Empowering the Grid: Unleashing the Potential of Self-Healing Solid-State Transformers

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RESILIENT POWER

Bridging the Gap in EV Charging Infrastructure

Solid State Transformers; Promises and Challenges

PROMISES

- Advanced substation to enable new functionalities.
- Enhance control of power flow, grid voltage support.
- Increasing reliability, resiliency, efficiency, flexibility and security of the grid.

CHALLENGES

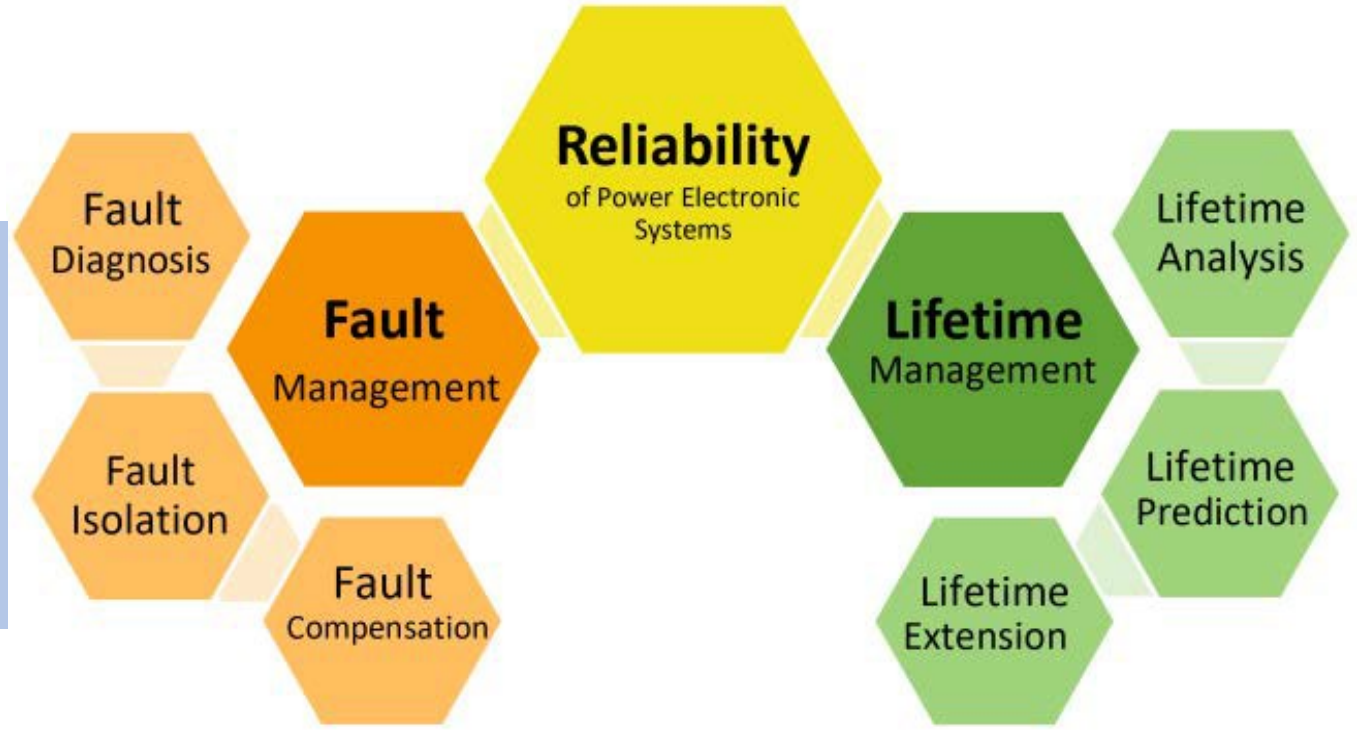
- Reliability
- Cost
- Size
- Stresses from internal and external faults i.e lightning surge and short circuits

Reliability of Power Electronics Systems

Reliability can be discussed from two aspects:

Fault management

It deals with catastrophic faults and how to protect the system.



Lifetime management

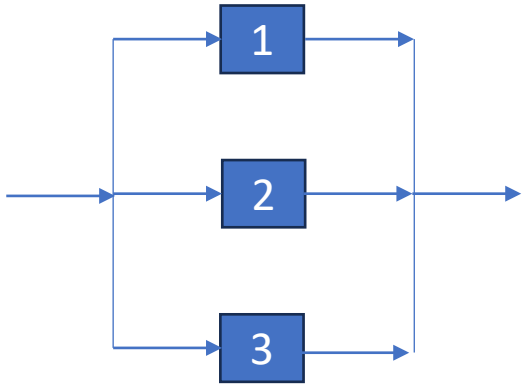
It is about predicting and extending the lifetime of power converter.

