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
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
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

C1: Input parallel and output parallel
- Flexible partial power control
- \( V_1/V_2 = n_1/n_2 \)
- No voltage regulation
- 20kV devices
- 100kV insulation

C2: Input parallel and output series
- Partial power
- Voltage regulation
- 20kV devices
- 100kV insulation

C3: Input series and output parallel
- Partial power
- Voltage regulation
- No 20kV devices
- 100kV insulation

C4: Input series and output series
- Partial power
- No 20kV devices
- \( V_1/V_2 = n_1/n_2 \)
- No voltage regulation
- 100kV insulation

C5: Primary side cascaded
- Voltage regulation
- No transformer
- 20kV devices
- No partial power

C6: Primary side input parallel and output series
- Partial power
- Voltage regulation
- 20kV devices
- 100kV insulation

C7: Secondary side cascaded
- Voltage regulation
- No 20kV devices
- No transformer
- No partial power

C8: Secondary side input parallel and output series
- Partial power
- Low voltage insulation
- Voltage regulation
- No 20kV devices
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
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

MV HF Bridge
MV Unfolding Bridge
MV Primary Side
Controller + Aux Power Supply

LV Secondary Side
Bypass Contactor

30"

48"
Innovation Update

**The MV AC-AC SST Tested**

3500V Standalone SST Operation

HF Transformer Current
Input AC Voltage
System PLL
Output AC Voltage

Measured Efficiency vs Output Power @ 3500V/500V operation

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%”
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
The 500kVA HSST - High Power Circulation Test

- 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)
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

A generic representation with $V_2$, $I_2$, and $\theta_2$ is used for both operation modes

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

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