DOE Office of Electricity TRAC

Peer Review

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

PROJECT SUMMARY

Modular Hybrid Solid State Transformer for Next Generation Flexible and Adaptable Large Power Transformer

- Develop and demonstrate a modular Hybrid Solid State Transformer (HSST) for next generation Flexible and Adaptable large power transformer (LPT)
- Demonstrate advanced control functions of the H-SST that is currently not available in traditional transformers

PRINCIPAL INVESTIGATORS

Alex Qin Huang, Professor,
Semiconductor Power Electronics Center
The University of Texas at Austin

WEBSITE

https://spec.ece.utexas.edu

Project Participants

Project Advisors

The Numbers

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
DE-FOA0001876

LOCATION:
Austin, Texas

PROJECT TERM:
03/18/2019 to 5/31/2022 (With NCE)

PROJECT STATUS:
Incomplete, No Cost Extension

AWARD AMOUNT (DOE CONTRIBUTION):
$1,730,000

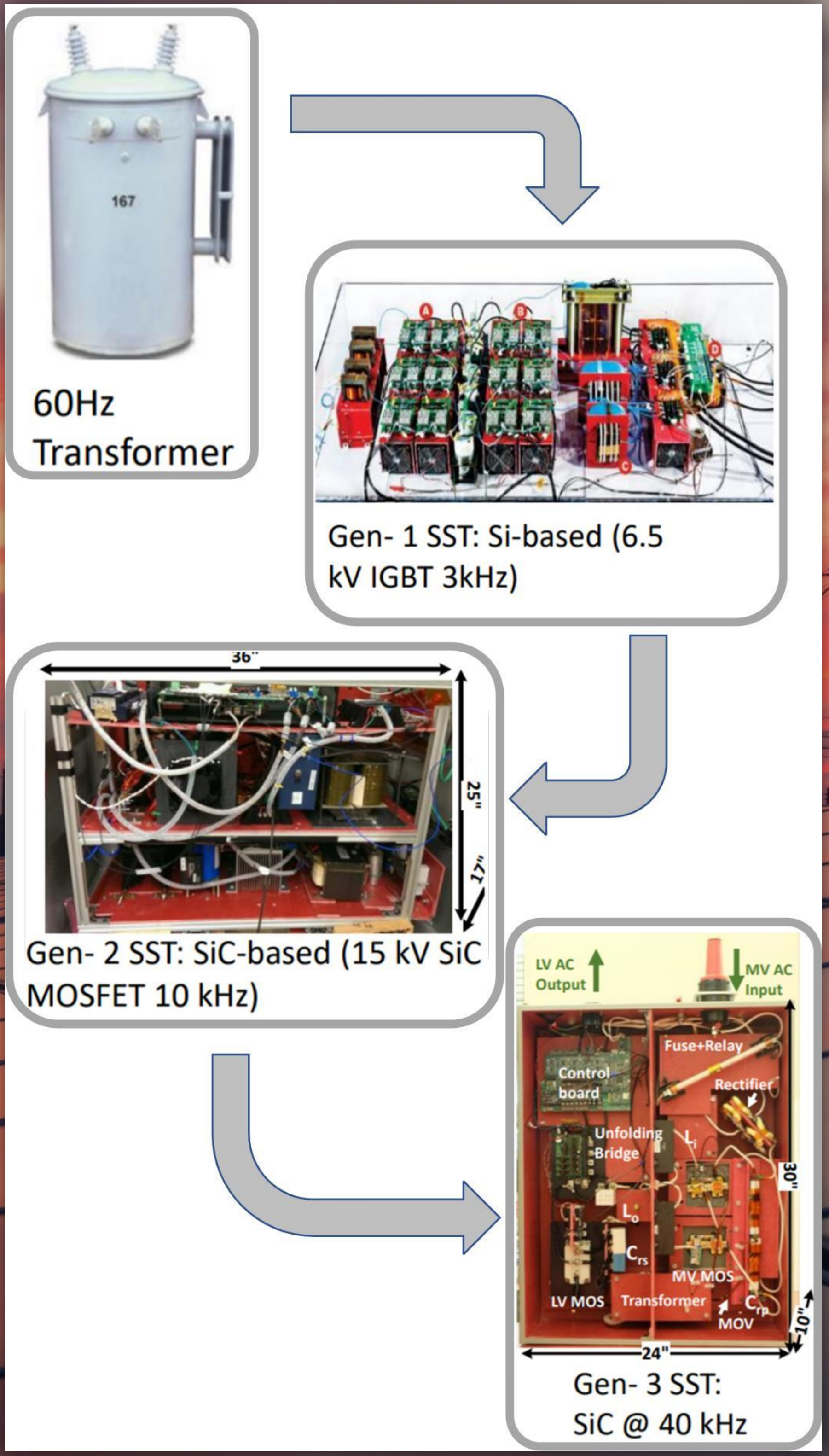
AWARDEE CONTRIBUTION (COST SHARE):
$433,000

Motivation

- Transformers have been a mainstay of power grids for over a century, utilizing large amount of materials (iron/copper etc). Very reliable, efficient and cost effective.
- However, they are passive, offering no controllability such as voltage regulation or power flow control, or protection against harmonics and other grid disturbances
- Integration of renewables is also a challenge
- Large Power Transformers further have several logistical issues – large, heavy and bespoke – requiring large turn around time. Not easily transportable or replaceable

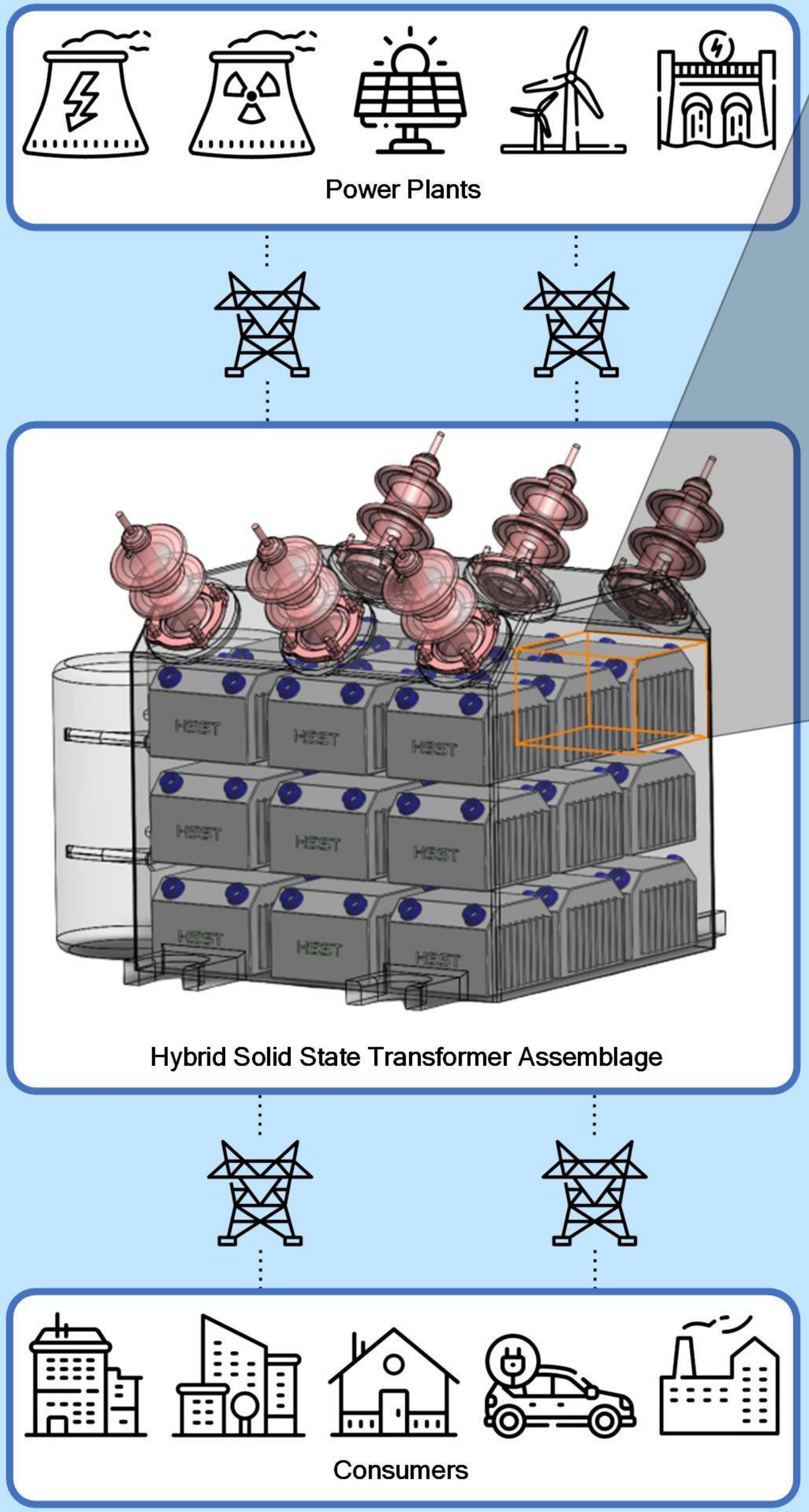
Motivation

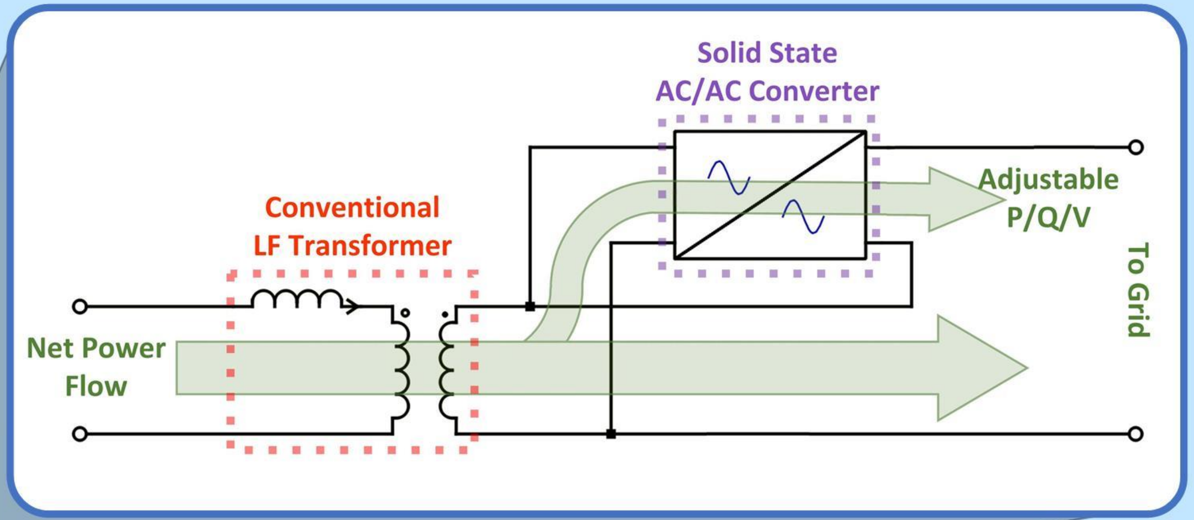
- Solid State Transformers (SSTs) have been touted as a respite, offering not only a whole array of controllability, but also smaller in size and weight
- With advent of wide band gap devices, SSTs are approaching LFT efficiencies while offering broad range of control and flexibility
- However, large costs and issues at scaling to higher voltages and powers have resulted in slow adoption of the SST in T&D applications. Adoption in distribution system is expected first



