National Centre for Photovoltaic Research and Education (NCPRE)

Indian Institute of Technology Bombay

Research Activities in NCPRE Phase III

Presented By

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NCPRE

National Centre for Photovoltaic Research and Education (NCPRE)

- **NCPRE** was established at IIT Bombay in September 2010 by the Ministry of New and Renewable Energy (**MNRE**)

Phase I (2010-2016)

Phase II (2016-2021)

Phase III (2023—)

- **R&D** activities under **NCPRE** encompasses areas related to solar photovoltaic (PV), and also **education** and **training**
- Total **direct funding** for Phases I and II: approximately **INR 110 crore**
  - additional **indirect funding and support from IITB,** in terms of faculty, student support, space and infrastructure facilities, access to IITB administrative systems, etc.
- **International collaborative projects** with universities and R&D centers
  - USA (**NREL**), Germany (**Fraunhofer**), UK (**Cambridge**, **Oxford**), Norway, Sweden, Netherlands

National Centre for Photovoltaic Research and Education (NCPRE)

- NCPRE was created with a **highly multidisciplinary** vision
  - Involves faculty and students from **9 Departments at IITB**, including Centre for Policy Studies (**CPS**), Centre for Technology Alternatives for Rural Areas (**CTARA**), Chemical Engineering (**ChE**), Electrical Engineering (**EE**), Energy Science & Engineering (**ESE**), Mechanical Engineering (**ME**), Metallurgical Engineering and Materials Science (**MEMS**), **Physics** and **Chemistry**
  - **34 faculty** members and about **170 post-graduate students** contribute to various activities under NCPRE
- **Excellent research facilities** have been set up at NCPRE
- NCPRE has **published** over
  - 22 **Patents**, 245 **Journal** papers, 325 **Conference** presentations
- NCPRE is guided by an **International Advisory Committee,** which has been meeting in Mumbai every year since 2011

Department	Faculty
CTARA	S. Agnihotri
ChE	A. Sarkar
EE	**B. G. Fernandes* (PI), A. Kottantharayil* (Co-PI),** K Chatterjee*, N. Siradkar*, B. M. Arora, P. Nair, K. L. Narasimhan, J. Vasi, J. Nair, A Kulkarni, A Kohli, S Anand, S. Chakraborty
ESE	**S. Doolla* (PI), S. Mitra* (Co-PI),** B. Kavaipatti*, P. Sharma*, M. Neergat, V. Ramadesigan, Z. Rather, C. S. Solanki
ME	D. Marla
MEMS	P. Bhargava, A. Mukhopadhyay, D. Gupta, S. Mallick, A. Yella, A. Singh
Physics	D. Kabra*, M. Aslam, A. Alam
Chemistry	A. Kumar

