Executive Summary

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1. Title of the Project: Solid State Transformer Technology for Emerging Trends in Electric Mobility and DC Micro-grid

2. Date of Start of the Project: 01/10/2021.

3. Aims and Objectives:
    - Pioneer research work towards adoption of Solid-State Transformer technology with specific reference to Wide Band Gap (WBG) semiconductor technology and HighFrequency Magnetics for enhanced efficiency and improved reliability.
    - Development of Solid-State Transformer working prototype employing DC interface port for charging of electric vehicles.
    - Design of bi-directional, isolated, and soft-switched converter for automotive and traction applications to promote e-mobility to replace conventional, non-isolated and hard-switched counterparts.
    - Development of resilient industrial DC back-up system for critical loads in industry and DC Micro-grid environment.
    - Technology transfer to industry / setting up pilot scale charging station for electric vehicles.

4. Significant achievements (not more than 500 words to include list of patents, publications, prototype, deployment etc)

In this project, the following important research findings are established:

Fault-Tolerant, Soft-Switched DC-DC Converter for SST Applications: Developed a topology (as shown in Fig. 1) for Solid-State Transformer (SST) applications. Incorporated a Voltage Restorer Rectifier to handle switch open/short circuit faults, ensuring a smooth and reliable transition between pre-fault and post-fault operation.

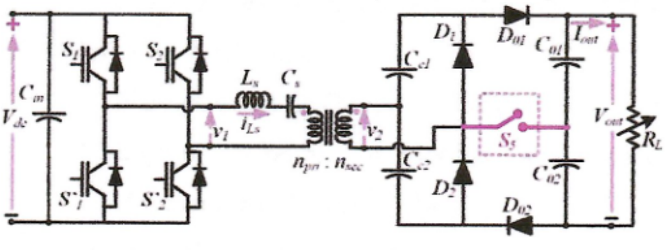

Fig. 1 Schematic of Fault resilient DC-DC converter with reconfigurable Voltage Restorer Rectifier

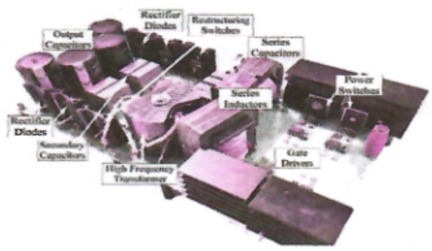

Fig. 2 Actual photograph of 1.25 kW hardware

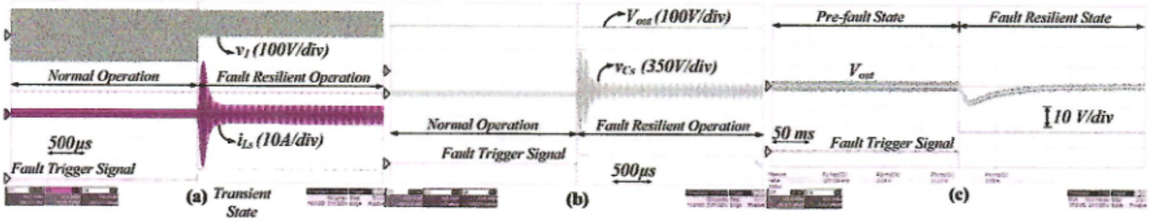

Fig. 3. Experimental waveforms for switch S'_2 short-circuit to demonstrate fault resilient operation: (a) Resonant current (i_{Ls}) and input tank voltage (v_1). (b) Output voltage and resonant capacitor voltage (v_{Cs}). (c) Output voltage transient during fault resilient operation and fault trigger signal.

overall converter gain without requiring a high transformer turns ratio. This design also reduces the equivalent AC resistance, resulting in a minimized value of resonant inductance for the design frequency and quality factor.

High Efficiency: Demonstrated impressive efficiency, achieving a maximum of 95.67% in normal operation and 93.87% in the fault state, favoring reliability and power density.

Experimental Validation: Utilized a 1.25 kW converter prototype (Fig. 2& Fig. 3) to validate findings under dynamic and steady-state conditions, confirming alignment with research objectives.

Critical Design Considerations: We examined critical design considerations, including the selection of core materials, wire materials, isolation requirements, and alternative transformer structures.

Alignment with Research Objectives: This research aligns with the objective of developing industrial backup DC systems, contributing to enhanced reliability and efficiency in critical power applications.

- **International Journals:**

1)D. Govinda, H. M. Suryawanshi, P. P. Nachankar, Chintalapudi L. Narayana, and Ankit Singhal, "A Modified Voltage Controller with Advanced Droop Control for Load Sharing in Standalone AC Microgrid Under Different Load Conditions," ***IEEE Transactions on Industry Applications***, Accepted. [SCI]

2)Pratik Nachankar, H. M. Suryawanshi, P. Chaturvedi, Dipesh Atkar, Ch. L. Narayana and D. Govind, "Design of Interleaved Three-Phase DC Transformer with ingenious Control for Morden Data Centers," ***IEEE Transactions on Industry Applications***, Accepted. [SCI]

3)Mary, N. M., Sathyan, S., &H. M. Suryawanshi,"A Three-Level Resonant DAB Conve7890. [eaturing Minimized Circulating Losses for EV Battery Charging," ***IEEE Transactions on Industrial Electronics***, vol. 70, no. 8, pp. 7879-7890, Aug-2023. [SCI]