S. Rahimpour, H. Tarzamni, N. V. Kurdkandi, O. Husev, D. Vinnikov, and F. Tahami, "An Overview of Lifetime Management of Power Electronic Converters."

Redundancy Improves Reliability

- Serial Reliability
  - Even best components aren't enough
  - $R(t)_{serial} = R_1(t) * R_2(t) * R_3(t)$
  - Example : 0.9 * 0.9 * 0.9=0.73

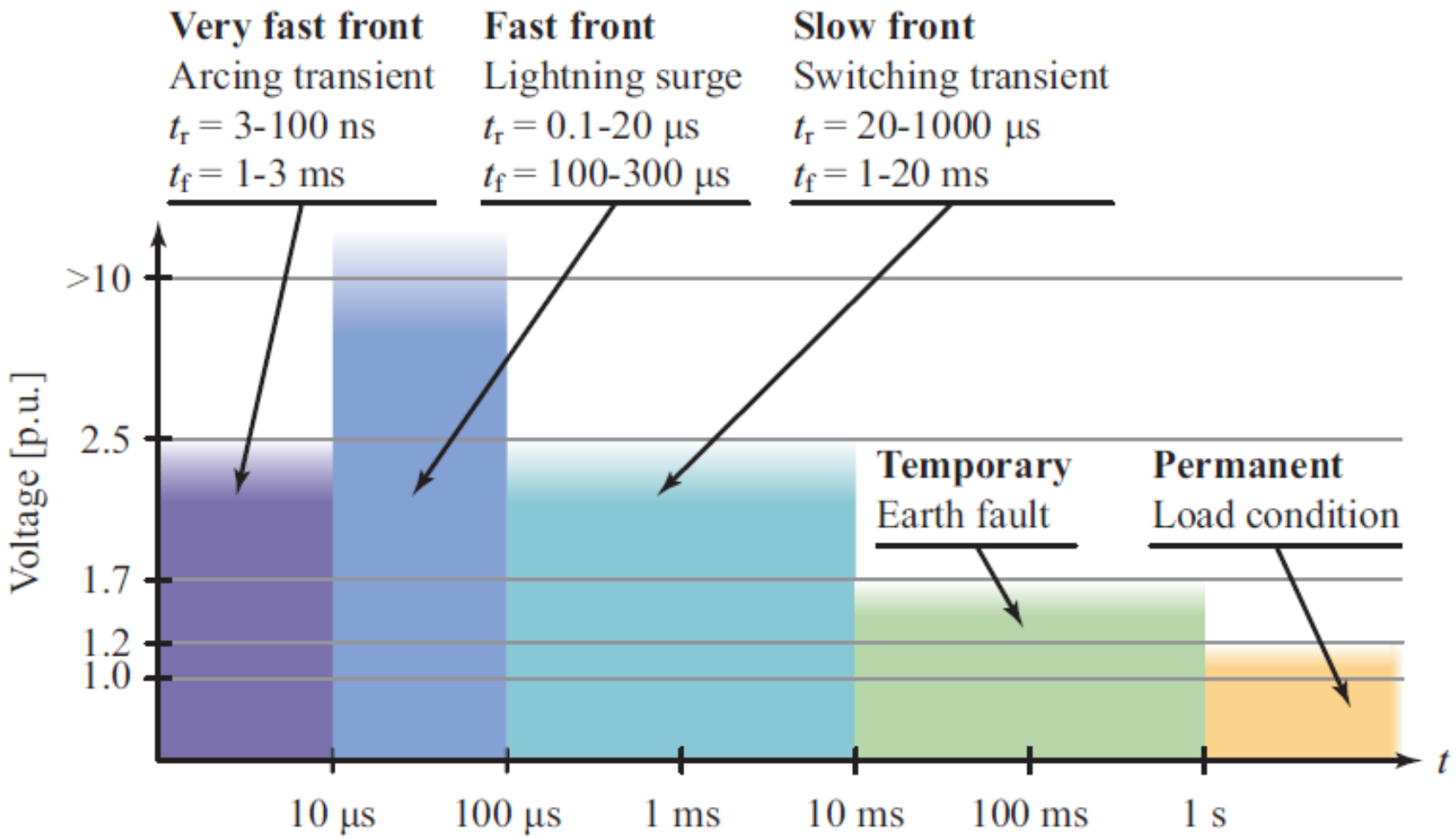
- Parallel Reliability
  - Redundancy improves reliability
  - $R(t)_{parallel} = 1 - [(1 - R_1(t)) * (1 - R_2(t)) * (1 - R_3(t))$
  - Example : 3 @ 0.9= 0.999