Thus presenting ……

The Hybrid Solid State Transformer

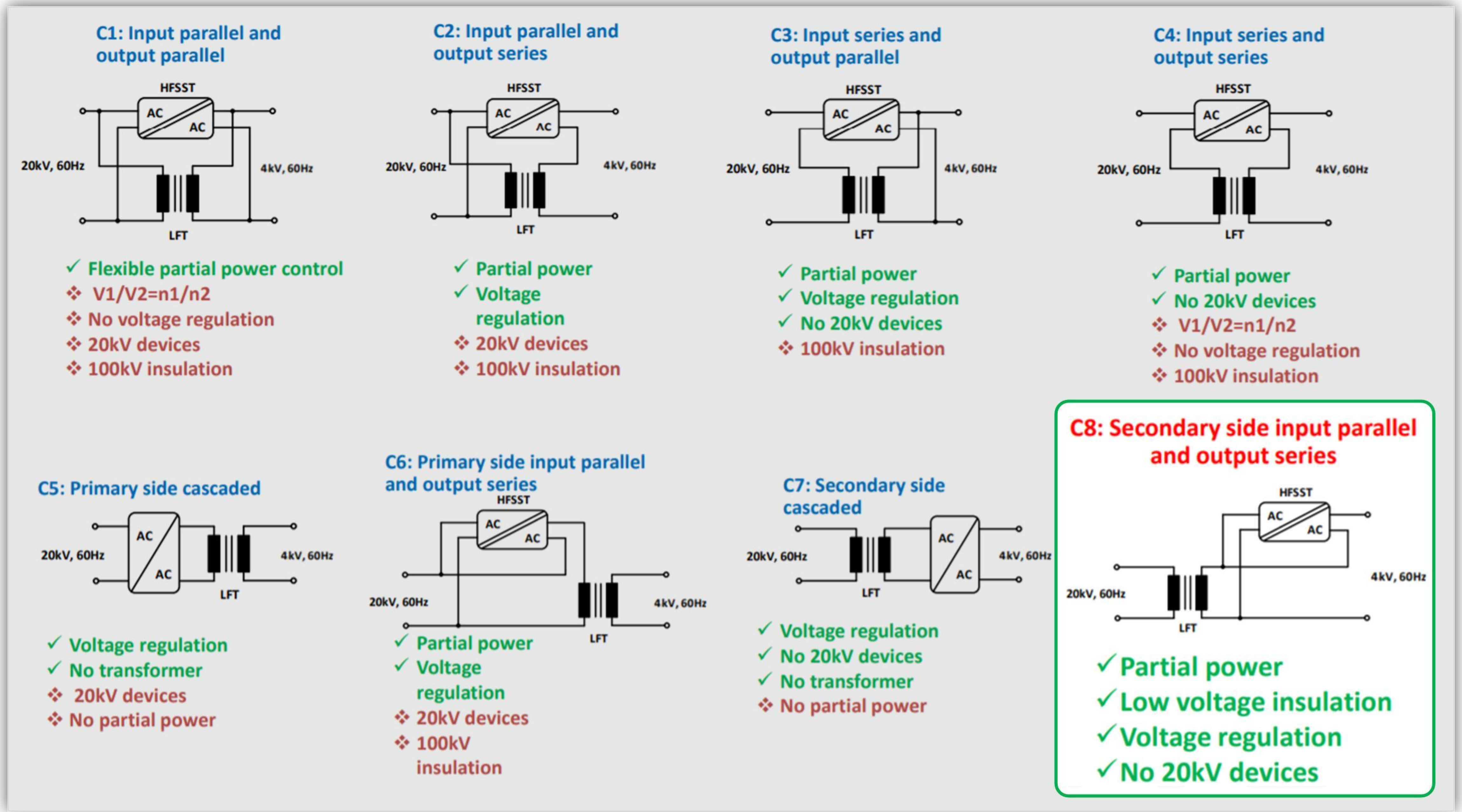




- Modular, standardized designs pave way for faster deployment time
- Lower costs thanks to possibility of mass production and hybrid design philosophy
- Swappable and fast deployable units improve system reliability and resiliency
- Advanced control provide additional protection and power flow functionalities
- Compact and lightweight units aid in transportation and logistics

Primary Innovation

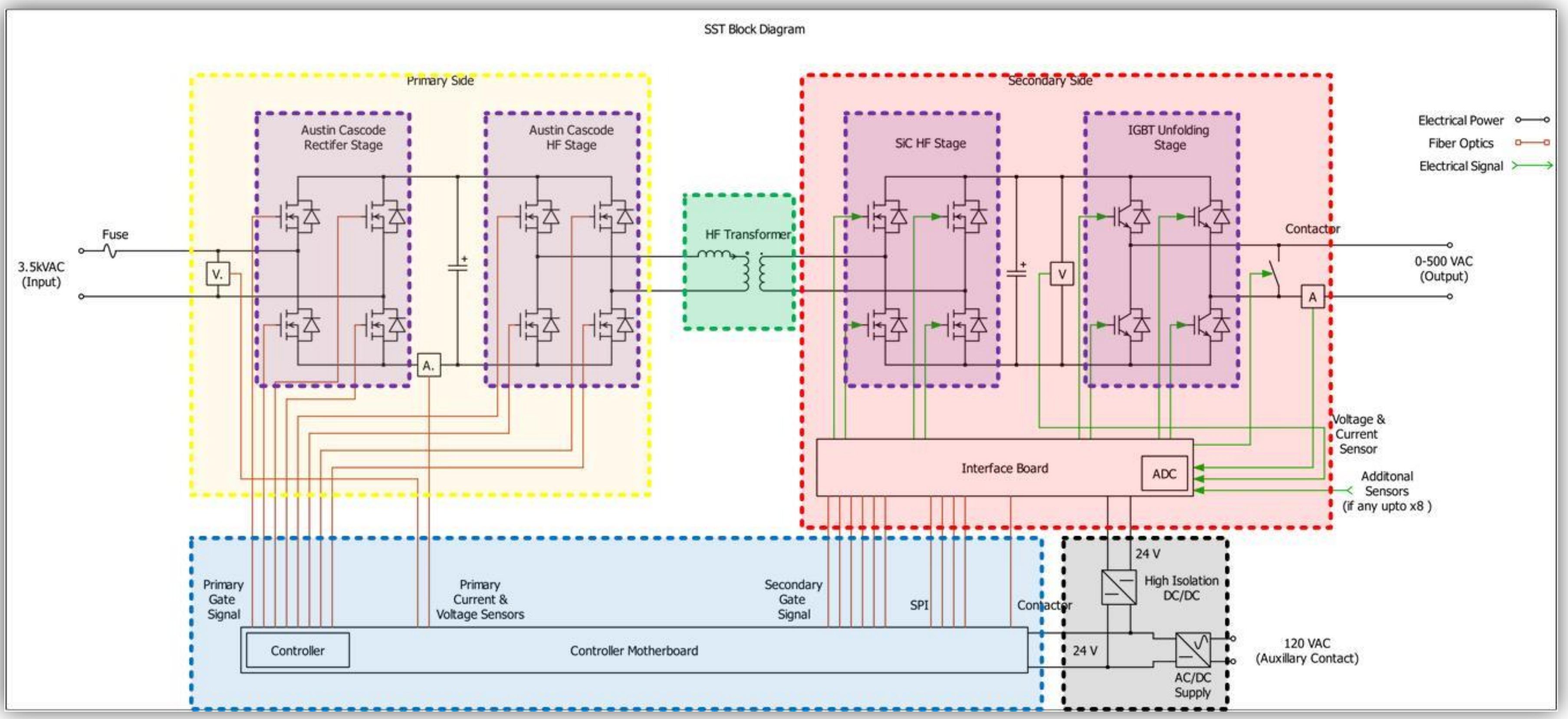
The suitable HSST configuration



Innovation Update

The MV AC-AC SST

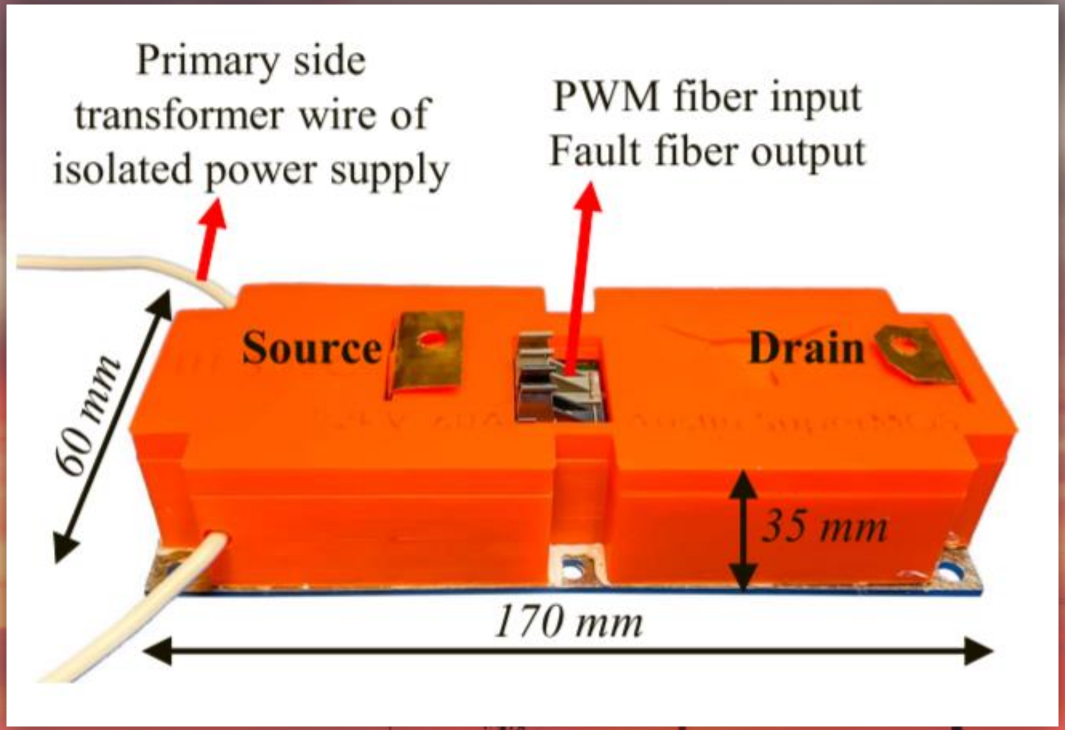
- A single stage Dual Active Bridge based AC-AC SST
- Inherent ZVS operation to keep efficiency high
- High power density due to lack of bulky DC Link capacitors
- Direct MV to LV AC conversion avoids the need for 60Hz transformers or auxiliary windings

