally. To cater this requirement, various diagnostic techniques: expansion rate Explosive Filled Metallic Linear, Pulse diagnostic to measure performance of FCG output Current /Voltage. The electric field measurement techniques has been established to determine electric field intensity and radiated power in line of sight of antenna. In addition to this, various type of High Energy Sources have also been developed for standalone testing of electrical sub-system as: FCG, Pulse Transformer and Calibration of High Voltage and Current Sensors.

Flux Compression Generator is most challenging explosive driven electrical system. On initiation of high explosive, metallic liner compresses pre-established magnetic flux which amplifies the initial current to several times depending upon design.

Simulation software have been developed for analysis and optimization of various electrical sub system. Experimental studies are in progress to further improve upon these systems. This paper describes various critical technologies, challenges and technologies developed in TBRL for explosive driven pulse power system including FCG, Pulse Shaping Network, Capacitor Bank, FCG Simulator, Voltage / Current sensors etc.

Key words: Flux Compression Generator, Pulse Power Source, High Explosive, Field Sensors

References: [1] CM Fowler, “An Introduction to Explosive Magnetic Flux Compression Generator “, Los Alamos Report. LA-5890-MS, 1975.

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[3] Y. Tkach, A Text Book on “Magneto Cumulative Generator”, Spring Ver Log-2000.

*****INVITED TALK*****

REVIEW OF COCKCROFT-WALTON HIGH VOLTAGE LOW CURRENT DC POWER SUPPLIES

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High voltage power supplies are key system for the development of particle accelerators, neutron generators, x-ray systems, ion implantation etc. This paper reviews various developed high voltage low current power supplies based on Cockcroft-Walton voltage multiplier circuit for accelerator based neutron sources and other industrial and medical applications. The paper presents a detailed review of the topology of the power supply used for the high voltage generation, the key design parameters, key active and passive components used in the high voltage (HV) system, key experimental results, protection and measurement circuit used in the power supply and about the system performance. The improvement occurred in the size and performance of the power supplies due to the development in technology of the magnetic components, semiconductors and energy storage devices in successive years is apparent in discussion. Finally challenges and possible solutions for the compact design and system performance are concluded for the development of high voltage low current power supplies.

Fabrication of graphene/ natural fibre dielectric composite for electromagnetic interference eradication

Akshita Yadav, Priyanka P Singh and Ganeswar Nath*

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Abstract:

The emerging trends in advanced communication inherent with 5G technology leading to challenging issues in development of functional material in present scenario. As the natural fibrous material are indigenously available creates the enthusiastic development of carbon based composites. With the excellent structural and electrical properties natural fibers have attracted significant attention. In this study, natural carboneous fiber was dispersed in an epoxy matrix with the addition of graphene fibers to enhance its properties. The composites were fabricated using a hand layout moulding technique. The fabricated composites were characterized using scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and dielectric testing. The results showed that the addition of graphene and biodegradable fibres significantly improved the microwave assets and Reflection loss of the composites. The highest impedance matching is at 0.5845 @ 10.53 GHz and reflection loss of -15.6 dB was achieved at equal wt. % of carbon fiber loading. The results shows that the improved performance of composite can be attributed to the high electrical conductivity and unique electromagnetic properties of graphene and natural fibre. This study provides a promising approach for developing lightweight and high-performance EMI shielding materials for various industrial applications such as in stealth and in electronics sector.

Keywords: Electromagnetic interference, Shielding material, microwave properties,

FLASH X RAY SYSTEM

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Flash X-Ray (FXR) radiography is a technique used to take stop-action pictures of dynamic events. Such dynamic events may include detonation of high explosives and in ballistic testing. FXR sources provide a unique method of imaging very fast events, which cannot be captured utilizing normal high speed and ultra-high speed photographic techniques. Flash X-ray technology has become the primary imaging and engineering diagnostic tool on nearly every ballistic and explosive test range worldwide and has many applications in Nuclear, Defense, Space and other industries. FXR sources are pulse power driven and can generate short duration (sub-microsecond), high intense bursts of X-radiation.

This article describes the development of four channel FXR system that can generate a dose of 25 mR at 1m distance and can image dynamic events with spatial resolution of ~ 1 mm. Spatial resolution is determined by a number of parameters – object motion during the exposure, the source size and detector resolution to list a few. This system has four MARX generator driven portable compact FXR tubes that can generate pulsed X-ray (2-3mm source size) of 150 – 500 keV voltage range. Timing sequence (1µS – 1s) and operating voltage (20kV-40kV) of all the four channels can be controlled from the integrated control console.

Important subsystems of this system are listed below.

- High voltage DC power supply
- High voltage pulse generator (Marx Generator)
- Trigger Generator Unit
- Flash X-ray tube
- Control Console system
- Vacuum & Pressure system
- Computed radiographic imaging system

DEVELOPMENT OF 40KJ, 20KV EMM SYSTEM

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Electromagnetic Manufacturing (EMM) system is the state of art technology for shaping and joining of metals based on Electromagnetic Forming (EMF) and Electromagnetic Welding (EMW).These techniques are based on Lorentz Force to achieve the goal. The force is generated when a high voltage charged capacitor bank discharges through a forming /displacement coil placed in the proximity of work piece. Forming and welding are achieved without physical contact between tool and job piece. Hence it has obvious merits over convectional processes such as brazing, welding, expansion, contraction, contour formation etc., when used for some special applications.

This sophisticated technique has many advantages such as precision, reproducibility, high production rate, no tool marks, minimization of manual error, automation ease etc. These preparatory procedures such as preheating, lubrication, etc. are not needed. Since the bond is achieved by impact/pressure, this method is ideally suited for joining/welding of dissimilar metals with large difference in their melting points. The Electromagnetic Forming/Welding is achieved by helical coil/flat/spiral/depending on the geometry of the job This technique has applications in automobile, electric, defence, aeronautical and other industries. Moreover, it has tremendous potential for use in the manufacture of appliances and consumer products.

ECIL has developed 40KJ, 20KV EMM System with design support from APPD, BARC and supplied to IIT, Goa. This system has peak short circuit current capacity of 400kA, short circuit frequency of 20 kHz and system inductance less than 225 nH.

This system has two capacitor sub-banks with eight energy storage capacitors of rating 14uF, 25kV, ESL < 40mH in each sub bank. The constant current HV variable DC power supply (0-20kV) is used for charging the capacitors; Resistive charging is employed due to its simplicity and ruggedness. Single trigatron type spark gaps are employed as switches. Two switches are used, one for each sub-bank. A solid-state switch based trigger generator provides two simultaneous trigger pulses for firing the spark-gaps when master trigger command is actuated with jitter less than 5 ns. A HV dump switch is provided for conditioning of capacitor bank and also when pulse power is not required to be transferred to the load coil. PLC is used for control and monitoring.

Gas purging system and Delrin container for spark gap switches and coaxial chambers are not required for this system which makes it simple, more reliable and cost effective.

Development of Tooling Coils for Electromagnetic Manufacturing of Metallic Sheets

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Electromagnetic forming (EMF) is a manufacturing process that utilizes the principles of electromagnetism to shape and deform metal components without direct physical contact. A high-voltage capacitor bank or pulsed power supply discharges a large amount of electrical energy through the tooling coil. The discharge of this electrical energy generates a powerful magnetic field that induces a strong electric current in the workpiece. The interaction between the induced current and the magnetic field creates a Lorentz force that exerts pressure on the workpiece, causing it to deform and take the shape of a die or tooling that is positioned opposite to the coil. Thus, the tooling coil is an essential component in the manufacturing assembly, producing the necessary pressure required for workpiece deformation. The design and optimization of tooling coils in electromagnetic forming are active research and development areas. In this study, we present the necessary electromagnetic principles and components involved in designing pulsed power electromagnetic (EM) actuators or tooling coils for manufacturing applications to understand their working principle and how they can be optimized. The study has led to the development of a novel dual-channel uniform pressure actuator (DC-UPA) for pulse forming of metallic sheets. The performance of the designed tooling coil was compared to that of the conventional uniform pressure actuator (UPA). The comparison revealed significant improvements in various aspects, including a substantial increase in tooling coil current, enhanced applied electromagnetic pressure, and effective stress mitigation on the tooling coil.

The attractive forming of metallic sheets is another challenging class of manufacturing techniques to produce an attractive force on non-ferrous materials. In principle, it is difficult to achieve this with single discharge circuits as the magnetic fields and induced currents are highly coupled. Conventionally, electromagnetic attractive forming techniques require specialized equipment and pulsed power source assemblies. Dual frequency discharge methods are presently being utilized where the process parameters, such as magnetic field strength and duration, must be carefully optimized for each specific application. This study also presents the design of a single integrated universal uniform pressure tooling coil (UUPTC) that can be used for both attractive and conventional repulsive pulse forming without any change in the assembly configuration or the design of the pulse power source. The designed tooling coils have been simulated for their electromagnetic performance and experimentally validated in both cases.

A MOLECULAR DYNAMICS STUDY TO COMPUTE GLASS TRANSITION TEMPERATURE OF CROSS-LINKED EPOXY RESIN

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Nanodielectrics have gained significant interest due to their enhanced insulating properties in high-voltage equipment compared to conventional composite dielectrics. The considerable modification in composite properties despite the addition of only a small quantity of nano-filler is still under research. Dielectricity of a material is modified at nano-scale levels, and therefore requires molecular level understanding of the behaviour of the material. Molecular dynamic (MD) simulations appear to be an attractive proposition to study nano dielectrics.
First and foremost, this requires the preparation of a computational sample of the neat epoxy resin, whose properties must be studied in detail. In this work, neat epoxy is modelled at the atomistic level and materialistic properties like density, glass-transition temperature (T_g) are obtained with respect to the polymerisation degree and different curing agents. The materialistic properties obtained through MD are compared with the experimental data reported in literature[1] and with the experimental measurement done at author's laboratory[2]. The epoxy resin used in this study is Bisphenol A diglycidyl ether or DGEBA ($C_{21}H_{24}O_4$) which is cross-linked with two different hardeners (also known as curing agents) Diethylenetetramine or DETA ($C_4H_{13}N_3$) and Triethylenetetramine or TETA ($C_6H_{18}N_4$). An MD model of DGEBA cross-linked with DETA and TETA is simulated and material properties of both these samples with varying curing agent and degree of crosslinking is computed.

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Generative design of 110kV condenser bushing using Artificial Neural Networks

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Bushings are an essential component in high voltage equipment, particularly in systems rated above 66kV. Condenser bushings have become the preferred choice in such systems due to their reduced weight, owing to a high electric field utilization factor. Traditionally, optimal design parameters for a condenser bushing at a given voltage rating, such as the number of foils, foil spacing, and length of foils, are arrived at using analytical methods[1], resulting in a uniform field distribution in the bushing. The next step in the process involves validating the design through Finite Element Analysis (FEA) and tuning the design to meet certain design and manufacturing criteria. Recent advancements in Machine Learning and Artificial Intelligence have led to the development of models employing Neural Network architectures for generative design of complex mechanical, thermal, and electrical systems[2]. In this work, we propose an Artificial Neural Network (ANN) model capable of generating design parameters for a condenser bushing rated at 110kV. The ANN model uses a dataset of previously simulated bushing design to learn the relationships between design parameters and their impact on the performance of the bushing. The model is then trained using this data and is capable of generating optimized design parameters for a given voltage rating. The design generated by the ANN model is validated using FEA.

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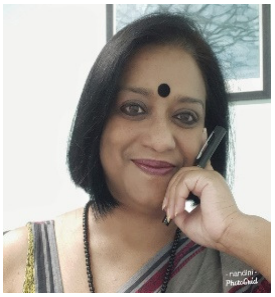

Introduction to Topology Optimization for the Design of High Voltage Insulators

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High Voltage Insulators play a vital role in power transmission systems and are subjected to combined electrical, mechanical, and thermal stress. Common design strategies for HV insulators involve Semi-Analytical methods and Finite Element Analysis (FEA) to arrive at designs that meet certain design and manufacturing criteria [1]. Topology Optimization (T.O) is a design strategy widely adopted to minimize the weight and volume of the design while retaining the performance of the design [2]. In this work, we propose a modification to the traditional Topology Optimization (T.O) process to minimize combined electrical and structural compliance in HV insulators. This modification incorporates electric field considerations in the T.O process, which is not typically done. The proposed optimization strategy is applied to optimize the design of a 66kV epoxy insulator.

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Balaji Sriram


Harivinay Varadaraju


Nandini Gupta

HYDROGEN PLASMA STREAM HEAT SOURCE FROM PULSED PLASMA ACCELERATOR AT CPPIPR

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Hydrogen plasma stream as a heat source has an importance in the fusion devices A high density pulsed hydrogen plasma stream is being generated in a pulsed plasma accelerator (PPA) facility at CPPIPR. The PPA is powered by a 200 kJ Pulsed Power System (PPS) which consists of a parallel assembly of two high energy capacitor banks each of energy 100 kJ. The capacitor bank modules are discharged through inductors and damping resistors using high current ignitron switches. The discharge current pulse from the 200 kJ PPS has a time period ~ 1 ms with a peak current of 100 kA. The gas discharge in the PPA produces a high density ~ $10^{20}/m^3$ hydrogen plasma stream with a high energy density. The heat generated from this plasma stream is measured using a calorimeter consisting of 4 K-type thermocouples. Besides this, the plasma stream is characterized using different diagnostics method such as OES to estimate the different plasma parameters and high speed imaging to know the morphology of the plasma stream. The effect of an external longitudinal magnetic field on the plasma stream is also observed and presented. A maximum energy density of 0.224 MJ/m^2 is achieved in the presence of the magnetic field at a plenum (gas storage unit of gas injection valve) pressure of 2.4 bar. The observed heat load from the hydrogen plasma stream is comparable to the heat load imparted to material surface in tokamaks during the frequent outburst of plasma called ELMs with energy density ~ 0.2 - 1 MJ/m^2.

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UPGRADATION OF PULSED POWER SYSTEM FROM 200 KJ TO 300 KJ AT CPP-IPR

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A 300 kJ pulsed power system (PPS) is under developing stage at CPP-IPR by coupling additional 100 kJ capacitor bank with an existing 200 kJ PPS. The system will consist of three numbers of identical 100 kJ capacitor bank modules. In general, the high voltage is made to produce a fast output pulse (time period of few microseconds) according to their requirements. In contrast to the conventional power system, the PPS under development at CPP-IPR will produce a relatively longer duration (around 1.0 ms) output pulse. Each 100 kJ capacitor bank will consist of 5 numbers of high voltage energy storage capacitors which will produce a sinusoidal output pulse with peak current in the range of kilo ampere (maximum peak discharge current from each capacitor bank is 50 KA). The total peak current is around 150 kA for a time period of 1.0 ms. Each 100 kJ capacitor bank will be discharged through dummy load simultaneously by triggering three separate high voltage ignitron switches (NL8900) with the help of a fiber-optic triggering unit. Circuit simulation was carried out with PSpice estimate the parameters of the circuit components to achieve the required current pulse. Using these parameters, the design of the PPS was made keeping into account about the critical issues involved and the ratings of the components, some of which were fabricated in house. This paper basically includes the criticality of the operation of a long-pulse PPS under negative operating voltage. It is noted that the performance of existing developed 200 kJ PPS[1] is just fine that can generate 100 kA peak current at load for around 1.0 ms without any significant jitter between the two current pulses from the two 100 kJ banks. This PPS is successfully coupled with a Pulsed Plasma Accelerator[2] that produces high density, high velocity plasma stream with around 20 km/s speed.

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UTILIZATION OF CAPACITOR BANK FOR ELECTROMAGNETIC PULSE CRIMPING*

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Capacitors play an important role in an electrical system. They have numerous application in the field of lasers, fast X-ray and neutron sources, electromagnetic pulse generator, electron beam accelerators, plasma generation and electromagnetic welding of materials. One of the applications of high voltage capacitors as energy storage and discharge devices is in crimping of cables using electromagnetic pulse forming technique.

This research paper investigates the use of a high-voltage energy storage capacitor with a capacitance of 208 microfarads to perform electromagnetic pulse crimping. The capacitor is designed to operate at 12 kV and is discharged to produce a high current that generates a strong magnetic field, which is utilized for joining of the cable conductor and the lug. The study examines the performance of the capacitor under different operating values such as voltage, capacitance, discharge time and investigates the effect of these parameters on the weld/termination quality. The paper presents the experimental results of the crimping, which include the contact resistance, weld strength, microstructure, and defects of the welded joints. The results indicate that the capacitor-based electromagnetic pulse crimping produces welds with high strength and minimal defects. Additionally, the paper discusses the future scope of research in this area and the potential applications of such capacitors in other welding techniques. The findings of this research paper provide valuable insights for engineers and researchers working in the field of energy storage, high-voltage applications and welding.