SST's components over-stresses

- **Internal faults:** Should not have significant impact on the grid or load
- **Transient Over Voltages:** Such as lightning surge, and switching transients due to capacitor switching and fault clearing
- **MV-side or LV-side faults:** Producing over voltage and over current stresses. The SST control system stops gating in microseconds range.
- **Thermal stresses**

Transient over voltages in MV grid



Guillod, F. Krismer, R. Färber, C. M. Franck and J. W. Kolar, "Protection of MV/LV solid-state transformers in the distribution grid," *IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society*, 2015, pp. 003531-003538.

NERC Guidance on Transient Over Voltages Ride Through for Inverter Based Resources

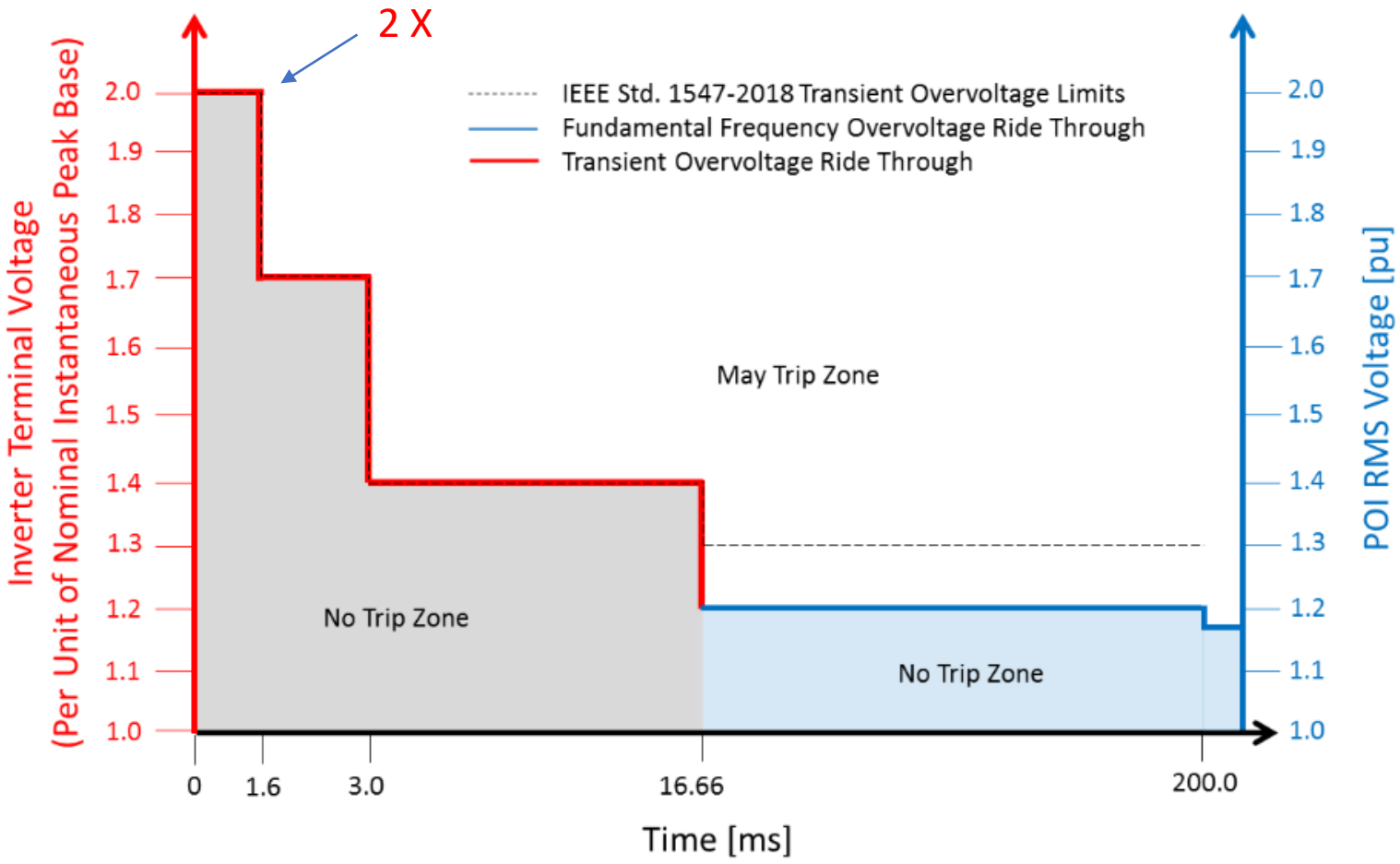


Figure 4.6: Recommended Overvoltage Ride-Through Curve

