CONTROLLED SWITCHING FOR CIRCUIT BREAKERS WITH PRE-INSERTION RESISTORS ENERGIZING SHUNT CAPACITOR BANKS

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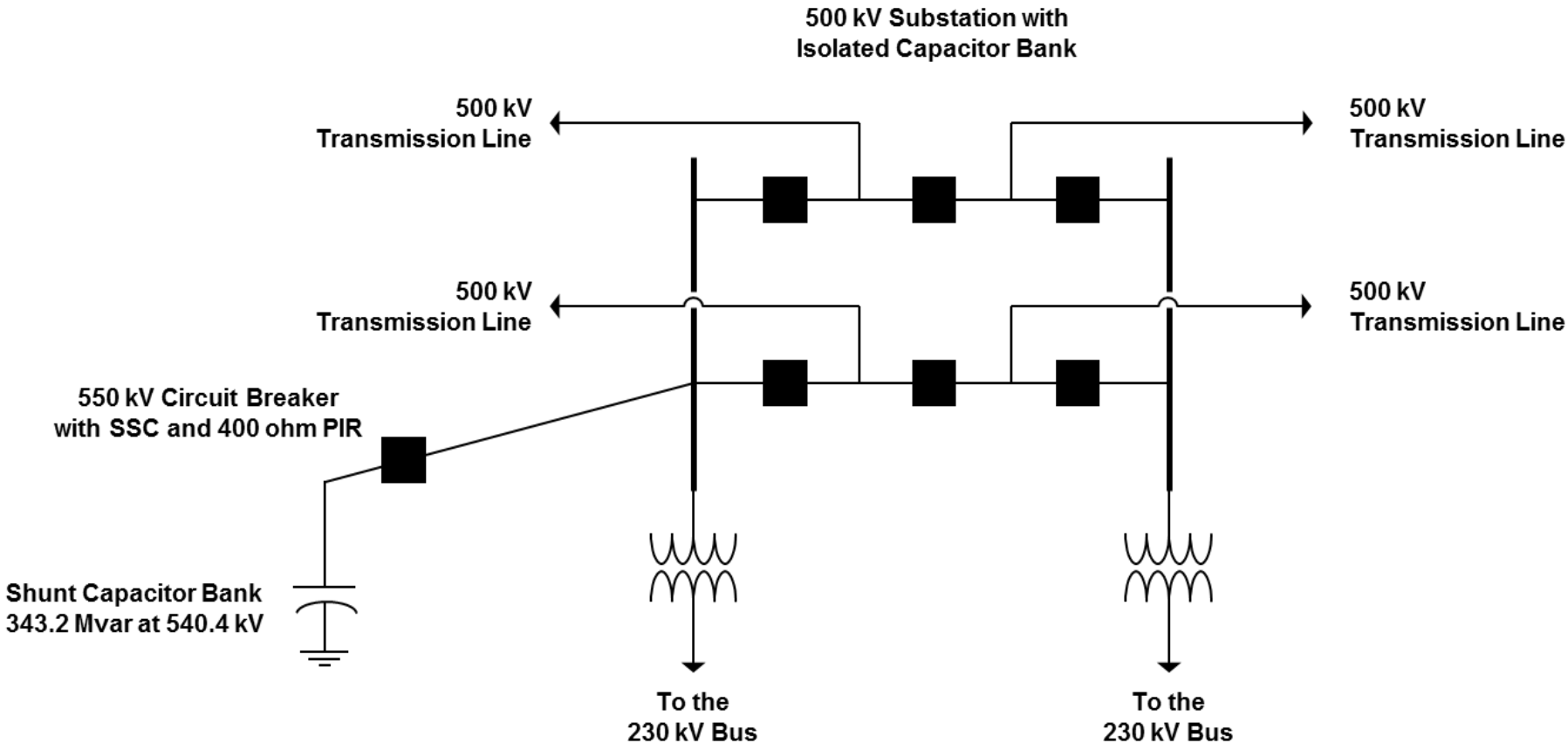
Introduction

- Shunt capacitor switching often requires controlled closing, especially at higher voltages
- Closing resistors sometimes used for shunt capacitor switching at 550kV and higher
- This case study analyses different switching strategies using EMTP-RV and verifies that result with an in-service circuit breaker