DEVELOPMENT OF PULSED MAGNETIC FIELD FOR INTERACTION WITH PLASMA STREAM

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A pulsed electromagnet is being developed at CPPIPR to enable its interaction with a high speed pulsed plasma stream produced from a pulsed plasma accelerator (PPA). The magnetic field will facilitate an external pulsed transverse magnetic which will have effect on dynamics of the plasma stream of the PPA. For this an electromagnet with a maximum field strength of ~ 0.4 T is designed, fabricated and positioned between the source and the target chamber of the PPA. The magnetic field is simulated using the Poisson-Superfish code and finite element magnetics method. For the generation of the required electromagnetic pulse, a 12 kJ pulsed power system (PPS) is being built. The PPS consists of a capacitor bank of 6 capacitors each having a capacitance of 1000 µF. The capacitors are charged to a voltage of 2 kV to achieve a peak discharge current of 20 kA by transferring the energy to the load through a silicon controlled rectifier (SCR). In the design consideration, the pulsed electromagnet is taken as the pulse shaping inductor of the PPS to achieve a time period of 23 ms while the damping of the pulse is provided by invoking a resistor of 100 mΩ to the circuit. The relatively longer duration of current pulse of the electromagnet has been kept for the ease of synchronization. The synchronization of the pulsed electromagnetic field is carried out in such a way that the peak portion of discharge pulse for the electromagnet match with the time of the peak discharge pulse from 200 kJ PPS that produce the plasma stream. In this presentation, we are reporting the whole work that has been carried out for developing the electromagnet from designing, fabricating and then commissioning it to the PPA system.

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COMPARATIVE ANALYSIS OF THE MUZZLE VELOCITIES OF PROJECTILES IN HORIZONTAL AND INCLINED CONFIGURATIONS OF THE COIL GUN

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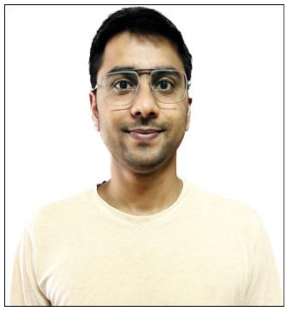
A coil gun is a type of Electromagnetic Launcher (EML) which can accelerate a projectile by converting electrical energy stored in high energy storage capacitors to kinetic energy of the projectile. In this paper we analyze and compare performance of a single stage coil gun in terms of muzzle velocity of the projectile when the coil gun is in horizontal and inclined configurations. The launch angle (angle of inclination) is taken as 45 degrees with horizontal which shall give maximum range if air drag and friction are ignored. Inclined configuration is especially suitable for shorter range applications wherein the launched objects need not escape the denser layers of atmosphere. The results are obtained using commercially available FEM based ANSYS® Maxwell software. The electromagnetic force on the projectile in the inclined position is opposed by the component of weight of the projectile in the direction of motion resulting in reduced muzzle velocities. As the electromagnetic force on the projectile also depends on the rate of change of mutual inductance between the coil and projectile, a comparison of optimum initial position of the projectile in both cases is also made. An experimental single stage coil gun is also being developed in the lab to verify the results. Suitable arrangements will be required to keep the projectile at the optimum initial position before the coils are energized for inclined configuration to avoid sliding of the projectile due to gravity. These results will be helpful in optimal design of the induction coil gun used in certain applications.



DESIGN AND DEVELOPMENT OF A FOUR-STAGE INDUCTION COILGUN

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Various agencies have widely deployed the archetypal chemical propellant-based launchers (e.g., guns, missiles, spacecraft launchers, etc.) with their hot trailing plume over the decades. However, because of certain disadvantages of these systems and the physical limitations associated with their designs, electromagnetic launchers (EMLs) seem to offer an alternative way forward as the next-generation hypervelocity (>3 km/s) launchers. They are being researched in select countries around the globe due to their promising capability to replace the chemical launchers in hypervelocity launching applications successfully. The multistage induction coilgun is one such futuristic class of EMLs that works on the principle of electromagnetic induction between an array of coils (or drive coils), which are wound on a long insulating barrel of appropriate length, and an electrically conducting projectile (or armature) placed inside the barrel. Previously charged high-voltage capacitor banks are sequentially discharged into the coils through high-voltage solid-state switches leading to the generation and flow of high-magnitude pulsed currents through the coils. Time-varying electromagnetic flux thus produced by the pulsed currents through the coils interact with the projectile inside and induce a resultant current on it. The propulsive electromagnetic force exerted on the projectile is a product of the excitation current through the coil, the induced current on the projectile, and the mutual inductance gradient (i.e., the change in mutual inductance between the coil and the projectile as the projectile travels through the coil). The "turn on" and "turn off" of the coils in the various stages must be precisely and appropriately synchronized during the multistage operation to achieve a higher projectile velocity. This makes its successful design and operation a challenge. This presentation will focus on the authors' design and developmental work successfully carried out on a four-stage induction coilgun-based EML at the pulsed power laboratory of the Department of Electrical Engineering at the Indian Institute of Science, Bangalore. Our research work aims to understand the factors contributing to achieving a higher muzzle velocity for a projectile of a given mass while launching a payload with the coilgun. The study on the muzzle velocities of the sleeve projectiles of different dimensions and materials (aluminum, copper, mild steel, and stainless steel) having different electromagnetic properties will be presented in this paper. An empirical relationship between the projectile muzzle velocity of a coilgun and the charging voltage of the capacitor bank, which have been formulated for the first time by the authors, will also be presented in this paper.

Novel Halbach Permanent magnet solenoid Design using Finite Element Method

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Abstract

To generate the high axial field usually Electromagnetic Coils solenoid is used but it consumes large DC power supplies and cooling system and is not compact. The PM (Permanent magnet) solenoid on contrary can give fixed axial field profile and are very compact and does not require any energy source as they are themselves energy source. PM solenoids are usually designed using large radial and axial magnetized magnets. The drawback of such a design being using large radial magnets which are often unavailable with assembly problems.
The paper discusses the novel Halbach solenoid configuration design and uses ref [1] solenoid results to verify it. The finite element magneto static method used to analyze the two models. The FEM magneto static analysis done in Magnet Infolytica FEM magneto static analysis package.

Key Words: Solenoid, magnetization, remnant field, Halbach. PM, FEM

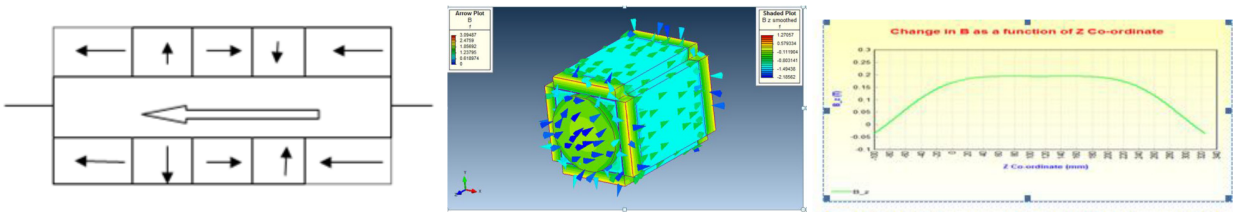

Fig: Halbach solenoid design

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STUDIES ON THERMAL SIMULATION OF PFN CAPACITORS OF PULSED KLYSTRON MODULATOR FOR 10MeV 10kW INDUSTRIAL LINAC

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RRCAT has developed and deployed 10MeV, 10kW Industrial Linac. The Linac has been powered using a high power, pulsed klystron based amplifier. Pulse modulator provides high power pulses to klystron amplifier. PFN capacitors used in pulse modulator are manufactured by an Indian company to meet functional requirements of maximum charging voltage, peak current and repetition rate of 40 kV, 800 A and 300 Hz respectively. However, it is desired to improve performance of these capacitors in terms of lower heating and higher PRR operation. A task force consisting of RRCAT and BARC engineers is working on development of reliable capacitor which can handle high voltage at high PRR operation up to 400Hz and manufacture these capacitors in Indian industry. This paper describes an approach for thermal simulation of the PFN capacitor, including thermal modelling and steady state thermal analysis using ANSYS to investigate temperature distribution. Based on thermal analysis, design improvements of the capacitors can be made to achieve low heat loss at high PRR operation.

CARBON-NANOTUBE BASED SUPERCAPACITOR ELECTRODE FOR ENERGY STORAGE APPLICATIONS

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Supercapacitors are high-energy and high-power capacitors which bridge the gap between electrostatic capacitors and batteries as energy storage devices. Supercapacitor electrodes require porous surface with high surface area, which makes Carbon nanotube (CNT) forests as appropriate candidate for electrode material. The growth of CNT forest over a suitable current collector is a sophisticated process requiring fine-tuning of various growth parameters. Also, the as-grown CNTs are hydrophobic and their wettability must be improved before being used as supercapacitor electrodes. In this paper, the fabrication of a CNT electrode on carbon paper using catalyst dip-coating technique and Chemical Vapor Deposition (CVD) method is discussed in detail. The dipping time is varied between 5-30 minutes to vary the catalyst coating thickness. The various factors that affect the growth mechanism are also elaborated. The fabricated electrode is electrochemically characterized to evaluate the capacitance. The capacitance is found to lie in the range of 50-70 F/g.

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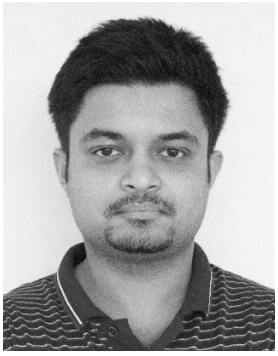
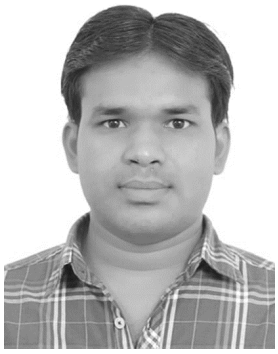

MAGNETIC PULSE COMPACTION OF SS POWDERS

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Traditional powder forming of metals, ceramics, etc uses techniques like uni-axial press, cold iso-static press, etc. The dynamic pressing techniques have unique advantages like better densification with fine microstructures. In this study, Magnetic Pulse Compaction (MPC) technique for powder densification is demonstrated. Here, the energy stored in the capacitor banks is discharged into a electro-magnetic tool coil to generate a time-varying magnetic field. The interaction of this magnetic field with a conductive liner experiences a Lorentz force, which transfers the mechanical pressure to the powder and leads to its densification. In this article, the effect of discharge energies on the relative density of compacts has been studied. Also, the effect of central mandrel on final density is also analyzed. The SS powder has been compacted using a 6 disc bitter coil using 208 μF capacitor bank with 10 kJ stored energy. The final dimensions of the compacted sample are with 13 mm diameter and 8 mm in length. The bulk density of the sample has been measured using Archimedes principle and found to be 78 % of theoretical density. The sample is also subjected to micro tomography and the results are also reported.

Experimental Investigation of Interface Diffusion in Electro-Magnetic Welding

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ABSTRACT

Electro-Magnetic Welding (**EMW**) is a solid state welding process that is accomplished by a magnetic pulse causing a high-velocity impact on two materials, resulting in a true metallurgical bond. In this research work elemental diffusion were studied for D9 tube –SS 316 L (N) and Al 6061- SS 316 weld combinations. Mo and Ti are present only in D9 material, diffusion of Mo and Ti is investigated by point scan and line scan technique using FAG-SEM. In case of Al 6061 tube-SS 316 plug, migration of Al from Al 6061 to SS 316 side and migration of Ni, Cr and Fe from SS 316 to Al 6061 side were investigated. Diffraction patterns were analyzed using TEM and EDS line scan has been carried out in STEM mode to investigate the chemical composition near interface. Numerical simulations were conducted in FEM software COMSOL to estimate temperature rise and impact velocity of colliding surfaces during EM welding.

Keywords: Atomic diffusion, interface layer, point scan, diffraction patterns and line scan

Upgrade of 250 kJ capacitor bank system in ADITYA-U tokamak

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ADITYA tokamak [1] consists of multiple capacitor banks with several energy storage capacitors of different capacitance and voltage values with a total stored energy of approximately 250 kJ [2]. This system is under application for the last 30 years for tokamak experiments for energizing different magnetic coils to obtain plasma discharges. This system is also used with external inductive load to generate current pulses of varying magnitude (kA order) and pulse width (ms order) on magnetic coils of ADITYA-U tokamak [3]. One of the main aims of the ADITYA upgrade was to improve the operational aspect of the capacitor bank system with the incorporation of automatic voltage charging control and monitoring, better system availability by reducing the trigger system downtime, programmable trigger option and reliable crowbar operation. Therefore, an effort has been initiated to upgrade the existing capacitor bank system by using cost-effective solutions in different phases along with its testing and operation. The PLC-based system is integrated with multiple motorized auto-transformers for automation of capacitor charging and it's monitoring from the tokamak control room using a LABVIEW-based graphic user interface. The system has the facility to have automatic as well as manual options along with the user-defined voltage and time. Later on, the existing RC-based trigger system for ignitron switches was replaced with industrial modular system. Subsequently, a programmable FPGA-based system multiple trigger output system with LABVIEW-based GUI is integrated with the ignitron firing system using optical fibre-based electrical isolation. Moreover, a new automatic crowbar system is also incorporated within the capacitor bank system. This upgraded bank has reduced the complexity of system handling, its monitoring and simplified the operation from the control room computer. The upgraded bank is successfully integrated with the ADITYA-U tokamak system and is under application for different experiments. Moreover, new units of multiple air-core reactors are under integration with capacitor banks to improve the rise time of the current pulse length. Similarly, current limiting resistance is also added to the system to restrict the current peak value. New energy storage capacitors and ignitrons will also be integrated with the capacitor bank systems for the new range of plasma experiments. Detailed results from the system will be presented in the paper.

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Capacitor Bank-Based Power Supply used for Shaped Plasma Operation in ADITYA-U tokamak, a milestone in Indian Fusion Program

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Shaped divertor plasmas are the preferred mode of operation for all advanced contemporary tokamaks, as well as future fusion reactors like ITER [1], due to their reduced plasma-wall interaction compared to the older circular shape. Gaining experience and expertise in shaping plasma operations is crucial for the Indian fusion program. ADITYA, the first Indian tokamak, was upgraded to ADITYA-U [2] to accommodate the sets of divertor coils required for shaped plasma operation, as a step forward in this direction. Two capacitor banks of 5kV rating were used to energise top & bottom divertor coils to conduct initial shaped plasma experiments. These two capacitor banks have capacitance ~30 mF and 14 mF, which were developed by a parallel combination of a single capacitor of 0.7 mF. External reactor units of inductances of 12 mH and 18 mH, respectively were used in series with the main divertor coils to govern output current magnitude and pulse width. The capacitor bank charging voltage and firing time of the coils were remotely controlled via a LabVIEW-based graphical user interface (GUI) [3].
The divertor coils were gradually operated at incremental current, up to the maximum capability of the capacitor bank supply. The start time, current ramp, and delay between the top and bottom divertor coils were systematically scanned in 100 plasma shots to achieve optimized shaped operation. These experiments have given us practical knowledge of the conditions required for achieving a shaped plasma regime with an optimised plasma position, parameters scenario and duration. The operation of capacitor banks for divertor coils yielded critical data and knowledge to build a specialized power supply unit for the divertor coils. In this paper we will present the experimental setup, results, and key insights gained from these experiments which can be applied to future projects.

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A STUDY ON RECENT ADVANCEMENTS IN DIELECTRIC MATERIALS WITH RESPECT TO HIGH VOLTAGE ENGINEERING APPLICATIONS.

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With increased use of HVDC and HVAC lines in the power system network the design of power equipment and hardware such as power transformers, indoor insulators, underground cable etc. needs more suitable dielectric materials to meet the new challenging voltage stress conditions. Also, the industrial applications of high voltage engineering like ESP, Pulse power etc. requires a careful investigation of testing parameters for dielectrics to be adopted. Apart from High Voltage Engineering, dielectric materials find widespread usages in other engineering fields like Electronics, Photonics, Biotechnologies etc. as electricity storages, super capacitors, electrostatic capacitors, batteries etc.

In this paper we will start with a brief introduction and summary of conventional dielectrics with their pros and cons and will proceed towards newly engineered dielectrics suitable from high voltage engineering point of view like Polymer composites, Nano composites, Advanced ceramics, nanodielectrics, multilayer structured dielectrics, Synthetic Ester-based dielectric liquids. Also, we will have a glance on future dielectrics like Organic and inorganic hybrid dielectric, thermally conducting dielectrics, Graphene based dielectric.

