Protection From Lightning

• Presented by Alan Lipsky
  – Consultant
    • Grounding
    • High frequency power conversion
    • Feedback control
Organization

• Lightning:
  – Cause, Current Range, Prevalence, Damage

• Mitigation:
  – Grounding
  – Protection of AC Power and PC-board inputs with surge protection
  – Maintain Ground reference to protect communication ports

• Surge tests
Lightning

Large negative charge forms in cloud; inducing large positive charge below:

- Negative low current downward leader followed by upward high current stroke,
- Current ranges from a few hundred amps to more than 500 KA,
- 20 KA to 40 KA usually used to estimate magnitude of strike.
- Sometimes 3 to 5 distinct strokes roughly 60 milliseconds apart
  - 20 k Amps for first, ½ that for following strokes
  - Last stroke could be followed by 150 Amp current lasting 100 milliseconds
Duration and Frequency

- Typical strike duration 50 to 100 microsecond.
- Most spectral energy below $1\text{ MHz}$ with < 1 microsecond rise time;
- Energy down to dc and above $1\text{ MHz}$,
  - Maximum flash densities in North America in Gulf coast and Florida Peninsula.
Lightning Damage

• Damage caused by large current or the heat caused by current flow
  – Electronic circuits damaged by high current or voltage caused by that current.
• If lightning occurs near an overhead electric or telephone line, large current induced or injected into the line.
• Charge can also be injected into soil. Arcing to nearby buried conductors at distances up to 100 m.
Lightning Related Failures

- Insulation breakdown
- Flashover
- Fracture
- Thermal and peak power overloads
Damage Mitigation

• Grounding
• Protection from Surges
• Testing
Grounding in Accordance with National Electrical Code

• Bond all Cabinets and other conductors such cable raceways together
• All components of grounding system must be connected together with a conductor
• Motivation is Safety and not necessarily protection from lightning
  • Purpose is to maintain conductive surfaces at or near the same potential
Common thread:
• Grounding electrode,
• Neutral wire and bus,
• Grounding bus bonded to service entrance cabinet,
• Insulated green wire ground conductors.
Safe System in Accordance with NEC
• Use Grounding suitable for high frequency
  – A Multi-Point Ground.
• Build a system reference structure, SRS.
  – High inductance grounding poses a safety and equipment hazard caused by large voltage differences between cabinets
• When circumstances permits bolt cabinets together and bond them
Grounding (Cont)

• Above 300KHz, and for protection from lightning, bond each cabinet at many points.
  – The single ground wire connecting each cabinet with ground has large inductance.
• Use grounding structure that resembles a plane, such as a large conducting sheet or a grid work of grounding wires bonded where they cross. Bond cabinets at all 4 corners. Wires in grid should be no more than 0.6 meters apart.
Mitigation Through Surge Protection

• Protection devices:
  – Metal Oxide Varistor
  – Gas discharge tube
  – Thyristors
  – Transient Voltage Suppressor (TVS)

• Each has different characteristics that makes their use complementary
Protect at Several Locations

• At building entrance
• At power panel
• At equipment power input
• At signal inputs
• At critical circuits
Gas Discharge Tube

- Withstand large surge current because it clamps at low voltage
- Low capacitance
- Relatively slow turn on
- Use on communication circuits and AC line
- Because of low voltage required to maintain arc, it may not extinguish after the surge is over
Metal Oxide Varistor (MOV)

• Action in PN junctions throughout bulk material
• Ratings
  – Maximum non repetitive surge current
  – Max energy
  – Clamping ratio 1.95
  – Response time – less than 20 ns
  – Clamps AC
• MOV voltage definitions:

• Maximum clamping voltage

• Varistor voltage @ 1mA

• Maximum continuous voltage

• Ground reference
Use

• Use at building entrance, Power panel, Equipment power input
• Not suited for data transmission lines because of large capacitance
• Main issue:
  – Pick continuous voltage to pass normal supply voltage.
  – MOV clamping voltage should protect user equipment
  – The MOV should be protected from as many surges, swells, and spikes on the line as possible.
    • May require higher voltage ratings on equipment.
Life for Various Number of Pulses
Transient Voltage Suppressor

- Lower clamping ratio than MOV’s
  - 1.6 versus 1.95
- Zener diode with a larger cross section designed for surge voltage clamping rather than voltage regulation
- Generally used at lower voltages than MOV devices
- Inserted between source of surge and circuitry being protected
- Some units manufactured for protection of data lines
• Specified in KW of peak pulse power
  – Clamping Voltage times peak pulse current
• Clamping Voltage
• Rated Working Peak Voltage (Rated Standoff Voltage)
• Peak Pulse Power Dissipation
• Peak Impulse Current
• Some units made with low capacitance for data lines
• TVS Voltage definitions:
  • $V_c$  Clamping voltage
  • $V_{br}$  Start of avalanche
  • $V_{wm}$  Rated standoff voltage
  • Ground Reference
Second Order Low Pass Filter

• Response to short voltage pulse:
  – Approximate by impulse equal to time duration times voltage amplitude
  – Amplitude of normalized impulse response depends upon damping constant
  – Amplitude = 0.38, damping = 1; Amplitude = 1, damping = 0
  – Impulse response of L-C network at end of 20 micro second pulse = 0.7% of final amplitude, $\omega_n = 2640$ rad/s
  – Normalized amplitude times $\omega_n$

• Used on: power rectifiers and high power factor rectifiers
High Power Factor Rectifier
High Power Factor Rectifier

- 88 Volts to 264 Volts
- Output power 270 Watt
- Inductor = 650 micro Henry; Capacitor = 220 micro Farad
- $\omega_n = 2640 \text{ rad/sec}$
- For 1000 volt 20 micro second pulse and undamped filter
  - $V = 53 \text{ volts}$
Surge Testing

• Standard groups specify testing standards for various types of overvoltage transients

• Standards:
  – IEC 61000-4-2 Electrostatic Discharge
  – IEC 61000-4-4 Electrical Fast Transient/Burst (EFT)
  – IEC 61000 4-5 Lightning strikes & Switching Transients
• Contains test for both power and communication lines

• Test levels:
  • Level open circuit Voltage Short circuit Peak Current
  • 1. Well protected 0.5 KV 0.25 KA
  • 2. Protected 1.0 KV 0.5 KA
  • 3. Typical Industrial 2.0 KV 1.0 KA
  • 4. severe Industrial 4.0 KV 2.0 KA
Surge Specifications

- Volts
- Duration
- Tf
Surge Pulse Characterization

• Front time (rise); Second time (fall time) to 50% of maximum
• Combination generator provides open circuit voltage and short circuit current
• Standard power circuit pulses:
  – 1.2 X 50 micro second open circuit voltage waveform
  – 8 micro second to 20 micro second short circuit current
• Telecommunications
  – 10 X 700 Micro second open circuit voltage waveform
  – 5 X 300 Micro second short circuit voltage waveform
References

- IEEE Recommended Practices for Powering and Grounding Electronic Equipment
- Varistor Introduction  Vishay, BC Components
- Selecting Varistor clamping voltage: Lower is not better  
  – F.D. Martzloff and T.F. Leedy
- Selecting a Littlfuse Varistor AN9771.1
- Micronotes  102, 104, 122, 125, 126
- TVS Diode Arrays (Low Capacitance ESD Protection)