

Coordinated network protection in DC Grids

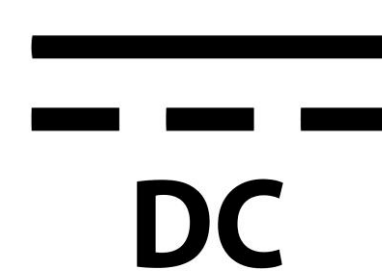
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BACKGROUND & MOTIVATION

Critical Industry Challenges



DC Fault

Lack of zero-crossings causes rapid DC fault current propagation.



Bidirectional Flow

Multi-source power paths making selective isolation difficult..

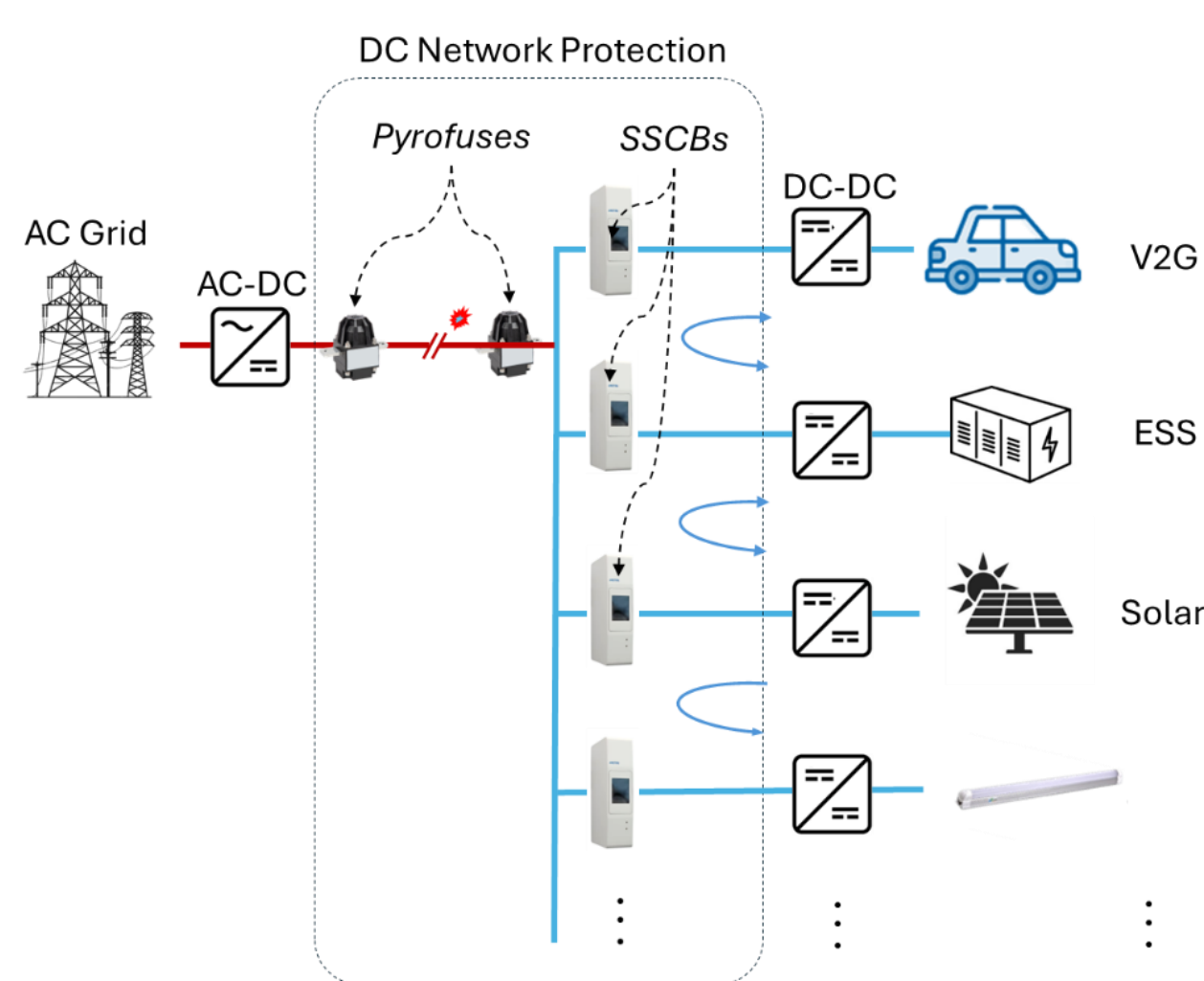


Cost vs Losses

High current SSCBs incur high conduction losses and cost; fuses lack selectivity.