4)Vijay Reddy P, B.L. Narasimharaju and H. M. Suryawanshi, "Implementation of Dual Control MPPT-based DC-DC Converter fed Solar PV Pumping System," ***IEEE Transactions on Industrial Electronics***, vol. 70, no. 09, pp.9016-9024, Sept-2023. (SCI)

5)Koteswara Rao Kothapalli, M. R. Ramteke and H. M. Suryawanshi, "ZVS-ZCS High Step-up/Step-Down Isolated Bidirectional DC-DC Converter for DC Microgrid," ***IEEE Transactions on Power Electronics***, vol. 38, no. 06, pp.7733-7745, June-2023. (SCI)

6)P. P. Nachankar, H. M. Suryawanshi, P. Chaturvedi, D. Atkar, C. L. Narayana and D. Govind, "Design of Electric Vehicle Battery Charger With Reduced Switching Frequency Variation," ***IEEE Transactions on Industry Applications***, vol. 58, no. 6, pp. 7432- 7444, Nov. 2022, (SCI)

7)P. P. Nachankar, H. M. Suryawanshi, P. Chaturvedi, D. Atkar and V. V. Reddy P., "Fault Resilient Soft Switching DC–DC Converter for Modular Solid State Transformer Applications," ***IEEE Transactions on Industry Applications***, vol. 58, no. 2, pp. 2242-2254, March 2022. (SCI)

8)M. S. Ballal, S. R. Verma, H. M. Suryawanshi, R. R. Deshmukh, S. A. Wakode and M. K. Mishra, "An Improved Voltage Regulation and Effective Power Management by Coordinated Control Scheme in Multibus DC Microgrid," ***IEEE Access***, vol. 10, pp. 72301-72311, (SCI)

9) K. Rajesh babu, M. R. Ramteke and H. M. Suryawanshi, "A High Gain Low ripple SEPIC Based DC-DC Converter for Micro-Grid Applications," ***International Journal of Circuit, Theory and Applications***, Accepted. (SCI)

10) D. Govind, H. M. Suryawanshi, P. P. Nachankar, C. L. Narayana and Ankit Singhal, "An Enhanced Master-Slave Control for Accurate Load Sharing Among Parallel Standalone AC Microgrids," ***International Journal of Circuit Theory and Applications***, vol. 51, no. 2, pp. 647-667, Feb.2023. (SCI)

11) K. Rajesh babu, M. R. Ramteke and H. M. Suryawanshi, "A High Stup-Up Soft Switched DC-DC Converter with reduced Voltage Stress for DC Micro-Grid Applications," ***International Journal of Circuit, Theory and Applications***, vol. 51, no. 04, pp. 1503-1969, April-2023. (SCI)

- **International / National Patents:**

National Patents				
Sr. no.	**Patent No.**	**Patent Title**	**Patentee**	**Status**
1	10618	A System for The Power Quality Indices Determination with Their Causes and Effects	H. M. Suryawanshi	**Granted 29-06-2022**
2	01418	A System for Better Operation of Multi-Microgrid	H. M. Suryawanshi	**Granted 29-06-2022**
3	394522	Standardization of Three Phases Four Wire Meter as Two Phase Four Wire Meter for Traction Metering	H. M. Suryawanshi	**Granted 08-04-2022**
4	392755	Breather Condition Monitoring System for Transformers (Brecoms-T)	H. M. Suryawanshi	**Granted 23-03-2022**
5	2021103474	Digital Error Compensation of Industrial Energy Measurement System	H. M. Suryawanshi	**Granted 09-03-2022**

6	357475	Hybrid Control of Resonant Converter for DC Grid Applications	H. M. Suryawanshi, R. K. Keshri& M. S. Ballal	**Granted** 01-Feb-2021

5. Concluding remarks

In the earlier stage, a fault tolerant, soft switched DC-DC converter was developed for SST applications intended for industrial backup DC systems. Currently, the research work for design and development of power electronic DC-DC converters employing planar magnetic components and SiC semiconductor devices is initiated after a detailed literature study. Based on the identified potential research area, after a thorough simulation analysis, a 1 kW, 400/48V hardware prototype is designed and fabricated employing planar magnetic transformer & inductor elements using SiC power switches. The idea is to validate the converter performance on proof of the concept basis. During this phase, we carefully procured the materials and components needed to design and build the solid-state transformer (SST). We carefully considered the high-frequency (HF) or medium-frequency (MF) transformer, which is a key component of the SST, in accordance with the specific application requirements.To realize an optimized SST, we explored different topologies to find the most suitable configuration. Our research identified key characteristics of an ideal SST topology: a low-voltage (LV) DC link, modularity, unidirectional or bidirectional power flow control, a minimized number of components, and soft switching.Our evaluation showed that two-stage topologies with an LV DC link are particularly well-suited for SSTs. These topologies can provide the essential features needed for future energy systems.We have focused on two-stage topology with an active front-end rectifier stage (AC-DC), an intermediate DC-DC stage with an HF or MF transformer, and a final back-end inverter stage (DC-AC). These topologies are the most promising and practical choices for SST applications, and they meet the specific demands of our chosen application. Initial experimental studies are encouraging for EV, Medical Oxygen Cylinder Trolley etc. and details of the experimental research findings will be conveyed in the near future.