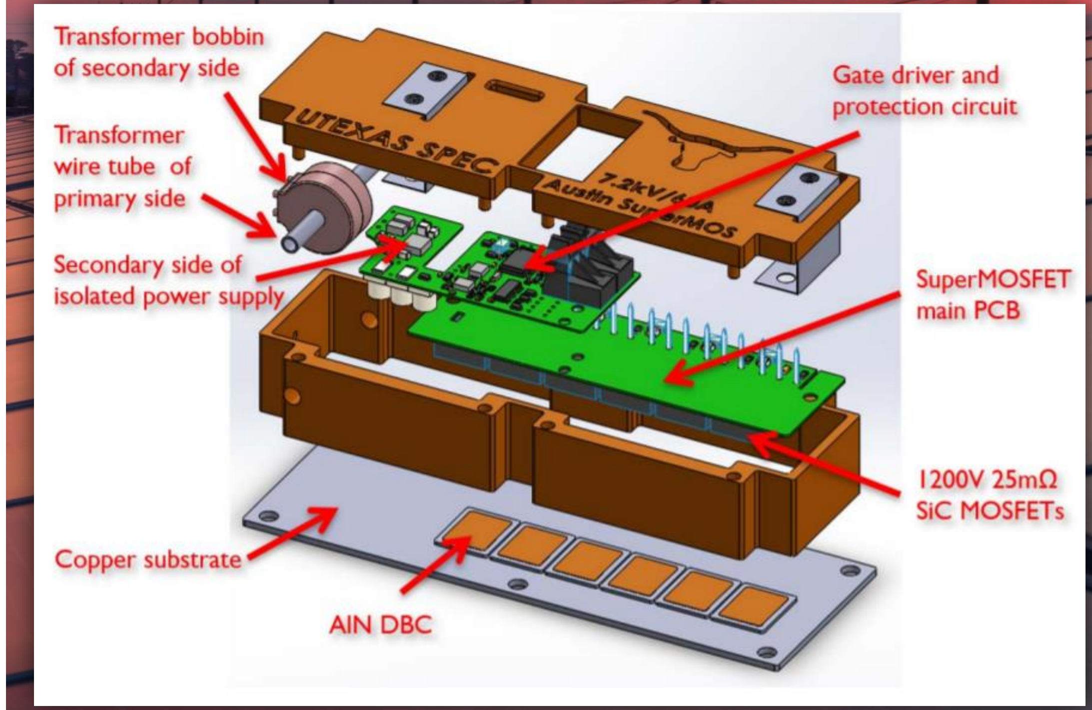


Innovation Update

The 7.2kV SiC Austin SuperMOS

- UT Austin developed low cost and high performance medium voltage switch serves as a key enabler for medium voltage SST applications
- Integrated gate driver with overcurrent protection and highly isolated power supply
- High blocking voltage with low on-resistance (7.2kV / 60A / 0.18Ω)
  - Future developments (leveraging other funding) underway for even higher voltage and current devices