ON-BOARD POWER CONVERTER FOR BATTERY CHARGING APPLICATION OF E-MOBILITY VEHICLES

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The topologies for high power supply modules are emerging and transforming in advent of dynamically changing application requirements, and continuous growth in the semiconductor device technology. This paper proposes a simples design procedure for single phase 7.2kW two stage power supply module to cater need of battery charging and other energy storage application. The three phase interleaved Totem pole AC to DC power factor controlling bridgeless converter is used at front end to regulate input power at high power factor. The Dual Active bridge(DAB) topology is used in second stage for high power DC-DC conversion. The ultra wide gap Silicon Carbide (SiC) power mosfets are used in both the stages to increase power density, reduce losses and increase overall system efficiency .The average current control algorithm is used for Pulse width modulated(PWM) control of power switches separately for both the stages which can be easily be implemented using digital microcontrollers. The magnetics design for inductor of Totem pole PFC and high frequency transformer is DAB is presented. The power supply can be powered from single phase 100-230VAC,50Hz .The DAB generate output of 7.2kW at 150-200V to charge an 30kWh Li-Ion battery bank. The hardware design of the power supply module is presented . The simulation results of the power supply module is presented and the results are compared with the existing low power classical single phase power supply module.

STUDY ON ADVANCEMENTS IN DIELECTRIC TESTING IN HIGH VOLTAGE APPLICATIONS AND ASSESSMENT OF EFFECTS OF AGEING ON DIELECTRIC PROPERTIES

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The reliability of power system relies heavily on the performance of insulation or dielectric materials used in various equipment like power cables, transformers, generators, switch gears, capacitors, reactors and arresters. However, dielectrics can degrade over time due to various factors, including electrical stress, temperature, humidity, and other environmental conditions. The degradation or failure of insulation can lead to equipment malfunction, power outages or even a catastrophic failure. Therefore, a periodic assessment and monitoring of insulation health and integrity through proper dielectric testing mechanisms serves as an essential tool for safe and sustainable operation of an electrical power system.

This paper also addresses the development of aging models and predictive tools for assessing the remaining life of dielectric materials in high voltage applications, valuable insights into the long-term performance and reliability of dielectrics, enabling improved maintenance strategies and design guidelines for high-voltage systems.

Keywords: Dielectrics, high voltage applications, testing, aging, dielectric properties, insulation resistance, partial discharge, breakdown voltage, accelerated aging, reliability.

An Experimental and Numerical Study: To investigate the Feasibility of SF_6 Admixture as a Potential Replacement to SF_6 in Gas Insulated Application

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Sulphur hexafluoride (SF_6) gas is a potent greenhouse gas. Therefore, there has been research into more environmentally friendly alternative gas as a replacement to SF_6 in high voltage (HV) equipment. The research into alternative gases has shown that SF_6 admix have a promising dielectric property as comparable to pure SF_6. The breakdown experiments have been carried out in indigenously developed co-axial sparkgap switch with corona discharge electrodes for an inter-electrode distance of 4mm. The insulation tests have been performed in the test platform with 5%, 10%, 25% and 50% of SF_6 in SF_6/N_2, Ar for pressure levels in between 5 psi to 30 psi. From experimentation, the breakdown voltage of SF_6/N_2, Ar admix with 5% SF_6 is found to be ~60% and 30% of pure SF_6 respectively. With increase in the volumetric concentration of SF_6, the relative breakdown strength increases in SF_6/Ar whereas in SF_6/N_2 as SF_6 concentration exceeds 50% there is no further improvement in the breakdown voltage as the effects have reached saturation. In addition to experimentation, a discharge model has been developed using 3D PIC/MCC code for the subjected experimental constraints. In the simulations, ionization by interactions of SF_6/N_2, Ar atoms are considered whereas dissociative ionization and plasma chemistry of SF_6/N_2, Ar has been ignored. The effect of SF_6 concentration on average electron number density, breakdown voltage and E_Z during discharge process are investigated through numerical simulations. The calculated breakdown voltage data is found to have a good qualitative and quantitative match with the experimental breakdown data in SF_6/Ar. Furthermore, the critical field required for a stable propagation of streamer has been estimated from the streamer field distribution. From this study, usage of SF_6/N_2 as a replacement to SF_6 in Gas Insulated application is found to be a favorable way to optimize the HV equipment due to short-comings of 100% SF_6.

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Derating of a DC Capacitor subjected to Polarity Reversal under FCG Simulator Application

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Pulsed power applications have been a topic of extensive research in the field of defense applications worldwide. A lot research has been focused on creating a non-destructible and a repeatable pulsed power system with Flux Compression Generator (FCG) simulator topology being widely accepted in this regard. It has been observed that a FCG simulator based on electrical components suffers from peculiar issues. Under the influence of polarity reversals experienced in FCG simulator evident degradation of the energy storage capacitors occurs. These high voltage energy storage capacitors are nominally designed for a rated peak current and designated charge and discharge cycles. Due to the experienced polarity reversals the expected life of the capacitors is observed to decreased and they fail before the designated cycles. It is thus a topic of research to quantify the damage accumulated by these capacitors under polarity reversal conditions in a FCG simulator application. The damage calculated will allow us to find an appropriate measure to derate the capacitors and help in the design aspect to suit the pulse power applications by avoiding failures.

Applications of high voltage capacitor in pulse power systems

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Abstract: Several pulse power applications like High Power Microwave (HPM) generation, electromagneti c welding and neutron generation using plasma focus require very high current of few kA to hundreds of kil o amperes for time duration of few microseconds to few milliseconds. Energizing capacitor bank at high vo ltage and discharging it into high current device is the most popular technique in these applications. This pa per highlights the design of capacitor bank, which were developed for various pulse power systems develop ed at BARC like MARX generator, Backward Wave Oscillators (BWO), Electromagnetic welding and Den se Plasma Focus (DPF) system

Design, Development and Performance Evaluation of HV Energy Storage Capacitors for PFN based klystron modulator applications

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The high power klystron modulators and microwave systems are the workhorse for the linacs. Linacs find applications in industry, medical and research. In industry, electron linacs are mainly used for irradiation of food products for improving the shelf life, medical sterilization and radiography. All these applications demand reliable subsystems having high MTBF and low MTTR. Most commonly, the linacs are powered from a klystron based high power pulsed microwave systems. The pulse forming network (PFN) based klystron modulators are the most common type of modulators used for biasing the klystron amplifier. The capacitors used in the PFN are required to be capable of simultaneously handling the high voltages, high peak currents, high RMS currents, and high pulse repetition rates (PRR). The energy storage capacitors from Indian industries have limited life. Also in addition, modulator system developed at RRCAT using these capacitors, high temperature rise and failures were observed during their operation at pulse repetition rates of 300 Hz at rated voltage and current stress. The cause of temperature rise and failure was analyzed along with thermal simulation, carried out using ANSYS. The temperature rise and failures were majorly due to improper selection of dielectric material, manufacturing process and packaging. For improvement, low loss polypropylene material has been chosen as a dielectric material. Improvements in manufacturing process and packaging were carried out after discussion with Indian manufacturers. A 40 nF, 40 kV, 400 Hz polypropylene dielectric based capacitor has been designed and manufactured in Indian industry. The ESR and performance of the capacitor have been tested using indigenously developed test stand. The ESR value of ~ 100 mΩ has been achieved with the improved design. The temperature rise of ~ 4□ was achieved when subjected to 21 kV, 600 A peak current at 400 Hz pulse repetition rate (PRR). The background, design, construction, measurement, and performance qualification will be discussed in the paper.

Challenges in measurement of low value ESL and ESR of high performance PFN capacitors for klystron modulator

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Abstract

In the high voltage line type pulse modulators, pulse forming network (PFN) capacitors are one of the important components. These capacitors operate at peak kilo ampere current range and at repetition rate in the range of few hundred hertz.The performance of these capacitors is critical w.r.t. overall system performance, and they are required to operate at high power density and low losses with high reliability.The Equivalent Series Inductance (ESL) and Equivalent Series Resistance (ESR) are two critical parameters that affect the performance of these capacitors. PFN modulator demands capacitor of very low ESL and ESR for reliable operation and generation of high voltage pulses. Higher ESR value adversely affects the performance of the capacitor by rising its temperature and thus deteriorating its life. ESL value does not directly affect life, but it affects the quality of high voltage pulse. In RRCAT, the PFN capacitors purchased from Indian manufacturer were showing high temperature rise and failures. Therefore, new capacitors were designed to have a lower ESL and ESR values. Measurement of ESL and ESR is important to evaluate the performance of the capacitors. The low-value of these parameters makes their measurement a challenging task, and requires special techniques. For low value of ESL and ESR (less than 100 mΩ) measurement, differential measurement technique were used in which modification and different layouts were explored for improving the repetitive accuracy of the measurements.The differential ESR and ESL measurement technique with more emphasis on the low value ESR measurement will be discussed in the paper.

DEVELOPMENT OF 1 kV, 30 kW CAPACITOR CHARGING POWER SUPPLY OF SOLID STATE PULSE MODULATOR

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This paper reports the development of 1 kV, 30 kW Capacitor Charging Power Supply of Solid State Pulse Modulator. It provides variable output voltage 300-1,000 V & maximum current up to 30 A depending on load. The power supply design is based on DC-DC Series Resonant Converter. High frequency transformer's leakage inductance is utilized in resonant circuit to achieve zero switching losses. In view of switching current (125 A_{Peak}) and switching voltage (1.2 kV_{Peak}) at resonating frequency (100 kHz) in the resonant circuit; low loss metalized poly-propylene film capacitors are required. A variable switching frequency controller has been implemented to maintain the output load voltage at the specified DC level.

With these considerations, 1 kV, 30 kW capacitor charging power supply has been designed, simulated and developed. It is assembled in the standard 19-inch, 6U electronics rack. Development of resonant converter based power supply leads to compact size, easily controllable, low cost, highly efficient (≥95%) and precise output voltage regulation (±1%). Also, high frequency (100 kHz) sinusoidal-current envelope significantly contributes in the mitigation of harmonics as well as EMI.

The main advantage of this power supply is its ability to operate under short circuit to open circuit conditions, thus improving reliability of the overall system. The developed power supply has been tested on the simulated load. Subsequently, it was integrated with solid state pulse modulator. The supply charges energy storage capacitors of pulse modulator up to 1 kV with 25 A maximum charging current. The maximum operating charge/discharge cycle is 220 per second. 30 kW power supply was developed & deployed. Its design & test results are presented in this paper.

Miniature High Voltage Capacitor Charging Power Module

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In pulsed power applications high voltage (HV) capacitors are employed for energy storage. This energy is transferred to load in a very short time typically nanosecond to micro second. HV capacitor requires a power supply which can charge to a voltage level as per energy requirements. This power supply should be compact to accommodate in a limited available space and to be fed from on board batteries. This types of power modules are not available in Indian market. This paper presents a power supply which operates from a 12 V battery input and generates the output voltage of 4 kV. Generally for this application flyback topology is suitable due to its low cost and low component count. This paper discuss the design of power supply built around a commercially available controller LT3751 for capacitor charging application. The LT3751 is a high input voltage capable flyback controller designed to rapidly charge(constant current mode) a large capacitor to a user-adjustable high target voltage set by the transformer turns ratio and three external resistors. This controller operates in boundary conduction Mode (BCM) during charging which reduces turn ON losses and improves the efficiency. The other important element is flyback transformer[2] of the power supply, which also affects operation, and overall efficiency of the system. Mainly transformer parasitics play an important role in converter operation. The parasitics of transformer are reduced through employing stringent winding technique to control the secondary winding capacitances. Software simulation results are compared with experimental results of power module of 4 kV, 2 mA (size:100 mm x 40 mm x 45 mm) and are in good agreement.

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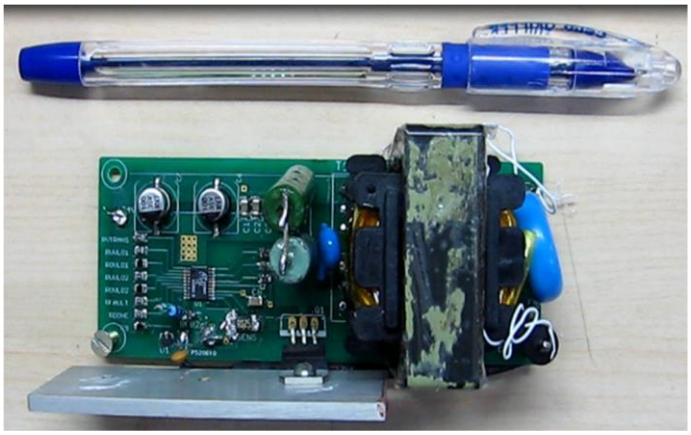

APPLICATIONS OF HIGH VOLTAGE PULSE GENERATORS IN PHYSICAL SECURITY OF CRITICAL INFRASTRUCTURE

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The High Voltage Pulse Generator, also known as an Electric Fence Energizer, is a crucial component of an Electric Fence-based Perimeter Intrusion Detection System used for the physical protection of Critical Infrastructure. Its primary function is to provide deterrence to intruding adversaries and detect intrusions at the facility's perimeter. The design of the system presents a challenging task of ensuring that the electric shock received by the intruder is non-lethal yet sufficient to deter them. The BIS Standard IS 302-2-76 (1999, reaffirmed 2004) provides the guidelines for designing the system. This paper discusses the design of an Electric Fence-based Perimeter Intrusion Detection System, including parameters related to human safety, its advantages and limitations, and a comparison with other technologies for similar applications. Additionally, the paper proposes methodologies to overcome some significant limitations of the system..

NOVEL TECHNIQUE FOR GENERATING DESIRED DELAY AND COMPRESSION IN THE OUTPUT CURRENT PULSE OF FLUX COMPRESSION GENERATOR (FCG) SIMULATOR

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Conventional pulsed power systems employ capacitor banks which use electrical energy. When high enough energy in the range of 100 kJ or more is required, the size of the systems becomes massive. Flux compression generators (FCG) are compact devices which utilize the energy of explosives to generate electrical current pulse. This type of pulse power system is compact and portable and can be used for various applications such as proof of concept, plasma studies, High power RF generation etc. Several times, the output current pulse of an FCG needs to be conditioned before use. This pulse conditioning system needs to be optimized before it is ready to be connected with FCG. It becomes almost impractical to optimize this conditioning unit with FCGs since these are single shot devices i.e. no possibility of non-destructive testing for fine-tuning and optimization. On the other hand, an FCG simulator based on electrical components allows for inexpensive, repeatable, and non-destructive testing of the pulse conditioning systems in non-explosive experiments. Therefore, designing an optimum FCG simulator for generating desired delay and compression in the output current pulse with non-destructive testing is considered important from application point of view. Traditionally pulse compression was implemented using magnetic switching[1, 2] in a capacitor bank system to generate FCG like waveform. The authors propose a novel technique for generating arbitrary delay and compression in the output current pulse of a FCG simulator which utilizes spark gaps and magnetic switching both for generating such a type of waveform. The technique was extensively tested in laboratory and a prototype utilizing the above was successfully demonstrated in field. Any arbitrary delay can be implemented with aim of current pulse compression using this technique. The output current waveform closely resembles the actual FCG waveform with exploding wire fuse with presence of clear inflexion points in load current waveform demonstrating the compression of the current waveform. This type of system is easier to configure and much more flexible in the sense that inflexion points can be varied easily.

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EMI EMC: Background, Standards and Design Aspects

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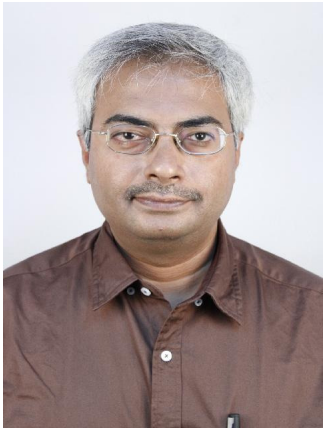
In a multi subsystem environment, in order for the subsystems to interoperate, electromagnetic interference and compatibility aspects have to be addressed. This is a critical aspect of the design but is often overlooked and retrofits are often required post design to fix interoperability issues. This situation can be avoided by addressing and identifying the EMI and EMC aspects at the specifications stage itself, lending to a better final design outcome. This paper discusses the what, why and how of EMI/EMC and also provides a brief overview of the current standards. Given the harsh EMI/EMC environment of Military equipment, Nuclear systems and sensitive nature of Medical Electronic Implants, corresponding standards like MIL-STD-461 for Airborne Systems, IEC 61000 family of standards for Nuclear and Industry and ISO14708, IEC60601 for medical implants have evolved. This group from CnID, BARC has expertise in successful EMI EMC qualification of airborne systems and medical implant devices.