System Architecture

Target Topology: 800V/400kW
bidirectional DC microgrid

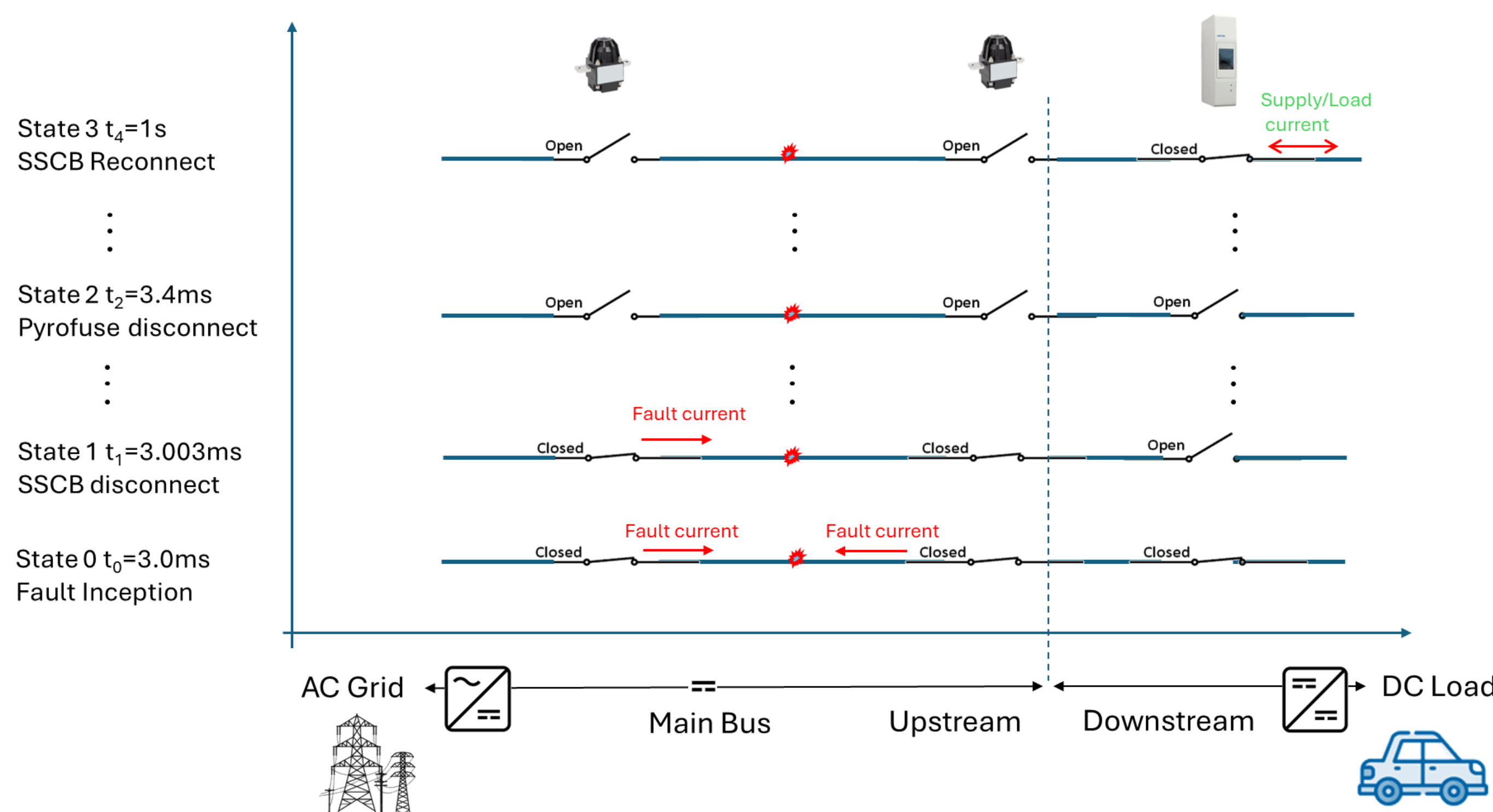


The Proposed Solution:

- Centralized Pyrofuse on main bus + Distributed Branch SSCBs.
- Zero main-bus semiconductor conduction losses
- Communication-Free: Uses protective devices inherent physical speed margins
- Branches can isolate main bus faults and reclose to local ESS backup

PROTECTION & COORDINATION LOGIC

Multi-stage Sequence



Selective Branch Trip:

Local SSCB disconnects in 3us for branch faults; main bus remains fully powered

Main Bus Protection:

SSCBs block back-feed in 3us. Pyrofuse quenches up to 15. kA fault in 350us

Communication-Free Isolation:

Uses natural hardware speed margins (3us SSCB vs. 350us Pyrofuse)

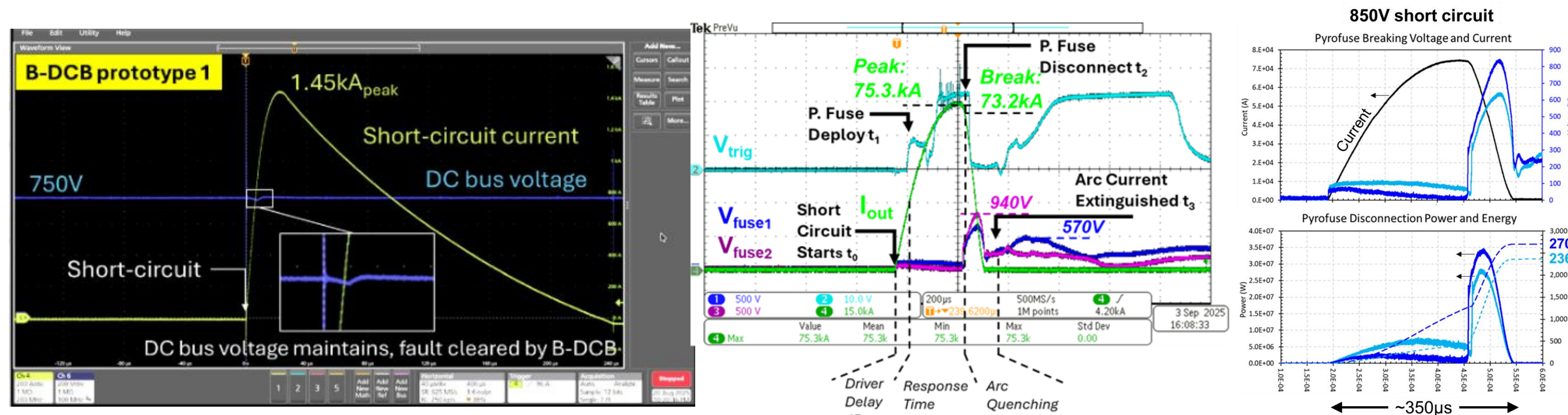
Key Advantages:

- Zero communication latency or signal dependency.
- Eliminates liquid cooling needs on main distribution bus.
- Downstream SSCBs reclose for localized ESS-to-load power backup

References

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EXPERIMENTAL VERIFICATION



Energy Dissipation: Safely absorbs 2360J during main bus fault interruption.