Table 4.1: Recommended Overvoltage Ride-Through Characteristic

Curve Section	Voltage (pu)	Time (sec)
Instantaneous Inverter Terminal Voltage	≥ 2.000	Instantaneous Trip Acceptable
	≥ 1.700	0.0016
	≥ 1.400	0.003
Fundamental Frequency RMS POI Voltage	≥ 1.200	0.0167
	≥ 1.175	0.20
	≥ 1.150	0.50
	≥ 1.100	1.00

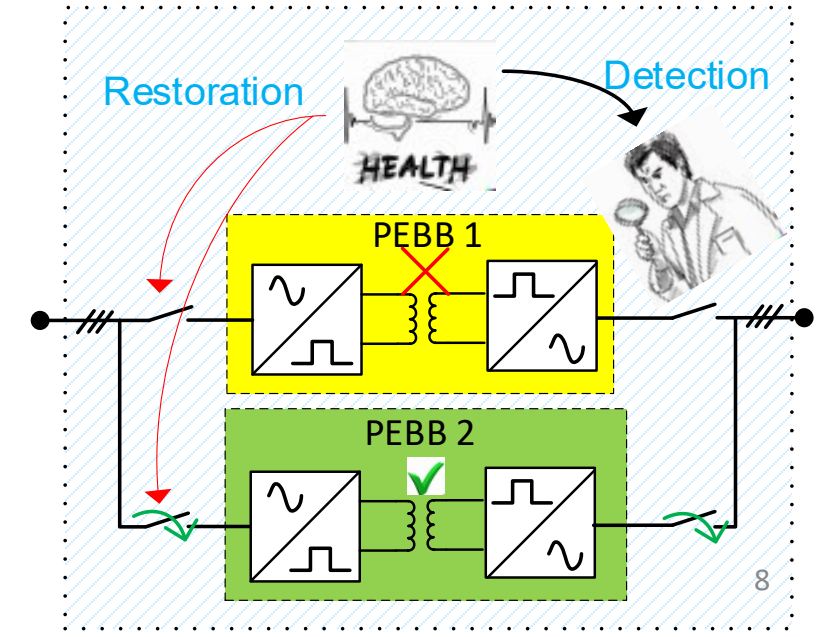
Introducing Self-Healing Solid-State Transformers (SSTs) for Grid Applications

Conventional transformer

- Limited controllability
- Vulnerable to faults

Self-healing SSTs

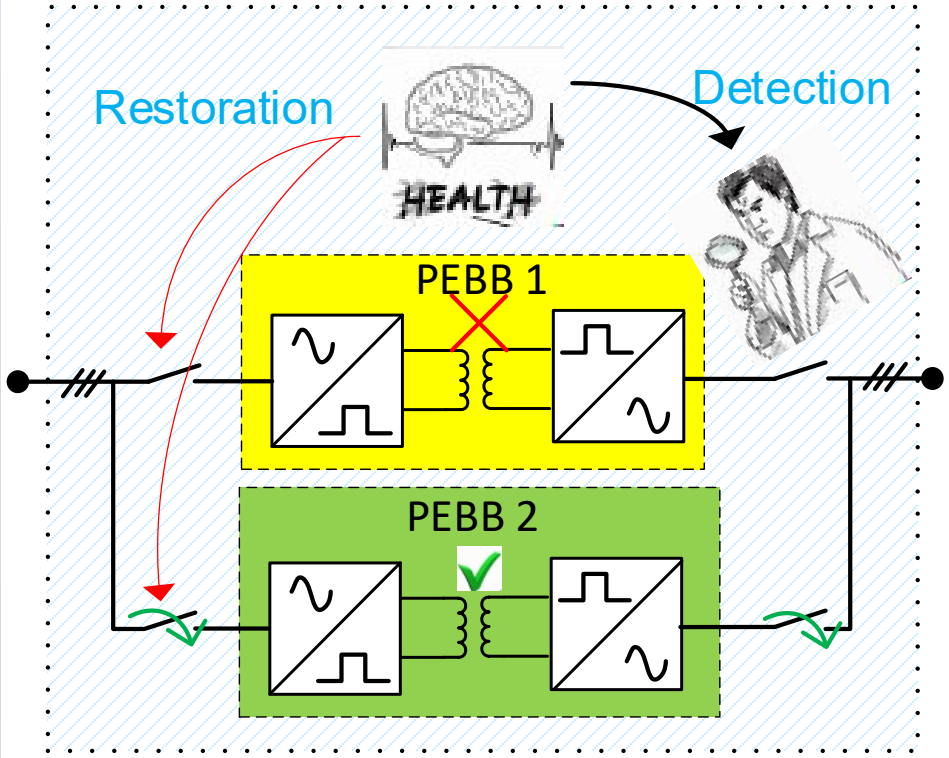
- Combines the functionalities of conventional transformers with advance power electronics control systems
- Automatic fault detection and restoration
- Improved grid resilience, reduced downtime and enhanced fault tolerance
- Integration of SST's with smart grid technologies for efficient power distribution and grid management