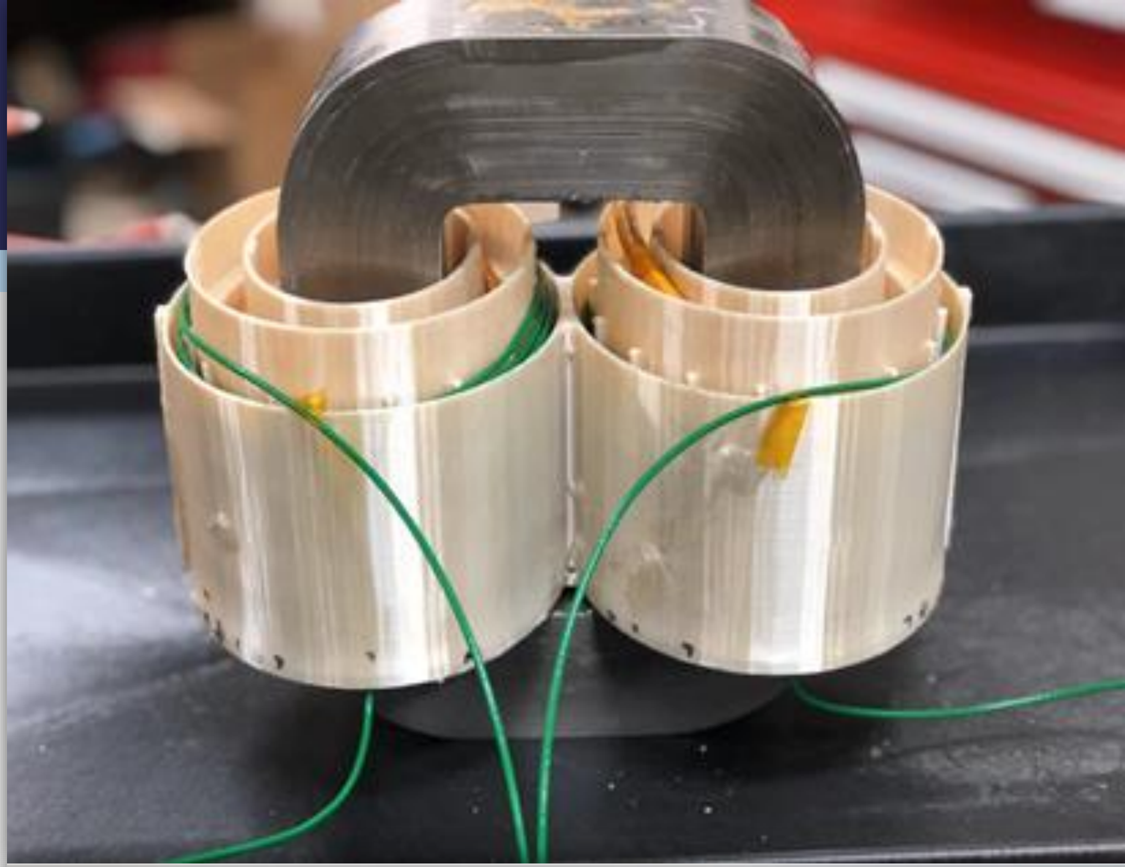


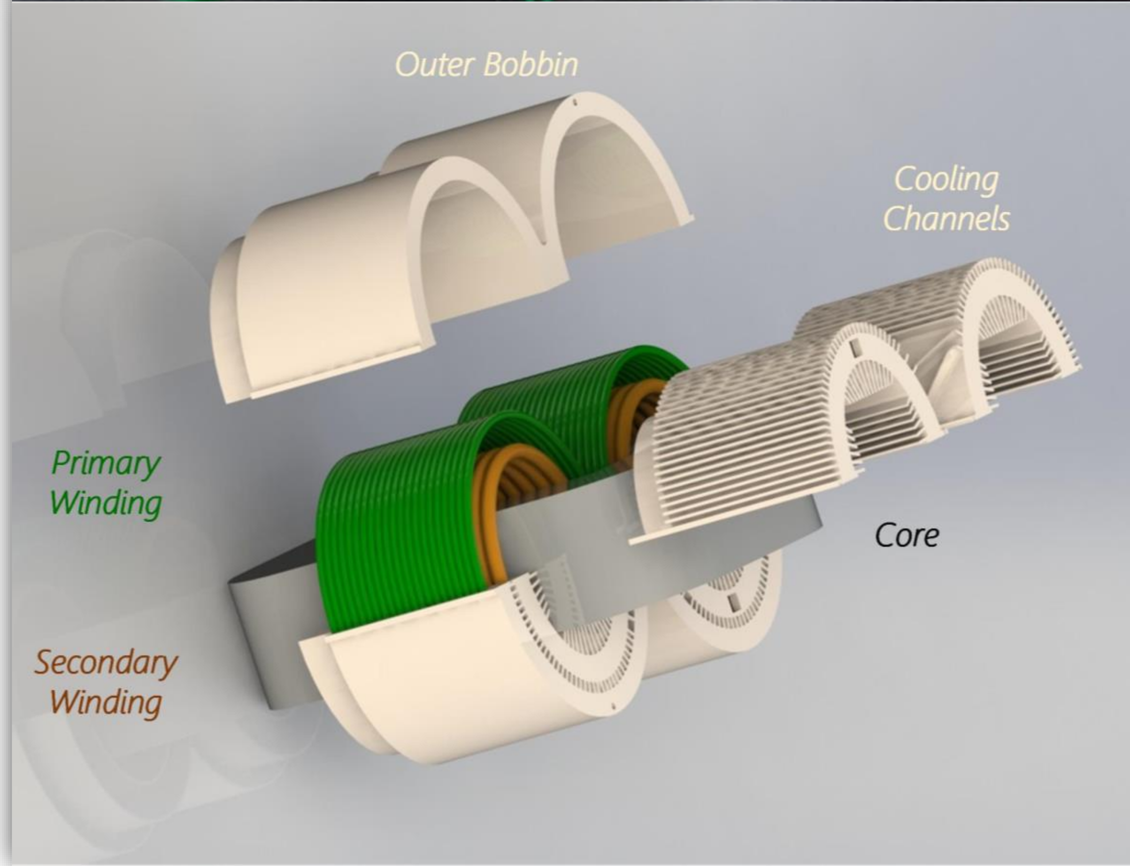


Innovation Update

The High Frequency and High Isolation Transformer

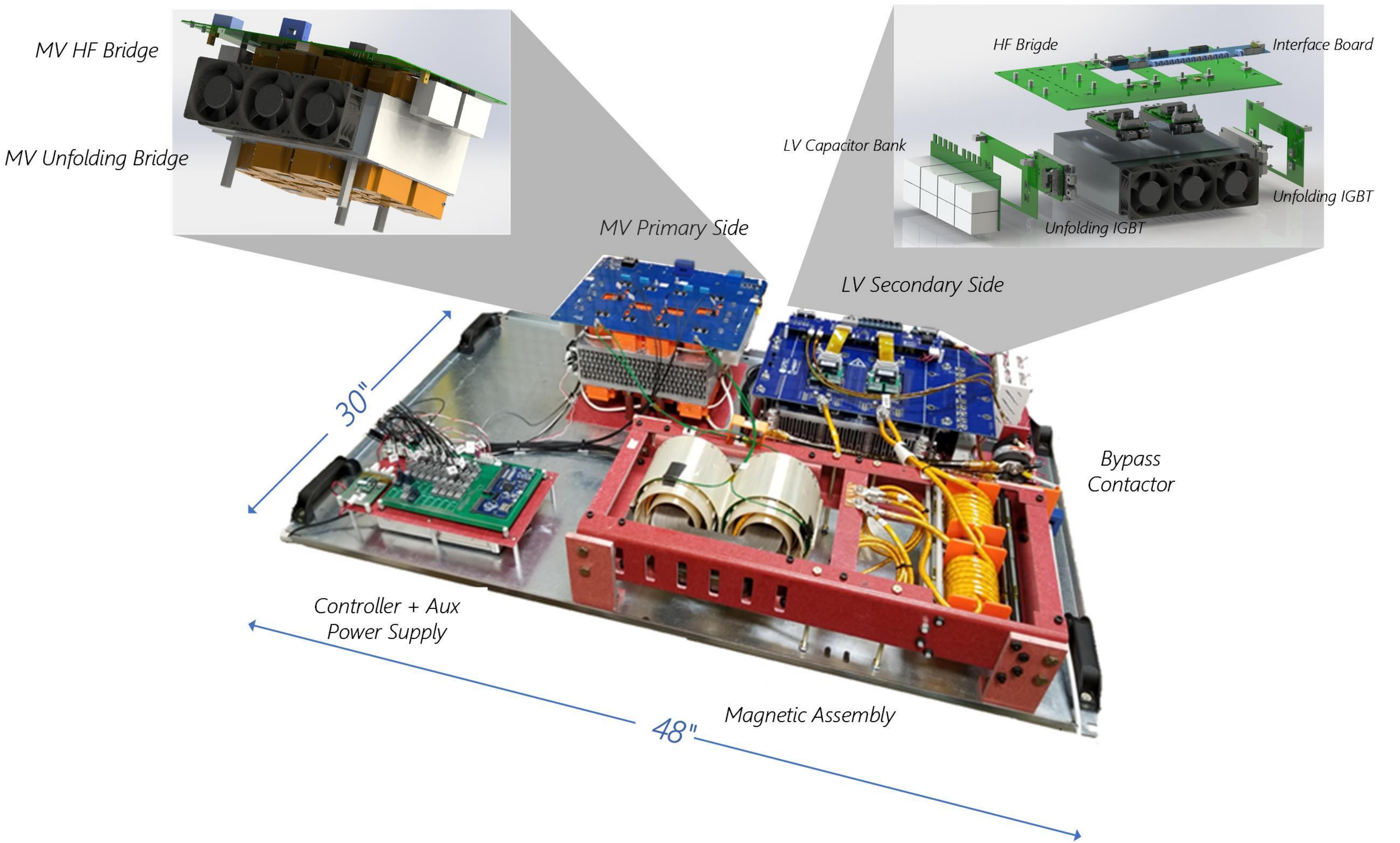
- Designed for 100 kVA/20 KHz operation with a turns ratio of 7:1
- A novel 3D printed bobbin design that offers an impressive 14kV isolation (tested for partial discharge)
- Intricate cooling channels in bobbin help keep thermals at bay





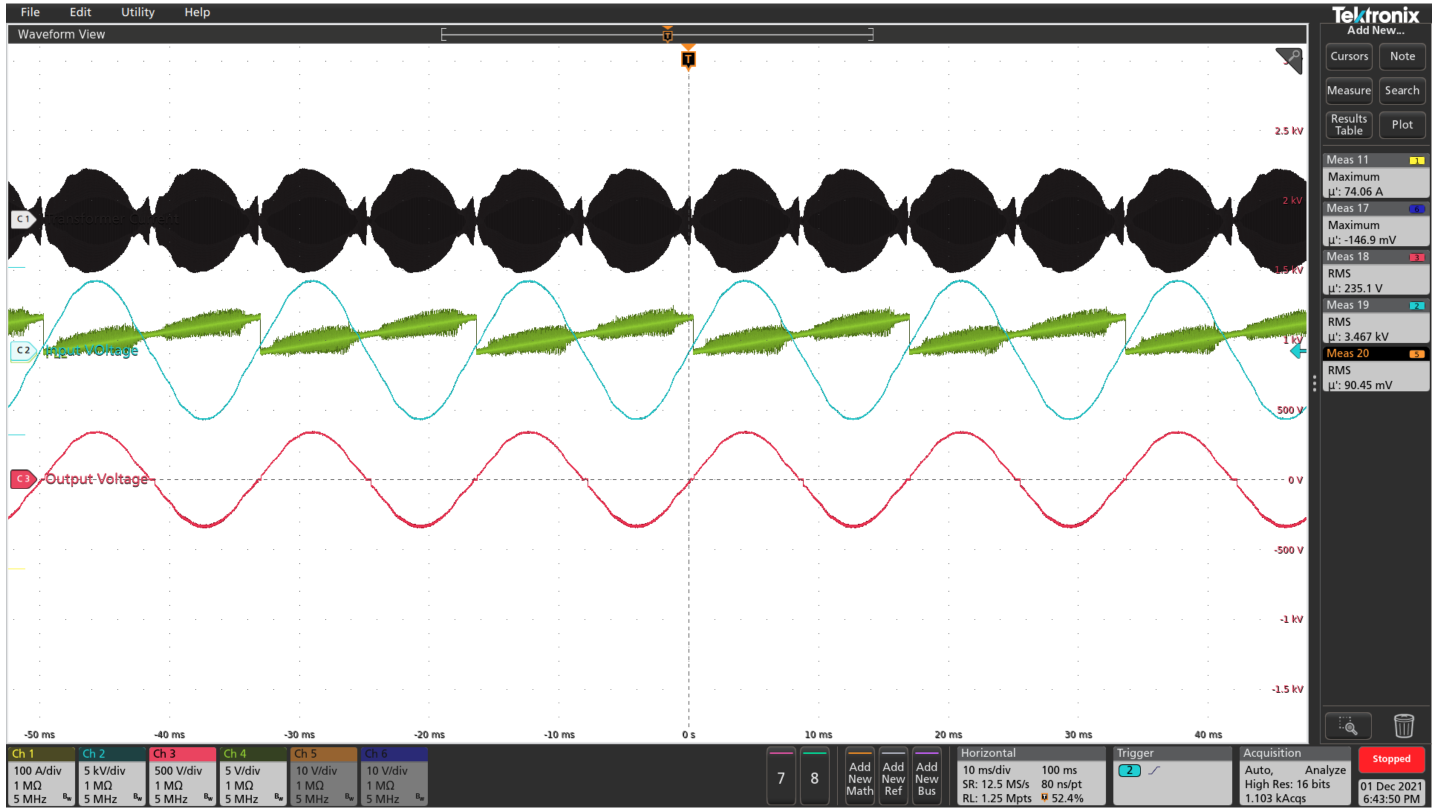
Innovation Update

The MV AC-AC SST



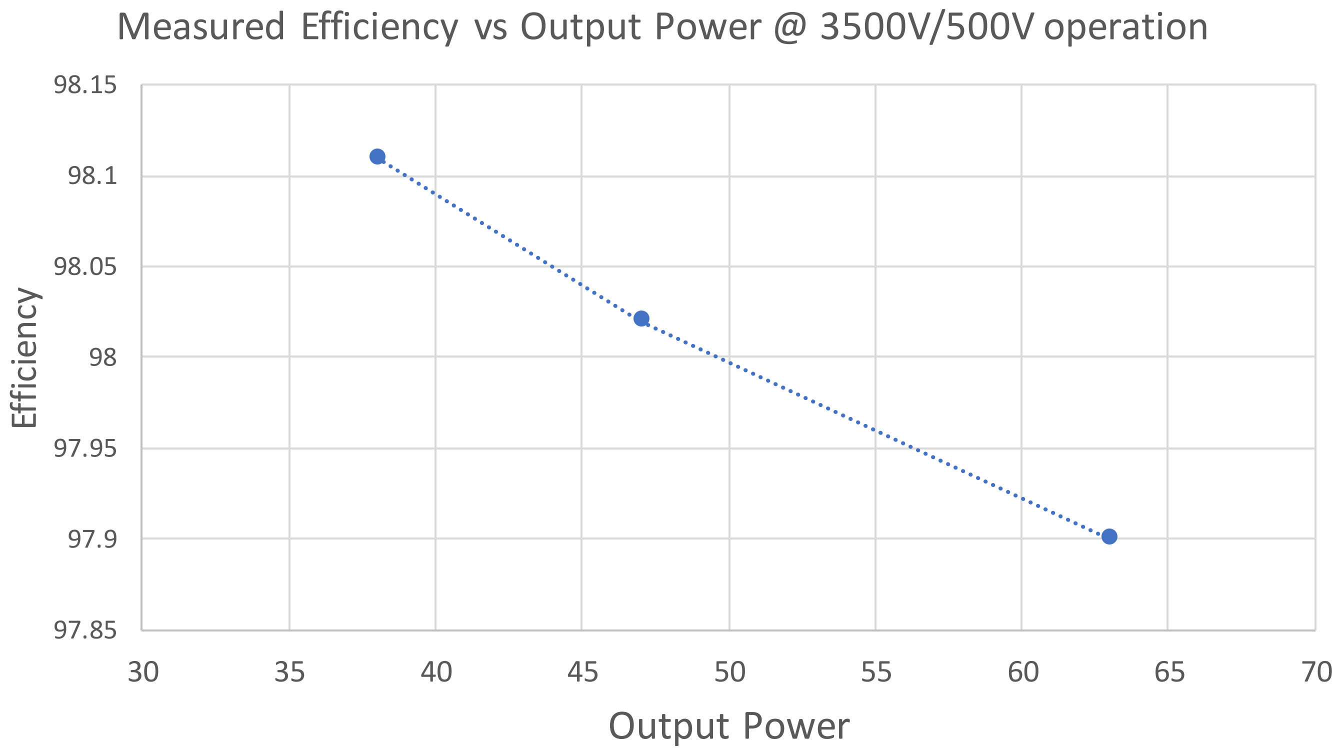
Innovation Update

The MV AC-AC SST Tested



3500V Standalone SST Operation

HF Transformer Current
Input AC Voltage
System PLL
Output AC Voltage



DABSST Efficiency vs Output Power
** Calculated using back-to-back circulation test bed operating in DC-DC mode*

