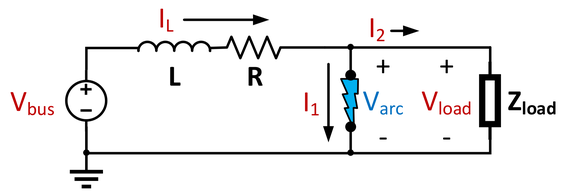
Experimental Observations of the Transient Characteristics of Series dc Arcs with Capacitive Loads

Center for High Performance Power Electronics

Student members: Eric Bauer, Matt Foster, Bailey Hall Advisors: Jin Wang, Daniel Schweickart*, Dennis Grosjean**

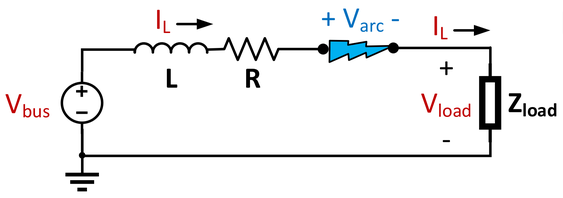
*** Air Force Research Laboratory (AFRL-RQQE) ** Innovative Scientific Solutions Inc.**

1. Dc Arcing Basics



Low Impedance Arc

Occurs in parallel
High overload current
High energy



High Impedance Arc

Occurs in series
Inserts arc impedance
Reduced load current

Minimum Arc Voltage

- Electrons must transition from solid to ionized gas
- State change results in voltage drops at cathode & anode
- Minimum arc voltage is sum of voltage drops
- Copper electrodes require a V_{min} of 12.2 V - 13.3 V

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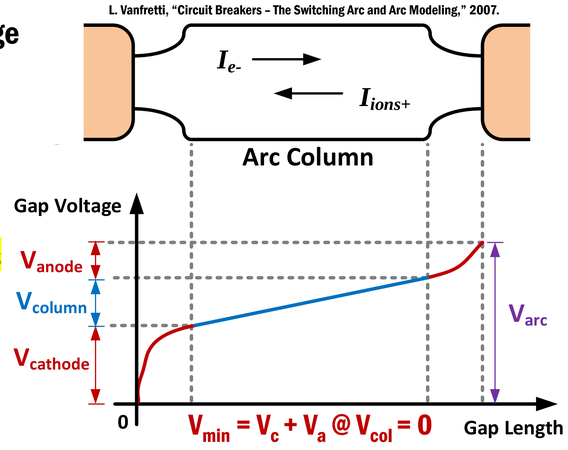

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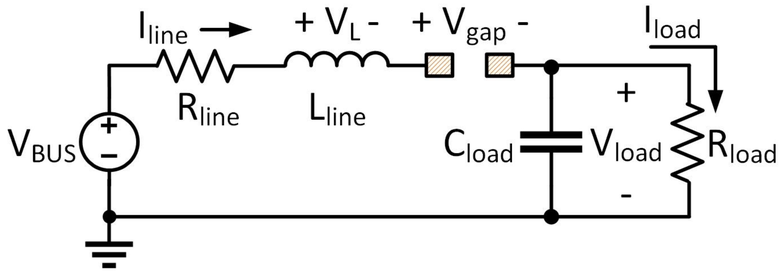
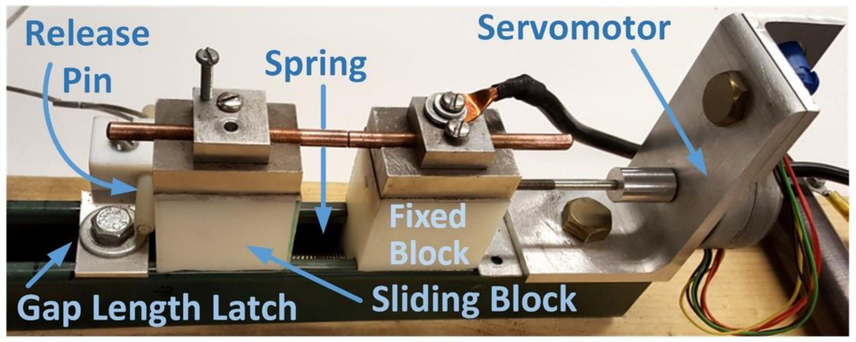
Equivalent dc Load Circuit



Electrode separation → **Inductive voltage boost** → V_{min} satisfied → Arc
Inductive voltage boost depends on stored inductor energy (E_L)
When stored inductive energy reaches 0, capacitor voltage drops by V_{min}