* Members of the NCPRE Executive Committee, which meets twice monthly

Facilities, Prototypes and Products Developed at NCPRE

Glove Box Integrated with Evaporator and Probe Station

Field Emission Scanning Electron Microscope

Dynamic Mechanical Loading System

Electron Beam Evaporator System

Coating Machine

Needle Testing Machine

Electrochemical Capacitance Voltage (ECV) Dopant Profiler

Belt Furnace

Automated Screen Printer

LED Solar Simulator

Module Tester

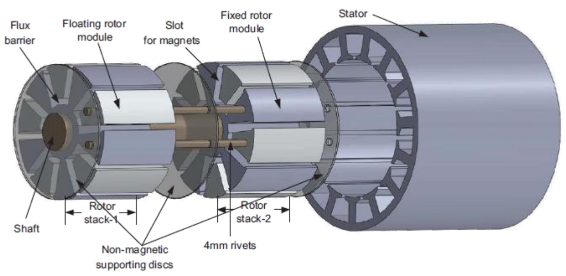
Battery Testing Unit

Environmental Chamber

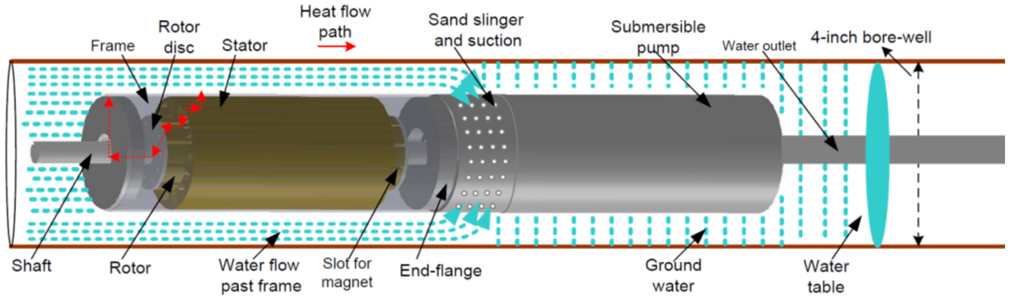
Solar Simulator

Facilities, Prototypes and Products Developed at NCPRE

1.5 kW, 2,880 RPM Ferrite Semi-modular Dual-stack Spoke-type (SMDS) BLDC Motor for Solar PV Based Deep Borewell Submersible Water Pump [1]



SMDS Spoke-type BLDC motor



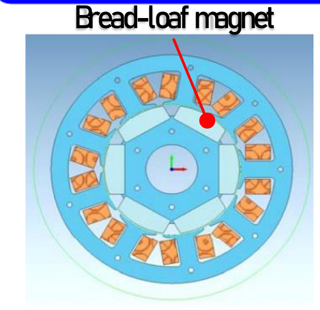
Deep borewell submersible pump and motor arrangement

Prototype of 15 slot, 10 pole SMDS spoke-type BLDC motor

Field Testing of submersible BLDC motor and controller

- Design constraints: tubular shape (low D/L ratio), must fit 4-inch borewell (100 mm), submersible operation
- Ferrite (ceramic) magnets → alternate design approach for **replacing rare earth permanent magnets** → **lower cost**
- Spoke-type magnet arrangement → **improves flux concentration** → higher airgap flux density and torque, lower current density
- Semi-modular Dual-stack (SMDS) design → retains **rotor integrity** at high speed, **minimal flux leakage**, full load efficiency > **88%**
- Further details are published in DOI: 10.1109/TIE.2016.2609841 [1], DOI: 10.1109/TMAG.2016.2618343 [2] and DOI: 10.1109/JESTPE.2018.2810506 [3].

2.2 kW, 3,000 RPM BLDC Motor and Controller For Solar PV Based Surface Water Pump



FEA Model

Kirloskar pump (KDI-335) retrofitted with BLDC motor

Field Testing of surface pump BLDC motor and controller

- 6 poles, 9 slots, rated for **7 Nm** at **3,000 RPM**
- **Sensorless control** → reduces component count, lowers cost

[1] S. Sashidhar and B. G. Fernandes, "A Novel Ferrite SMDS Spoke-Type BLDC Motor for PV Bore-Well Submersible Water Pumps," in IEEE Transactions on Industrial Electronics, vol. 64, no. 1, pp. 104-114, Jan. 2017.
[2] S. Sashidhar and B. G. Fernandes, "Braking Torque Due to Cross Magnetization in Unsaturated IPM BLDC Machines and Its Mitigation," in IEEE Transactions on Magnetics, vol. 53, no. 1, pp. 1-9, Jan. 2017, Art no. 8200209.
[3] S. Sashidhar, V. Guru Prasad Reddy and B. G. Fernandes, "A Single-Stage Sensorless Control of a PV-Based Bore-Well Submersible BLDC Motor," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 7, no. 2, pp. 1173-1180, June 2019.