Avalanche Transistor Based Nanosecond Pulse Generator

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There is an increasing interest in fast rise time high voltage (HV) pulse generators employed in various applications such as spark-gap triggering, x-ray generation, microwave antenna, pulse laser, plasma research, biological effects on cells and industrial applications. Traditionally, Marx generators are employed for these applications with gas breakdown spark gaps. However, these Marx generators are limited to a higher rise time, due to parasitic inductances and capacitances of the spark gaps and electrical connections. This in turn increases the volume of the system. In order to reduce parasitic inductance and capacitance a compact and modular design is proposed. This pulse generator was used to trigger gaseous spark gap which requirement of trigger voltage of more than 5kV. This gaseous spark gap is powered from a power module of 5kV and similar voltage is available for trigger generator. LT-Spice simulation studies were performed to get output voltage of 10 kV with 6 ns peak time. In this paper two stage marx-circuit based pulse generator is designed and experimentally validated using avalanche transistors (AT). Each stage consist of thirteen ATs (FMMT417- Zetex Semiconductor) in series and disc capacitor which charges up to supply voltage through the isolating resistors. In order to achieve fast rise time minimization of loop inductance was achieved through assembly of these components in a strip line geometry over a double sided printed circuit board (PCB). Experimentally, Output voltage of 10 kV peak , rise time of 3.5 ns and 2.0 ns jitter in rise time with multiple switching of the single AT marc-circuit was achieved. Experimental and simulation results are found in good agreement.

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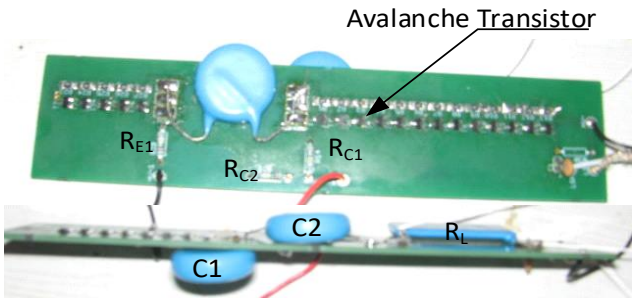

COMPARATIVE STUDY OF DIFFERENT
HIGH VOLTAGE SWITCHES USED IN PULSED HIGH VOLTAGE APPLICATION

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High voltage switches play a crucial role in pulsed power applications, where the efficient and reliable control of high voltage pulses is required. This study aims to compare different types of high voltage switches commonly used in Pulsed power systems including, Electromechanical switches, vacuum switches, Gas filled switches, Triggered spark gaps and Solid-state switches.

The comparison study focuses on key performance parameters such as voltage handling capability, Current carrying capacity, Turn-On time, repetition rates are considered to provide a comprehensive study and analysis of the switches suitability for different pulsed power applications.

Gas filled switches such as Spark gaps, thyratrons and ignitrons have been used in pulsed power systems due to their high voltage handling capability and low switching losses. However, they suffer from limited lifetime and require maintenance and periodic replacement. Solid-state switches, i.e. silicon-controlled rectifiers (SCRs), insulated gate bipolar transistors (IGBTs) and metal oxide semiconductor field effect transistors (MOSFETs), offer advantages in terms of longevity, reliability and reduced maintenance. However, they have limitations in high voltage applications and exhibit higher switching losses.

The findings of this comparison study will assist researchers, engineers, and system designers in selecting the most appropriate high voltage switch for pulsed power applications, considering the specific requirements and constraints of the system. This will ultimately contribute to the advancement and optimization of pulsed power technologies across a wide range of scientific, industrial, and strategic applications.

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Design and Simulation of 200 kV, 100 Hz Repetitive Spark Gap

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This study focuses on the design and simulation of a 200 kV repetitive spark gap for pulsed power supplies. The research addresses the challenge of residual plasma in spark gaps and proposes gas circulation[1] as a solution to remove the plasma and optimize performance. Through electrostatic and computational fluid dynamics simulations, the study aims to improve the spark gap's efficiency by reliable repetitive operation[2].

Spark gaps have been extensively studied as switches in pulsed power supplies due to their simple construction and cost-effectiveness. However, a significant limitation of spark gaps is their repetitive operation. After the spark is extinguished, a region of relatively low breakdown strength persists between the electrodes due to residual plasma. To enable repetitive operation, this residual plasma needs to be effectively eliminated. One approach is to employ forced gas circulation through the electrodes to remove the residual plasma and ablated particles from the electrodes.

Gas circulation must address two crucial aspects: maintaining adequate breakdown strength between the electrodes from an electrostatic perspective and removing residual plasma from the electrode region before the next voltage pulse. The minimum limit on gas velocity in the region can be determined as [1,2], $\boldsymbol{v = fR}$ where $\boldsymbol{f}$ represents the pulse repetition frequency (PRF) and $\boldsymbol{R}$ denotes the radius of the electrode.

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KALI 30 GW EXPERIMENTS FOR FLASH X-RAY GENERATION

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KALI 30 GW (1 MV, 30 kA, 80 ns) system in APPD, BARC has been utilized for pulsed intense relativistic electron beam (IREB) generation and its conversion to Flash X-rays (FXR). IREB is generated from a cold cathode by explosive electron emission. A MARX generator and Blumlein (BL) pulse forming line (oil dielectric) based topology provides the high voltage pulse up to 1 MV to the electron beam diode. A cylindrical FXR diode with SS knife edge cathode and Tungsten rod as anode was used for FXR generation in the voltage range of 350 – 420 kV. Radiography of different metallic samples was acquired with imaging units; one comprising of scintillating screen, front coated mirror and ccd camera and the other a CMOS flat panel detector. The axial dose measured at 1 m distance from the X-ray window was 20 mR.

Design and simulation studies of 40 kV, 80A solid state magnetron modulator

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Magnetron as a source of microwave is extremely popular in the field of RF accelerators that are used for industrial & medical applications. High power pulsed modulators are widely used for driving magnetron sources. A Solid state switch based PFN (pulse forming network) type magnetron modulator is designed for driving Nelson made VE2093 tunable X-band magnetron. This modulator consists of five parallel PFN modules and each module contains fourteen capacitors connected in double layer structure. All the PFN modules are discharged simultaneously using IGBT switches into the primary of a fractional winding pulse transformer. While discharged, 40 kV 5μS pulse voltage appears across the matched load of 500 Ohm. Details of the design, optimization and simulation of PFN structure and fractional winding transformer are narrated in this paper. Experimentally measured voltage waveforms are found to be in close agreement with simulated results.

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3.65T Pulsed electromagnet for Gyrotron testing

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Abstract—A gyrotron is a class of high-power beam vacuum tubes which generates millimeter-wave electromagnetic waves by the cyclotron resonance of electrons in a strong magnetic field. The gyrotron is a type of free-electron maser that generates high-frequency electromagnetic radiation by stimulated cyclotron resonance of electrons moving through a strong magnetic field.
The paper presents the design and test results of a electromagnet tested with 1000A , pulsed current source for gyrotron. This magnet can provide high magnetic field of 3.65T for desired time about 100-400msec.

Keywords: - Gyrotron, Pulse field , pulse power supply , field uniformity

Fig :Electromagnet and its pulsed power supply

Exploring Electropulsing Treatment as a Novel Strategy for Achieving Strength-Ductility Balance in Light Weight Steel

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The automotive industry faces significant pressure to enhance fuel efficiency and reduce emissions, and one approach is to reduce the weight of vehicles. Research indicates that a 10% weight reduction can lead to a 6-8% increase in fuel economy, resulting in substantial fuel consumption and CO2 emission reductions[1]. The industry strives to achieve high ultimate tensile strength (UTS) values for steel, surpassing 980 MPa, with total elongation (TE) exceeding 21%, or UTS of 1180 MPa with TE exceeding 14%. Some manufacturers even aim for UTS values exceeding 1470 MPa with TE exceeding 20%[2]. In line with these goals, this study focuses on the development of a lightweight steel alloy composed of Fe-18Mn-10Al-1C-6Ni and aims to improve its formability through the application of electro pulsing treatment. To evaluate the structural changes induced by the electro pulsing treatment, various microstructural characterization techniques such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), and X-ray diffraction (XRD) are employed. Mechanical testing, including tensile and hardness tests, is conducted to assess the ductility and strength properties of the lightweight steel. The material exhibits a yield strength of 1224 MPa, ultimate tensile strength of 1425 MPa, and a plastic elongation of 11%. Following the application of electro pulsing treatment, the developed steel demonstrates a yield strength (YS) of 1198 MPa, ultimate tensile strength (UTS) of 1398 MPa, and a total elongation (TE) of 17%. The results indicate that the electro pulsing treatment effectively enhances the ductility of the Fe-18Mn-10Al-1C-6Ni steel while maintaining its strength characteristics. This study makes a valuable contribution to the development of lightweight materials with improved ductility and offers potential applications of electro pulsing treatment in the automotive industry, particularly for the production of high-strength yet ductile materials.

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Simulation & Analysis on Stage Capacitor bank of Symmetrical Cockroft Walton multiplier column of 1MeV, 100kW DC Accelerator

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Electron Beam Centre (EBC), Beam Technology Development Group (BTDG), BARC is developing 1MeV, 100kW DC Accelerator for electron Beam Waste Water Treatment (EBWWT). The accelerating potential of -1000kV DC is generated by Symmetrical Cockcroft Walton Multiplier (SCWM) circuit pressurized at gas mixture of 95%N_2-5%SF_6 at 6kg/cm^2 pressure for HV insulation. The accelerated electron beam passes though graded accelerating column with vacuum better than 10^{-6} mbar. The multiplier column is powered through 45kV-0-45kVp, 10kHz transformer alongwith IGBT based inverter and DC Power supply (DCPS). The multiplier has 15 stages with stage capacitance of 20nF/120kVDC. The accelerator has been tested at 1000kV DC at no load and 950keV at 50kW beam power. The accelerator was operated at 25kW level for 24 hours continuously. Unbalance in the Multiplier input was noticed which was due to faulty capacitor on the capacitor bank. These paper describes about the failure mode on capacitor used in the accelerator. Simulation has been carried for electric field analysis on capacitor. Simulation results and analysis has been discussed in these papers.

Shielding effectiveness of HV-HF transformer for accelerator applications

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Abstract—High voltage high frequency transformers are employed in DC accelerators. High frequency produced by inverter at lower voltage is stepped up to several tens of kilovolts using step up transformers. These transformers are subjected to high frequency transients from voltage multiplier column. Electrostatic shielding is very effective in common mode noise reduction. However in accelerator applications, shielding effectiveness obtained using conductive shields are found compromised in practice. This paper investigates the reasons behind this phenomena and explores remedial measures.

NUMERICAL COMPUTATION OF ELECTRIC FIELD DISTRIBUTION FOR HVDC SYSTEMS AT R&D FACILITIES

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High voltage technology is widely used all over the world at various R&D facilities for development of pulse power generators, particle accelerators, X-ray generators, neutral beam injectors, etc. An UHVDC laboratory consisting of 600 kV Cockcroft-Walton generator, 750 kV and 300 kV voltage dividers, 500 kV load banks, 200 kV transformer-rectifier units and power converters have also been recently installed at the Institute For Plasma Research (IPR), Gandhinagar for Nuclear Fusion research and particle accelerator innovations[1]. An accurate electric field prediction is pivotal for design and fabrication of any HVDC apparatuses for avoiding partial discharges and also indispensable with regard to human safety and Electromagnetic interferences (EMI) [2]. This paper involves electric field analysis of air-insulated HVDC systems with respect to corona ring design and ground clearance for HV generators, dividers, load bank and transmission lines. Various tools are available nowadays for high voltage field calculations such as the finite difference method (FDM), finite element method (FEM), charge simulation method (CSM), surface charge simulation method (SCSM), etc. However, each method has its own pros and cons which have also been discussed in this paper. For different corona ring configurations, CSM has been employed in this paper and a MATLAB code has been developed for electric field and charge density estimation at ground level for HVDC transmission wires. The techniques employed have been highly useful for development of HV-facilities at IPR.

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Development and testing of Solid state E-gun modulator

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Abstract:
E-gun modulator is an important component of electron Linac which helps in injecting electrons in Linac cavity for high energy acceleration. Existing electron Linac at EBC have line type e-gun modulator which are comparatively larger in size and number of components are more. A solid state modulator has been designed and developed using BEHLKE switch which is compact in size and performance is comparatively better. This modulator has been successfully tested up to peak voltage of 40kV. Details of the modulator and its test result will be presented in this paper.

Development of High Life and High Current Spark Gap Switch

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There is great demand of high life, high current (300 kA), energy transfer switch in various high voltage (HV) pulse power applications, such as electromagnetic welding, high yield plasma focus based neutron generator (10^7 to 10^9 neutron/sec), rail and coil guns etc. There are various types of HV switches such as a rail spark gap, trigatron spark gap, thyatron, ignition, semiconductor switches such as IGBT/MOSFET etc. Compact spark gap switch is designed in a coaxial geometry, which has low inductance and high current discharge capability. The spark gap breaks down through the air instead through the surface of the insulator body at the time of triggering. As a rule of thumb air break down may be considered as 3 kV/mm for a dry air at atmospheric pressure. Surface creepage is kept as per experimental breakdown value as 3 mm/kV. In order to have low erosion and good surface finish Brass and copper – tungsten materials are used as main electrodes and trigger pins. Derlin insulating material has good insulation properties as a dielectric strength (20 kV/mm) and tensile strength of 80 MPa. This makes, delrin as a favorable for support structure of spark gap assembly. This paper discusses development and testing spark gap rating (10 kV, 300 kA). Air-gap can be adjusted between main electrodes and trigger pins. Four trigger pins are located between main electrodes to increase the life. Four solenoid based selection switch assembly is developed to electrical connect only one trigger pin at a time. Therefore, only one trigger pin takes part in the conduction of the spark gap and in every next shot the position of the trigger pin is changed through solenoid system. In totality the erosion of the electrodes is distributed among four points and it enhances the life of the spark gap for high current applications.

HIGH ENERGY MODULAR CAPACITOR BANK FOR PULSE POWER APPLICATIONS

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High Energy Capacitor bank systems play a crucial role for carrying out laboratory experiments and for performance evaluation of systems and sub-systems. A modular 120kJ Capacitor bank system has been developed in TBRL to meet current and futuristic requirements of experimentation for various applications viz. Seed source for Flux Compression Generator, Pulse power source for Exploding bridge wire based Pulse shaping experiments, calibration of Current and Voltage Sensors. In this system, for providing a wider range of energy discharges, two modular capacitor banks of 60 kJ each have been developed that can be operated individually or in parallel mode to provide pulsed energy discharges over a wide range up to 120kJ depending upon the requirement. Each modular bank has its own charge and discharge mechanism, high current switch for bank firing and dump mechanism for abort operation/ safety. Use of two capacitor banks provides high operational life capability along with redundancy up to 60kJ, faster rise times at lower energy levels, use of lower rated components especially high cost current switch. The complete system has been successfully integrated, installed and commissioned at TBRL.

Design and development of High Voltage Capacitor banks for 1MeV/100kW DC Accelerator for EB waste water Treatment

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Accelerator and Pulse Power division, BARC is developing 1MeV/100kW DC electron accelerator for Waste Water Treatment application. The high voltage generator of DCA is based on efficient, 15-stages symmetrical Cockcroft Walton multiplier operating with a 90kVp, 10kHz input power source and housed in a pressure vessel filled with high purity Nitrogen at 6kg/cm^2 pressure. HV generator comprises of various sub-systems viz. Acrylic Support, Capacitor modules, rectifier-stacks, resistive voltage divider, HV Terminal etc. Reliability of the HV generator depends on the design, testing and quality control of these sub-systems. The Capacitor modules are made by series-parallel stacking of 40kV, 3.3nF ceramic disc capacitors. This paper describes salient high voltage design aspects of these capacitor modules. The test procedures, quality control and reliability of these capacitor banks have been discussed in brief.

HV-ESCA-2023: DESIGN & OPTIMIZATION OF PHOTO NEUTRON TARGET BASED NEUTRON RADIOGRAPHY SYSTEM BASED ON 9 & 15 MeV LINAC

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Monte Carlo simulation has been used in the design and optimization of the photo neutron target-based neutron radiography system. Ta, Pb, W, Cu, and Mo have all had their bremsstrahlung yields analyzed for both 9 and 15 MeV electron sources, and then the photo neutron yield of the ^{9}Be target has been optimized. The experimentally determined flux of 6×10^{3} n/cm^{2}-kW was obtained using the indium foil activation method with L/D ratio of 50 (collimator aperture diameter of 1cm) in the presence of Cd cone for the design based on 9 MeV source. The simulated thermal neutron flux at the collimator end is found to be 8.263×10^{3} n/cm^{2}-kW, which is reasonably close to the experimentally determined flux. It has also been reported that additional design modifications are necessary to make it compatible with 15 MeV sources. With L/D ratios of 50, 60, and 70, several photo neutron target configurations for the 15 MeV source have also been simulated.