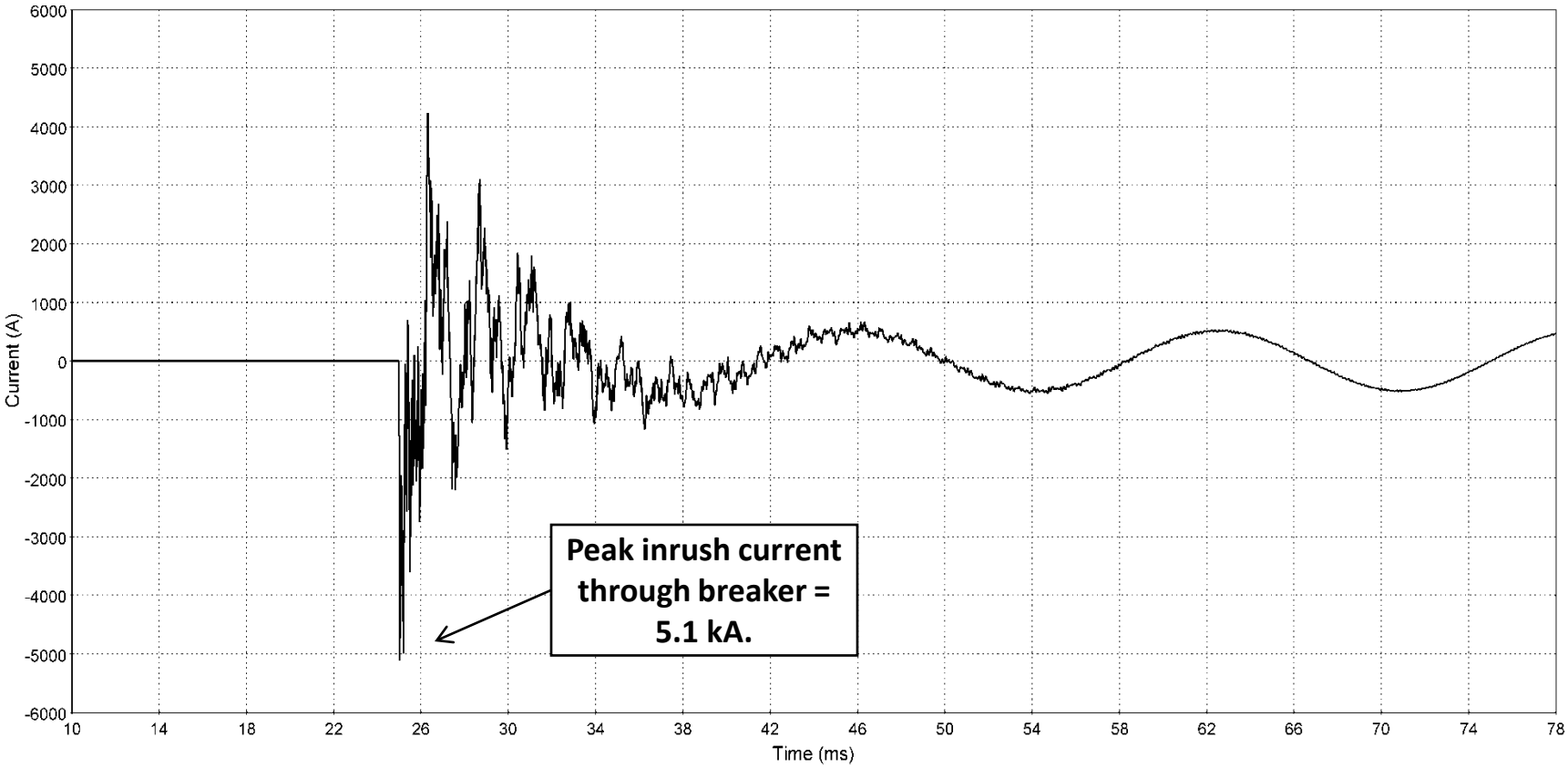
Case study substation layout



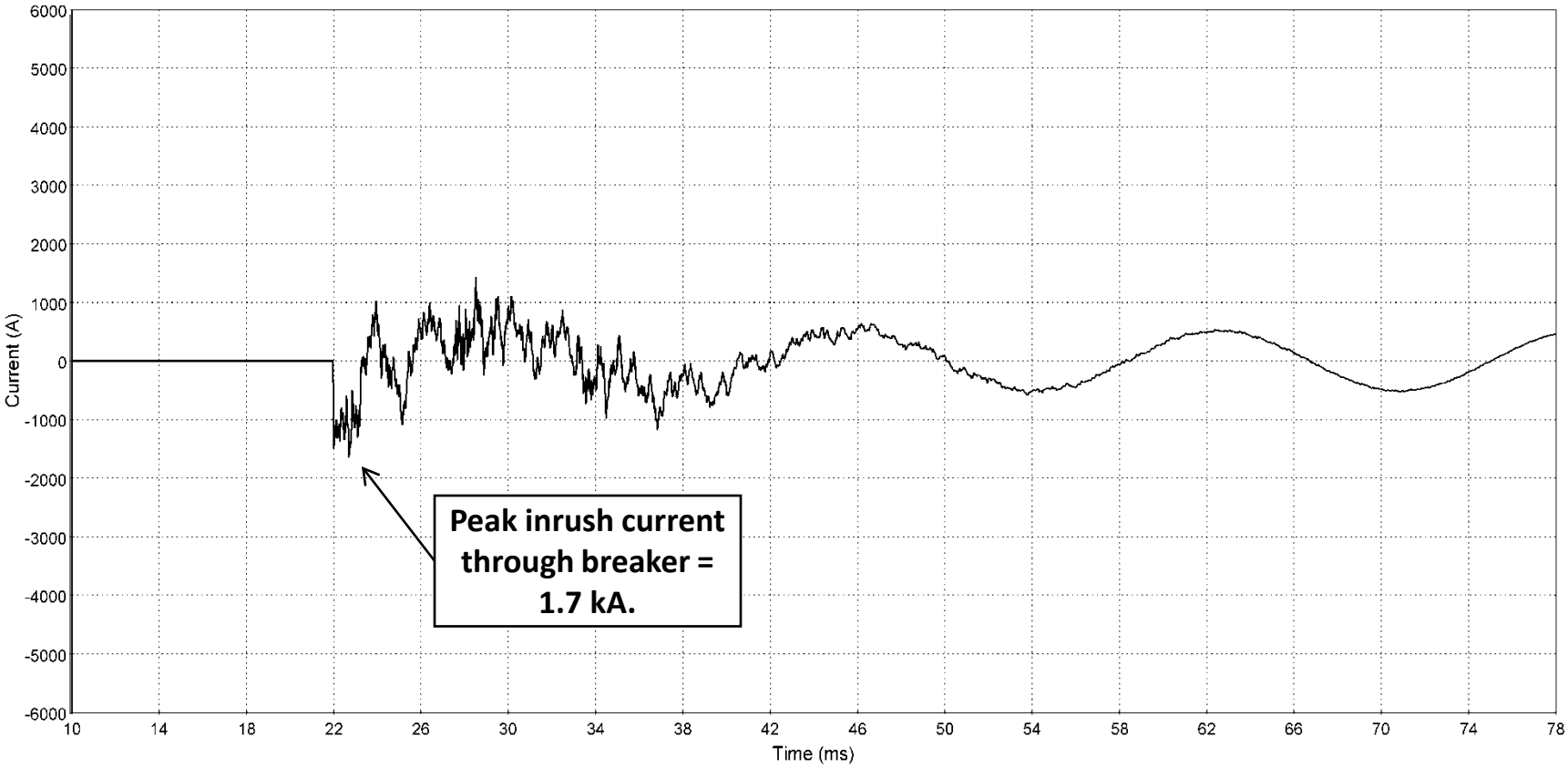
Original strategy

- Switching target originally was to initiate current near a voltage zero
- Improvement over no mitigation strategy
- Might be adequate, depending on capacitor bank, breaker design, CLR, maintenance cycle

Simulation of a close operation without controlled switching and closing resistors