Facilities, Prototypes and Products Developed at NCPRE

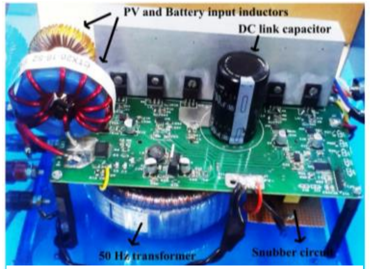
Power Electronic and Drives Experimental Bench (PEDEB) [1]

DOI: 10.1109/TE.2012.2200681 [1]

PE Based Programmable AC Source, BLDC Drive

Battery Integrated Standalone/Grid-tied PV Inverters

300W, Higher Life-time, Low Cost [2]

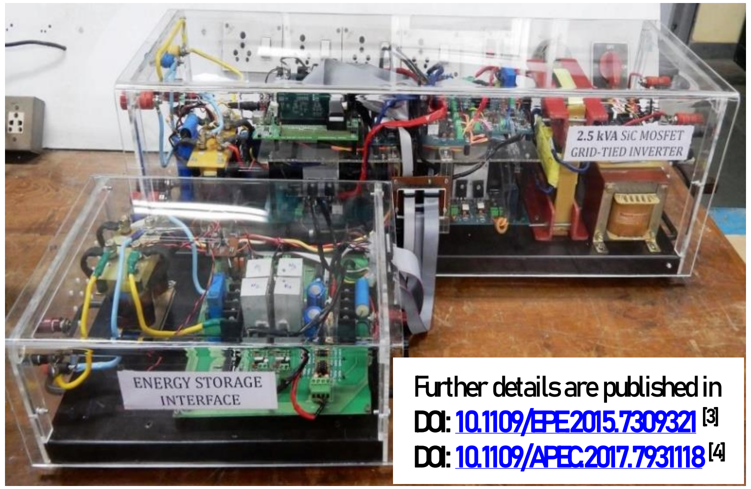


DOI: 10.1109/PEDES.2014.7042143 [2]

500W, SiC MOSFET Based Standalone Battery Integrated Inverter

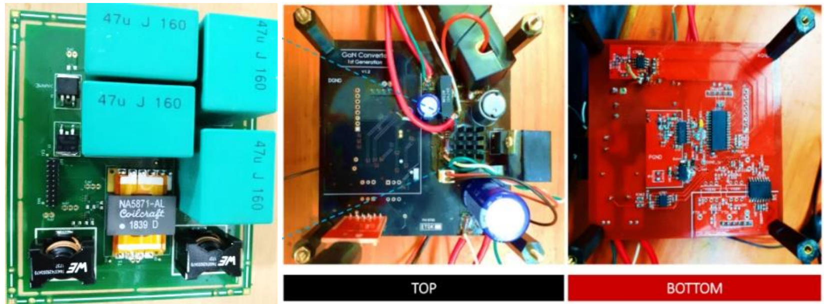
2.5 kW, SiC MOSFET Based Grid-tied Heric Inverter

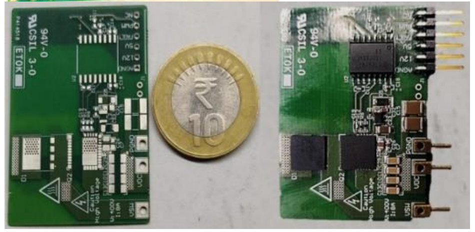
2.5 kVA Grid-tied Transformerless SiC MOSFET Based PV Inverter with Low $I_{leakage}$ and Minimum η > 95% [3,4]



Further details are published in
DOI: 10.1109/EPE.2015.7309321 [3]
DOI: 10.1109/APEC.2017.7931118 [4]

