IEEE ISGT 2022- NRF-SPECS Panel Discussions on Advances in DERs Integration and VPPs for Urban Grid Flexibility

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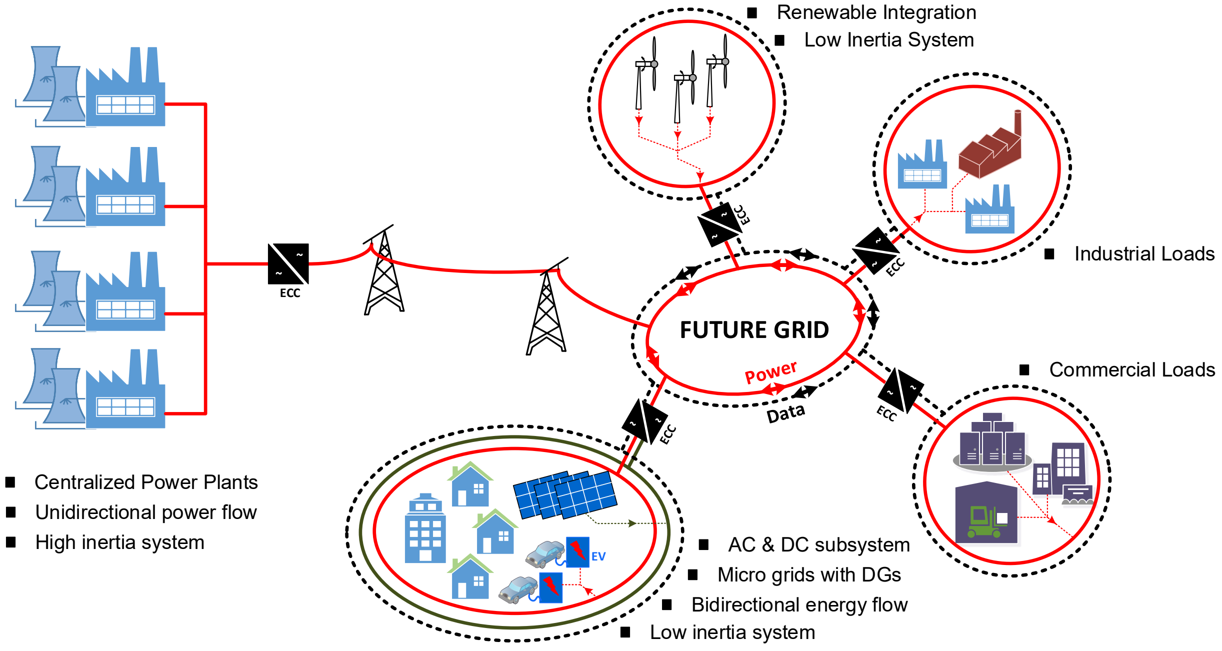
The Evolving Power Grid: Challenges can be Opportunities

- Energy grid 2.0:
  - Decentralized/distributed energy generation
  - Diversified nature of loads – both AC and DC
  - Bidirectional power and information flow

- Microgrids - building blocks of future grid

- *Key for economic and efficient operation of microgrids* - architectures that avoids multiple energy conversions

- **Microgrids are interconnected to other microgrids or grid at higher voltages through energy control centers (ECC)**