Simulation of a close operation with only controlled switching



Simulation of a close operation with the original controlled switching target

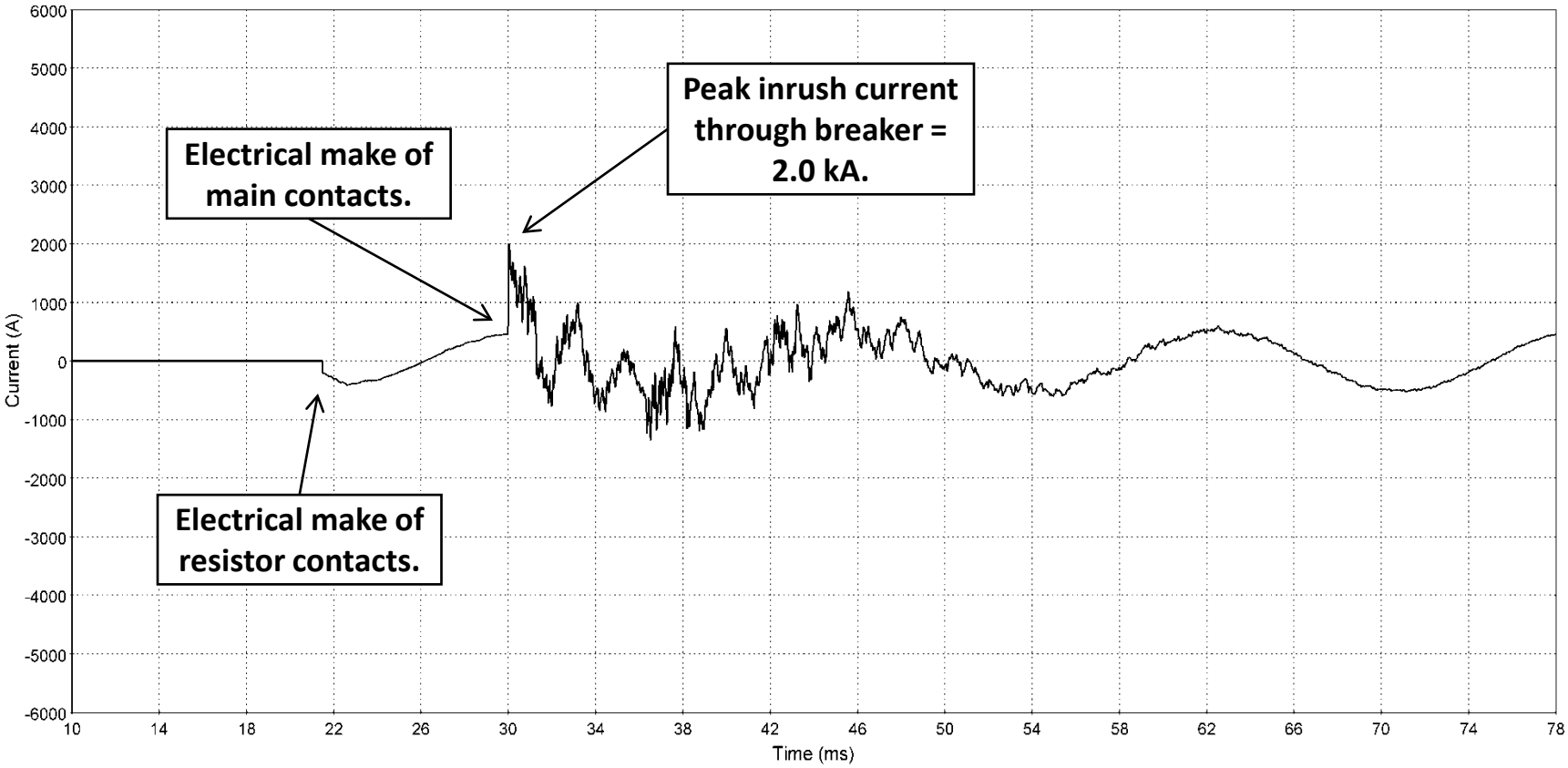
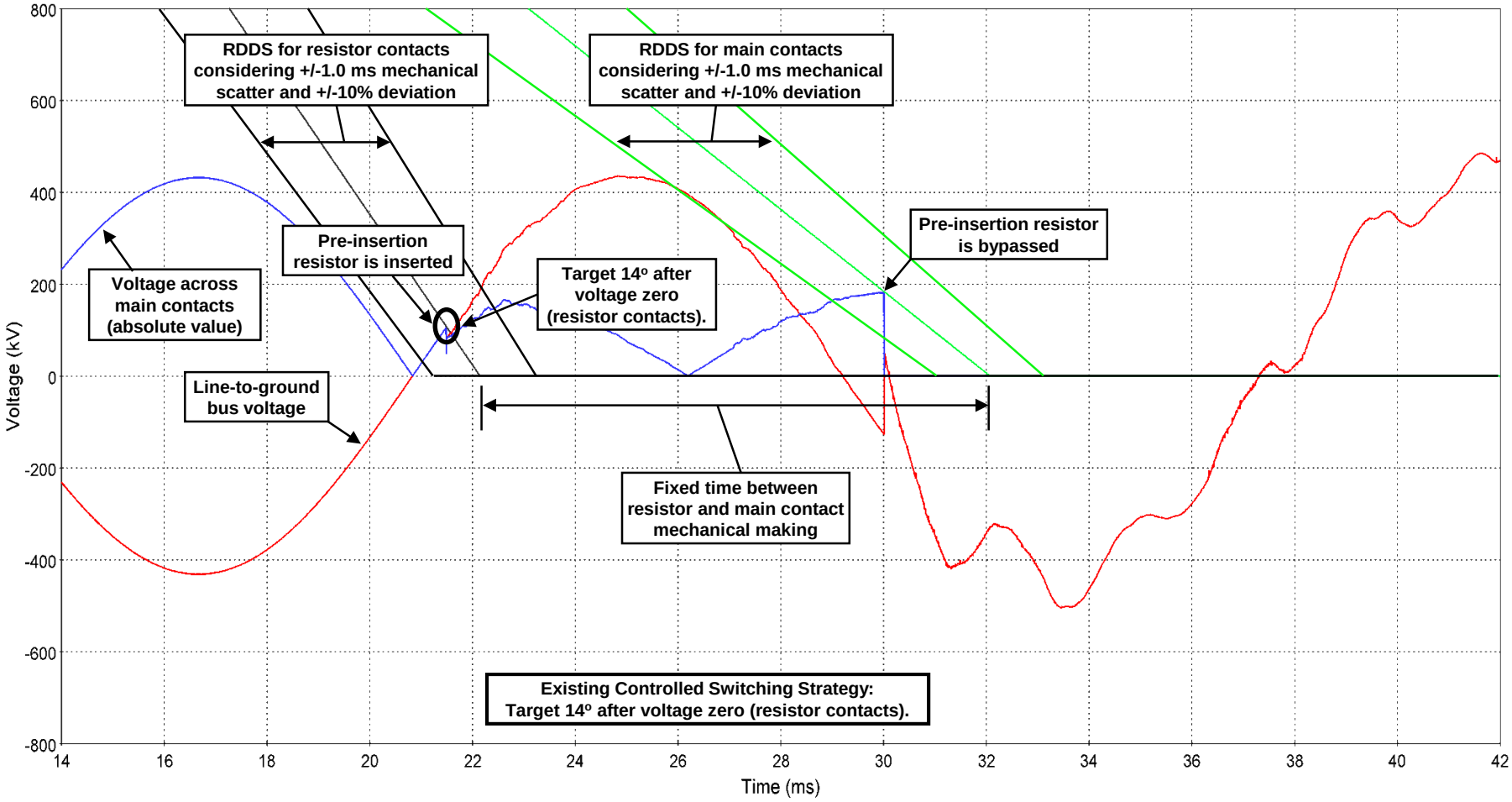