HSST efficiency is "LFT efficiency – 0.3%"

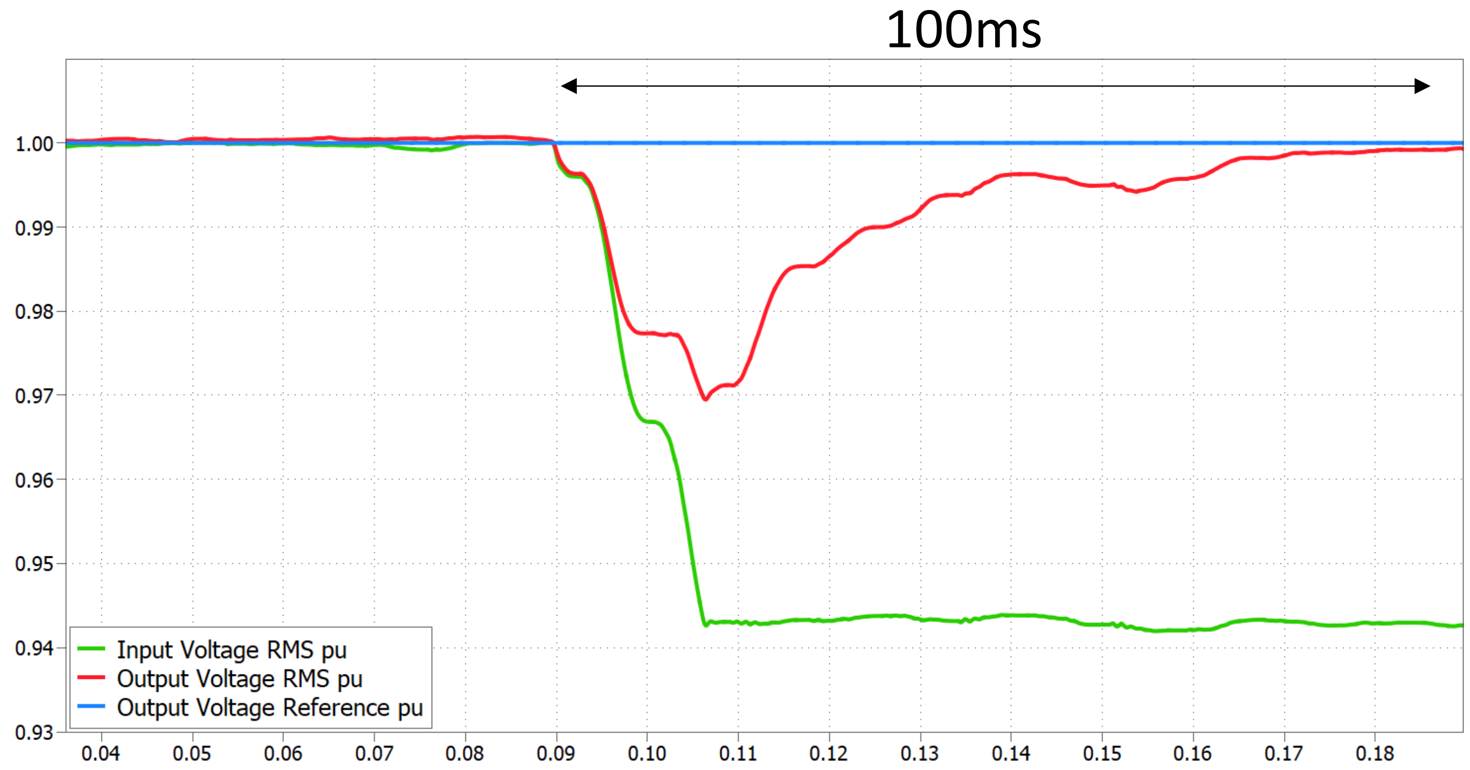
Innovation Update

The 500kVA HSST developed and assembled

- DABSST coupled with a standard dry type 500kVA 20kV/4kV single phase transformer
- Total system dimensions : 60″ x 62″ x 94″
- *DABSST is very small compared to the LFT*

Innovation Update

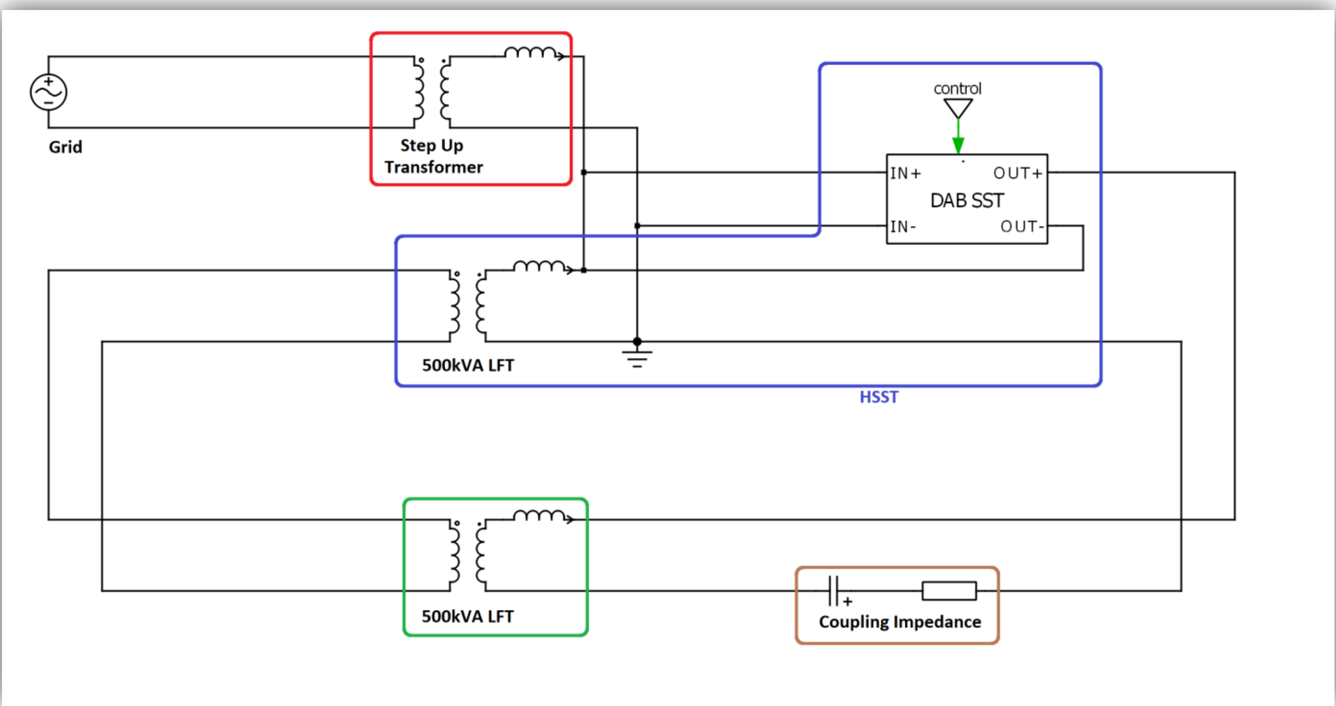
The 500kVA HSST - Voltage Regulation Capability



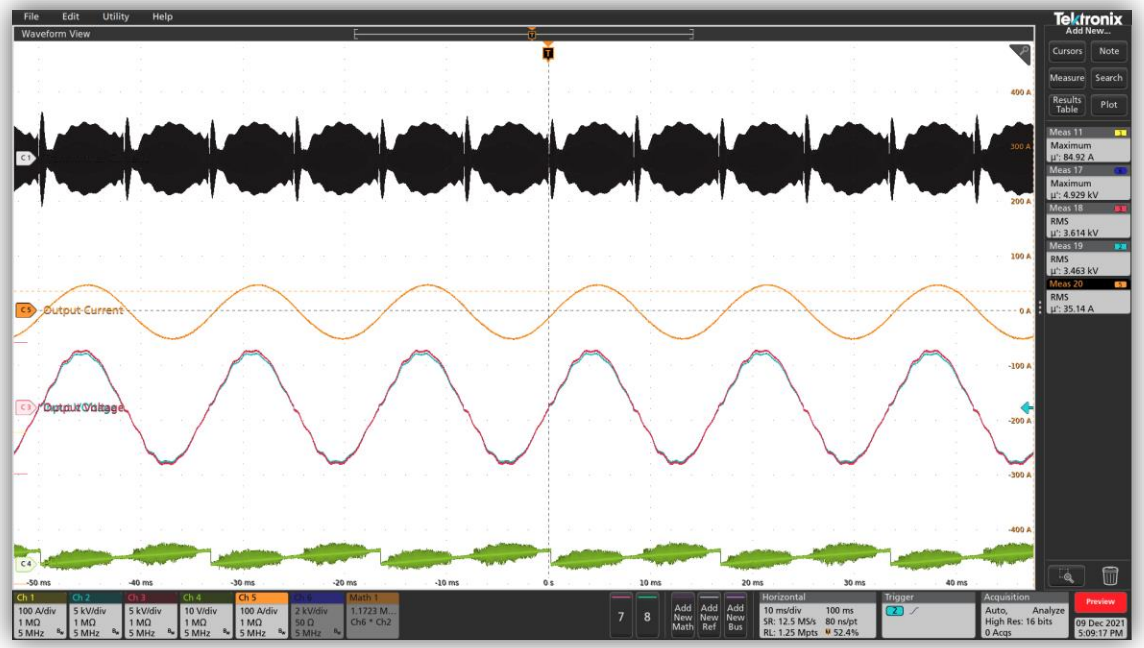
- HSST demonstrating voltage regulation capability (voltage sag of ~6%)
- this is a lower power operation at 14kVA @ 0.93pf leading power factor