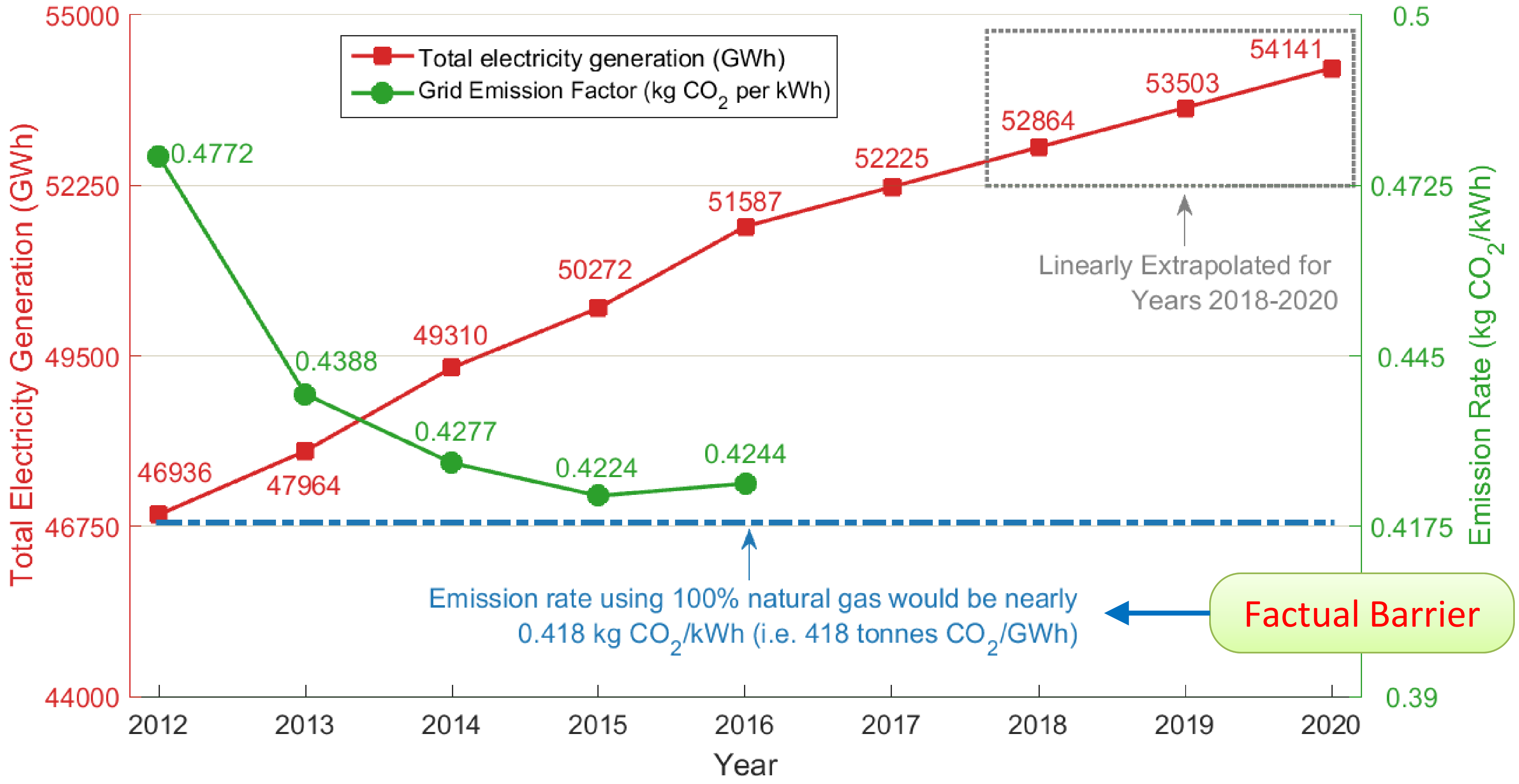


Future energy grid 2.0:

- Objectives of ECC:
  - Active power-flow control, compensation
  - VAR & harmonic compensation
  - Control of DC bus to integrate renewables & storage
  - Microgrid control during islanding/grid connection
  - Information sharing between microgrid and rest of the n/w