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Dose Estimation and Measurement of 500 kV Flash X-ray System

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Accelerator and Pulse Power Division (APPD), BARC has developed several Pulse power systems for Flash X-ray (FXR) applications. Flash X-rays generated from pulsed intense relativistic electron beams are used for capturing and studying high speed events i.e. dynamic radiography and for non-destructive testing of high density materials. This paper presents dose estimation and measurements carried out in collaboration with Radiological Physics & Advisory Division, BARC. Flash X-ray pulses are generated from a Marx based high voltage pulse source rated for 500 kV, 10kA, 40ns. In this system, the Marx generator output voltage pulse is applied to portable FXR tube through a high voltage cable feed through arrangement [1]. Measurements were carried out at different locations around the FXR system using the TLD badges [2]. TLD badges were positioned on either side of the barriers (lead sheets) and above the ceiling. The measurement includes output (direct primary beam) of the Flash X-ray system at 1 m distance from the X-ray target at 450 kV, 6 kA, 40ns operating parameters. Dose of 140 – 200 mR for 10 exposures/day at 1 m was measured with TLD which is consistent with the measured value of 100 – 200 mR (for 10 exposures/day) using pocket dosimeters.

Key Words: *Flash X-Ray*, *Marx generator, Thermo Luminescent Dosimeter (TLD)*

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EXPERIMENTAL STUDY AND SIMULATION ANALYSIS OF MAGNETIC FIELD DENSITY IN COIL WITH FIELD SHAPER IN A MAGNETIC PULSE WELDING (MPW)

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Magnetic Pulse Welding (MPW) is a solid-state welding technique to join two dissimilar metals by high velocity impact caused by magnetic field. MPW system is consists of 208 μF capacitor bank and weld tool coil. Capacitor bank is charged up to 15 kV and discharges current 170 kA @ 12.5kHz in tool coil. The weld tool coil has 6 turns copper disc and a copper field shaper. For better welding quality we have need high magnetic field density to create high Lorentz force to move high velocity of flyer part towards the parent parts. For enhancement of high magnetic field in a coil we need a field shaper. Field shaper enhanced the field in a small area and it found to be four folded of intensity of field due to insertion of field shaper in the coil. In this paper we simulate the multi-turns coils to measure the magnetic field density on the surface of flyer parts. The experimental results and simulations showed that, during the welding of the aluminum tube with the copper parent, the maximum magnetic field in the gap between the field shaper and the flyer is achieved much earlier than the maximum of the current pulse of the coil and that the first half-wave pulse of the magnetic field has two peaks. Experimentally measure the field density on the surface of flyer part by tesla meter. We developed a 2-D model to study the effect of field shaper on the magnetic field density for 6 turn coils using COMSOL Multiphysics. From simulation results, we observed that for capacitor bank discharge current, I ~170 kA @ 12.5 kHz average magnetic field intensity was found be ~ 35 T. The field density is approx. constant throughout the axis surface of field shaper.

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EMI-EMC OVERVIEW AND QUALIFICATION OF FLOW INSTABILITY DETECTION & WARNING SYSTEM (FIDWS): A CASE STUDY

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Electromagnetic interference (EMI) occurs when an operating electronic device is disrupted by an electromagnetic (EM) field. Maximum electronic equipment fails initial tests of EMI/EMC qualification if not safeguarded for the targeted requirements in the early stages of product development. EMI can be minimized by properly selecting components, logic families, PCB design, shielded cables and housing. The instrumentation and control (I&C) systems of nuclear power plant are often based on conventional analog technology. With the technological advancement, existing analog technologies are being upgraded to advanced digital systems. Though the upgradation looks powerful and flexible due to programmable hardware, these digital systems are more vulnerable to EMI due to fast switching of components. The issue can be resolved through the implementation of an effective EMI reduction techniques and good understanding of regulatory requirements.
This paper presents an overview of EMI/EMC requirements and describes measurement and reduction techniques for I&C system used in industrial application and nuclear application as well. The paper also provides a case study of the EMI/EMC qualification of the Flow Instability Detection and Warning System (FIDWS). FIDWS – a distributed architecture based system has been developed to detect the onset of the flow oscillations induced by thermal hydraulic instabilities in nuclear reactor by continuous monitoring of channel flow signals. Various design considerations and qualification testing performed on FIDWS system along with test results are presented here. Reasons for failure and appropriate measures for EMI/EMC compliance testing is also discussed in the paper.

Electromagnetic Coils for DC and Pulsed Accelerator Magnets

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Magnetic Field plays a critical role in particle accelerators for bending, steering, focusing, and chromatic aberrations correction of charged particle beams. Permanent, normal conducting and superconducting magnets are used for generating the magnetic field of required profile and parameters. In Normal conducting and Superconducting magnets, electromagnetic coils generates the required magneto-motive force. Design, development, testing and installation of these coils require multidisciplinary expertise. These are more critical for water cooled, pulsed magnets and Superconducting magnets. This paper gives a comprehensive detail of Electromagnetic coil design, fabrication, testing and installation. Design choices includes choice of material, nature of cooling, electrical insulation, mechanical stability and operating parameters. These are discussed for both normal conducting and super conducting magnets. These coils are designed for operating life of about 20 years. Production of coil need to satisfy this requirement. Same is verified by rigorous testing for electrical, thermal, and hydraulic parameters. This paper detail the Inductance, resistance, hi-pot, ring, temperature rise and flow versus pressure testing. Paper also briefly discuss the coil safety interlocks including Quench detection and protection circuits for superconducting magnets. The paper is drafted in light of experience of development of about 100 magnets including quadrupoles, dipole, steerer and bending magnets for accelerator and other specific applications at Bhabha Atomic Research Centre. Design, testing, production and installation of coils for these magnets will be detailed in the paper.

Precision, High Stability High Voltage Module Power Supply for Analytical Instrumentation

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In any analytical instrument e.g. mass spectrometer, where precise measurements are made, a highly stable environment is required. A minute fluctuation in supply can cause large errors in measurements. For accelerating the ions in a mass spectrometer a highly stable high voltage power supply is required. High voltage power supply up to 30kV /10W with 10ppm short term stability, is one the key power supplies used in various analytical instruments like mass spectrometers/PMT& CEM / Scanning Electron Microscope and Electron Spectroscopy etc.

This paper will illustrate the design concept & implementation of a compound regulatory system, where a series regulator feeds the power to the switching regulator (ZVS mode double ended fly-back DC-DC converter) operating around 100 kHz.

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Design & development of magnet power supply for burst mode repetitive High Power Microwave sources

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Abstract

Single frequency High power microwave sources like Backward Wave Oscillator, Relativistic Magnetron etc. requires high magnetic field of about 1T to 4T for efficient operation. Single shot HPM systems usually consists of pulsed magnetic system. However, for repetitive HPM generation, continuous magnetic field is required. To obtain continuous high magnetic field in the required volume usually three solutions are worldwide preferred i.e. permanent magnet, DC electromagnet with cooling arrangements and superconductor based magnetic coil. All these three systems are bulky, expensive and technologically demanding. In this paper a novel power supply has been suggested that discharges a charged capacitor through a magnetic coil keeping the discharging current constant for a small period of time like hundreds of millisecond to a second. An IGBT switch is used to discharge the capacitor. Duty cycle of the IGBT switch is controlled using current feedback signal from the coil, thus keeping the current steady at a preset reference value. Experimental set up has been developed using 300mF capacitor. A constant current up to 500A is achieved for 200 ms. This system is scalable. For longer duration of operation more capacitor modules need to be added. Details of design, development and experimental results are presented in this paper.

PROGNOSTIC MODEL FOR ELECTROLYTIC CAPACITORS USING DATA DRIVEN APPROACH

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Electrolytic capacitors are used in most electrical and electronic circuits as they can achieve high capacitance and voltage ratings in a cost-efficient manner. They are commonly used as filtering components for reducing ripple in supply voltage. They are also known to be prone to failure and regarded as the weakest components in the power supply [1]. Due to their higher failure rate, in Nuclear Power Plants, these electrolytic capacitors are replaced based on periodicity. This approach, although taken to ensure the safety of the Plant is conservative, time-consuming and laborious. If the RUL (Remaining Useful Life) of these capacitors can be quantified with acceptable uncertainty, the periodicity of the capacitor replacement activity can be extended which can result in considerable saving of cost and efforts.

Prognostics is the process of predicting a system's RUL by predicting the progression of a fault, given the current state of degradation, load history, and anticipated future operational and environmental conditions, to estimate the time at which the system will no longer perform its intended function within the desired specification [2]. That is, it involves the modeling of degradation and forecasting its progression for future operating conditions. This progression of degradation is a non-linear estimation problem.

In this work different data-driven prognostic techniques such as Bayesian-based and Artificial Neural Network has been studied & compared for prognosis of electrolytic capacitors using open source degradation data. These algorithms have then been compared based on prognostic metrics; Prognostic Horizon (PH), α-λ Performance and Relative Accuracy (RA) for EOS and TOS Dataset.

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Preliminary results of Marx based 1 MV Flash X ray system

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Flash X-ray (FXR) systems are used for dynamic radiography; however, depending upon speed of the object to be radio-graphed very short pulse duration (~25 ns) X-ray pulses will be required for image acquisition without motion blur. A coaxial Marx generator has been designed and simulated to generate 1 MV output voltage, 10 kA peak current and 40 ns Full width half maxima (FWHM). Innovative CST simulation of coaxial Marx generator has been carried out to verify the design parameters. The high voltage interface between FXR diode and Marx generator is corrugated conical insulator structure. Field stress analysis of the system was carried out using CST electrostatic module. Particle-in-cell simulation of X-ray diode was carried out from different anode cathode gap for operating voltages from 850 kV to 1000 kV. Estimated X ray dose is 100 mR at 1 m. The initial testing of Marx generator up to 220 kV has been carried out.

Key Words: *Flash X-Ray*, *Marx generator*

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SIMULATION STUDIES ON DIELECTRIC WINDOW BREAKDOWN AT THE VACUUM DIELECTRIC INTERFACE

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Microwave window breakdown is a serious concern for microwave tube designers. The microwave window is required for extraction of microwave from the microwave source which is in vacuum to the external side which is in air or pressurized SF_6 medium. At the SF_6 dielectric window, the window breakdown can be avoided by increasing the SF_6 gas pressure. Problem remains at the vacuum dielectric interface. At the vacuum dielectric interface breakdown happens due to multipacting of electrons under the influence of electric field exerted by extracted microwave. A 3D particle in cell simulation study is presented here to determine the underlying factors leading to the breakdown of microwave window at the vacuum dielectric interface. These factors primarily are the peak electric field exerted by the microwave, microwave frequency and secondary emission coefficient of the dielectric material. With decrease in the microwave power the breakdown probability of the dielectric window reduces which is obvious. Lowering of the secondary emission coefficient significantly reduces the breakdown probability.

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Review of High Voltage Pulsed Power Supplies and Power Electronics in Pulse Power Generation

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Recent decades have seen a rise in demand for pulse-shaped power delivery. Pulsed power's adjustable forms and varied pulse specifications make it a versatile and effective supply technique. The release of basic subatomic particles (electrons, protons, and neutrons) in an atom (ionisation process) and the synthesising of molecules to generate ions or other molecules require vast amounts of immediate power. In addition to the decomposition process, pulsed power has been requested for combining molecules (fusion, material joining), gessoes radiations (electrons, lasers, and radar), explosions (concrete recycling), wastewater, exhausted gas, and material surface treatments. The need for more efficient and versatile pulse modulators is expanding due to the rising demand for pulsed power in industrial and environmental applications. Plasma fusion and laser guns require higher-quality repeating pulses. Marx Generators (MG), Magnetic Pulse Compressors (MPC), Pulse Forming Networks (PFN), and Multistage Blumlein Lines (MBL) supply many uses. Pulse modulators use gas/magnetic switching technologies like spark gap and hydrogen thyratron due to their high voltage ratings and low rising times. They are inefficient, unreliable, repeatable, and short-lived. These devices' weight, bulkiness, and expense are downsides. Solid-state switching technologies can replace these devices, benefiting pulse supply. High-frequency switching allows pulsed power supply repetition. They are compact, efficient, affordable, reliable, and long-lasting. Solid-state transistor applications may not meet switch voltage rating and rise time criteria. Solid-state high-voltage pulse generation is achievable with several power electronics configurations.

ESTIMATION OF THE IMPEDANCE OF A DISTRIBUTED MODEL OF A TRANSMISSION LINE UNDER A FREQUENCY SWEEP

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The sweep frequency response analysis (SFRA) test is very common in the diagnosis and condition monitoring of power apparatus. In the SFRA test, a sinusoidal voltage signal is swept over a band of frequencies at any two terminals of the testing equipment (one of the two terminals can be ground or main core), and the corresponding amplitude and phase angle of current and voltage are obtained. This test is quite capable of condition monitoring in different power apparatuses, however, a scarce amount of research is performed in transmission line regarding the use of SFRA. In this paper, an attempt has been made to explore the Driving Point Impedance Function (DPIF) of the transmission line. This can be done by constructing the DPIF of a transmission line from SFRA data and comparing its frequency response with the measured frequency response. The DPIF has an extra edge when compared to other transfer functions since only one terminal end is required to be operated. The measured data must be represented as a polynomial in the form of "s", to construct a rational function. This rational function has to satisfy some properties so that the proposed ladder network can be synthesized. The conditions that must be satisfied are: the measured data corresponds to DPIFs; the rational function generated should be real and positive. Of these, the first one can be checked by performing experiments. Carefully planned experiments are performed for this purpose. To check physical reliability every function must conform to a Hurwitz polynomial. It is proposed that this test can be done for power transmission lines with certain changes in the testing circuit when compared to the testing circuit of other power apparatus. A generalized analytical equation for the driving point impedance function which is a function of polytopic numbers is also used for comparisons of the obtained impedance graph and derived equation. The results indicate excellent matching of frequency responses of impedance functions constructed from simulated SFRA and analytical function, thus establishing the feasibility of the application of the technique for transmission lines.

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BEHAVIOURAL STUDY OF THE IMPULSE WAVEFORM SUPERIMPOSED WITH SINUSOIDAL POWER FREQUENCY IN TRANSMISSION LINE

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In this paper, a study of traveling waves of superimposed high-frequency pulse with a sinusoidal voltage of power frequency on a transmission line is presented. Traveling waves are voltage and current waves which travels from the source end to the load end of any power equipment, especially of a transmission line during transient condition. In short and medium length transmission lines are represented by equivalent T or π-model and line parameters are considered as lumped parameters but this is only feasible for the steady state condition of the system. However, whenever a transient took place or in the case of a long transmission line, these parameters cannot be treated as lumped. Therefore a distrusted telegraphic model of a transmission line has to be considered to estimate the effect of distributed inductive and capacitive reactance. In a lossy transmission line, traveling waves propagate with a velocity less than the speed of light. During normal operating conditions, the load of the transmission line matched with the surge impedance of the transmission line to avoid any reflection. However, whenever there is a mismatch in the impedance within a transmission line or in the load, this high-frequency pulse will be reflected as well as refracted. Behavioral study of this impulse waveform can able to detect any possible defects or pre-fault as well as post-fault locations which happen due to a mismatch in the total impedance of the circuit. This paper summarized the behavior study and extraction of superimposed impulse waveform with sinusoidal voltage on transmission lines for faults and defects at different locations.

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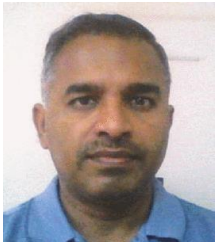
Aritra Das



C. C. Reddy

INVESTIGATION OF PLANAR ANTENNA PERFORMANCES ON COMMERCIALLY AVAILABLE DIELECTRIC MATERIALS

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Planar RF antennas with their conformal geometry, good RF performances and ease of construction find a wide range of applications ranging from mobile phones to RADAR, wearable electronic gadgets to medical implant devices. The selection of a suitable dielectric material is by far most the crucial step in the antenna design process in order to achieve the desired RF characteristics. The directivity, efficiency and bandwidth of an antenna depend on the substrate dielectric constant, loss tangent and material thickness. This paper investigates the RF worthiness of two planar antennas designed using two commercially available dielectric materials namely RT Duroid and FR4 for with a 3D-EM tool are discussed. The results show the superior RF characteristics of the antenna designed using RT Duroid over FR4. The antenna designed with RT Duroid substrate is fabricated and the measurement results obtained are found to be in good agreement with the simulation results.