2. Test setup and parameters



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Aeronviornment ABC-600 dc source, variable load resistor bank
Tektronix DPO4045B, 10MS/s, 11-bit resolution, 100ms record length
Spring separation mechanism

Test parameters

(V_{bus}, I_{load})	C_{load}	Gap	Trials
350 V, 3 A	35 µF	2 mm	15
350 V, 25 A	105 µF	4 mm	
450 V, 10 A	213 µF		
540 V, 6 A	375 µF		
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	1385 µF	900 tests	

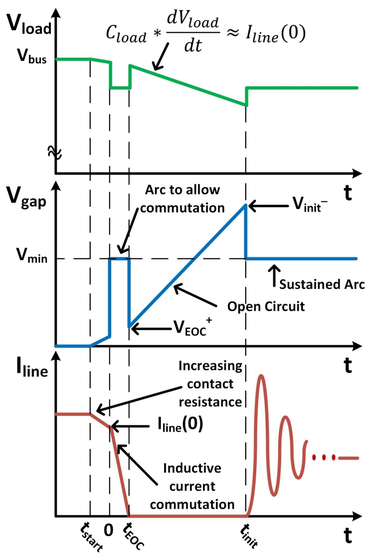
Every (V_{bus},I_{load}) pair tested with every C_{load} for both gap distances 15 times

Room temperature
Room pressure

Copper electrodes (6 mm Ø)

Fixed line inductance

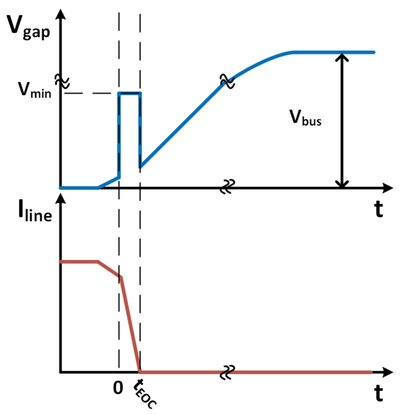
3. Generic Transient Waveforms



t_{start}: brief period of increasing contact resistance
$t = 0$: electrodes completely separate
$I_{line}(0)$: line inductance at the moment electrodes separate
E_{com}: commutation energy provided by the line inductor to the arc column
V_{min}: minimum voltage needed to arc
t_{eoc}: time when line current reaches 0, and the commutation arc extinguishes
V_{eoc}^+: voltage at start of open circuit
t_{init}: time when a sustained arc occurs
V_{init}^-: voltage before a sustained arc

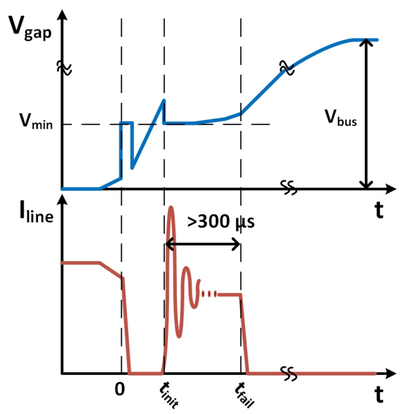
4. Arc Severity Classification

Open Circuit



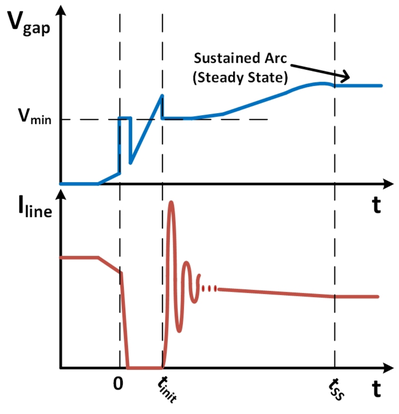
Least severe case - best outcome
Re-ignition for 30 µs – 150 µs
Commutation still occurs

Failed to Sustain



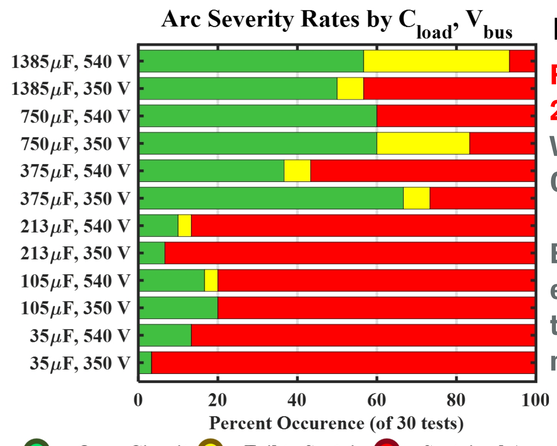
Medium severity – not tolerable
Non-zero arc current for > 300 µs
Current transients present