Innovation Update

The 500kVA HSST - High Power Circulation Test



HSST Circulation Test Circuit

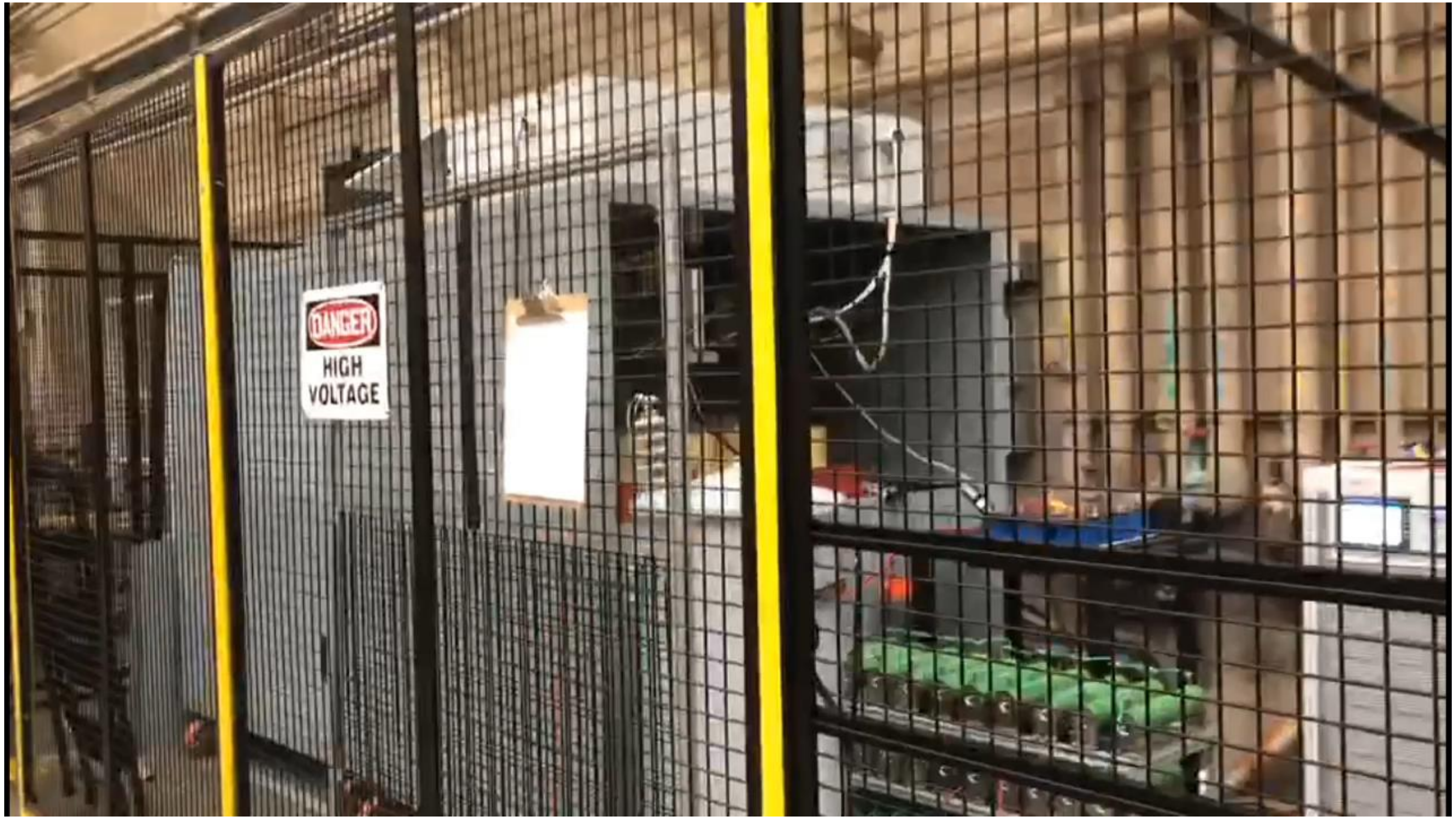


Test Waveforms @ 136kVA 0.98 lagging

HF Transformer Current
Output Current
Input Voltage
Output Voltage
System PLL

- HSST tested at rated voltage and high power through a novel circulation test setup
- Power flow controlled remotely through optical communication interface (video demonstration at end)

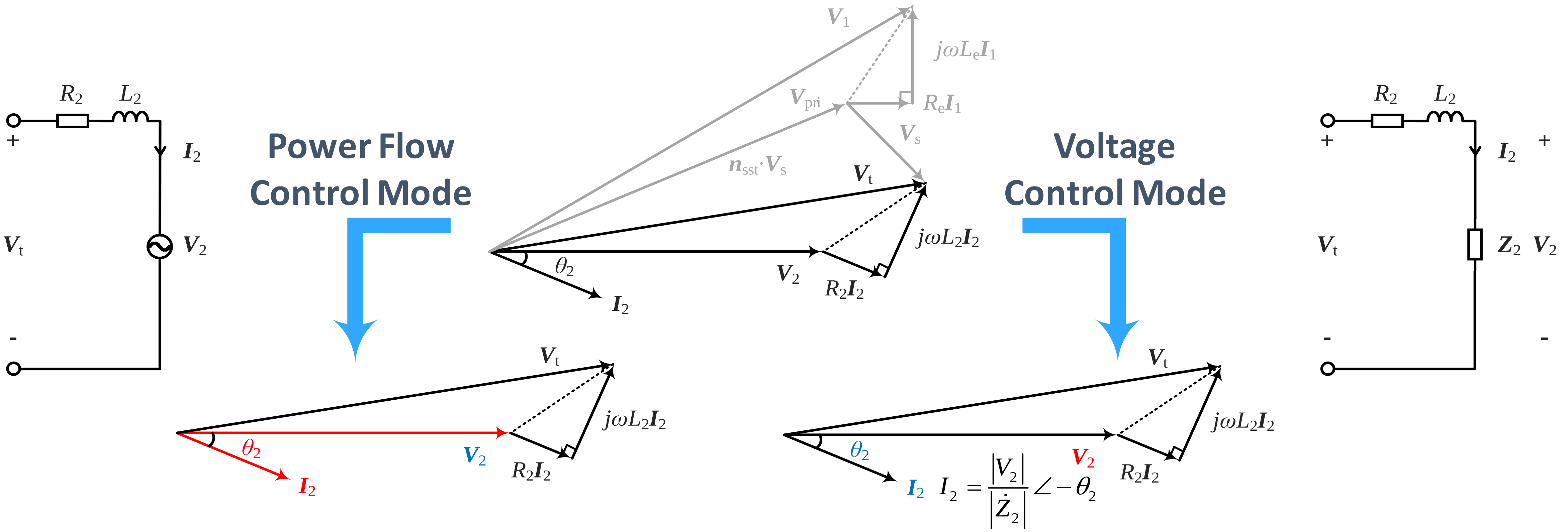
Video/Picture



HSST Rated Voltage Circulation Testing (3500V/3750V/136kVA@0.98pf lagging)

Innovation Update

HSST Phasor-Domain Modeling



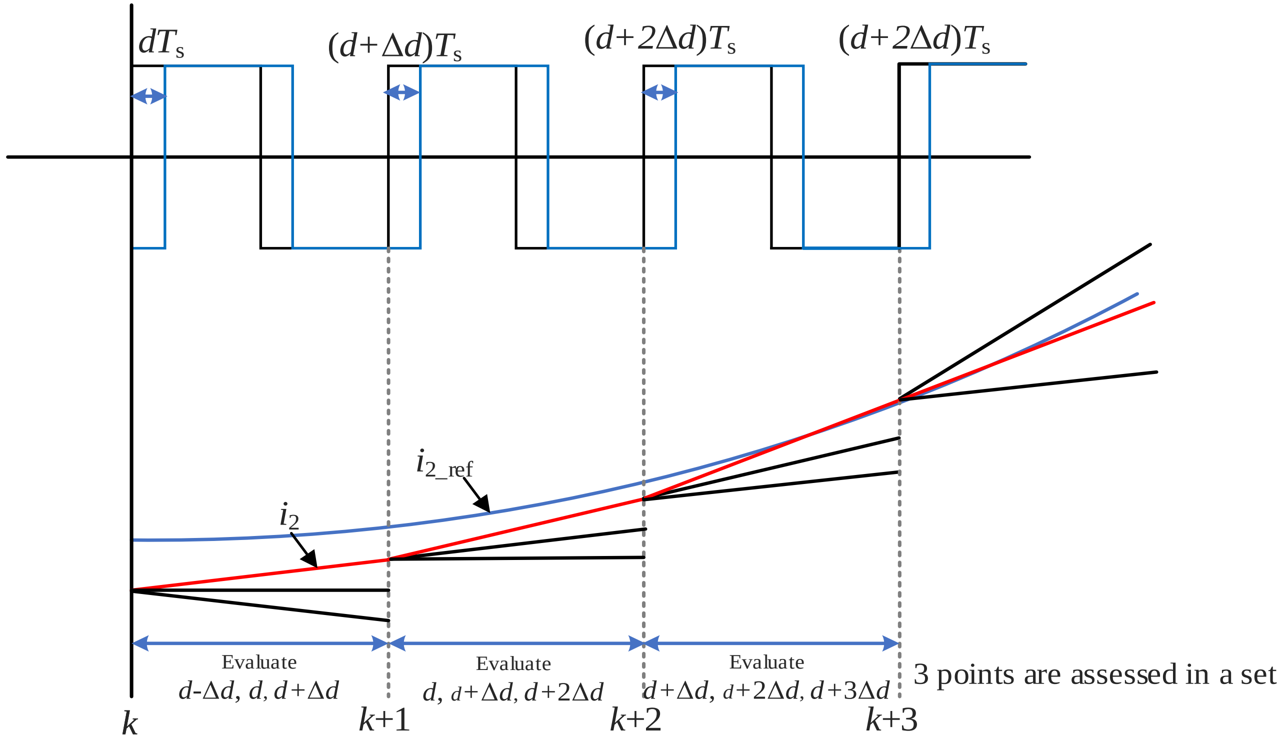
- Secondary side grid voltage is present
- Secondary side current phasor is set in the control diagram

- Secondary side load is present (w/ load amplitude and phase angle)
- Secondary side voltage phasor is set in the control diagram

