Battery Energy Storage System (BESS) with three phase Grid Integrated Inverter using 3D printed Magnetics components with Nanocrystalline soft magnetic material

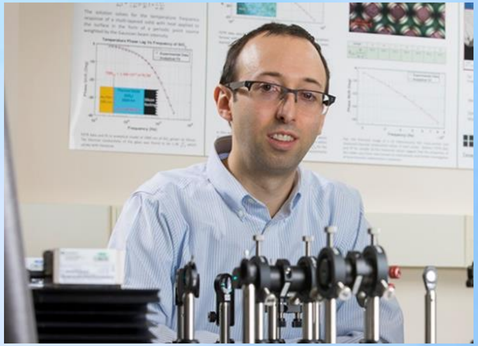
SBIR Project DOE Award #DE-SC0021784

C4V

BINGHAMTON UNIVERSITY

State University of New York

Team



Seshu Tatikola PI
MAM Inc. (Est.2006)

- Design/manufacture high frequency magnetic components for RE Inverters.
- Co-owner of 4 Amorphous Metal components patent.
- MAM is the First company to Introduce Sendust Block core based components for Utility scale RE Inverter in 2008
- Investigate and develop the fabrication of High frequency Magnetic components using Additive Manufacturing Process.

Dr. Shailesh Upreti, CEO
C4V – BU incubator Pioneer

- IP of over 100 patents in the Li ion cell chemistries
- Strategy: More energy storage and cost competitive cell relative existing options in the market
- Locally sourced supply chain zero reliance on China.
- Fireproof cell configuration
- Gigafactory commissioning in progress in Endicott
- Many MOUs with Allied countries to initiate the giga-factory , to address storage cell needs of Local markets

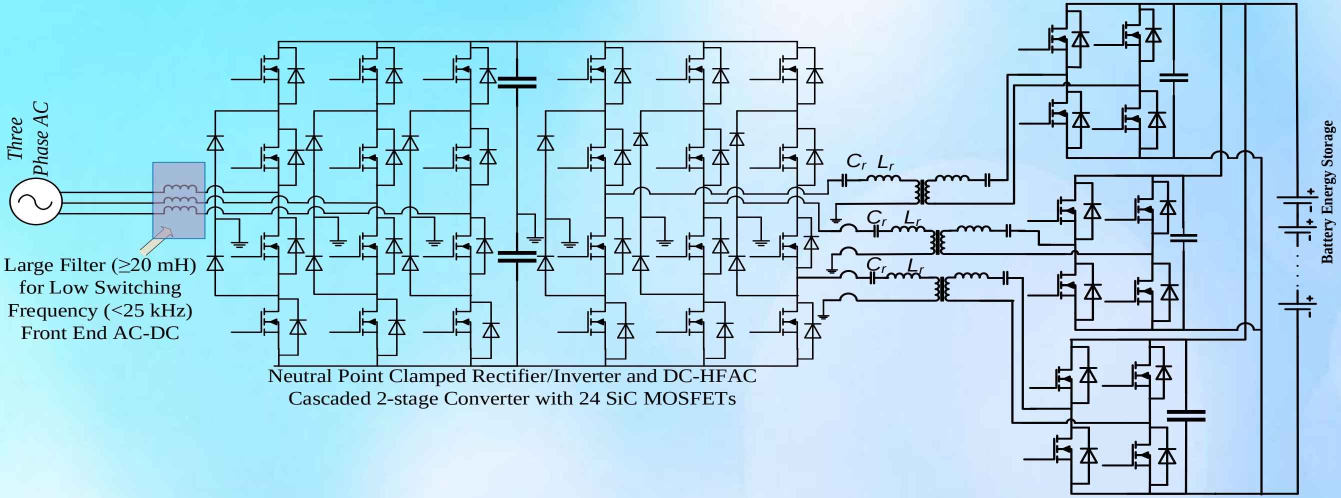
Dr. Scott Schiffres
Binghamton University
Mechanical Engineering

- Expertise in additive manufacturing with the emphasis on AM for electronics cooling and packaging.
- Recipient of NSF CAREER Award for a project related to advanced electronic cooling
- Is engaged in inventing novel printing methods to incorporate nano-crystalline powders to create the freeform magnetic component of SST envisioned for proposed converter.

