Resilient Energy Systems
Mission Campaign

DEVELOPMENT OF SANDIA'S LOW-MODULATION-INDEX 3-PHASE SOLID STATE TRANSFORMER TECHNOLOGY

Solid-state transformer (SST) technology continues to be the subject of intensive research, building on work over the past 15 years. SST technology is vitally important to both grid modernization and future grid resilience. However, SSTs cannot replace conventional transformers and be successfully commercialized until they can simultaneously meet several demanding application requirements. Sandia's "low-modulation-index 3-phase solid-state transformer (LMI3-SST)" technology is intended to address current obstacles to wide-spread adoption and provide the first commercially viable SST circuit topology.

THE CHALLENGE

The high-speed, low-loss, high-voltage, high-current semiconductor switches required to implement SST technology tend to be expensive, and relatively limited in voltage capability. Moreover, ohmic and other losses in such semiconductor switches impose limits on solid-state transformer efficiency, power handling capability, and scalability. Yet another difficulty in the implementation of solid-state transformers is the high potential for generation of electromagnetic interference (EMI), such as that which plagued early switching power supply circuit designs, despite operating at relatively low power levels. Finally, any proposed solution to simultaneously address all the above challenges must also meet extremely stringent cost and long-term reliability requirements. The challenge is then to develop and execute an approach that can enable mass producing a solid-state transformer that can meet all the disparate but non-negotiable requirements of real-world applications.

APPROACH

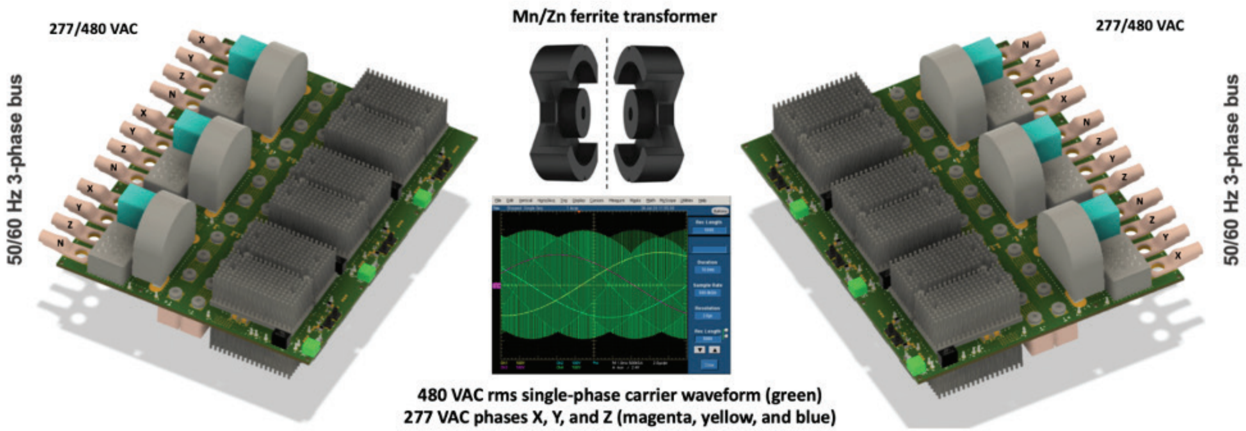
Extensive scoping of both market and technology landscapes confirm that the successful introduction of first-generation ac/ac SSTs is key to initial market acceptance of SST technology. High-volume sales of first-generation ac/ac SSTs is required to (1) overcome skepticism of SST technology and (2) stimulate aggressive investment in wide-bandgap semiconductor switches with reduced on-state resistance and increased voltage-handling capability while also driving down per-unit cost. This is important for wide-scale deployment of ac-ac SST technology, which will confer many immediate benefits from the standpoint of grid modernization and grid resilience. These benefits include addressing threats related to EMP weapons, Coronal Mass Ejections, and the problem of very long lead times for replacement of damaged transformers.