A generic representation with V_2, I_2, and θ_2 is used for both operation modes

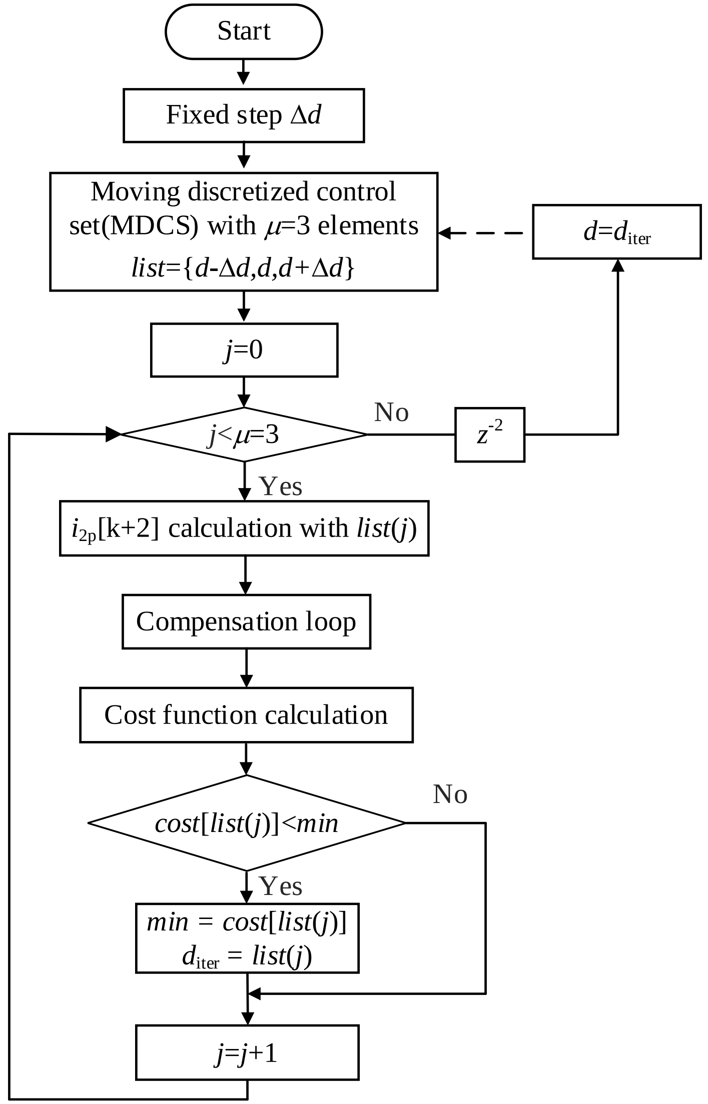
Innovation Update

HSST Dynamic Modeling w/ Model Predictive Control (MPC)



$$f_{cost} = \alpha_1 G_1 + \alpha_2 G_2$$

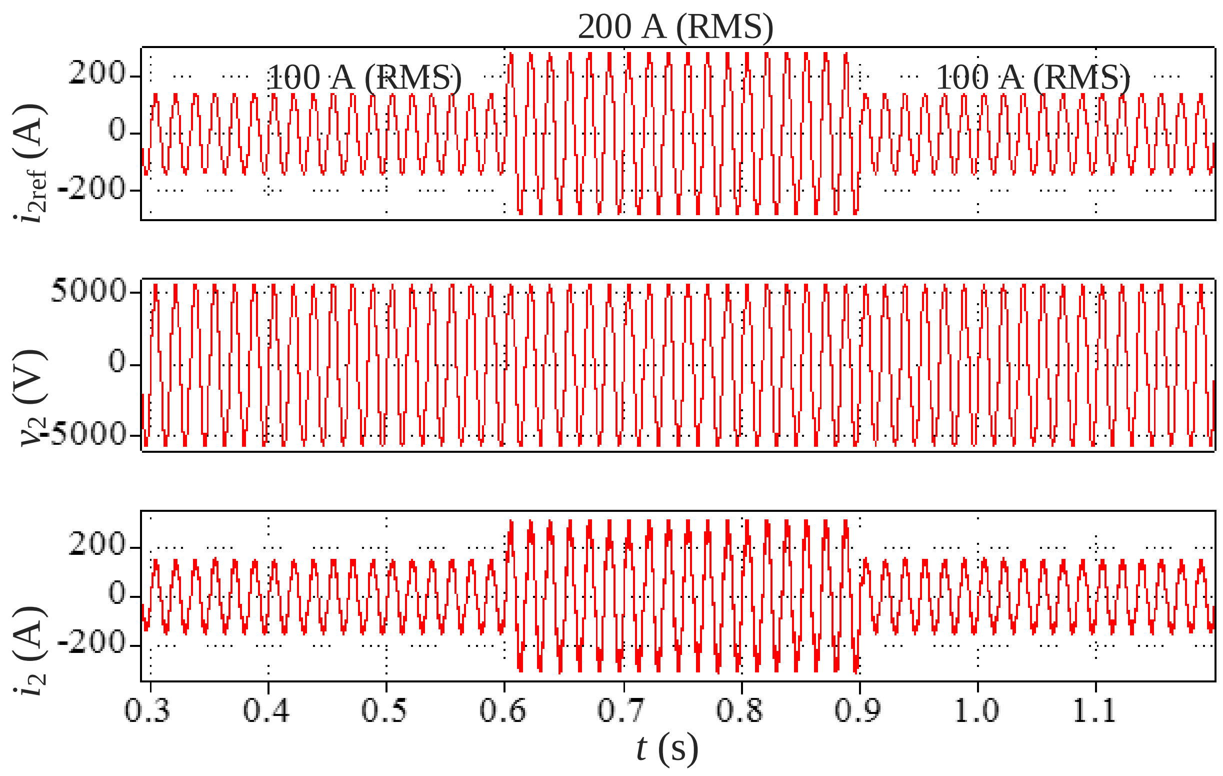
$$G_1 = (i_{2\_ref} - i_2)^2,\ G_2 = (i_{2p}[k+3] - i_2[k])^2$$



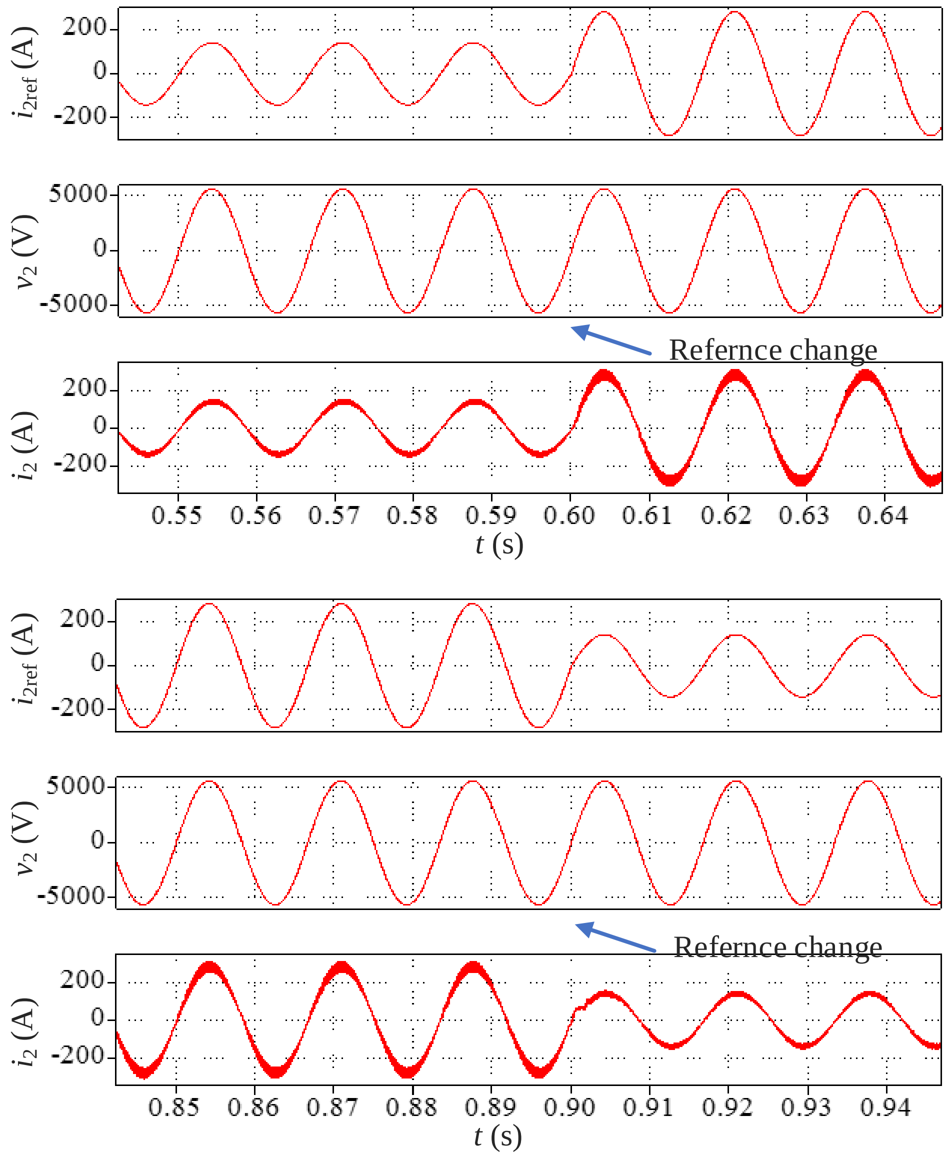
- A model predictive control developed for the HSST is also developed
- MPC model tasked for two modes of control - Voltage mode control for output voltage regulation i.e., distribution applications, and Current mode control for Output power control i.e., transmission applications