Sustained



Most severe – remove power
Can have FtS before sustained
Steady-state voltage – Ayrton-Paukert

5. Key Factors of Arc Severity



Bus Voltage Effect

Fixed I_{load} = 25 A
2 mm & 4 mm data
Voltage has no effect for $C_{load} \leq$ 213 µF

Bus voltage has little effect on arc severity, due to the relatively low minimum arc voltage

Fixed gap – 2mm
Grid point - arc severity
Each point – 15 tests
Except, 25 A – 30 tests

C_{load} < 213 µF
Increase load current → Increase in arc severity

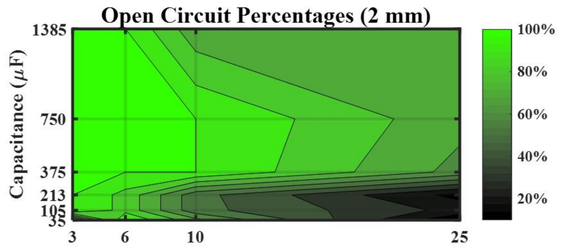
Under 10 A, open circuits become failed to sustain

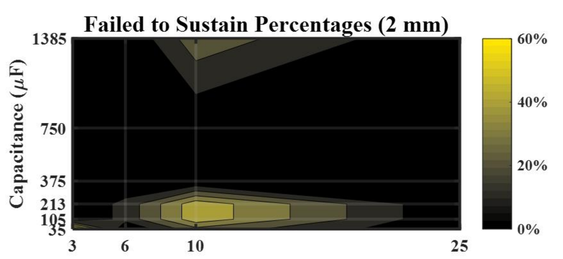
213 µF < C_{load} < 375 µF
Increase load current → Increase in arc severity

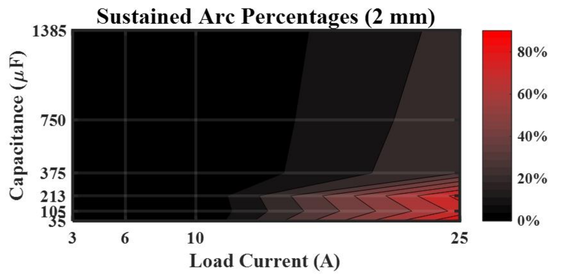
Increase C_{load} → Decrease in arc severity

C_{load} > 375 µF
Increase load current → Increase in arc severity

Less cases of failed to sustain arcs







For a gap length of 4 mm, sustained arcs vs C_{load}-I_{load} has similar contour
C_{load} has less of an effect on open circuit percentage
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6. Conclusions

Generic dc arc transient waveforms created
3 arc severities defined – open circuit, failed to sustain, and sustained
Effects of circuit parameters on arc severity studied
Increase in load capacitance reduces severity of arcing
Decrease in line current reduces severity of arcing

7. Future Research

Explore the arc energy balance and the effects on arc severity
Explore energy accumulation in stages – commutation v open circuit
Explain the different transient waveforms in more detail
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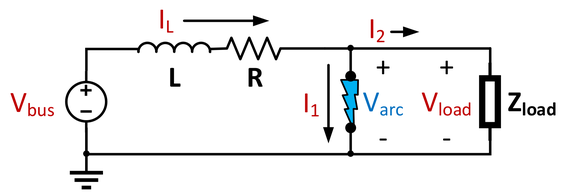

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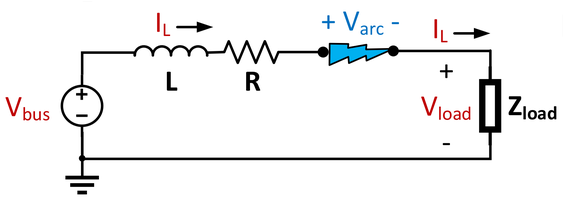