Conventional wire-wound steel transformers require grid assets, distributed over hundreds of thousands of square miles, always remain locked in frequency and phase. The fragility of the resulting system makes it widely vulnerable to various threat scenarios. As conceived in a longer-term technology development roadmap, second-generation ac/dc/ac SSTs will provide important additional electrical grid functionality, most notably the ability to arrest propagation of cascaded outages. Other benefits of ac/dc/ac technology include low-cost VAR support to further stabilize the grid, and the more natural integration of dc assets such as PV solar generation, electric vehicles, and battery storage. Improved solid-state switch technology will be realized in second-generation, ac/dc/ac SST technology, which place even greater demands on semiconductor switch performance.

Accordingly, the focus of FY22 R&D is the design, construction, and testing of a 100-kW ac/ac SST based on the LMI3-SST circuit topology. In addition to 100-kW operation, other goals include achieving 98.0% efficiency at full operating power, as well as regulatory compliance for conducted EMI.

EXPECTED RESULTS

Investments made by the Resilient Energy Systems Mission Campaign to date has allowed our technical team to undertake a comprehensive study of prior art SST technology and devise a circuit topology to simultanseously meet requirements for cost, efficiency, EMI regulatory compliance, voltage scalability, and operating lifetime. During FY22, the LMI3-SST team will focus on construction and testing of 100-kW demonstration unit that targets 98% efficiency and full EMI regulatory compliance. Results will be published in



Sandia's patent-pending LMI3-SST architecture is a fully bidirectional circuit topology that optimizes MOSFET usage and transformer losses.

The LMI3 switching algorithm converts 50/60 Hz three-phase power to a single-phase high-frequency carrier waveform that is coupled through a ferrite transformer, followed by mirror-image demodulation back to 50/60 Hz ac power.

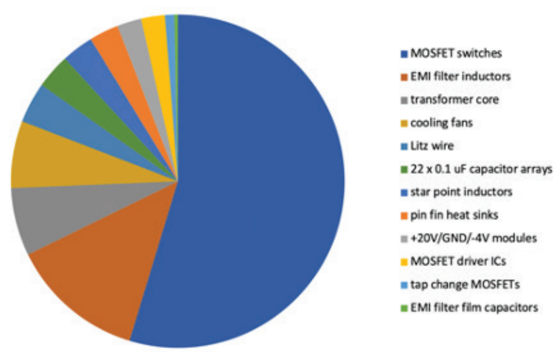
IEEE Transaction on Power Electronics. Addtionally, the 100-kW prototype will be used to engage potential commercial partners in conjunction with Sandia Tech Transfer. Follow-on R&D would include work to demonstrate voltage scalability, 40-year service longevity (via accelerated lifetime testing), and advanced thermal management. Concurrent Techno-economic anlaysis will continue to be a guiding force throughout this R&D effort and commercialization effort.

EXPECTED IMPACT OF THIS RESEARCH

If successful, the proposed 100-kW SST demonstration will be without precedent, signaling to potential commercial partners that real-world SST technology is coming to fruition. Beyond FY22, the proposed research lays out a complete roadmap to achieving the ultimate objective of second-generation ac/dc/ac SSTs. The techno-economic viability of the proposed technology, in conjunction with large-scale and enduring market demand will drive industry participation. Sandia's initial role is to demonstrate to the electric ultility, transformer manufacturers, semiconductor industries, and regulatory bodies, that a viable pathway to SST proliferation exists.

Sandia's investment in this project is part of its Resilient Energy Systems (RES) portfolio of projects, coordinated R&D that addresses the resiliency of the nation's energy systems. Earlier strategic investments made by RES were used to rigorously prove the hypothesis that solid-state transformer technology can exert a profound effect on grid resilience. SST circuit topology R&D undertaken under RES leadership is unique in its holistic approach to ensuring that all real-world application requirements are met.

Cost breakdown of major system components:



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