Comparative deformation studies for different field shaper materials in Electro-Magnetic Pulse Welding

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Abstract: Electro-Magnetic Pulse Welding (EMPW) is a solid state welding technique in which no external heat input is applied for melting the base materials. In EMPW, the weld joint is achieved by collision of flyer part with the stationary parent part, by using the Lorentz force produced with the help of a tool coil and a field shaper. The field shaper plays a significant role in the performance of the process for repeating the weld trails. In this article, a simulation study has been performed to understand the deformation patterns in various materials at different applied pressure. The applied pressure is varied in steps of 100 MPa from 600 MPa to 1000 MPa. The simulation is repeated with various materials viz. Tantalum, Copper, Beryllium Copper, Aluminium. It is noticed that the deformation is maximum with Aluminium field shaper. The simulation has been performed using commercially available FEM software.

Usage of Energy Storage Capacitors in TE Gas Laser Pulsers

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Abstract: An energy storage capacitor is crucial for both electrically pumped and optically pumped pulsed lasers. In electrically pumped lasers, the energy stored in the capacitors directly impacts the lasing medium, while in optically pumped lasers, it affects the flash lamp. The flash lamp emits light that then pumps the active medium of the optically pumped laser. In this paper, our focus is on the application of energy storage capacitors in the operation of electrically pumped pulsed gas lasers. The ability to scale the power of these lasers by increasing the pressure of the active gaseous medium has greatly advanced gas laser pulser technology. This progress has led to the development of transverse electric discharge pumping, enabling easy scalability of gas pressure and the achievable output power. A transverse electric (TE) gas laser pulser is the driving force behind these lasers. It functions by extracting energy from the source to charge the capacitor and then allowing the capacitor to discharge its stored energy into the gaseous medium with the help of a switch. An ideal TE pulser efficiently charges the capacitor with minimal energy dissipation on the charging element. It also facilitates a rapid and uniform transfer of the stored energy into the gaseous mixture. Resistive charging, that inherently possesses poor charging efficency, is often replaced with inductive charging, called DC resonant charging, in particular for repetitive operation of the laser. The voltage droop issue, which is inevitable in this method, can be addressed using command resonating charging two switches in the citcuit. In this paper, we will discuss the operation of laser pulser and the modifications it has undergone over years in an effort to suitably tailor the charging and discharging features of the capacitor and improve the energy coupling into the laser load. Additionally, we will describe the operation of a TE gas laser pulser that enables the homogeneous transfer of energy stored in the capacitor to the gas mixture without the usage of an external switch.

Phase Resolved Partial Discharge (PRPD) Patterns in Epoxy Nanocomposites

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Incorporating nanoparticles into the epoxy matrix enhances the material's properties, including mechanical strength, thermal stability, and electrical insulation performance. Epoxy resin is commonly used as an electrical insulation material in power cables, transformers, and other high-voltage equipment. However, epoxy resin is not entirely free from defects and impurities during manufacturing. These imperfections act as inception sites for electrical treeing. Initially, the tree channels may be small and filamentary. However, with time and exposure to electrical stress, these channels can extend and branch out, forming tree like patterns. Continued PD activity within the channels can result in tree elongation and ultimately lead to electrical failure.

Epoxy nanocomposites have gained prominence as the next-generation electrical insulating materials because of their enhanced material properties including a mechanical, thermal and dielectric performance. The objective of this work is to present a comparative analysis of PD activity within electrical tree channels in pure epoxy and its nanocomposites, aged and unaged. The results highlight the superior performance of nanocomposites in suppressing PD and mitigating electrical tree growth, demonstrating their potential as effective and better insulation.

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Electromagnetic Powder Compaction: An Experimental Study of its Effects on Titanium Powder

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The compaction of metallic powders plays a crucial role in powder metallurgy and enabling the fabrication of high-performance components with desirable mechanical properties. This study focuses on examining the compaction characteristics of titanium (Ti) powder utilizing the electromagnetic powder compaction technique. The electromagnetic powder compaction technique offers several advantages, such as enhanced control over the compaction process, improved density uniformity, and reduced compaction time. This technique employs a pulsed magnetic field to consolidate metallic powders into solid compacts, ensuring optimal densification and minimizing defects. To investigate the compaction characteristics of Ti powder, a series of experiments were conducted. Firstly, Ti powder with specific particle size distribution and morphology was selected. Subsequently, the Ti powder was subjected to electromagnetic compaction under varying discharge energy. The compaction behavior of Ti powder was evaluated through various characterization techniques. The density, porosity, and dimensional stability of the resulting compacts were measured to assess the effectiveness of the electromagnetic compaction technique. Additionally, the microstructural analysis and mechanical testing, such as hardness and compression test were performed to evaluate the quality and mechanical properties of the compacts. The experimental results revealed the influence of different discharge energy on the compaction behavior of Ti powder. It was observed that variations in discharge energy significantly affected the density, porosity, and mechanical properties of the compacts. Furthermore, the microstructural analysis provided insights into the grain morphology, grain boundaries, and potential defects within the compacts.

Design and Evaluation of High Voltage High Frequency Testing Transformer

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Abstract: High voltage high frequency testing transformer is required for testing the high voltage components like filament transformer, gun power supply with extraction transformer, HV rectifier chains, HV capacitor banks, compensating HV inductor etc. The design criteria of HV and HF transformer having step-up ratio of 6 is very stringent because both the primary and center tapped secondary windings are 10 kV and 30 kV – 0 – 30 kV respectively. Selection of suitable magnet wire for both the windings, considering electric field and skin effect is an important design criterion. Electric field is calculated for both the windings considering the polarity of the windings. The gap between measurement and estimation of high frequency resistance of the windings using Dowell method is discussed in detail. Design parameters and achieved results of the transformer like step up ratio, resonant frequency, coupling factor are closely matching. It is an essential tool for HV & HF testing of the DC accelerator components. Due to wide scope of test loads tuning is necessary and mandatory step during testing with the testing transformer

EXPERIMENTAL AND NUMERICAL INVESTIGATIONS ON ELECTRO HYDRO FORMING OF AL 6061 SHEET FOR OIL DEFLECTOR APPLICATIONS

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The oil deflector plays a vital role in redirecting oil flow within various machinery and engines, preventing potential leaks and optimizing performance. However, the conventional forming methods for manufacturing oil deflectors often involve complex tooling and time-consuming processes, leading to increased manufacturing costs and limited design flexibility. In this study, we propose the utilization of high-speed Electro Hydro Forming (EHF) as an alternative manufacturing technique to surmount the limitations of traditional forming methods. EHF utilizes a combination of electroforming and hydroforming processes, which enables the rapid shaping of metal sheets through the application of electrical current and fluid pressure. The investigation begins with the design and fabrication of appropriate tooling and electrodes, taking into consideration the desired shape and dimensions of the oil deflector. The high-speed EHF process parameters, including voltage, thickness and width of vaporizer foil, are systematically varied to determine their influence on the forming quality and efficiency. Experimental testing is conducted by employing Al6061 sheet, commonly employed in oil deflector production, with varying width of vaporizer foils. The formed oil deflectors are subsequently evaluated for dimensional accuracy and surface finish. To overcome the inherent difficulties in simulating a multi-physics model, a simplified model was formulated. This simplified model integrated a pressure loading mechanism and incorporated the essential process and material parameters, along with a meticulously designed die model. The findings derived from this investigation contribute to the expansion of knowledge and comprehension of high-speed EHF technology for forming oil deflectors. The results provide valuable insights into the potential benefits and challenges associated with implementing this advanced manufacturing process in the oil and gas industry and other pertinent sectors.

EFFECT OF ELECTRODE PROTRUSIONS ON PROPERTIES OF POLYETHYLENE AS A DIELECTRIC FOR CAPACITORS

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Capacitors are a fundamental component for storage of electrical energy in electrical systems. In high voltage capacitors dielectric materials like polyethylene, polypropylene, etc. are being used. While operation, high voltage capacitor develops defects inside its dielectric arrangement or on the electrodes at the time of manufacturing or by mishandling of capacitors, or due to moisture ingression. The defects that mainly exists within a high voltage capacitors are voids, protrusions on the electrodes or inside the dielectric medium, impurities during manufacturing or moisture ingression. This initiates non uniform electric field distribution inside the capacitor at the interface of dielectric degrades the material over a period of time, stressed under high electrical field and ultimately leads to its failure. This is somewhat similar to partial discharge phenomenon, as observed in power cables[1]. Going through the literature, needle tip-plane model has been simulated for the first time in case of high voltage capacitor. In this paper, simulation of capacitor with protrusions has been carried out using COMSOL multiphysics software and various electric field profile due to protrusions is presented. Different protrusion geometry is being considered to see the effect on electric field distribution and significant results has been observed.

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Polarity Reversible Technique for Precision, High Stability High Voltage Module

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The polarity of the power supply in a system, dealing with ion dynamics like ion acceleration, ion focusing/defocusing and ion dispersion etc. depends on polarity of ions. Analytical instrument with fixed polarity of HV supply handles one type of ions. The conventional approach to utilize the instrument for other type of ions is to change the supply's polarity manually. Due to high voltage, polarity reversibility of the power supply is very challenging as arc/corona & electrostatic induction etc. are very prominent.

This paper will illustrate the design concept & implementation of a polarity reversible technique, where the HV supply output will be either positive or negative depending on the TTL control signal.

SIMULATION & PERFORMANCE ANALYSIS OF MODULAR ELECTROMAGNETIC LAUNCHER "RAFTAR"

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Projectiles are accelerated using electromagnetic energy by the electromagnetic rail gun. A FORTRAN program has been created in order to comprehend the device's mechanism of functioning and dependence on certain circuit parameters for performance. Studies have been done on the controlling force and the results of various retarding forces. Various heat loss methods are also taken into consideration. Both the contact force and dynamic resistance modeling have been done. Both with and without a crowbar mechanism, the circuit configuration has been tested. Both systems have undergone simulation, and the results showed that adding crowbarring to the circuit will result in a sizable performance boost. The railgun facility 'RAFTAR' has attained 1 km/s velocity with an 8 g bullet with crowbar circuit configuration.

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Study of electric field imbalancing effect of bias voltage in multi pin HV vacuum feed through used in 25kV,1kW EB welding machine.

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Electron beam welding machines (EBWM) are becoming indispensible in nuclear and aerospace industry, owing to its high depth to width ratio, precise and controlled heat input and low heat affected zone. In EB welding an intense beam of high-velocity electrons is impinged on the target to be welded. The work pieces melt and fuse together as the kinetic energy of the electrons is transformed into heat energy. The kinetic energy imparted to electron comes from high voltage applied between the electrodes. The applied high voltage requires multi pin HV feed through having air and vacuum interface at either side. These are also exposed to high temperature caused by heating of cathode inside the vacuum environment. The control of electron beam is done by the help of a bias voltage in the range of 1kV to 1.5kV which is super-imposed on the acceleration potential. Consequently, there is an imbalance in electric field around the multi pin vacuum feed through arises. The imbalance above is often results in High Voltage breakdown at considerable lower voltage. A simulation study to analyze above problems were carried out and is discussed in this paper.

Electric field analysis of single pin & multipin high voltage vacuum feed through for 25kV,1kW EB welding machine.

Sachin Gupta, Pravanjan Malik, Baibhaw Prakash, M.N. jha

Bhabha Atomic Research Centre

Electron beam welding machines (EBWM) are becoming more popular owing to its high depth to width ratio and low heat affected zone. In EB welding beam of high-velocity electrons is impinged on the target to be welded. The work pieces melt and fuse together as the kinetic energy of the electrons is transformed into heat energy. The kinetic energy imparted to electron comes from high voltage applied between the electrodes. The applied high voltage requires multi pin HV feed through having air and vacuum interface at either side. These are also exposed to high temperature caused by heating of cathode inside the vacuum environment. To make the EB gun compact and to withstand the acceleration voltage, the optimization of the spacing between the pins is carried out. The behavior study of the HV feed through to applied acceleration voltage in the range of 20kV t0 30kV is carried out and presented in this paper.

DESIGN AND DEVELOPMENT OF 10 MJ CAPACITOR BANK BASED PULSED POWER SOURCE FOR ELECTROMAGNETIC RAILGUN

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A Capacitor bank based pulsed power system with energy storage of 10 MJ was designed, developed and commissioned at ARDE for powering Electromagnetic Railgun. The 10 MJ Bank is modular in architecture with 25 Nos of 400 kJ Capacitor bank modules capable of generating module currents up to 150 kA. The module consists of High Voltage (HV) Capacitors, a main switch, a crowbar switch, a pulse shaping inductor and high voltage coaxial transmission cable. Four numbers of 100 kJ capacitors are connected in parallel to form 400kJ bank. The capacitors are of high energy density (1 J/cc) metalized polypropylene capacitors, with self-healing capability and rated for 11kV, used as energy storage component in each module.

Mercury based Ignitron switches are used as both main switch and crowbar switch for 16 modules. These ignitrons have Coulomb rating of more than 200C to account for high charge transfer needed for EM Railgun application. Stacks of semiconductor devices (thyristors and diodes with protection circuit) are used for main and crowbar applications, for the remaining 9 modules. These can handle module currents up to 150 kA. In order to limit the module current and extend pulse duration, a pulsed shaping inductor has been designed with values ranging from 25µH to 45 µH to sustain large magnetic pressure at a current of 180 kA. Specialized low resistance (400µΩ/m) coaxial cables were designed and manufactured to carry this large current from each module to railgun breech. The cables terminate in a two-level connector assembly at railgun breech to ensure arc free operation at high current and high Electromagnetic repulsion force. These modules serve as the building blocks for the 10 MJ capacitor bank based pulsed power source set up at ARDE.

These 400 kJ modules were assembled and integrated to form a 10 MJ Capacitor bank to drive railguns of different bore sizes and projectile masses. Current pulses up to 1.9 MA at a peak power of 100s of MW have been generated and injected into railgun to carry out firing trials to evaluate the dynamic performance. Powered by 10 MJ capacitor bank, the railgun was experimented to demonstrate muzzle velocity beyond 2,100 m/s for projectiles of mass 500 g.

MODELING AND SIMULATION OF HIGH ENERGY CAPACITOR BANK BASED ELECTROMAGNETIC RAILGUN

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Modeling and simulation studies were carried out to optimize the design parameters and study the performance of a 10 MJ Capacitor bank based pulsed power system for powering Electromagnetic Railgun. The bank operates at 11 kV charging voltage and is required to deliver a pulse current above 1.5 MA with pulse width of 4-7 ms. The 10 MJ Bank is modular in architecture with 25 Nos of 400 kJ Capacitor bank modules capable of generating module currents up to 150 kA each.

The firing scheme of the modules with triggering times is also decided based on modeling and simulation results to obtain the optimum output. The pulsed power system used low ESL / ESR capacitors with high energy storage density of 1 J/cc. Four capacitors of 1660 µF at 11 kV charging voltage are connected together to form a 'module' of 400 kJ of energy. Each module is discharged to the railgun through a switching element and is protected by a crowbar switch from the voltage reversal. Elements such as capacitors, inductor, cables and switches have been modelled as lumped elements. The railgun (the load) is modeled as a varying inductance and resistance which are function of both time and position of the armature inside the bore. Experimental trial data has been used to estimate inductance gradient (*L'*) of railgun which cannot be measure directly.

The model was simulated to various firing conditions for different projectile weights, charging voltages and module discharge sequences to evaluate the load and module currents, projectile velocity and the profile of in-bore position of the armature. Firing trials are carried out to verify the simulation results. As the trial results were closely matching with experimental results, the model thus developed has been used extensively for the analysis of system behavior as well as to predict outcomes for different firing configurations of the system installed at ARDE. This model has also been used to carry out the design of a weaponized 100 MJ EM Railgun for future development.

INVESTIGATION OF CRYSTALLINITY OF BIAXIALLY ORIENTED POLYPROPYLENE FILM (BOPP) USED FOR HIGH ENERGY DENSITY CAPACITOR ESTIMATED BY VARIOUS TECHNIQUES

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Biaxially Oriented Polypropylene film (BOPP) are commonly used in high energy density capacitor. Polypropylene films when stretched in longitudinal and transverse direction offer orderly stacks of folded chains (Lamella) which contributes to enhance the crystallinity of the polymer. The increase in crystallinity of BOPP results in increase in dielectric strength which is responsible for improving the charge density of the polymer. The crystalline nature in the polymer plays an important role for their application in high energy density capacitors. The biaxial orientation of the film enhances its thermal, mechanical, and electrical properties such as melting point, crystallization temperature, heat of fusion, density, tensile strength, dielectric strength, etc. The change in crystallinity in the BOPP film can be calculated by using various techniques. In this paper crystallinity of BOPP film studied by techniques such as Differential Scanning Calorimetry, X-ray Diffraction, Density, Fourier Transform Infrared (FTIR) are discussed in detail.