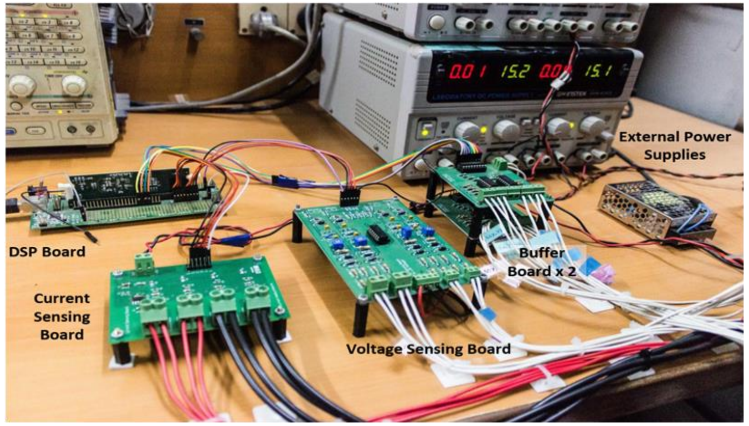
GaN-based Power Electronic Interfaces





Clockwise (from Left): (a) 500 W, Isolated Dual Boost Converter [5], (b) 1 MHz GaN Based Half-bridge Converter for Ultracapacitor and Battery for EV, (c) Half-bridge Leg for 1 kW Totem-pole PFC

Quad-Active Bridge (QAB) Power Electronic Interface for Electric Vehicle (EV) Drive Train [6]

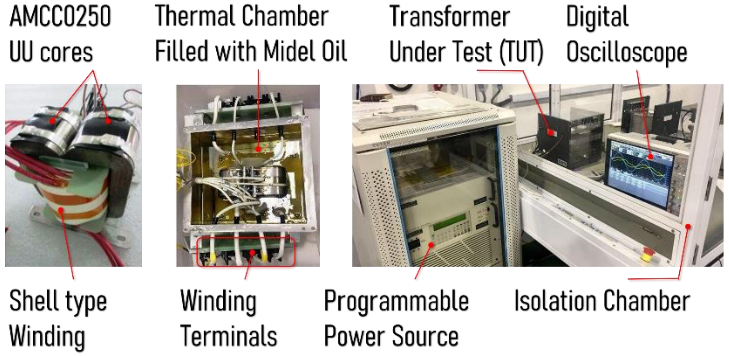


Further details are published in DOI: 10.1109/PEDES.2018.8707735 [6].

[1] S. Anand, R. S. Farswan and B. G. Fernandes, "Unique Power Electronics and Drives Experimental Bench (PEDEB) to Facilitate Learning and Research," in IEEE Transactions on Education, vol. 55, no. 4, pp. 573-579, Nov. 2012, doi: 10.1109/TE.2012.2200681.
[2] R. S. Farswan, H. Khan and B. G. Fernandes, "A low cost reliable stand-alone photo-voltaic system," 2014 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Mumbai, India, 2014, pp. 1-6, doi: 10.1109/PEDES.2014.7042143.
[3] R. S. Farswan, A. Datta, G. Kamble and B. G. Fernandes, "A low leakage transformer-less 3-level DC-DC boost converter for transformer-less PV inverters," 2015 17th European Conference on Power Electronics and Applications (ECCE-Europe), pp. 1-10, doi: 10.1109/EPE.2015.7309321.
[4] A. Datta, R. S. Farswan and B. G. Fernandes, "Development of a two-stage transformerless grid-tied photovoltaic inverter system using SiC devices," 2017 IEEE Applied Power Electronics Conference and Exposition (APEC), 2017, pp. 2964-2969, doi: 10.1109/APEC.2017.7931118.
[5] S. Akshatha, R. Vinayak and B. G. Fernandes, "Isolated Dual Boost Converter: Controller Design using Affine Parameterisation," 2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Chennai, India, 2018, pp. 1-6, doi: 10.1109/PEDES.2018.8707597.
[6] M. J. Vishal, A. C. Nair and B. G. Fernandes, "Quad-Active-Bridge DC-DC Converter based on-board Power Electronic Interface for Electric Vehicle," 2018 IEEE International Conference on Power Electronics, Drives and Energy Systems, pp. 1-6, doi: 10.1109/PEDES.2018.8707735.