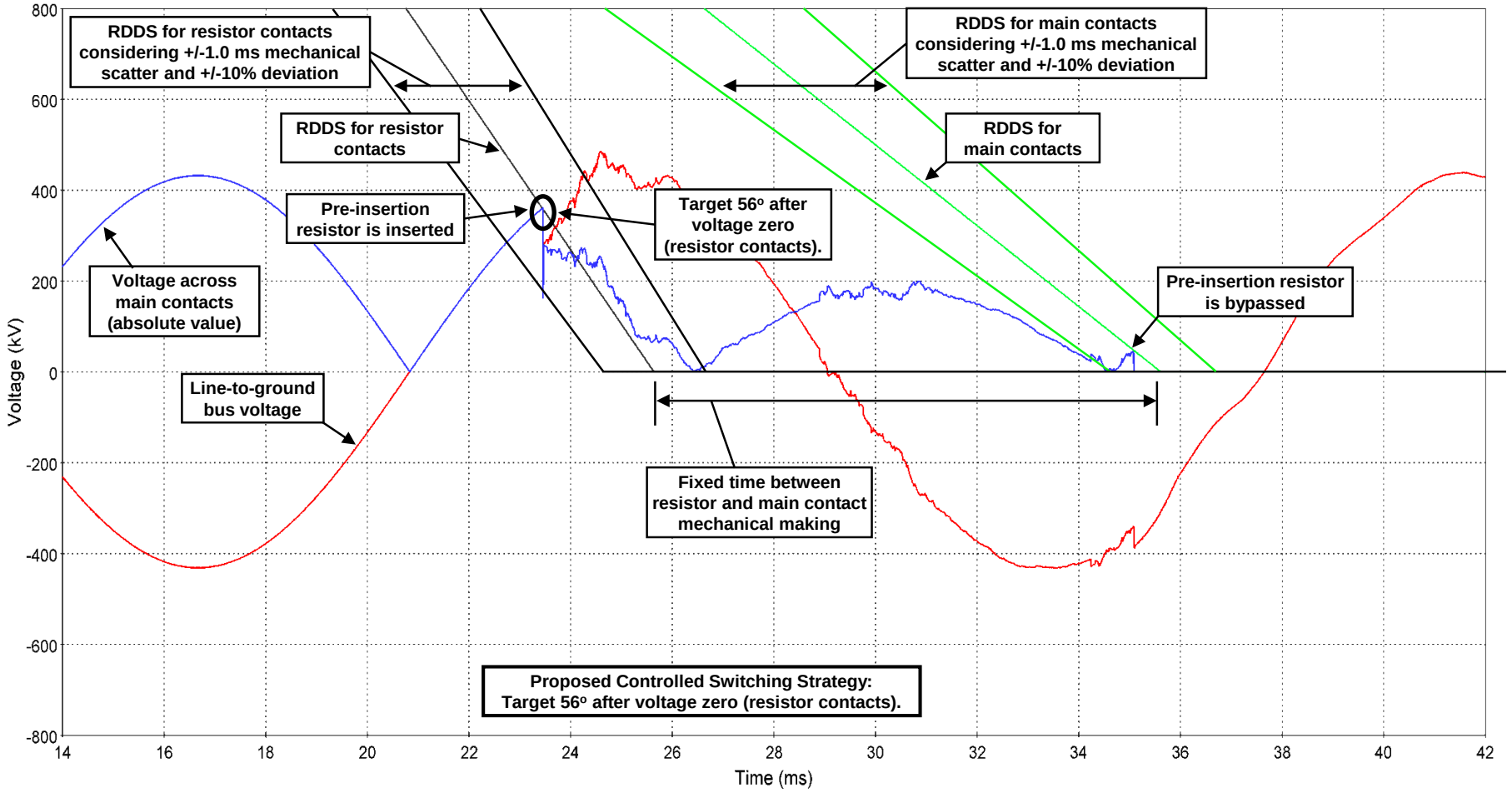
Illustration of original controlled switching strategy