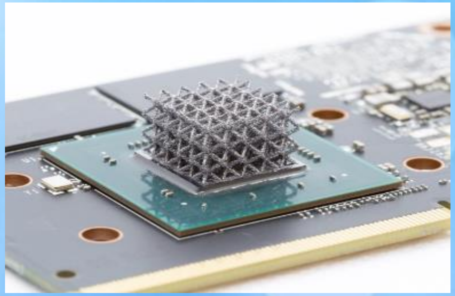
Dr. Pritam Das
Binghamton University
Electrical Engineering

- Expertise in single stage AC-DC power electronic converter topologies and control
- Expertise in integrated magnetic design for bi-directional resonant dual active bridge converter
- Over 90 publications in the area of power conversion
- 1 issued and 3 pending US patents
- Laboratory to test grid connected converters up to 15 kW of power
- Investigate high power density reduced device count novel single stage topology based solid state transformer and its novel integrated magnetics

Existing Battery Energy Storage Integration through Solid State Transformer/Prior art



Neutral Point Clamped Rectifier/Inverter and DC-HFAC Cascaded 2-stage Converter with 24 SiC MOSFETs

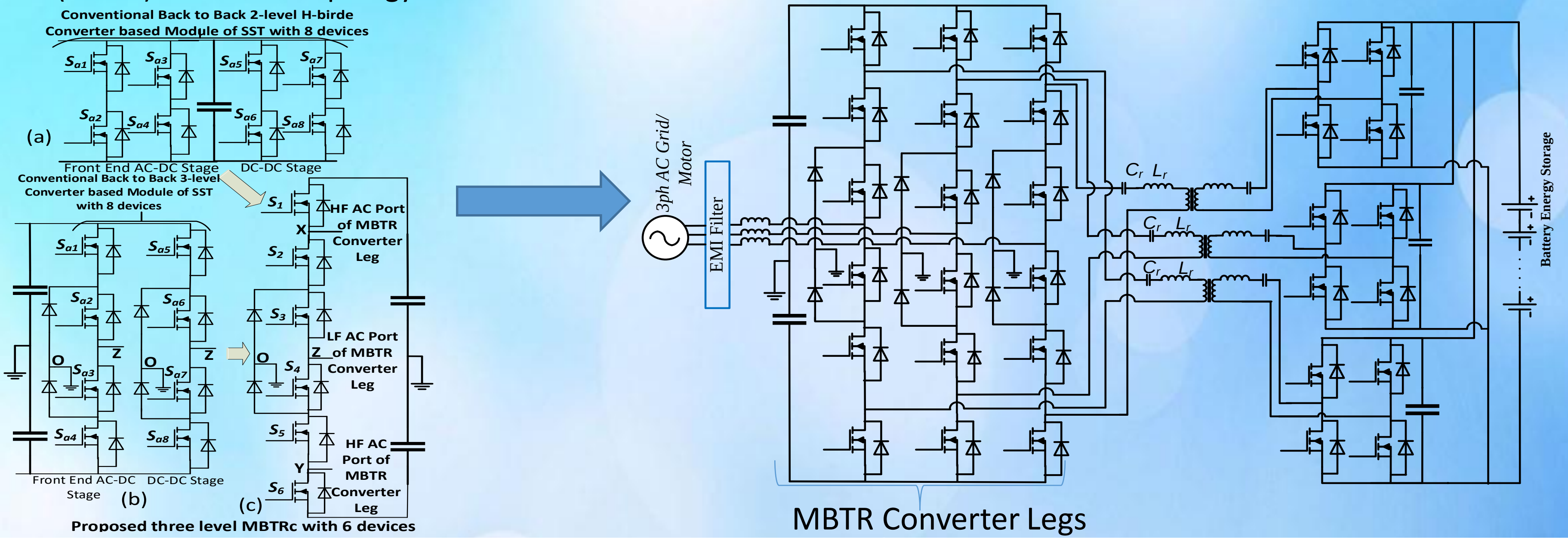


Prior art of fusing dissimilar materials (Heat sink printed on Silicon Integrated Circuit (IC) chip)

Li-ion Battery fully sourced and manufactured in the US at Endicott, NY Ni and Cobalt free composition