What are self-healing SSTs?

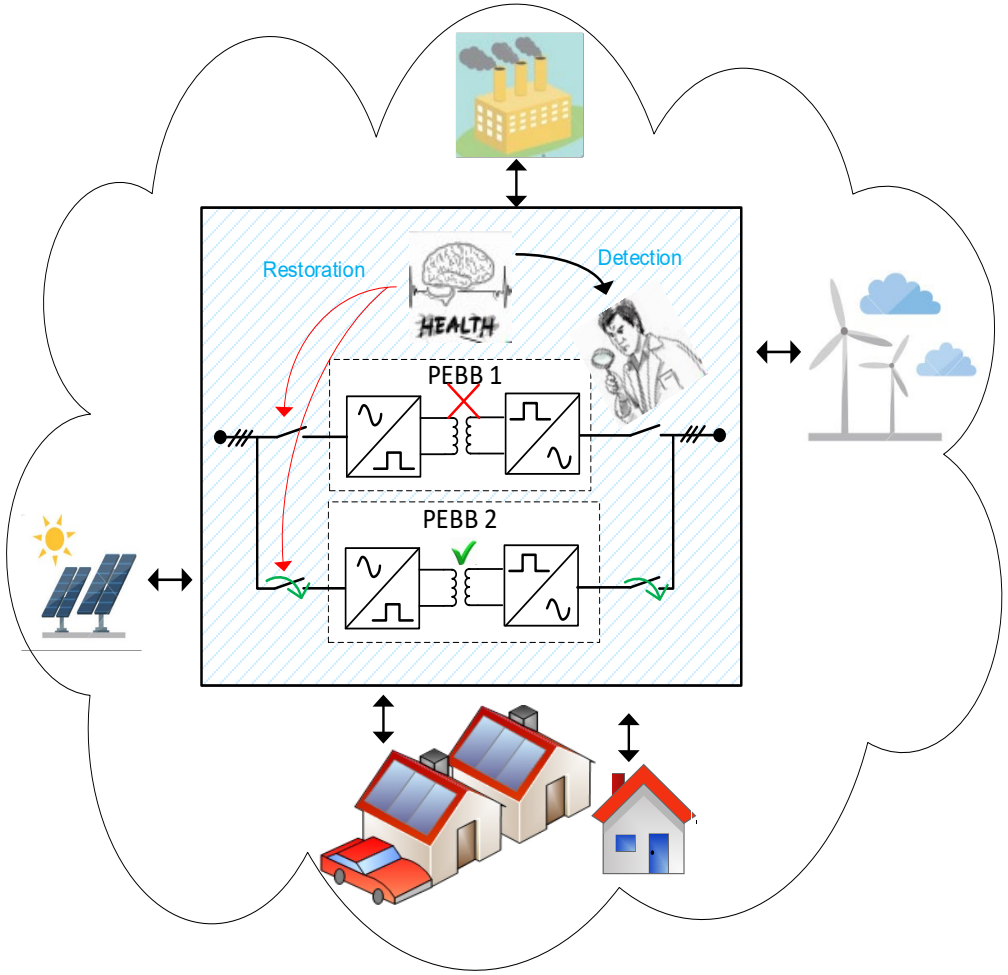
A revolutionary technology leveraging advanced power electronics and control system enabling :

- **Fault Detection and Diagnostics**– *Equipped with sensors and continuously monitor the SST performance and detect any deviations from normal operations.*
- **Isolation and Bypassing of the failure**
- **Adaptive Control and Reconfiguration**– *Dynamic reconfiguration of the SST in response to the faults. It optimizes the power flow and ensures grid's stability.*
- **Fault Repair and Restoration**– *Perform self-repair. Including components re-routing or changing the switching patterns of devices.*



