Pulsed Power

Professor Kishore N K

Kishore.n.k@ieee.org

Pulsed Power ?

- High Power – MW to TW
- Short Duration – ps – ns to ms pulses

  at times repetitive

Introduction

- 1920s- Erwin Marx – Marx Gen. – 2 MV – LOV simulation
- Fast Rise Marx- flash radiography – ion beam generation – plasma fusion MJ – sub us
- Power Modulators – Radars Magnetron ~100 kW – WWII
- Magnetron Repetitive 10-50 kV, 1-10 A, 1-10 kHz

- Spark gaps – while recover in short time scale – cant conduct high currents – were popular switches then
- Led to magnetic pulse compression
- Energy transferred in stages – time compressed in stages using saturable magnetic stages
- WWII – availability of HV Thyratrons and tubes- changed after 80s – High Power Lasers , UWB, Radars, Corona reactors etc

- Needed by nuclear weapons – inertial confinement fusion and directed energy weapons
- Industry – flash photography, metal forming, lasers, electric fences
- Industrial Electronics and High Energy Physics
- Flash radiography – sub us X-ray beams of 10-100 ns

- X-ray imaging of nuclear warhead test 1-10 MV, 1MA, 50-100 ns
- Fast rise high energy – Marx Banks in oil and transmission lines – oil /water
- $V_b = k\, A^{(-1/10)} d t^{(-1/3)}$ (MV)

Considering co-axial geometry , V_b is applied voltage in MV, k is 0.3 to 0.6 depending on oil/ water and polarity, d – radial separation and t – time to breakdown

- Los Alamos – Sandia – Naval Research Lab.
- Energise Krypton Fluoride Lasers (KrF) particle beams
- PBFA II, DEW – SDI – Reagan
- High Power Lasers – disable
- HPM – Disrupt enemy communication s

Peaceful applications

- Environmental Cleanup
- Material Treatment
- Bio-treatment
- Food treatment
- Rock breaking
- Apply High Fields to Corona Generating Assembly
- Nox removal needs 20 % by pulsed beams

Pulser Topologies

- Discharge @ a fast rate from an energy storage device
- Pulse Formation Circuit, switching and transmission line technique
- Capacitance based circuits are widely used
- Charging may take minutes for uF capacitors up to 50/100 kV if single shot or ms for nF in high repetition rate application

- Pulse width defined by load $\tau = CR_{load}$
- ns to us
- Pulse rise time affected by the closing switch and load inductance
- Improved by sharpening gap (s2)
- Peaker – peaking capacitor is of much lower value
- S2 breaks itself on peaker reaching a suitable high voltage

- Charging - resistive – DC – HW / Cockroft Walton multiplier – Switch mode HVDC
- Electronic Chargers
- Capacitors – Electrolytic – suitable for ms range due to high ESR
- Wound paper – foil / Plastic - foil- nF-uF – up to 100 kV few 100 ns
- Ceramic BaTio3 – ns typically 50 kV 100 pF to few nF
- Life proportional to degree of voltage reversals

Marx Banks

- Capacitors - limitation 50 to 100 kV – due to DC Insulation – DC Corona – power electronics – Transformer
- Pulsed Power – 100 kV to 2 MV
- Employ Spark Gap Switches
- Charged in Parallel – closure of switches (usually spark gaps) puts them in series
- Typically us pulse

- Load – transmission line – resonantly charged marx
- > 20 – 30 stages – reliable triggering necessary
- Bi-polar charging – multiple stacks (faster charging)
- Inductive charging – low loss – repetitive pulses
- Series time constant $\sqrt{LC}$ - a few us

Fast Rise Marx Banks

- Compact and HV systems
- 500 kV – 1 MV – 10 to 100 J/shot – Ceramic Capacitor
- Low inductive Capacitors – 4 to 30 stages, 10 – 100 ns rise time
- Spark Gaps – designed for low inductance – H_2 - HV hold off and fast recovery – 1 kHz - pressurised SF_6 insulation – UWB, DEW

Pulse Compression

- Resonantly transferred between two capacitors by a closing switch and a inductor
- By adding second LC loop it can be transferred to a third capacitor via second closing switch
- If $\sqrt{LC}$ is made shorter for the second loop – faster energy transfer with a higher peak current

- $T_1 = \sqrt{(L_1 C_0 C_1/(C_0+C_1))}$
- $T_2 = \sqrt{(L_2 C_2 C_1/(C_2+C_1))}$
- Second switch could be self breaking switch
- Problem is arduous switching duty in subsequent stages as pulses are high powered

Magnetic Pulse Compressor or Melvile Line

- 1940s by Melvile
- Inductors in the circuit have saturable soft magnetic cores like NiFe ferrite or amorphous metal
- When not saturated L presents high impedance ($u_0 u_r$), on saturation present low impedance (u_0)
- Transition occurs 10-100 ns time scales

- Important parameters being volt-second hold off and saturated inductance
- $(B_s - B_r)\, A\, N = \int V\, dt$
- B_s is saturated magnetic core flux density; B_r is reset magnetic core flux density;

  A is the magnetic core cross sectional area and N is number of turns

Operation

- MS0 in high inductance state initially
- On closure of Primary switch S – typically thyristor MS0 gets driven to saturation and cascades through MS1, MS2 and MS3.
- C0 transfers charge to C1 resonantly. MS1 designed so as to maintain high L till C1 fully charges, when it saturates.
- C1 resonates with C2 .