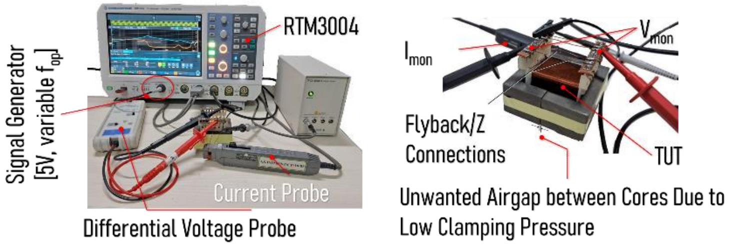
Facilities, Prototypes and Products Developed at NCPRE

99.55% Efficient, 10 kW, 0.5/5 kV, 1 kHz Transformer Optimized Using Gradient Method [1]



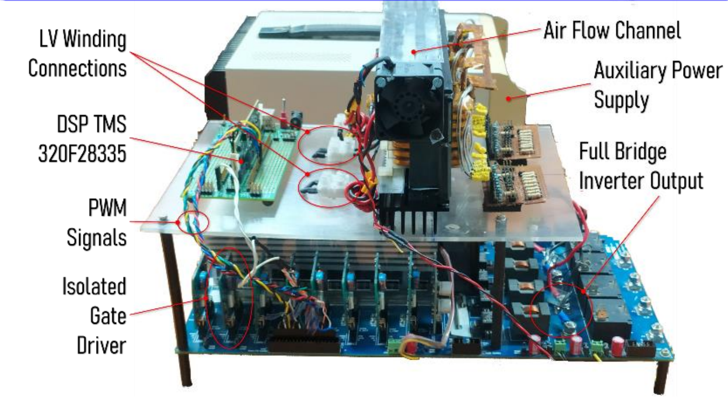
Power density (w/o tank) is **19.79 kW/dm³**, Maximum $\Delta T_j < 33\ ^\circ C$.
This work is done in collaboration with **ERIAN@NTU, Singapore**.
Further details are published in **DOI: 10.1109/APEC.2018.8341259** [1].

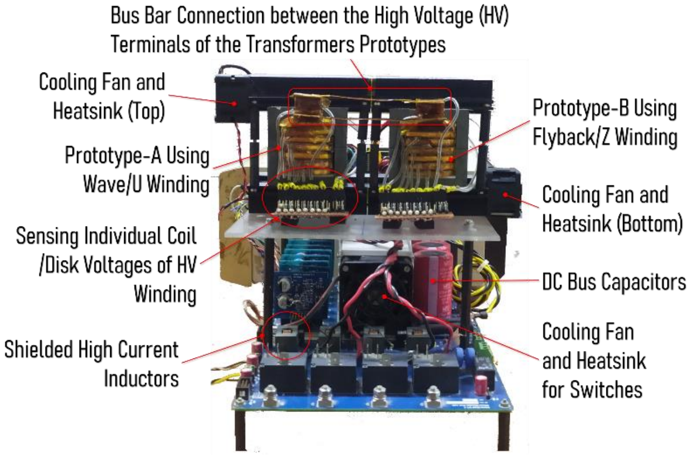
Modeling, dv/dt study and Diagnosis of HFT Using a Reduced-order Frequency-dependent π-model [3,4]



Energy based modeling of winding capacitances of two-winding transformer is detailed in **DOI: 10.1109/TIA.2022.3167018** [3].
Equivalent π-model is detailed in **DOI: 10.1109/TIA.2023.3306743** [4].

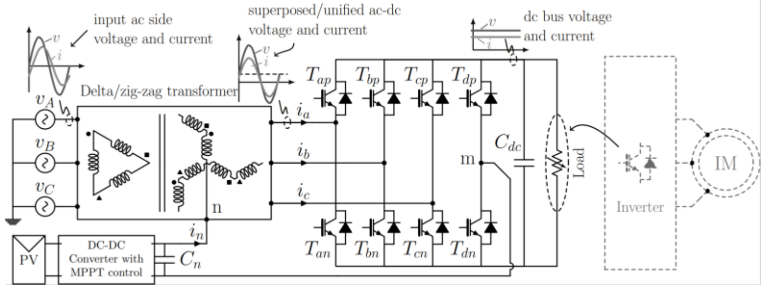
Design, Fabrication and Validation of 1.2 kW, 0.24/2.1kV, 20 kHz Foil Winding Transformers