Advantages of Self-Healing SST's in Power Grid

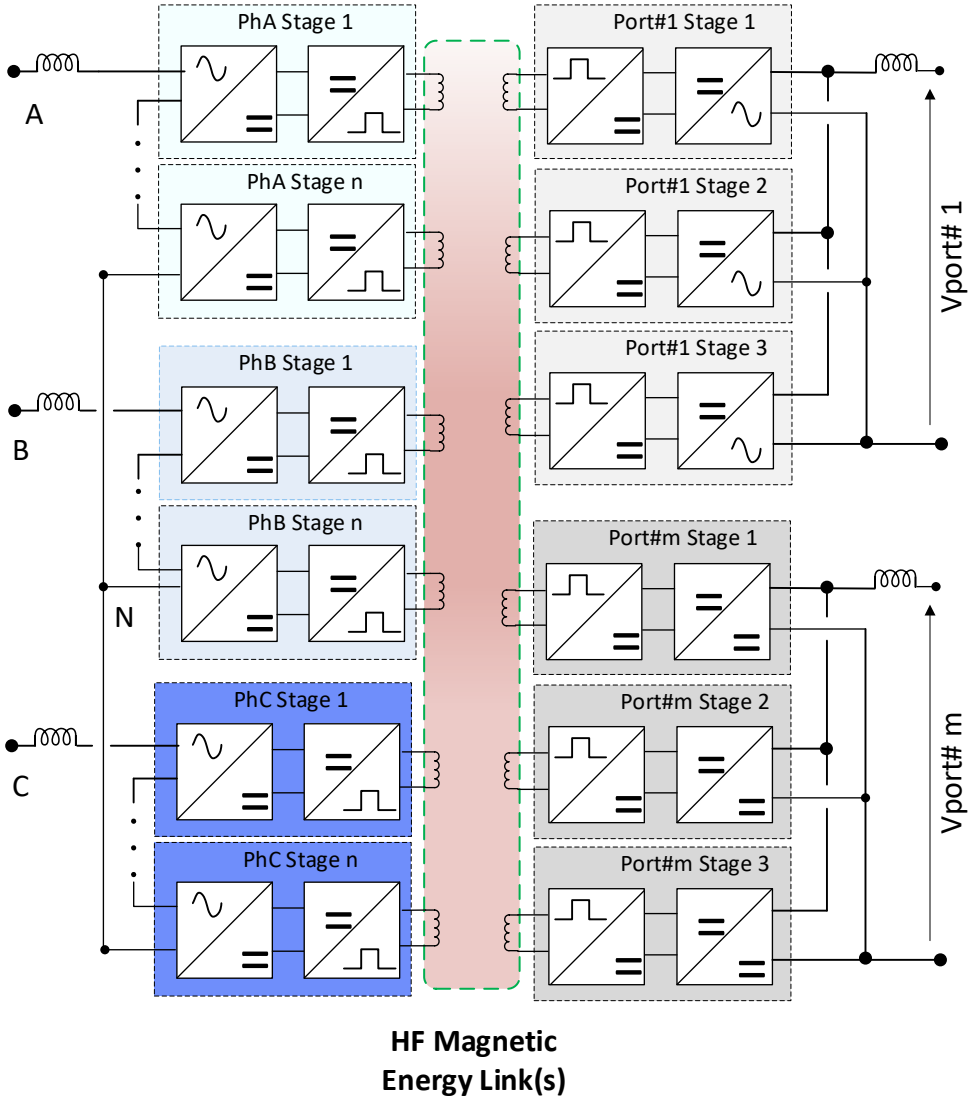
- **Enhanced Grid Resilience and Reliability**
  - Minimized downtime during grid disturbances
  - Reduces the risk of cascading failures
  - Enhances grid stability under challenging conditions
- **Improved Power Quality**
  - Efficient voltage regulation and power flow control
  - Mitigates voltage sags and surges
- **Smart Grid Integration**
  - Seamless integration with smart grid technologies
  - Enables real-time monitoring and control
  - Supports grid management and optimization
- **Cost Savings**
  - Reduces maintenance expenses with self-repair capabilities
  - Minimizes revenue losses due to reduced downtime
  - Long-term savings through enhanced grid performance
- **Future-Proof Technology**
  - Adaptable to evolving grid *requirements*
  - Potential for scalability and upgradability
  - Aligns with the future vision of grid modernization