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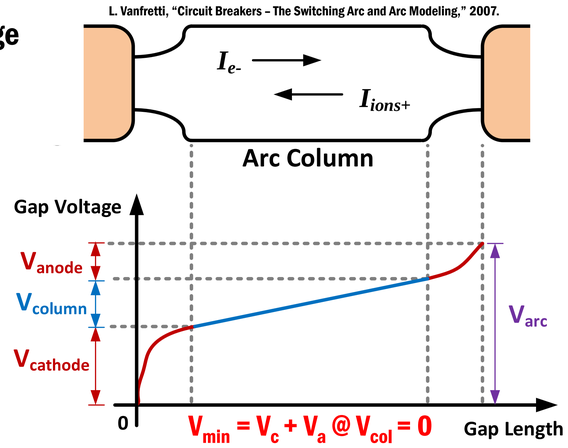

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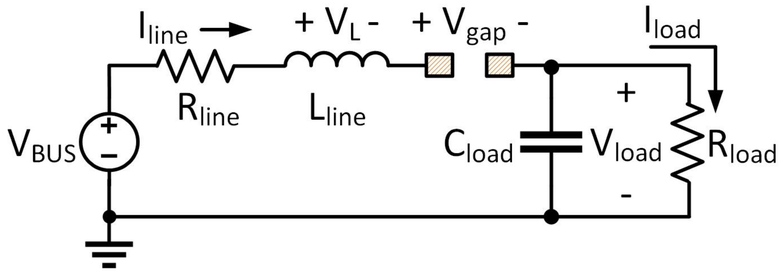

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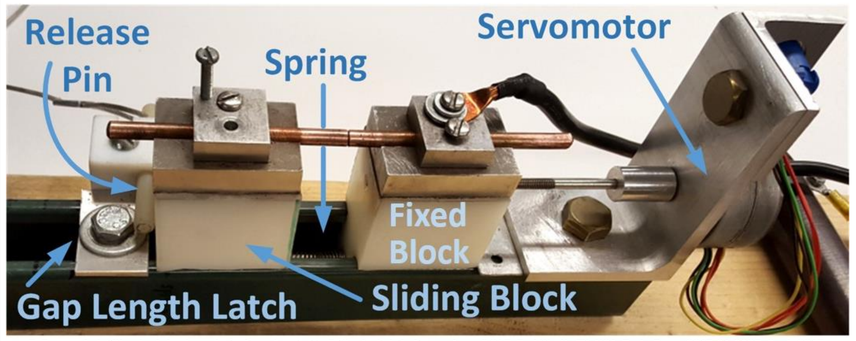

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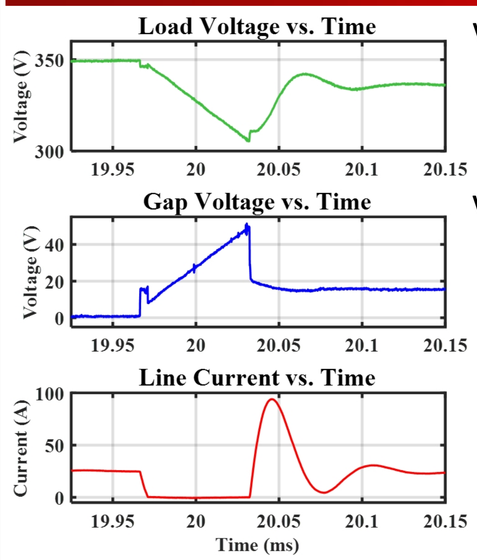

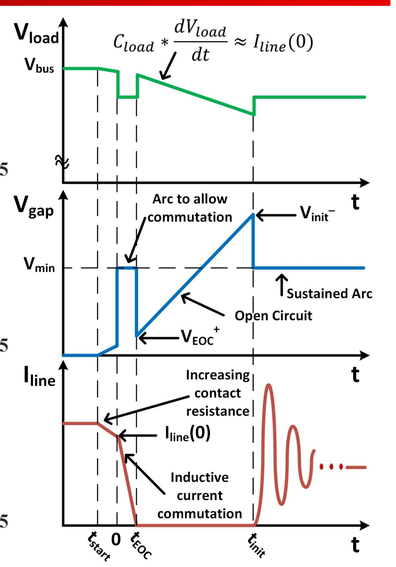

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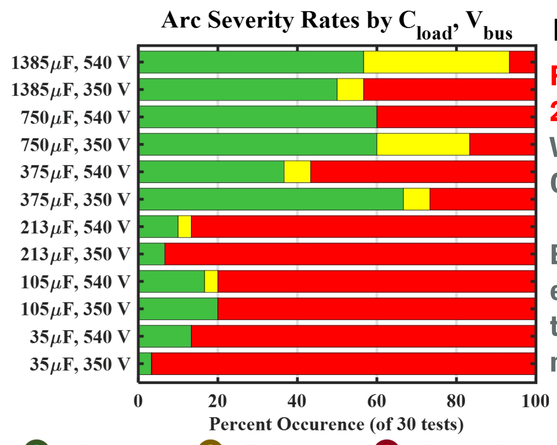