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ANALYSIS AND DESIGN ASPECTS OF PARABOLIC REFLECTOR ANTENNAS

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In the case of parabolic reflector antennas, the most important and dominant parameter that dictates the overall radiation characteristics is the f/D ratio i.e., focal length to the diameter ratio. Ideally in such antennas, feed horns are optimally designed to illuminate the entire surface of the reflector uniformly. However, the field levels at the center and edges of the reflector will be different which is attributed to taper/illumination loss (the ratio of the field levels at the edge and center is called edge taper). The edges of the parabolic reflector are farther from the focus compared to its center therefore due to larger path lengths, taper loss is high consequently reducing the overall aperture efficiency. On the contrary, if the modulus of edge taper is decreased, the power may get spilled out of the reflector resulting in higher spillover losses. So, there is a trade-off between spillover efficiency and taper efficiency to attain maximum aperture efficiency. Conventionally, the optimum edge taper is recommended to be in the range of 10 to 11 dB. In our recent study, we have observed that this contemporary assumption isn't applicable for all the f/D ratios especially when the focal length is less than the far field distance of the feed antenna. Detailed analysis of results obtained for various f/D ratios in large parabolic reflector antennas will be presented in this paper.

Generation of pulsed high magnetic field using high energy capacitor banks for magnetic pulse welding applications

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Abstract

Magnetic Pulse Welding (MPW) process uses pulsed high magnetic field for joining of two materials. It is a clean technology for joining of high strength dissimilar materials and alloys. The joining is obtained by impact of two surfaces at higher velocity due to high magnetic fields at room temperature with no external heat source and no thermal distortions. It has potential to replace brazing that reduce the possibility of corrosion by limiting the metallic interactions to just two metals being welded. MPW is limited to tubular geometries and lap joints. MPW process requires high voltage source, capacitor bank, discharge switch and a tool coil. Pulse high magnetic field is generated inside the tool coil by the discharge of pulse current form high energy capacitor bank. Tool coil can be made up using single turn coil, multi-turn coil, multi-turn coil with field shaper. Each type of coil has its own advantages and limits. Pulsed magnetic field up to 25 - 60 T is generated using these coils for joining of Al-SS, Al-Cu, Ti-Cu and Ti-SS.

SUITABILITY AND ADVANCEMENTS IN HIGH VOLTAGE CAPACITORS USED FOR VARIOUS APPLICATIONS

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Capacitor is the most vital passive electrical component that is being used in variety of applications like energy storage in pulsed power systems, as filters in DC power supplies, for DC blocking and coupling of fast transients, for power factor correction in AC transmission and distribution networks, as fast chargeable compact power supply module in strategic systems etc. It is remarkable to note that in each of the aforementioned example of application, the typical electrical characteristic requirement of high voltage capacitor distinctly varies and it is inherently dominated by the construction topology. This paper comprehensively elaborates on various dictating factors that are associated with its construction topology and latest advancements in recent years that govern the optimum electrical performance of high voltage capacitor to be best suited for specific pulsed/AC/DC application.

Distributed Capacitances in HV multiplier Circuits

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Abstract

HV multipliers are employed for generating high voltage DC output from high frequency AC source. Cockroft Walton Voltage Multiplier (CWVM) is one such cascade multiplier prominently used in DC accelerators. The CWVM is cascade of voltage doubler with output voltage of 2NV, where N is the number of stages in the cascade network and V is input voltage. However, the multiplication factor practically achieved is lesser than 2N owing to distributed capacitance in the multiplier circuit. 1MeV DC accelerator at EBC, Kharghar is based on symmetrical CWVM driven by 10kHz high voltage power supply. The multiplier consist of stage capacitor bank, rectifiers for rectification, protective components and shielding guards. It is housed in a grounded tank in 6kg/cm^2 N_2 environment. Distributed capacitances in CWVM of 1MeV DC accelerator is analyzed and simulated to study the effect on the performance of multiplier circuit.

Analysis of Transient During Discharges and Protective Filter Design for E-gun Power Supply of 1 MeV,100kW DC accelerator

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APPD has developed a 1 MeV 100 kW DC accelerator to be used for waste water treatment. This accelerator has a symmetrical Cockcroft Walton based voltage multiplier which generates 1MV voltage at the high voltage dome. The electron beam is generated by an indirectly heated cathode based electron gun. This electron power supply is derived from the last stage of the CW multiplier through an extraction transformer. The gun supply consists of a filament and an anode power supply which are regulated by saturable inductors connected in series. The gun supply remains floating at the dome potential. During dome discharge, transients of various voltage and frequency are generated in the system. They will enter the gun power supply and may damage it. The different modes of such transients are analyzed in this paper and a protective filter design for the gun power supply has been proposed.

COUPLED ELECTROMAGNETIC-STRUCTURAL-THERMAL SIMULATIONS FOR DESIGNING HIGH CURRRENT PULSE POWER INDUCTORS FOR PULSE SHAPING OF HIGH MAGNITUDE, LONG DURATION CURRENT PULSES

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This paper deals with a detailed study of a specific configuration of high current pulse power inductors for applications involving pulse shaping of high magnitude (>100 kA), long duration (few ms) current pulses[1,2]. In this configuration, a high conductivity metallic enclosure is placed concentrically around the inductor coil which substantially reduces the disruptive magnetic forces generated in such inductors, thereby significantly increasing their current handling capacity. Coupled finite element simulations involving electromagnetic, structural and thermal simulations of the inductor geometry have been carried out using COMSOL Multiphysics 6.0® to accurately predict the inductor behavior during a high current discharge and also to optimize the design parameters[3]. To account for dynamic loading of the inductor geometry, Johnson-Cook plasticity model was employed in these simulations.
Based on the optimized design parameters achieved, two numbers of 2 µH inductors were developed and tested on an already installed experimental setup. A current pulse of magnitude 220 kA and duration ~4 ms was successfully discharged through two such inductors connected in parallel without any observable deformation in the inductor geometry. Based on the validation of the design concept, pulse power inductors for handling even higher current magnitudes can be explored.

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X-PINCH AND HYBRID X-PINCH BASED SOFT X-RAY GENERATOR FOR RADIOGRAPHIC APPLICATIONS

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The x-pinch is formed when a fast and high current is passed through two or more thin wires mounted in between electrode in the form of 'X'. Due to small (µm) source size and short pulse width (ns) of x-ray radiation, these devices found their importance in point projection radiography of high energy density plasma. To achieve small jitter, the x-pinches are mostly developed on fast and high current generators (>1kA/ns). In the hybrid x-pinch (HXP) scheme, < 2mm long thin wire is mounted in between two conical electrodes. Due to simplicity in the mounting of HXP, these configurations can be used in higher mass loads and complex geometries. The drivers those employed for both x-pinch and hybrid x-pinches are expensive and bulky. We have developed x-pinch and hybrid x-pinch schemes on a single capacitor of 2 µF, which is providing ~100kA current in 1 µs. The single capacitor makes the device compact and versatile. In X-pinches, wires of different material (Cu, Al, W and Mo), and diameter were used to obtain the x-rays ranging from 100eV to 10keV at different time instances. The source size was obtained to be >10 µm. In hybrid x-pinches, the x-ray energy was observed to be <1.5keV. With Cu wire (20 µm) HXP, the success rate of the pinch is very low (<25% for 10 shots), it was improved with the use of thinner (7.5µm) and high Z material (W) wire. Use of carbon fiber produced the radiation in the EUV and even softer x-ray region. Further, the results on development and characterization of hybrid x-pinches and its comparison with x-pinches on compact slow current driven system will be presented in the conference.

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PARAMETERIC INVESTIGATION OF PULSE TRANSFORMER FOR CURRENT ENHANCEMENT IN CAPACITIVE SYSTEM

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Energy storage capacitor banks are the primary energy source in any pulse power application and to generate high pulse currents these are charged at high voltages. However in magnetic field driven applications such as electromagnetic projectile launchers [1], electromagnetic welding [2] and metal forming etc. pulse current of high amplitude with long rise time is required without much stringent requirement of high voltages. Long rise time of current pulse is normally achieved by using a pulse inductor in series to capacitor bank but at the cost of reduced peak current. To overcome this limitation, a concept of current step-up pulse transformer [3] is numerically investigated in present work.

A two-channel air cored co-axial pulse transformer has been numerically optimized in COMSOL® Multiphysics software for a load of inductance 1μH and resistance 10mΩ. The input energy is derived from a capacitive system of parameters 0.6mF, 4μH and 95mΩ. The objective is to increase the rise time of current pulse without compromising the peak current and maintaining a desired output voltage. Performance of this coaxial transformer is evaluated with respect to various design parameters such as thickness of outer conductor, its inner diameter, radius of turns etc. At present it is simulated to have two output channels, but in principle it may have multiple output channels also which may be used separately or may be connected in parallel to enhance the total current depending upon the application. Some proof of design experiments has also been carried out, which successfully validated the concept.

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DEVELOPMENT OF 150 J CAPACITOR BANK AND A MATCHING MINIATURE SEALED PLASMA FOCUS TUBE FOR A PULSED LOW YIELD NEUTRON GENERATION

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Plasma focus (PF) device is a Z-pinch based laboratory fusion device. It emits X-rays, ions, electrons and neutrons when operated with deuterium gas. In the direction of miniaturization of plasma focus device, a palm top plasma focus was developed using a compact capacitor bank consisting of commercially available cylindrical bipolar capacitors (each 2µF, 2 kV)[1]. However, shorter charge-discharge cycle of these capacitors limited their use in applications where repetitive operations of the plasma focus device were required. In order to overcome this, custom made capacitors (2µF, 5kV) were designed and fabricated for use as capacitor bank in the palm top plasma focus devices. These capacitors are rugged and can be used for more than 10000 charge-discharge cycle. A miniature size sealed PF tube (Φ3.5cm x 10cm long) was placed coaxially at the center of the 150 J capacitor bank along with the spark gap switch. The overall size and weight of the setup was 20 cm diameter x 15 cm long and 2.5 kg respectively. A battery operated power supply (30cm x 30cm x 30cm, weight: 20kg) along with a trigger pulse generator was used for capacitor bank charging and triggering of the spark gap switch [2]. A strong pinching was observed at 5kV (67kA) in current derivative signal and average neutron yield was measured to be in the range of 10^4-10^5 neutrons/pulse. Details about the experimental set up and experimental observations will be presented and discussed.

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DESIGN OF FAST AND COMPACT DETECTOR FOR WIDE RANGE OF YIELD OF PULSED NEUTRON SOURCE

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The capacitor bank-driven fusion neutron sources, such as the dense plasma focus (DPF) or the exploding fibers z-pinches are operated in single shot mode with a duration of neutron burst in few tens of nanosecond [1]. The neutron detectors used for yield estimate of these fusion devices are usually activation detectors, which have a high minimum detection level (typical 10^5 neutrons) [2]. Due to the long electronics processing time (microseconds) that causes pulse saturation, the yield estimate of these sources may be underestimated when proportional counters are used [3]. The neutron yield falls below MDL of activation detectors when fusion devices are operated on low energy capacitors (joules or millijoules). Similarly, the long processing time poses a challenge in the application where these single shot devices are used as an interrogating source. To address this issue, we have developed a ^{3}He filled neutron detector which can be used for yield measurement of single shot devices and in variety of other applications. The detector consists of 4, 23 cm long, 38 mm diameter detectors placed in an annular region around 70 mm diameter cavity where the head of low yield neutron generating device can be placed. The overall size of detector is 20 cm(Ø) x 40 cm (l). Detectors are connected to fast electronic module which amplifies and discriminates the pulses and produces signal of 3-5V height and 50 ns pulse width. The output of each detector is also observed so that pile-up can be avoided when used for high yield sources. The efficiency of the detector when the source placed at the center and at 50 cm in axial direction is found to be 2% and 0.03% respectively. The simulations carried out to design the detector and operation of the detector with pulsed neutron source will be further discussed in the conference.

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TWO STAGE ELECTRICALLY EXPLODING FOIL ACCELERATOR FOR LOW AMPLITUDE SHOCK STUDIES

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Electrically exploding foil accelertor[1] (EEFA), is an operationally simple, compact, and economical pulse power device for accelerating small dimension projectiles to high velocity and used for planar shock studies[2]. However, a desirable shock-generating setup should be able to probe a wide range of pressure for a comprehensive study of the material. In a conventional EEFA system (where flyer is placed adjacent to the foil), the minimum achievable flyer velocity is restricted by the inherent pressure generated at the time of foil explosion. Hence, to achieve still lower velocities an additional stage is added by accommodating an 'expansion barrel' in between exploding foil and flyer. In first stage the generated explosion plasma first adiabatically expands in the expansion barrel, thus reducing its initial peak hydrodynamic pressure as well as avoids the shock loading to the flyer in comparison to a conventional system. In second stage this expanded plasma accelerates the flyer at reduced speed. Experiments are performed on 6 µF capacitor bank with peak current of 120 kA and 1 µs rise time. The velocity profiles for various expansion barrel configurations are measured using an in-house developed Fabry-Perot Velocimeter[3]. The values of velocity after 1 mm travel from the initial flyer location are compared for different lengths of expansion barrel. A distinct velocity trend is observed as length of the barrel is increased, with an anomalous behavior near 2 mm of barrel length. At charging voltage of 20 kV, the flyer velocity of 2.60 km/s is obtained in a conventional single-barrel system however with two stages it is reduced to 1.68 km/s i.e., a 35% velocity reduction is achieved with a much smoother flyer travel and longer survival time as observed in velocimeter records. An impact experiment is also performed with double-barrel assembly in which a 10 µF bank was used to accelerate an Al flyer of thickness 100 µm and diameter 6 mm to impact the Tin target of thickness 127 µm at impact velocity of 1.4 km/s, by velocity measurements a shock pressure of 14 GPa is estimated in Tin target.

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ELECTRIC FIELD SIMULATION OF TRIGGERED VACCUM SWITCH FOR CAPACITOR DISCHARGE APPLICATIONS

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A triggered vacuum switch (TVS)is modelled in COMSOL which consists of stainless steel (SS)cathode,anode and SS trigger pin embedded in the cathode. The advantages of TVS include a wide range of working voltage, compact structure, quick recovery of gap and high charge transfer. The cathode and anode cylinders have a diameter of 35mm and 82mm length. The trigger pin is centrally located within the cathode with a diameter of 2mm. Aluminum oxide serves as a dielectric material for proper insulation between the cathode and trigger pin. Perfect vacuum is maintained in the simulation between the electrodes and trigger pin. High voltage of 25kV is applied to the trigger pin with cathode operated at 5kV and anode grounded. Simulations presented aid in understanding the potential and electric field development and behavior in the gap.

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SELECTION OF STATOR WIRE DIAMETER FOR HIGH CURRENT HELICAL FLUX COMPRESSION GENERATORS

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Helical Flux Compression Generators are powerful high current source for the pulse power application. These HFCGs utilize the energy stored in the high explosive to compress the magnetic flux between the metallic conductor and surrounding stator which results in amplification of current. Several parameters govern the current gain of HFCG. It is desirable to optimize parameters of FCG to maximize current amplification. For the fixed value of inductance of HFCG , the resistance of the wire adversely affect the current gain as it contribute to the series resistance. Moreover resistivity of the conductor also changes because of the ohmic heating of conductor and diffusion of the magnetic field into the conductor which further reduces the current gain of HFCG.

A software model has been developed in house and implemented in Matlab to simulate helical FCG. Simulations have been performed in order to select the stator conductor diameter and to study the effect of change in the resistance of stator wire conductor during amplification. Helical flux compression generator with constant pitch and an overall length of 600 mm has been chosen for study and its performance is analyzed for different wire diameters.A minimum diameter of wire has been deduced for desired output current which does not affect the performance of HFCG.

Flash lamp triggered spark gap for pulse current circuit/ electromagnetic machine.

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In pulse current application/ electromagnetic machine applications utilize Spark gap which are triggered by electrical signal. Electrical triggering circuit is complex and does not provide isolation between triggering circuit and main discharge circuit. This paper reports optical triggering of spark gap from flash lamp for pulse current circuit and its dependency on flash lamp discharge pulse energy. It examines how flash lamp discharge pulse energy and spark gap voltage affects the reliable triggering of Spark gap. Effect of flash lamp discharge pulse energy on synchronization of two spark gaps of different air gap size has also been discussed.