Power Grid

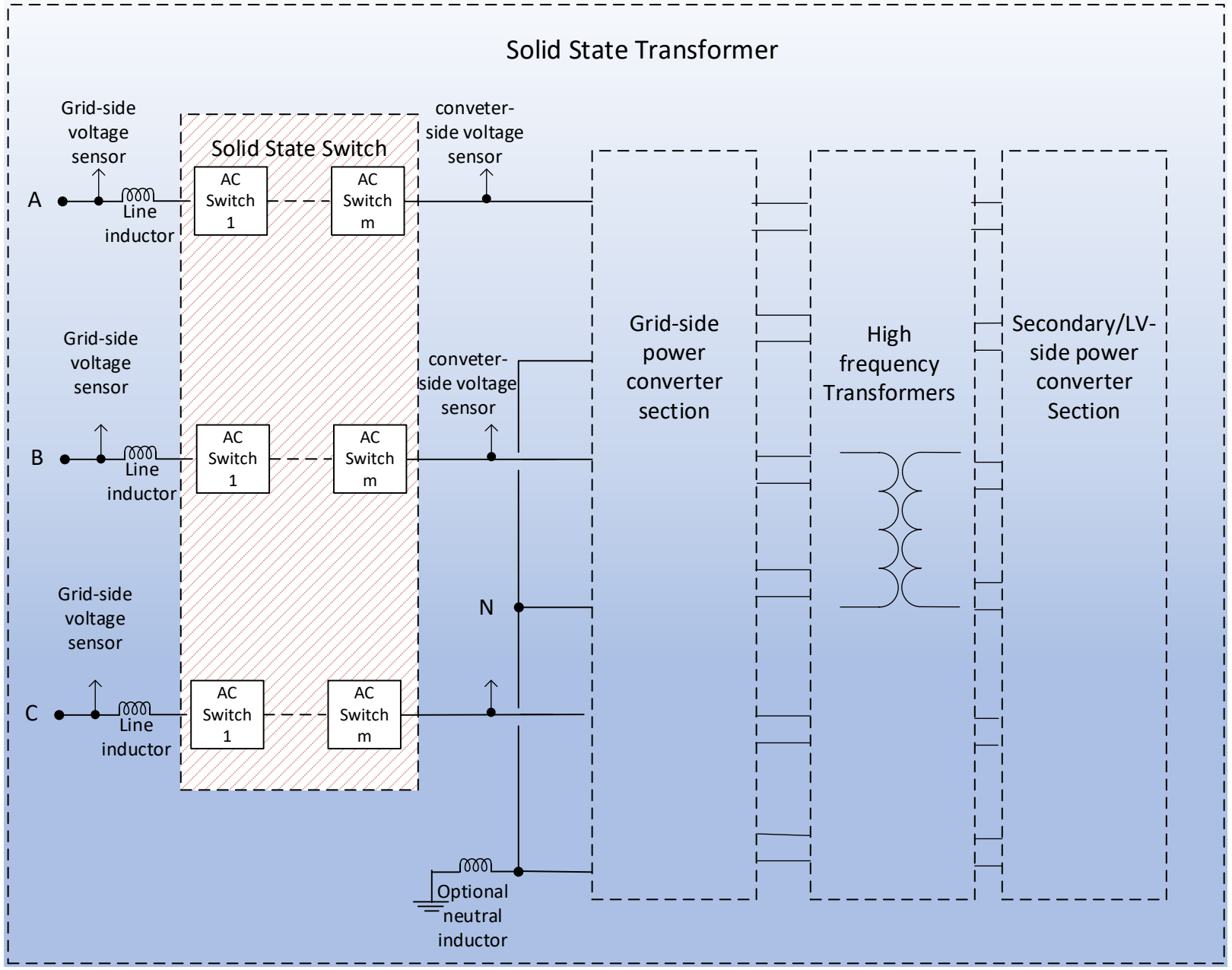
Resilient Power Technology

- Modular and scalable
- **(N+ x) redundancy in each section**
- Use of a common intelligent power module (IPM) throughout converter
- Use of reliable, proven, low-cost low voltage power devices
- Reconfigurable, self healed through redundancy and bypass
- Withstand 2x rated voltage for 1 min
- Magnetic-link and synchronous switching (RPS patent IP)
- Low capacitance in DC bus (Film capacitor)
- Arc flash free on the output ports