Innovation Update

HSST Dynamic Modeling w/ Model Predictive Control (MPC) – Simulation Results



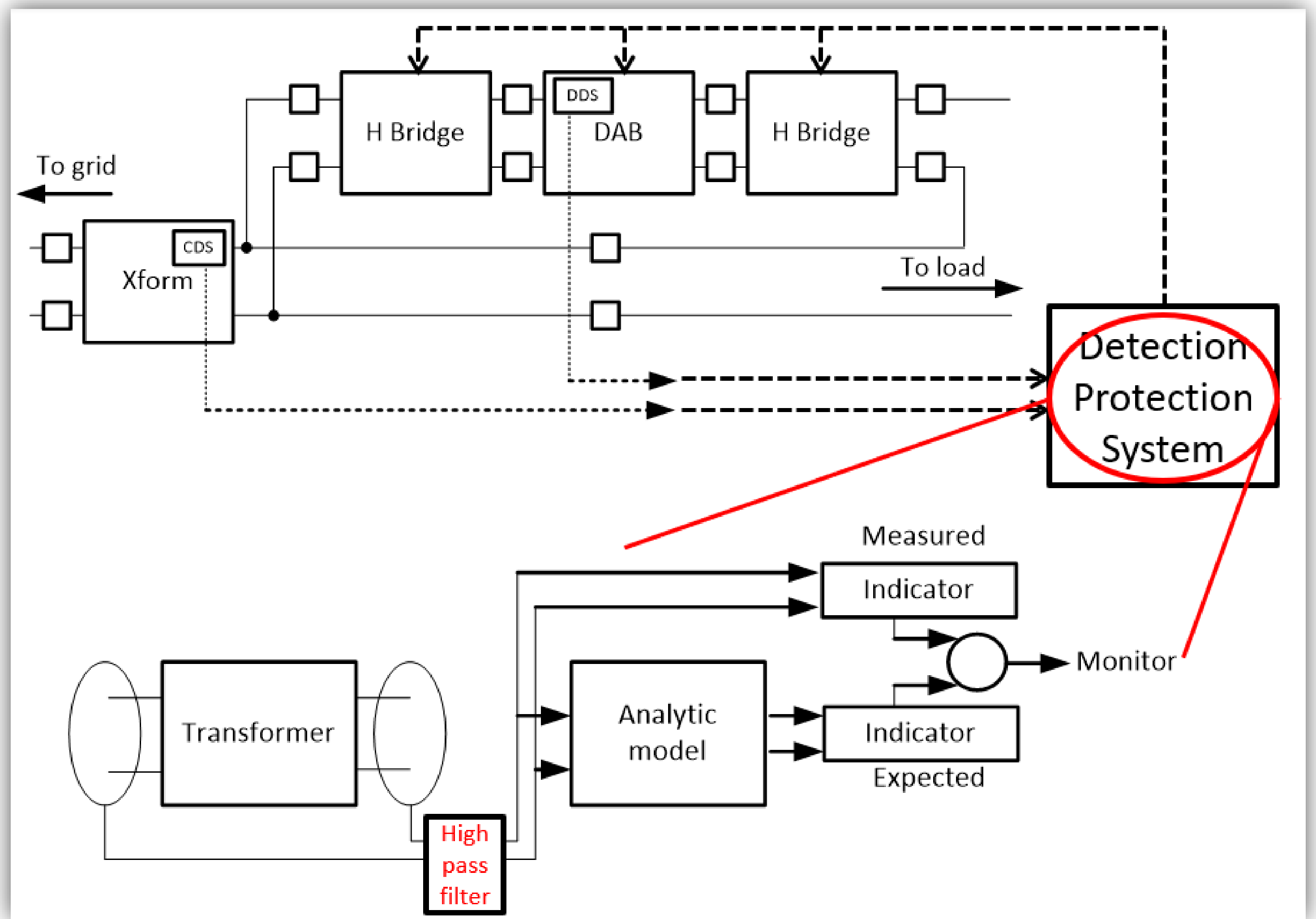
Current reference step-up and step-down changes



Innovation Update

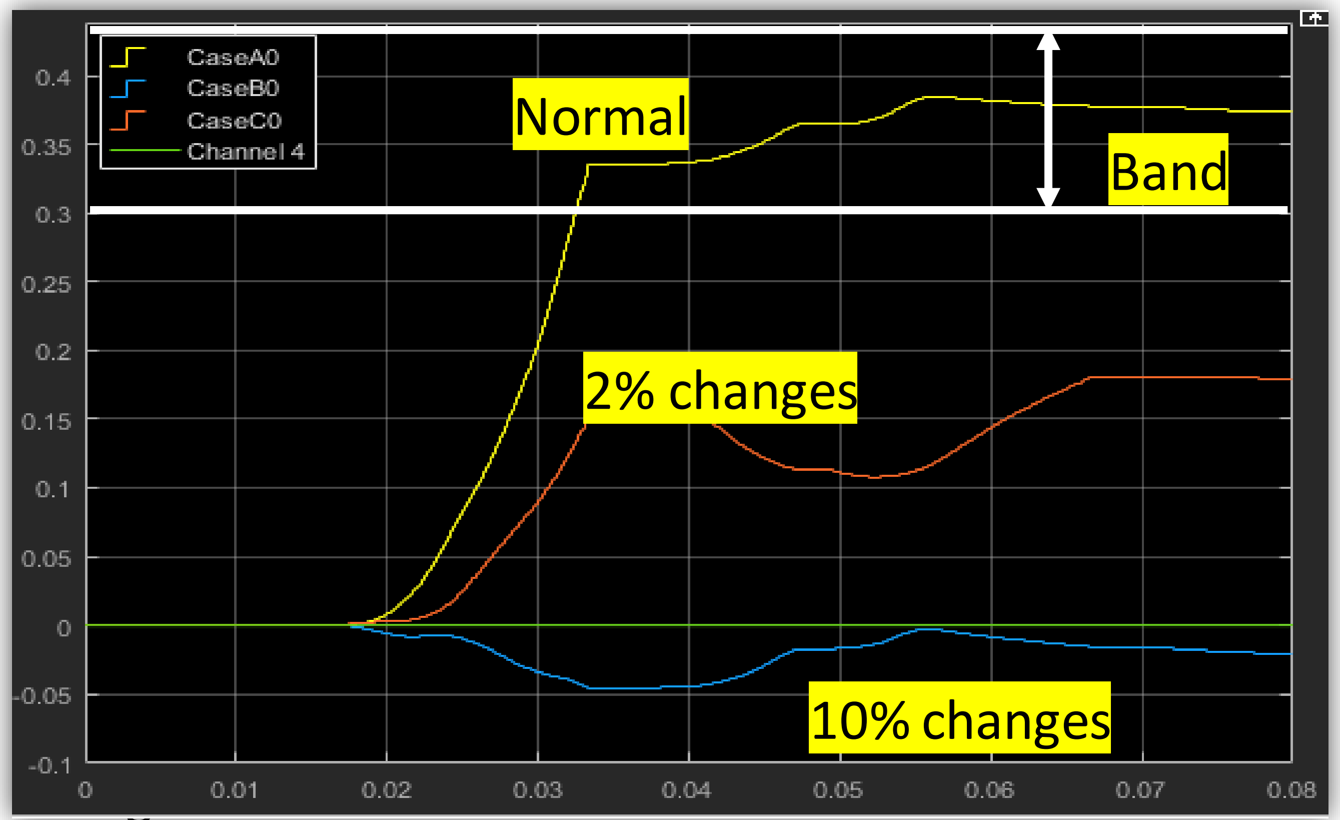
HSST – Online/Offline Monitoring and Fault Detection

- A comprehensive fault monitoring system has been envisioned to monitor the health of the high frequency transformer.
- Algorithm computes real time impedance of the transformer to detect any anomalies.



Innovation Update

HSST – Online/Offline Monitoring and Fault Detection

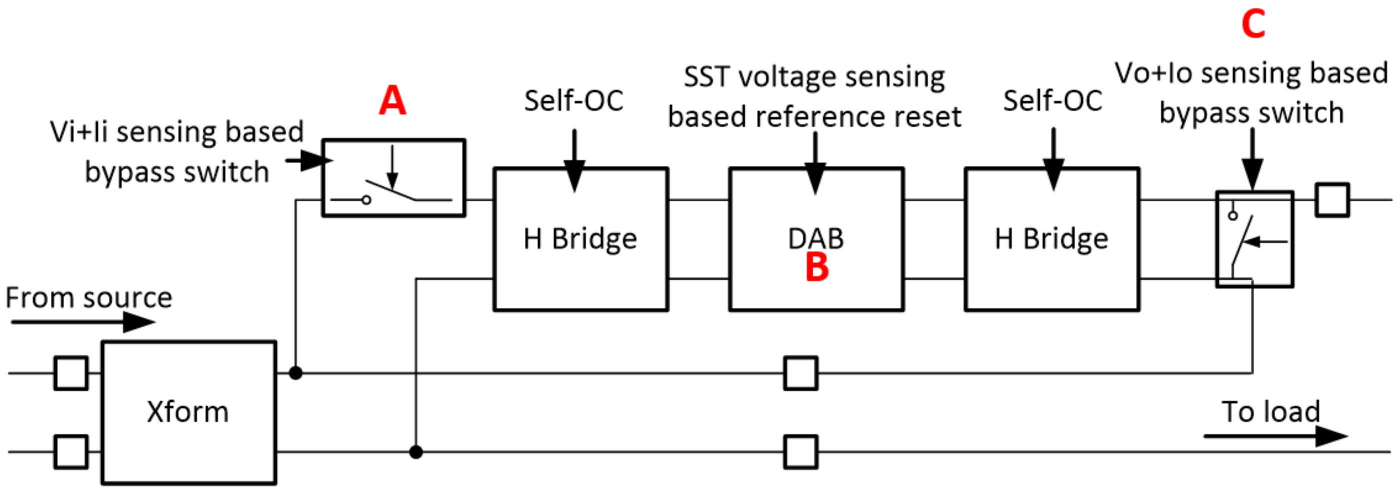


	L_{LX} (uH)	$\|Z_{sc}\|$ [%]
Healthy unit (case A0)	960	0
Case B0	960+20	2.1
Case C0	960+95	9.9

- Algorithm has been tested with actual test conditions (having altered the HFT impedances in the actual hardware)
- Proposed method has been proven to identify the system deformation and internal faults considering the measurement bias and noise.

Innovation Update

HSST – Proactive Protection Tool



A. Input voltage and current sensing based fast protection switch (optional)
B. SST input/output voltage sensing based reference reset (very fast)
C. Output voltage and current sensing-based bypass switch (the faster as better)

- A proactive protection tool has been envisioned to form a comprehensive protection concept for the HSST unit against grid faults and disturbances
- Several fault scenarios have been studied i.e.,
  - single module faults
  - multiple module faults
  - inter phase faults under both wye and delta configuration
- Simulation results have demonstrated ability the protection system to safely contain the issues and prevent SST damage.

Acronyms

HSST – Hybrid Solid State Transformer

SST – Solid State Transformer

DAB – Dual Active Bridge

HF - High Frequency

LPT – Large Power Transformer

MPC- Model Predictive Control

ZVS – Zero Voltage Switching

MV – Medium Voltage

LV – Low Voltage

THANK YOU