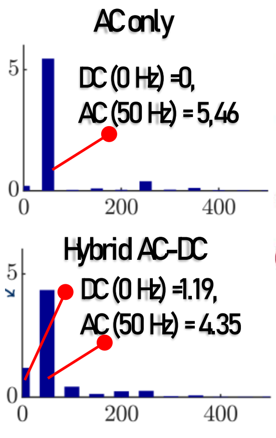




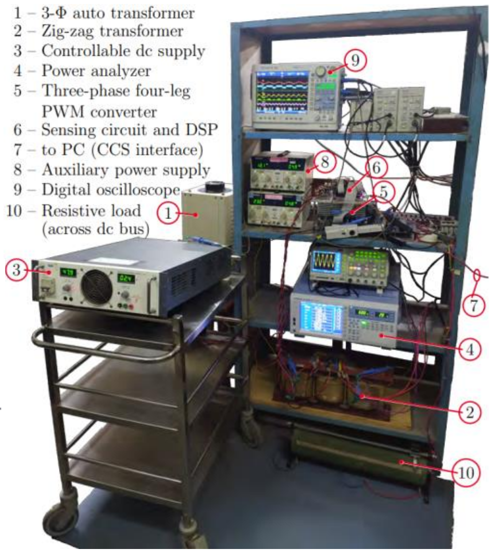
Two foil winding transformers of similar ratings but different winding schemes (**wave** and **flyback**) are shown connected in **back-to-back** fashion (Sumpner's test) along with the converter.

Hybrid AC-DC Single-stage Multifunctional PWM Converter for Integrating LV PV with 3-ϕ AC [2]





FFT of the zigzag winding current



Low voltage solar PV is integrated with three-phase ac grid using a delta/zigzag transformer and four-legged PWM converter.
This work is supported by **DST-Netherland (NOW) joint project**.
Further details are published in **DOI: 10.1109/JESTPE.2020.3019730** [2].

[1] A. K. Das et al., "Multi-variable optimization methodology for medium-frequency high-power transformer design employing steepest descent method," 2018 IEEE Applied Power Electronics Conference and Exposition (APEC), San Antonio, TX, USA, 2018, pp. 1786-1793.
[2] V. Chitransh et al., "Evaluation of Multifrequency Power Electronic Converters: Concept, Architectures, and Realization," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 9, no. 3, pp. 3582-3597, June 2021.
[3] A. K. Das and B. G. Fernandes, "Estimation of the Resonance Frequencies Using an Electrostatic Energy Based Capacitance Model of a Two-Winding Medium/High-Frequency Transformer," in IEEE Transactions on Industry Applications, vol. 58, no. 4, pp. 5301-5316, July-Aug. 2022.
[4] A. K. Das and B. G. Fernandes, "An Analytical Method to Obtain A Wide Frequency Range Equivalent π-model of a Two-winding Medium/High-frequency Transformer," in IEEE Transactions on Industry Applications, doi: 10.1109/TIA.2023.3306743.

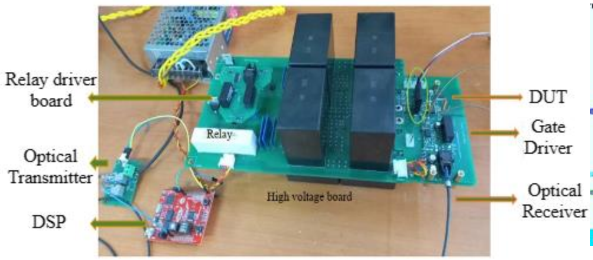
Deliverables and Work Packages at NCPRE Phase III