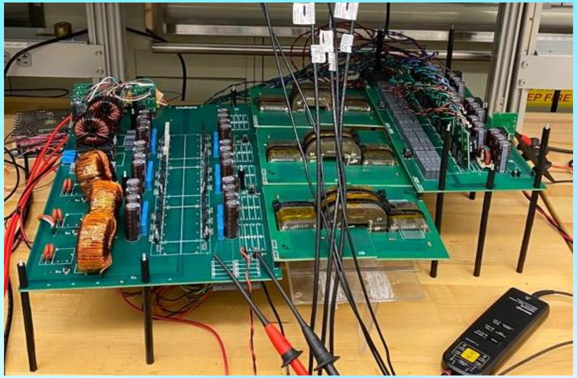
Advantages of existing SST	Drawbacks of SSTs where improvements are desired
• Elimination of Bulky Line Frequency Transformer • Simplifies integration of energy storage to AC grid • Enhances Portability • Adds Control Features for grid services	• Large number of Switches: Lossy, costly & deemed less reliable • Large AC side filters diminishes power density gain of removing line frequency transformer • Hard switching requiring large Electro Magnetic Interference (EMI) reduction filter to address Common Mode (CM) noise issues • Slow transient response (≥100 ms) • DC-DC side magnetic components show 20% parametric variation which degrades overall efficiency • Limitation of High ambient temperature operation of magnetic components in DC-DC section inhibits the Capabilities of Wide Band Gap (WBG) devices • Suffers from large variations of conventional magnetic components leading to degradation of efficiency, limitations of operating temperature and increased thermal management efforts on packaging

Proposed Solution : Battery Energy Storage Integration through Solid State Transformer (SST) based on Multilevel Bridge Tapped Resonant (MBTR) Converter Topology



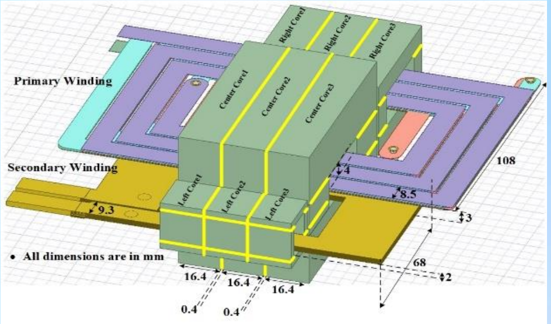
MBTR SST	Expected results
• 25% reduction of Power Device on the high voltage AC side • Both AC-DC and DC-DC operate above 90 kHz relative to state of art systems where AC-DC stage operates at 20 kHz and lower frequencies • Natural elimination of harmonics induced by distorted grid voltage • Soft switched High frequency AC –DC and DC-DC stage operation • Additive Manufacturing (AM) based Printed magnetics components for DC-DC stage using FINEMET material offer tighter tolerance and enhanced higher temperature operating capability	• Reduces cost/losses and enhances circuit reliability • Capable to Integrate fast transient loads • Eliminate the need of large input filter improves power density • Reduces the EMI generated which impact size of EMI filter • Better realization of Integrated magnetics, wider operational range, help realize the full potential of WBG Silicon Carbide (SiC) devices • Last but not the least reduce the supply chain hick ups with magnetic component manufacturing

Breadboard of proposed MDTR Topology Using the Conventionally produced Magnetic Component

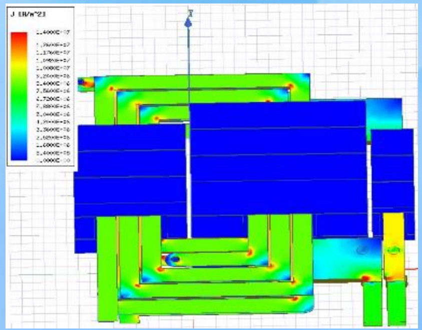


Why FINEMET?

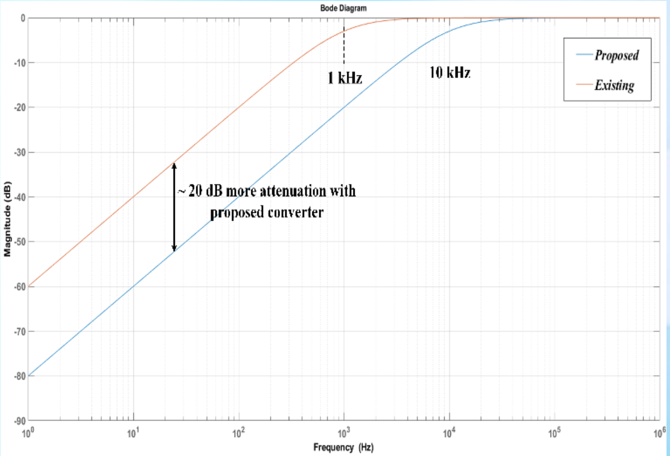
- Enables high ambient temperature due to high of Curie Point above 550C.
- Best in class theoretical high frequency core loss relative to other soft magnetic materials
- High Saturation Flux- enables the size reduction of magnetic Components.