Evaluation of Fe and Cr doped Zinc cobalitite in symmetric and asymmetric supercapacitor

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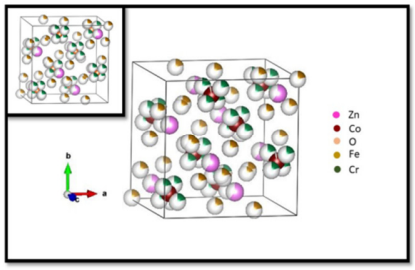
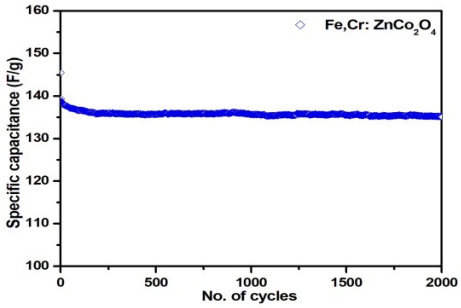
Abstract

Cobaltite with spinel structure as an electrode offers a great potential for specific kind of super capacitor technology. In the present work, the Fe, Cr: $ZnCo_2O_4$ is achieved by facile sol-gel method is reported for the first time. Half cell constructed with Fe, Cr: $ZnCo_2O_4$ as an electrode with platinum as counter electrode has shown a specific capacitance value of 320 Fg^{-1} with 1M KOH electrolytic solution. In order to explore the influence of Fe, Cr: $ZnCo_2O_4$ on the full cell performance, systematic research is carried out by constructing both symmetric and asymmetric devices. The symmetric supercapacitor employing Fe, Cr: $ZnCo_2O_4$ as both electrodes exhibited an areal energy density of 16 □Wh/cm^2 and a power density of 1200□W/cm^2. Carbon prepared, from Plasma firing of *Prosopis juliflora,* already reported[1] is utilized as counter electrode for asymmetric devices that resulted in an areal energy density of 34.7□□Wh/cm^2 and a power density of 2842□□W/cm^2. The asymmetric devices showed a capacity retention of 85% on long term cycling. The results are discussed in detail in the full paper.





Keywords: Fe, Cr: $ZnCo_2O_4$; Sol-gel; Symmetric supercapacitor; Asymmetric Supercapacitor; Cyclic Voltammetry

Occupational Health, Safety and Standards in High Voltage Applications

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High voltage applications are widely used in numerous industries and sectors for various purposes such as electrical power transmission and distribution; electrical grids; industrial processes, scientific research, experimentation and medical applications and utility applications such as electric vehicle (EV) charging etc. Exposure to high voltage electrical systems can cause serious injuries, fatalities, and damage to equipment if proper safety measures are not followed. Common high voltage hazards include electric shock, arc flash burns and injuries, arc blasts injuries and trauma, fires and explosions, injuries and fatalities due to equipment failures as a result of high voltage stress, and indirect injuries due to fall from heights.

Comprehensive safety measures, such as proper training, adherence to safety procedures, use of personal protective equipment (PPE), equipment maintenance, regular inspections, and compliance with relevant safety standards and regulations are essential to mitigate hazards arising from high voltage applications. Risk assessments and hazard identification are essential to identify potential high voltage hazards in the workplace and to workout proper mitigative measures. PPEs such as insulating gloves, arc-rated clothing, face shields, and safety glasses are essential for safeguarding individuals as they provide a barrier between workers and potential electrical hazards. High voltage work requires specialized training on electrical hazard., safe work practices, proper use of PPE, etc. Developing the SOPs for working on specific HV equipments, high voltage safety procedures, and emergency response plans are crucial for minimizing risks during the installation, operation, and maintenance of high voltage systems.

High voltage safety and standards are critical aspects of high voltage occupational practices as they ensure the protection of personnel, machine, and the workplace safety. Safety standards and guidelines for high voltage systems established by many international and national bodies exist such as International Electrotechnical Commission (IEC) standards, (IEC 61140) and National Electrical Safety Code (NESC) and Occupational Safety and Health Administration (OSHA) in the United States [1]. In India, high voltage safety standards are established and regulated by various organizations and agencies. The Bureau of Indian standards (BIS), provides standards related to electrical safety and guidelines for the safe handling and use of high voltage equipment in its code IS 2071:1993 [2]. Indian Electricity Act, 2003 outlines safety provisions and mandates compliance with applicable standards and codes.

A close study points to certain inadequacies and weaknesses in the existing standards. These include lack of universal standards, insufficient coverage of non- electric hazards or the indirect safety hazards, deficient or no focus on human factors and limited consideration of evolving and new technologies. The existing standards also do not adequately address ongoing maintenance and testing requirements. There are no systematic approaches to integrating safety into the design process from the very beginning.

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APPLICATION OF HIGH VOLTAGE ENERGY STORAGE CAPACITOR DISCHARGE GENERATED IRON NAOPARTICLES FOR REMOVAL OF WATER DISSOLVED HEAVY ELEMENTS

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The electrical pulsed power is a field of engineering which has found several applications in various areas. One such application is the production of metal nano-powder using the electrical pulsed power which is attained using the high voltage energy storage capacitors[1,2]. Such capacitors are charged to high voltages and discharged in low inductance matching configuration of load which is an electrically exploding conductor of specified dimensions. Different types of nano-powder are generated in optimized explosions achieved with one such scheme in enclosed environment inside a chamber filled with suitable gas like argon. Iron wire, when used inside such nano-powder generator, produces iron nano-powder which is collected in nearly 200milligrams and then immersed inside the water sample of less than a liter volume containing heavy elements as dissolved impurities. After stirring the water and iron nano-powder mixture, a permanent magnet which is covered with polythene is inserted in the water sample. The stirring of water is done using this magnet piece now and after some time in tens of minute, the magnet was taken out from the water sample. The water sample before the mixing of iron nano-powder and after mixing and removal of iron nanopowder was tested for its impurity content with respect to one heavy element. Approximately 7 % reduction of one particular heavy element was noted by this scheme in single experiment. Further experiments are required to be conducted to establish the efficacy of this method. The adsorption mechanism depending upon surface area of nanopowders may give better result of removal of heavy metals from water or any similar liquid with furtehr optimization.

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Effect of cobalt doping on the Electrochemical performance of the iron oxide based Supercapacitor

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Transition metal oxides have high theoretical specific capacitance but have insufficient electrical conductivity, which needs to be enhanced further to improve the charging and discharging of supercapacitors. The present work describes the preparation of iron oxide and cobalt-doped iron oxide nanomaterial via hydrothermal method. The physical characterization is carried out using scanning electron microscopy and x-ray diffraction whereas the electrochemical performance is characterized by cyclic voltammetry and galvanostatic charge/discharge. The cobalt-doped iron oxide improves the conductivity of the iron oxide-based nanomaterial and increases the pseudocapacitance. There is an improvement in the charging/discharging of the cobalt-doped iron oxide due to opening of the new sites with the increased number of cycles. Therefore, this improved electrochemical performance makes cobalt-doped iron oxide a perfect candidate for the supercapacitor application.

Variable repetition rate simulation of magnetic pulse compression based pulse power supply

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Abstract – This study focuses on the analysis of the electrical impact of varying the repetition rate in magnetic pulse compression (MPC) based pulse power supply (PPS). While these systems are typically designed for fixed repetition rates, applications such as exciting the copper vapor laser require the flexibility to adjust the repetition rate based on the dimensions of the laser head. In this research, a simulation model of the PPS is used to investigate the effects of marginal changes in the operating repetition rate. Specifically, the PPS designed for operation at 9 kHz is tested with three different repetition rates: 7 kHz, 9 kHz, and 11 kHz. The study aims to provide insights into the electrical behavior of the pulse power supply when the repetition rate is varied, enabling better understanding and optimization of the system for excitation of copper vapor laser.

SAFETY ASPECTS DURING INSTALLATION OF HIGH VOLTAGE (HV) ELECTRICAL EQUIPMENTS

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The installation and commissioning of high voltage electrical equipment is a critical phase in the life cycle of power systems. Ensuring safety during this phase is of paramount importance to prevent accidents, injuries, and damage to equipment. Installation and commissioning of these equipment pose significant safety challenges that must be effectively addressed to ensure the well-being of personnel and the integrity of the electrical system. This paper describes the potential hazards associated with high voltage equipment, including electric shock, arc flash, and electrical fires. It emphasizes the importance of understanding and complying with relevant safety standards and regulations to mitigate these hazards effectively. The paper also highlights the significance of conducting thorough risk assessments prior to installation and commissioning activities. This includes the proper use of personal protective equipment (PPE), adherence to safe work practices, and the implementation of safety interlocks and isolation procedures

This paper deals with design guidelines considered for high-voltage system. This paper also addresses the procedure to be followed before and during the installation along with the test to be conducted before commissioning of high voltage equipment such as transformer, HT switchgear panels and HT cable.

Keywords: High voltage electrical equipment, safety challenges, safe work practices, personal protective equipment (PPE), design guidelines, tests before installation and commissioning.

High voltage pulse generation using super capacitor

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A high voltage (20 kV) pulse is generated using a 55 F super capacitor at the input. This super capacitor was developed in-house using high surface area mesoporous nitrogen-doped carbon aerogel. Its total energy storage capacity is ~ 4 kJ and has ESR of ~10 mΩ. The super capacitor is initially charged to 12 V DC and output of the capacitor is connected to a high frequency bridge inverter operating at 90 kHz using MOSFET switches. The square wave output of bridge inverter is fed to a series LC resonant circuit and then to a high frequency transformer. The output of 180 V peak from high frequency transformer is fed to a four stage Cockroft Walton multiplier circuit to charge a 1 µF secondary capacitor. The stored energy in 1 µF capacitor is discharged into the primary side of pulse transformer using thyristor switch to generate high voltage 20 kV pulse.The generated high voltage is used to trigger a 400 mm. Xenon flash lamp.

INSTALLATION OF DENSE PLASMA BASED PULSED NEUTRON GENERATOR AT VDG – BUDLING, BHU

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A Dense Plasma Focus (DPF) device based pulsed neutron generator developed by Pulsed Power & Electromagnetics Division, BARC Facilities, Visakhapatnam has been successfully installed and commissioned in VDG – Building, Department of Physics, Banaras Hindu University, Varanasi in March, 2022 with the help of scientists from PP&EMD, BARCF, Visakhapatnam. Plasma focus devices are one of the most powerful and intense sources for producing short burst of neutrons [1-2]. The plasma focusing occurs when a discharge current of certain amplitude and duration flows through a coaxial electrode assembly in a chamber filled with a pure deuterium or deuterium-tritium gasmixture. This device produces an average yield in the order of ~ 10^9 neutrons per pulse of 2.45MeV energy for a pulsed duration of ~ 50ns. The pulsed power system with maximum stored energy of ~10kJ that is used to drive the plasma focus device is segregated into four modules of ~2.5 kJ each and it cumulatively delivers a peak current of ~ 600kA in a quarter time period of ~2μs. The residual inductance and resistance of the capacitor bank is about ~35 nH and ~8 mΩ, respectively. The energy stored in capacitor modules is rapidly transferred into the plasma focus head through four parallel-operated pseudo spark switches. The entire system is contained on a moveable trolley having dimensions 1.2m × 0.9m × 0.9m and total weight is about 300kgs. Neutron emission characteristics of this device will be presented in the paper.

References:

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Development of a compact ion extraction current measurement circuit for use in Laser Isotope Separation Process

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Abstract:

Timely extraction of photoplasma from the neutral background is a vital aspect in Laser Isotope Separation (LIS) process. Photo-ions are generated due to interaction of Laser with the atomic vapour. The selectivity in the photo-ionisation of the desired isotope comes from the narrow line width of the Laser. Photoplasma is extracted by biased electrode system surrounding the plasma and transporting it on to an electrode maintained at a lower potential [1]. In this article, we have studied the ion extraction and collection geometry [2] with decelerating grid and converging electrodes for achieving a soft landing of ions on cathode surface for avoiding the sputtering of atoms from the cathode. Elaborate measurement setup has been made for monitoring all the electrode currents for getting a clear insight in to the extraction process in real time. Since the laser is pulsed, the ion collection current is also pulsed at the repetition rate of the laser. The ion collection current is dropped across a shunt resistor and the voltage is sent to an oscilloscope through a coupling capacitor. A parallel isolated signal was used for determining the real time ion collection behaviour of the system. This paper describes the ion-collection circuit and brings out the considerations in choosing the various components.

PERFORMANCE OF HIGH VOLTAGE and HIGH-Q CAPACITORS AT LOWER AND HIGHER OPERATING TEMPERATURES- EXPERIENCE DURING LAST DECADE

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ABSTRACT

High voltage and High-Q capacitors are widely used in AC power systems for various applications such as reactive power compensation, improving the system voltages, harmonic filters etc., in the presence of excessive inductive loads. These capacitors are required to function effectively in the operating temperature range of -50^0C to $+55^0$C. It is required to ascertain the performance at these capacitors at various temperatures enabling them to function for intended use in the power system. Evaluation of these capacitors by performing tests or as per various International/National standards and as per specific customer protocols based on the applications of these capacitors in the various locations and at different operating temperatures. Over voltage test is significant for evaluation of performance of High voltage and High-Q capacitors at lower temperatures and long duration ageing test for higher temperatures. The paper discusses the performance of High voltage and High-Q capacitors at lower and higher temperatures by following the requirement stipulated in the relevant National/International standard and experience during last decade were discussed. Important findings of evaluation of performance are presented in the paper.

Key words: Reactive Power Compensation,High Voltage capacitors, Over Voltage test, Ageing test, IEC standards..

EVALUATING THE BEHAVIOUR OF METALLIZED POLYPROPELENE LV SHUNT POWER CAPACITORS DURING DESTRUCTION TEST

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ABSTRACT

Industrial loads in the Low Voltage(LV) ac distribution networks are generally inductive. The resultant lagging power factor occurring on account of these industrial loads are compensated by the usage of suitable LV capacitor banks. Shunt capacitors of the Metallized Polypropylene(MPP) type are generally used either in fixed bank configuration or as dynamic switched bank configurations. These shunt power capacitors are exposed to high inrush current and switching surges due to switching and overloads on account of harmonics. As the elements of these capacitors are housed within hermetically sealed containers, any internal faults developed in the elements are so dangerous that the resultant force induce high pressure within the containers. Due to the electro-mechanical stresses, at times the resultant explosive force experienced tend to rupture the container and could lead to a potential fire hazard. For protecting the safety of personal and proximate equipment, the containers of these capacitors are integrated with an over-pressure dis-connector which is a very important safety feature introduced in these capacitors. Power capacitor standards cover this important safety feature by introducing a destruction test to check the capability of these integrated over-pressure dis-connectors, and very few laboratories are equipment to perform this important test. Power Capacitors Laboratory of CPRI is fully equipped to conduct Destruction test and a study was undertaken to analyse this important safety feature. Three test samples of different makes and ratings were considered for the study, to analyse and the results are presented in this paper. The analysis revealed the importance of this vital safety feature of the capacitor.

Key words: MPP, Shunt capacitors, Over-Pressure Dis-connector, LV Networks, Capacitance, APFC panels, Switching, Destruction Test.

Review of Emerging Techniques for control of BLDC motor based Servo Systems

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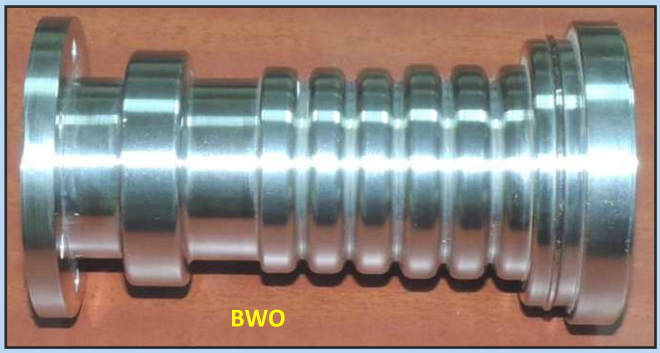
Abstract

Brushless DC motors (BLDC) are employed extensively in a variety of industrial settings because of their high power density and ease of control. Three phase power semiconductor bridges are typically used to drive these motors. Rotor position sensors are necessary for the inverter bridge's starting process as well as for delivering the correct commutation sequence to switch here on power devices. The motor needs the right speed controllers to work at the optimum level. Where there is some control complexity, like nonlinearity, load disturbances, and parametric fluctuations, issues may arise. Additionally, exact linear mathematical models are needed for PI controllers. The fundamentals of the BLDC drive system, converter topologies, as well as the fuzzy logic-controlled BLDC drive system with BLDC motor drives are all examined in this research. This paper presents the comparison of algorithms and methods to control BLDC motor. Researchers have explored many algorithms for fractional control of BLDC motor for various industrial applications. There are certain advantages of using this technique over conventional controlling methods such as consideration of variable loading. In this paper fractional controlling based methods like WOA algorithm, ABC algorithm, Super Twisting methods, Particle swarm technique etc. are studied and compared for different controlling parameters of Brushless DC motor.

Key Words: BLDC (Brushless Direct Control Motor, WOA (Whale optimization algorithm), ABC (Ant Colony Bee Algorithm) , PSO (Particle Swarm Optimization)

Intense Electro Magnetic Interference Generator

Pulsed Neutron Source



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