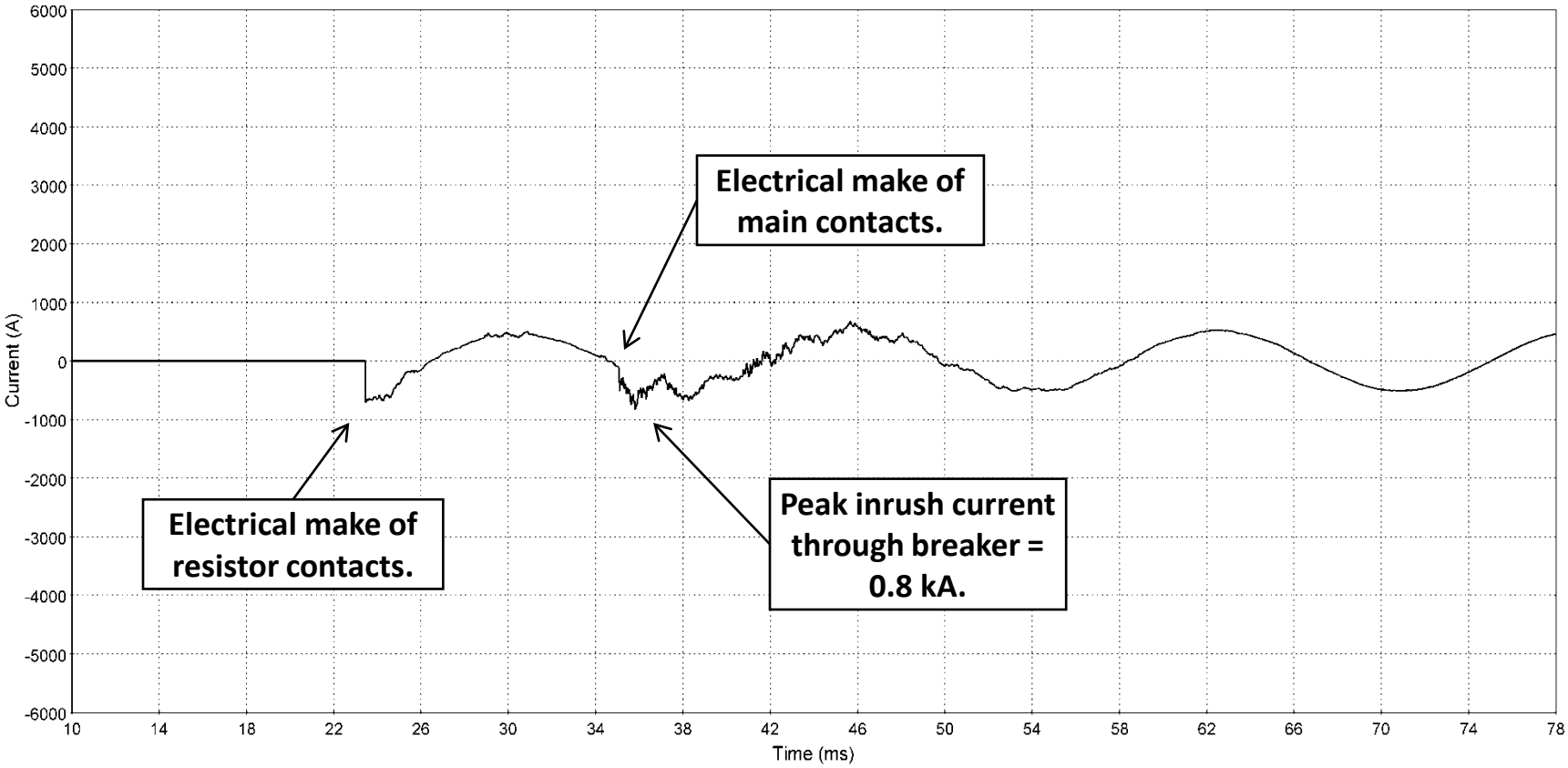
Original switching strategy was flawed

- Voltage on open arcing contacts is actually the voltage across the resistor, not system voltage
- Peak voltage is roughly 200kV due to 400Ω closing resistor
- Arcing contacts are electrically making at the peak voltage!
- What if we target arcing contact voltage zero rather than resistor contact voltage zero?