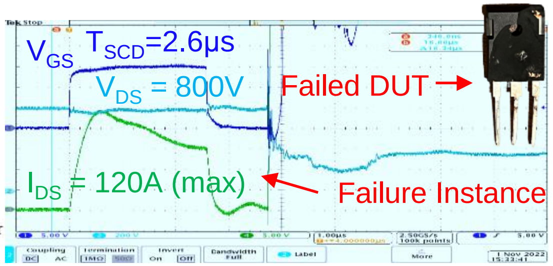
- **SiC-based Compact and Efficient Inverter for Direct MV Grid Integration**
  - SiC Gate Drive and Protection Circuits for Power Electronic Converters
  - Circuit Topology and Design of Medium Voltage Solar PV Inverter
  - Insulation and Transformers for Medium Voltage Medium Frequency Power Electronics
  - Controller for Medium Voltage Solar Inverter along with Grid Integration
- **Estimation and Improvement of Solar PV Inverter Reliability**
  - Condition Monitoring Techniques in Solar PV Inverters
  - Accelerated Ageing and Failure Models
  - Technology for Improving Reliability
- **Optimal Capacity and Technology Mix of Grid Scale Storage for Achieving High Penetration of Renewables**
- **Technical Report/White Paper on One Sun One World One Grid (OSOWOG) Project**

Deliverables and Work Packages at NCPRE Phase III

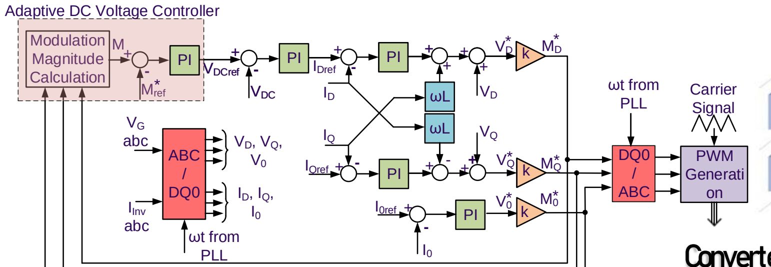
SiC-based Compact and Efficient Inverter for Direct MV Grid Integration

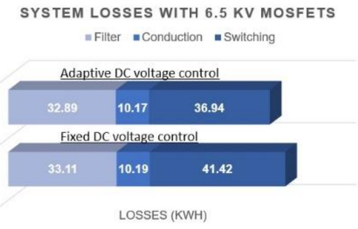
Short Circuit Protection of 1.2 kV SiC MOSFET





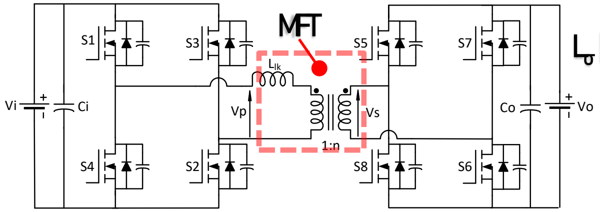
An Adaptive DC Voltage Control of SiC-based MV Solar PV Inverter [1]



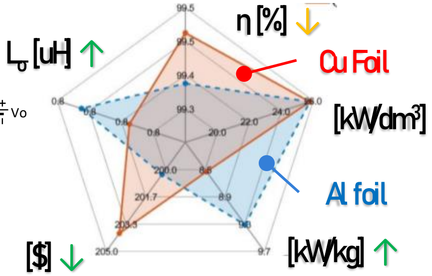


Converter Losses Reduced by 5.5%

Comparing High-power Medium-frequency Transformers with Cu and Al Foils [2]

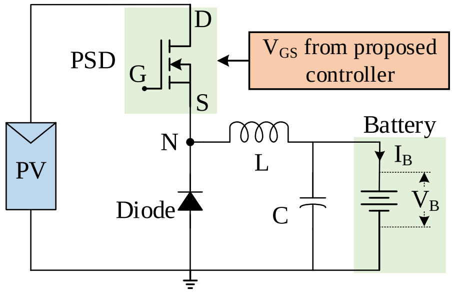


An Isolated Dual Active Bridge (DAB) DC-DC Converter

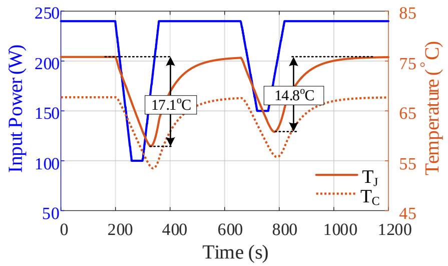


Estimation and Improvement of Solar PV Inverter Reliability

Gate Voltage Based Active Thermal Control of Power Semiconductor Devices [3]