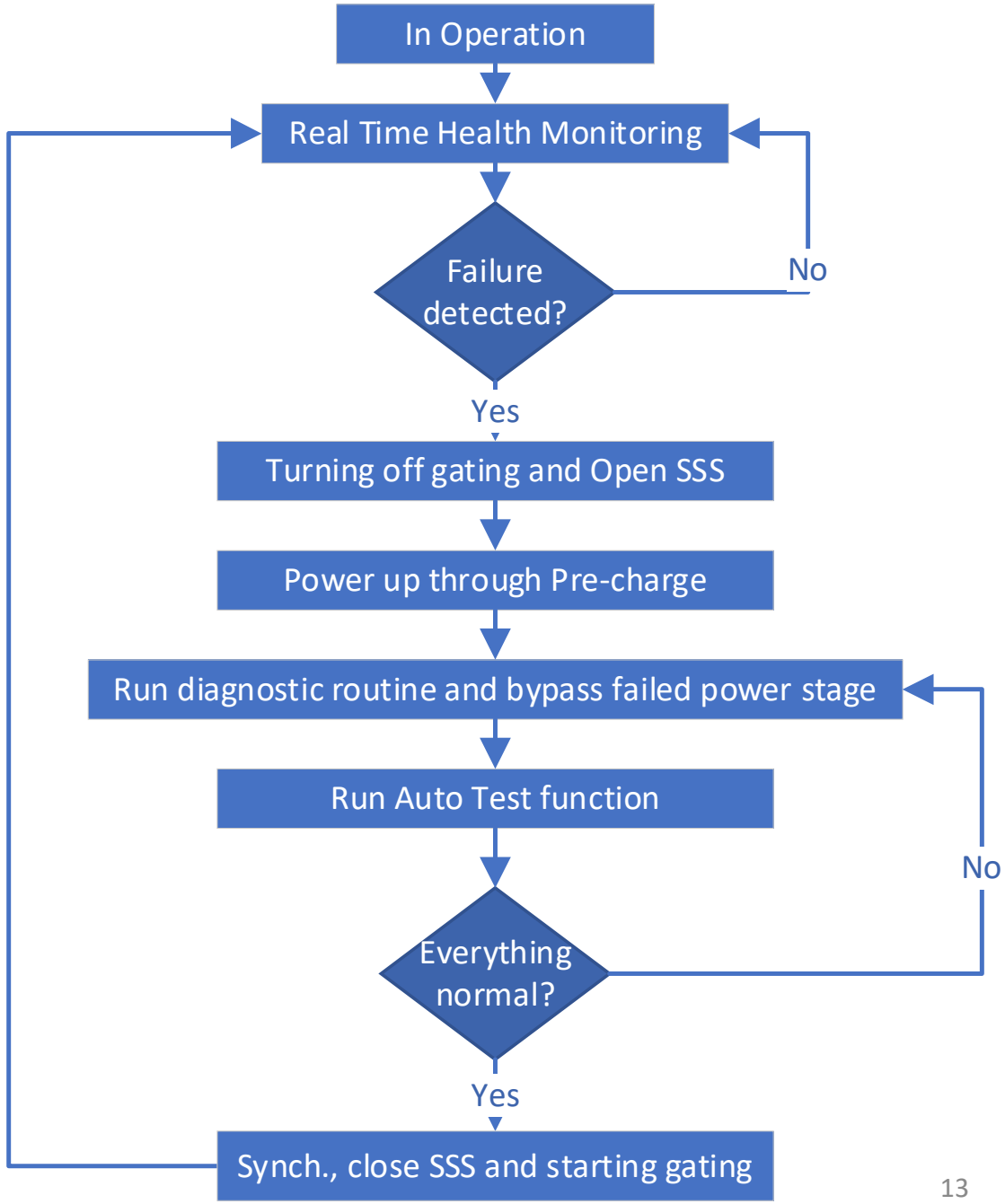


Fault Isolation and Reconfiguration

- **Solid State Switch** *to isolate the failures*
- *Distributed sensors and real time health monitoring(μSecs)*
- *Bypass capabilities within each section*
- *Self-test function at rated voltage with aux. power*



Self Healing Routine



Summary

1. **Challenges in SST Technology:**

   Reliability, size, and cost remain major obstacles impeding the widespread adoption of SST technology.

2. **Redundancy for Enhanced Reliability:**

   Incorporating redundancy in components, such as redundant power modules, significantly boosts the reliability of SSTs and plays a vital role in enabling their self-healing capabilities.

3. **Stress-Resistant SSTs:**

   SSTs demonstrate remarkable endurance against internal failures, grid faults, and transient overvoltages caused by switching or lightning through robust component monitoring and self-healing capabilities.

4. **Real-time Component Monitoring:**

   The Self-Healing SST efficiently detects faults, performs isolation, reconfiguration, and promptly restores service by continuously monitoring its components in real-time.

5. **Empowering Grid Resilience:**

   Self-Healing SSTs offer unmatched reliability, enhance grid resilience, and seamlessly integrate into smart grids, paving the way for a robust and efficient power distribution system.