Multi-core magnetic components : Trimetric view with mounted PCB windings and the equivalent electrical circuit of the magnetics based on FINEMET Nanocrystalline Material



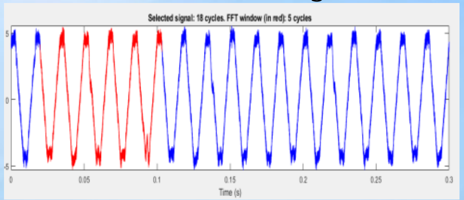
Ansys Maxwell Magnetostatic Simulation



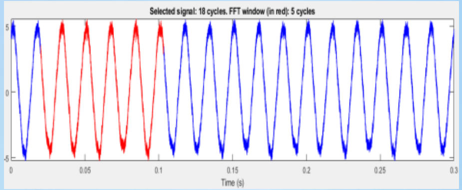
Theoretical Bode plots of disturbance rejection for existing and proposed converter

IEEE 1547/IEC 61727 limit	Individual Harmonic order odd %
H<11	4%
11<h<17	2%
17<h<23	1.5%
23<h<35	0.6%
35<h	0.3%
THD	5%

With existing converter



With proposed converter

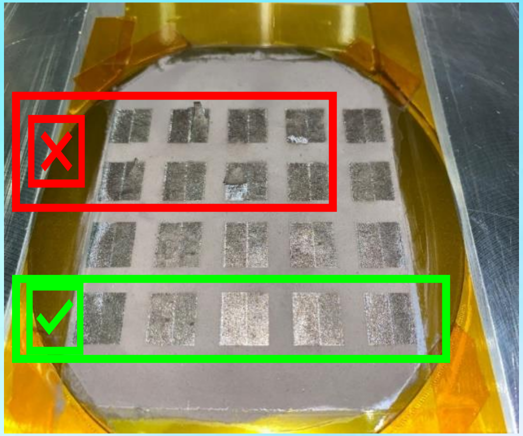


Experimental results: current harmonics with Grid Voltage THD (Total Harmonic Distortion) = 7.6 %

Harmonic currents	With existing converter	With proposed converter
i1	3.25A	3.22 A
i5	5.62%	1.78%
I7	3.46%	1.09%
I11	0.8%	0.47%
i13	2.2%	1.12%

Performance consistent with the Prediction

Magnetic Selective LASER Melting Print Strategy



- Printed alloy with heterogeneous composition of FINEMET elements
- Cooling rates in selective laser melting are millions of degrees per second, should form nanocrystalline domains
- Plan to form nitride metal films in place to create eddy current barrier, and then build on that layer subsequent layers
- Removes handwork and gluing of conventional nanocrystalline/amorphous cores

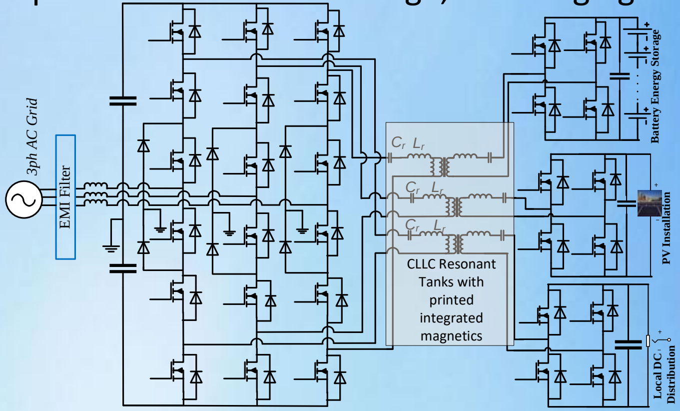
Fused Deposition method is also under investigation

Phase 1 goals

- Feasibility of 12.5 kW version of proposed SST
- Characterization of laser printed and/or filament-based 3D magnetics in the proposed configuration. Identify Best practice to realize mass production.
- Develop 10 kWH storage pack with advanced C4V cell and characterize the operations for residential and commercial energy storage application.

Phase II

Work metropolitan and Rural electric cooperative as a “Customer linked Commercialization strategy” to Develop Power Router into commercial product- links solar storage, EV charging into one router



Our Team sincerely wants to express our gratitude to DOE Energy storage Program- managed by Dr. Gyuk, Dr Atcitty – for the financial support and technical guidance with this project.

Seshu Tatikola
10, Hastings Court
Bridgewater NJ-08807
Tel – 908 448 6580
E mail- **statikola@maminc.net**

Thank You!