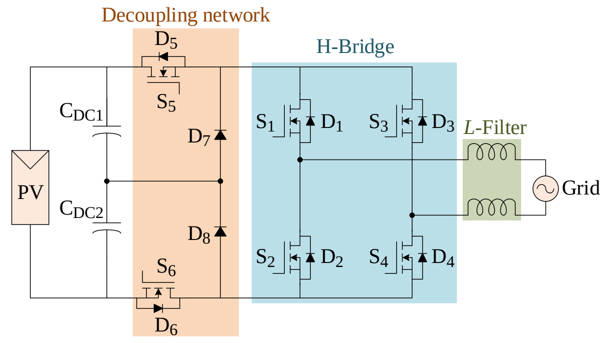


DC-DC Converter with Proposed Controller
Details are in DOI: 10.1109/TPEL.2023.3291808



Failures: Bond-wire Lift Off and Solder Fatigue
Reason of Failure: Junction Temperature Tj swings
Solution: Active Thermal Control – Manipulation of Tj

Thermal Stress Balancing for Lifetime Improvement of H6 Solar PV Inverter [4]

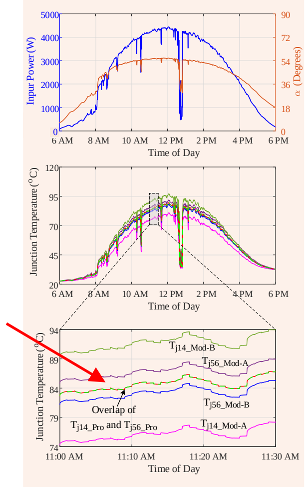


H6 Transformerless Solar PV Inverter

Further details are published in
DOI: 10.23919/EPE23ECCEEurope58414.2023.10264669

Selected Solar PV Mission Profile

Overlap of T_{j14_Pro} and T_{j56_Pro} validates the scheme and uniform stress distribution



[1] J. J. Attukadavil, S. Anand and B. G. Fernandes, "An Adaptive DC Voltage Control for SiC based Medium Voltage Photovoltaic Inverter," 2022 IEEE Energy Conversion Congress and Exposition (ECCE), Detroit, MI, USA, 2022, pp. 1-7, doi: 10.1109/ECCE50734.2022.9947823.
[2] P. Priya, A. K. Das, S. Anand and B. G. Fernandes, "Effect of Material Resistivity and Temperature on Leakage Inductance of Medium Frequency Transformers Made of Al and Cu Foils," IECON 2022, Brussels, Belgium, pp. 1-6, doi: 10.1109/IECON49645.2022.9968856.
[3] A. Chanekar, N. Deshmukh, A. Arya and S. Anand, "Gate Voltage-Based Active Thermal Control of Power Semiconductor Devices," in IEEE Transactions on Power Electronics, vol. 38, no. 9, pp. 11531-11542, Sept. 2023, doi: 10.1109/TPEL.2023.3291808.
[4] A. Chanekar, N. Deshmukh, A. Gangwar and S. Anand, "Thermal Stress Balancing for Lifetime Improvement of H6 Solar Inverter," 2023 25th European Conference on Power Electronics and Applications, Aalborg, Denmark, pp. 1-9, doi: 10.23919/EPE23ECCEEurope58414.2023.10264669.

Present Decade of Solar PV for India: 2020 - 2030

- India has plans to install 300 GW of solar PV by 2030. Currently, only about 35.7 GW has been installed (December 2019).
- Approximately 10 times the current installed capacity would be installed in next 10 years!
- At the same time, we need to ensure that the installed modules have desired quality and reliability to last for 25 years in hot climates.
- There is a strong push to have a considerable fraction of these upcoming installations from domestically manufactured PV cells and modules.
- Most the upcoming PV installations would be coupled with some form of storage (battery / hydro).
- NCPRE has a major role to play in driving the solar future of India.

Thank You