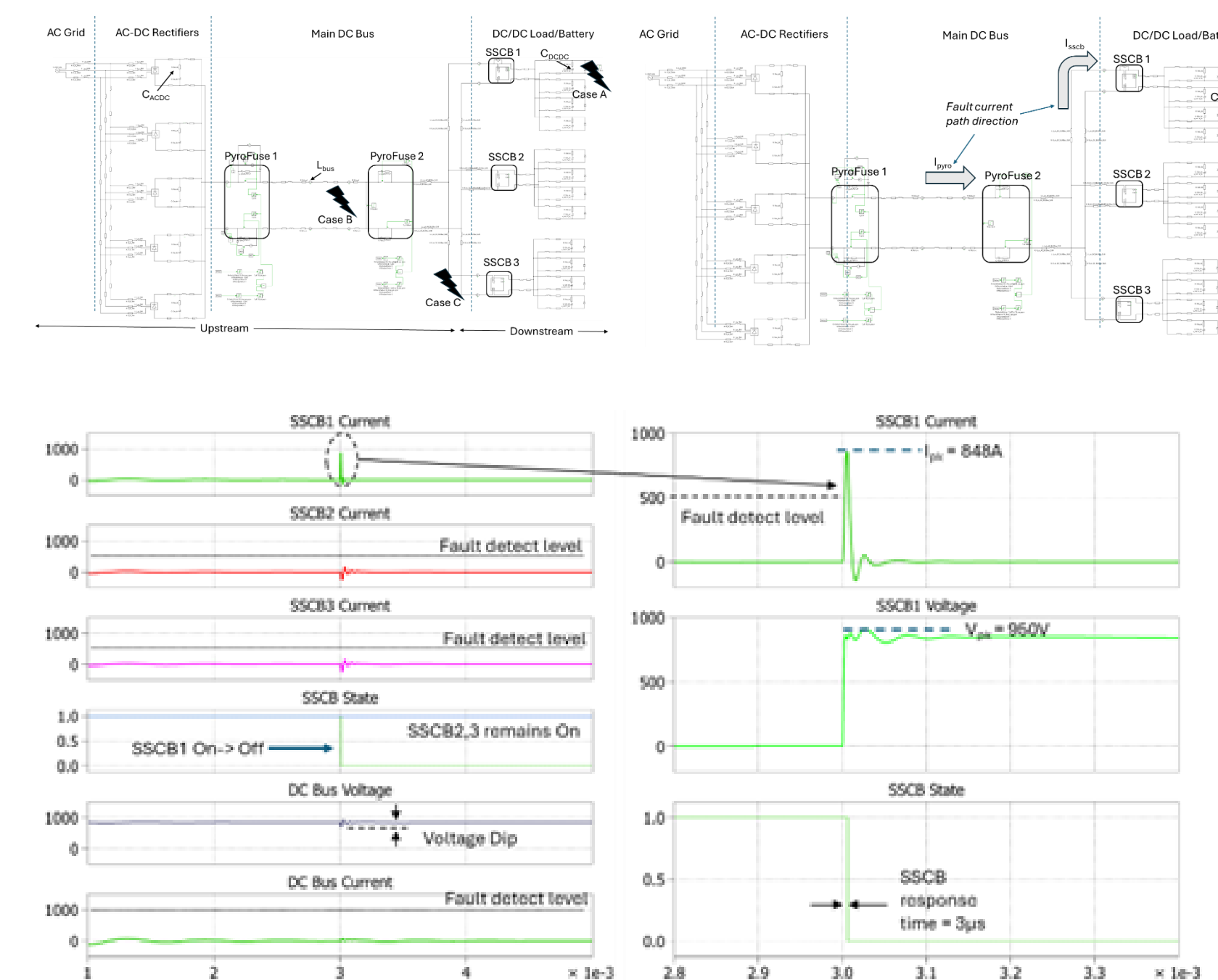
SSCB Transient Response: Limits fault current and clears branch faults in 3us under 800V operation.

Pyrofuse Characterization: Triggering/ignition in 245us, arc quenching in 85us (total clearing ~350us)

SIMULATION & SENSITIVITY ANALYSIS

System Dynamic Waveforms

DC system and network protection parameters for PLECS simulation.



Parameter Description	Variable	Target Value
System Nominal Power Envelope	P_{sys}	400 kW
Main DC Distribution Bus Voltage	V_{bus}	800 V DC
Main Pyrofuse Continuous Current Rating	I_{pyro}	500 A
Main Pyrofuse Fault Detection Threshold	I_{pyro_trip}	1,000 A
Zonal SSCB Branch Current Rating	I_{sscb}	100 A
Zonal SSCB Fault Detection Threshold	I_{sscb_trip}	500 A
ACDC Decoupling Capacitance	C_{bus_acdc}	680 μ F x 5 parallel
ACDC Decoupling Capacitance	C_{bus_dcdc}	55 μ F x 12 parallel
Bus Parasitic Loop Inductance (D=35mm)	L_{bus}	5.6 μ H (5m) 79.0 μ H (50m)

Branch Fault (Case A): Peak current limited to 848A, clamped at 950V

Busbar Fault (Case B): Pyrofuse successfully clears 15.8kA peak surge.

Analysis Finding:

- To evaluate scheme robustness against real-world applications: varying cable lengths, line inductances, and pyrofuse ignition delays
- Longer cables (higher inductance) reduces the fault current rises di/dt
- Proves the hybrid scheme maintains safe operating margins without requiring strict, precise line parameters or response times of pyrofuses

Conclusion

- Ultra-Fast & Coordinated Protection:** Successfully demonstrated a hybrid DC protection architecture combining branch SSCBs and main-bus pyrofuses.
- Zonal Branch Isolation:** Branch SSCBs clear localized short-circuit faults within **3 μ s**, limiting peak fault current and completely preventing voltage dips on adjacent healthy zones.
- Catastrophic Bus Fault Handling:** For severe main distribution busbar faults, centralized pyrofuses safely interrupt grid-level short-circuit currents exceeding **15 kA**.
- Optimal Cost & Efficiency Balance:** The hybrid design significantly lowers overall hardware costs and continuous conduction losses compared to purely solid-state solutions, providing selectively isolated DC power distribution for future DC microgrids and EV charging infrastructure.