Illustration of proposed controlled switching strategy



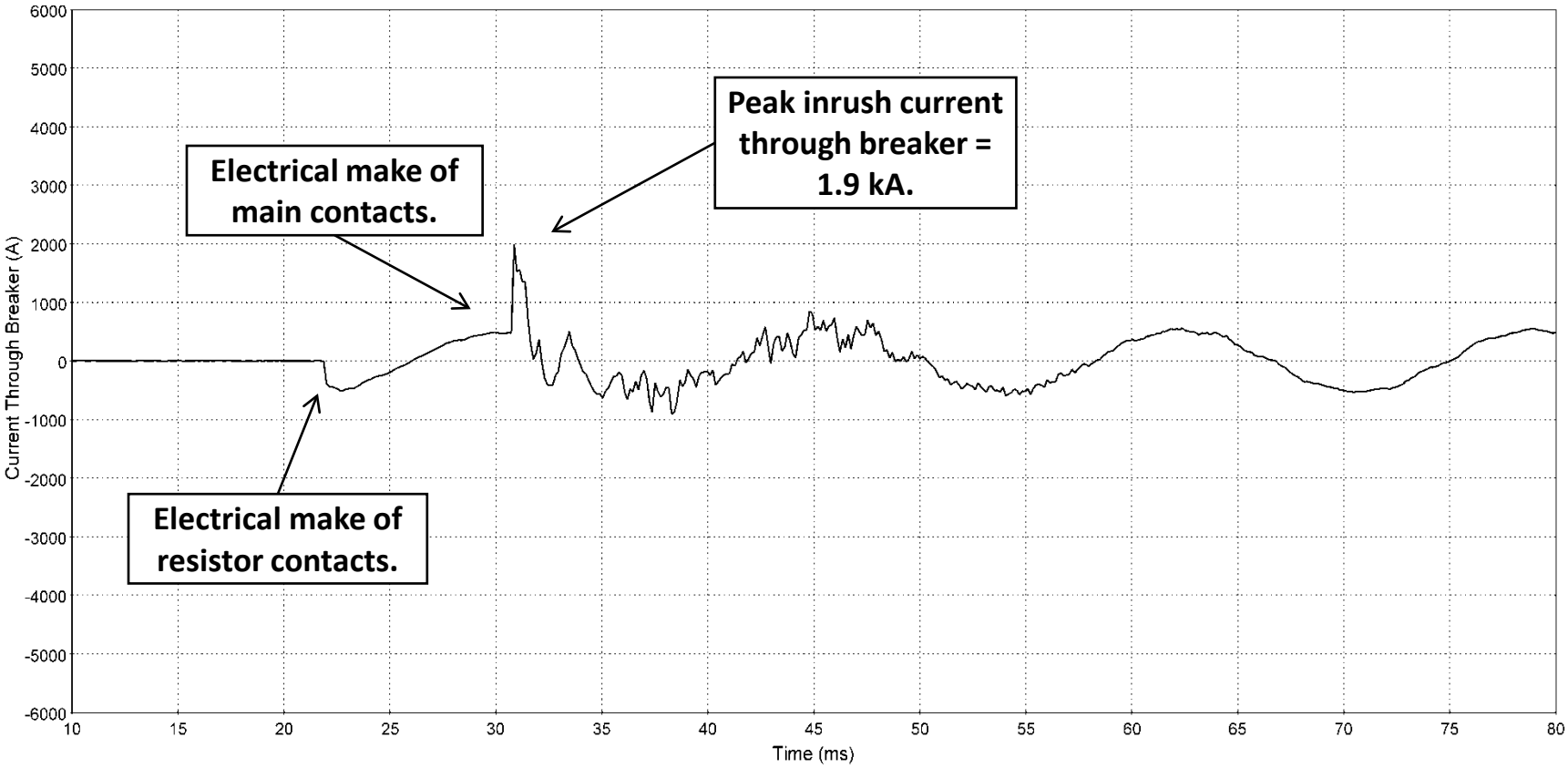
Simulation of the proposed controlled switching strategy optimizing arcing contact inrush