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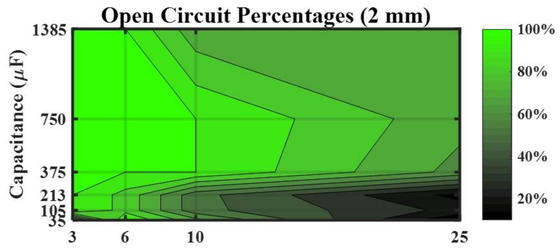

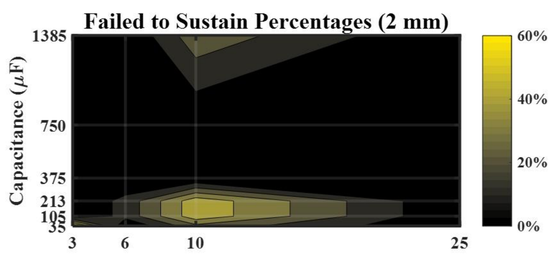

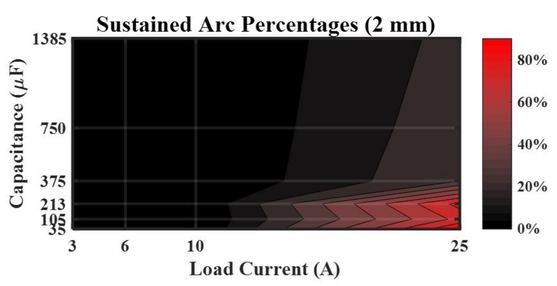

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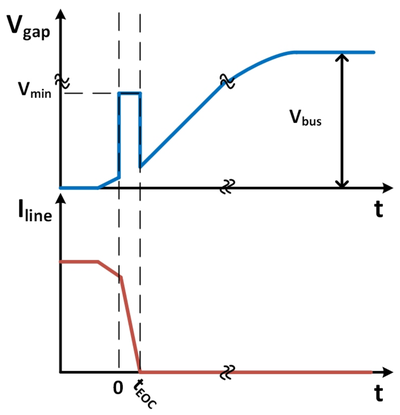

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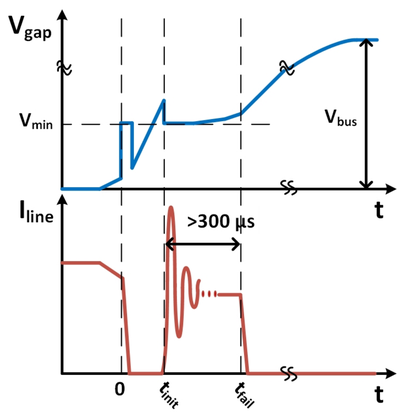

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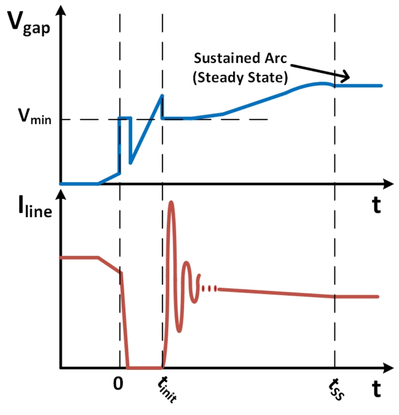

Most severe – remove power
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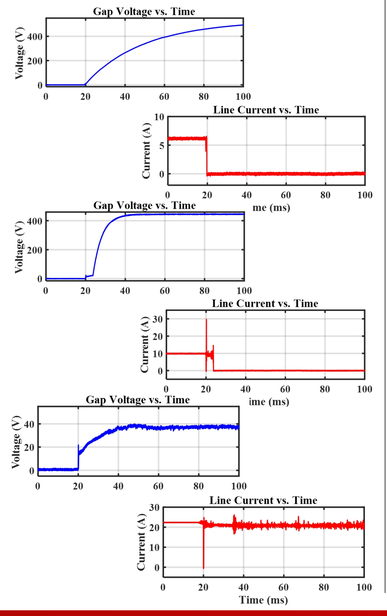
$V_{Steady\text{-}State}$ – Ayrton-Paukert



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