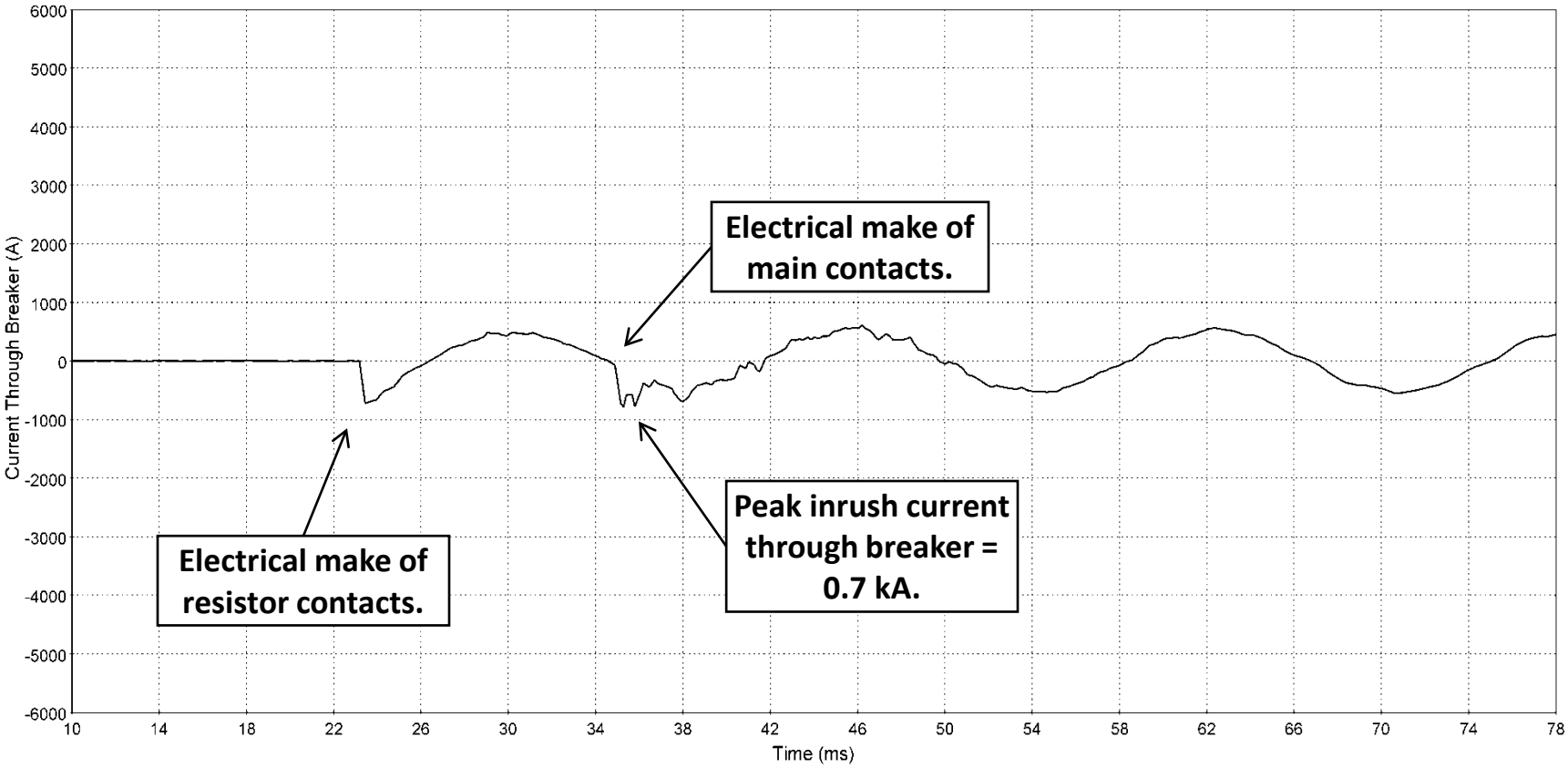
Real world measurements

- Simulations show significant improvement with the new switching target
- Does real data match simulations?
- Simulation:
  - 2.0 kA original inrush peak
  - 0.8 kA new inrush peak
- In-service measurement (average over 15 closes):
  - 1.9 kA original inrush peak
  - 0.7 kA new inrush peak

Measured closing operation with original controlled switching target



Measured close operation with new controlled switching target



Measured inrush current magnitude and pre-strike duration

Date	PEAK INRUSH CURRENT (A)			PRE-STRIKE DURATION (ms)		
	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
Original Target Points						
2-Feb-15	1809	1925	2042	2.1	2.1	2.1
5-Feb-15	2161	1858	1987	2.2	2.1	2.1
9-Feb-15	1907	1889	1894	2.2	2.2	2.1
10-Feb-15	1853	1842	1842	2.2	2.1	2.1
12-Feb-15	1962	2026	1819	2.1	2.2	2.2
Average =		1921			2.1	
New Target Points						
11-Jan-16	792	647	652	0.5	0.4	0.4
11-Jan-16	846	644	745	0.6	0.3	0.6
13-Jan-16	727	631	603	0.6	0.3	0.4
14-Jan-16	914	678	683	0.7	0.5	0.5
14-Jan-16	918	818	826	0.7	0.4	0.7
Average =		742			0.5	

Conclusions

- Simulations match measurements
- Inrush current peak: 1921 A → 742 A
- Pre-strike duration: 2.1 ms → 0.5 ms
- 96% reduction in pre-strike arc energy
  (using i^2t approximation)

- When multiple mitigation strategies are combined, their interactions need to be considered to achieve optimal results