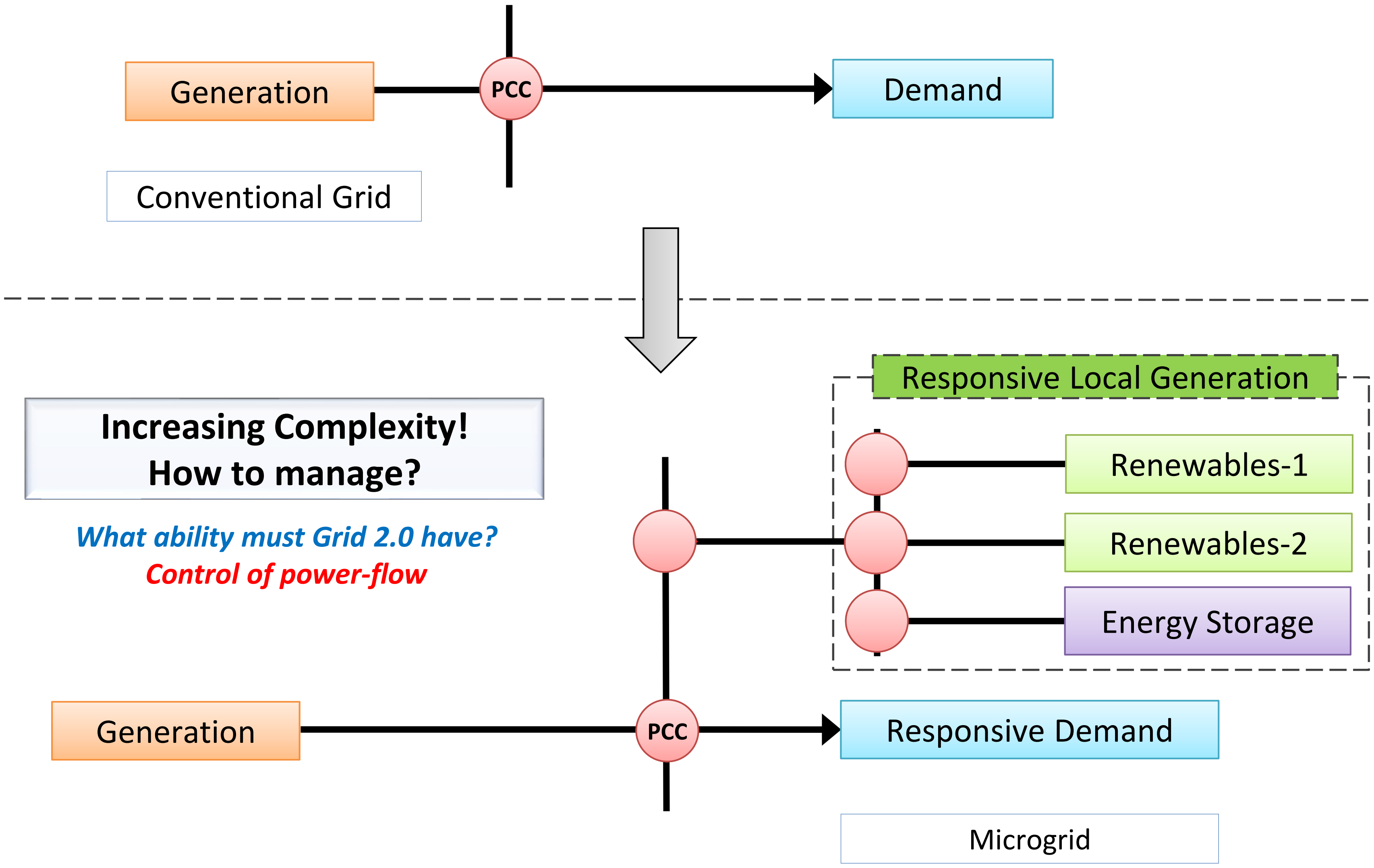
ECC is realized using **solid-state transformer** also know as **power electronic transformer** or **smart transformer**

The Challenge of Mitigating Carbon Emissions in Grid 2.0 of Singapore



The Grid Emission Factor (**GEF**) trend shown above (*source: Singapore Energy Statistics'17, EMA*) indicates that further reductions would be difficult. **Photovoltaic generation** is necessary to reduce GEF further.

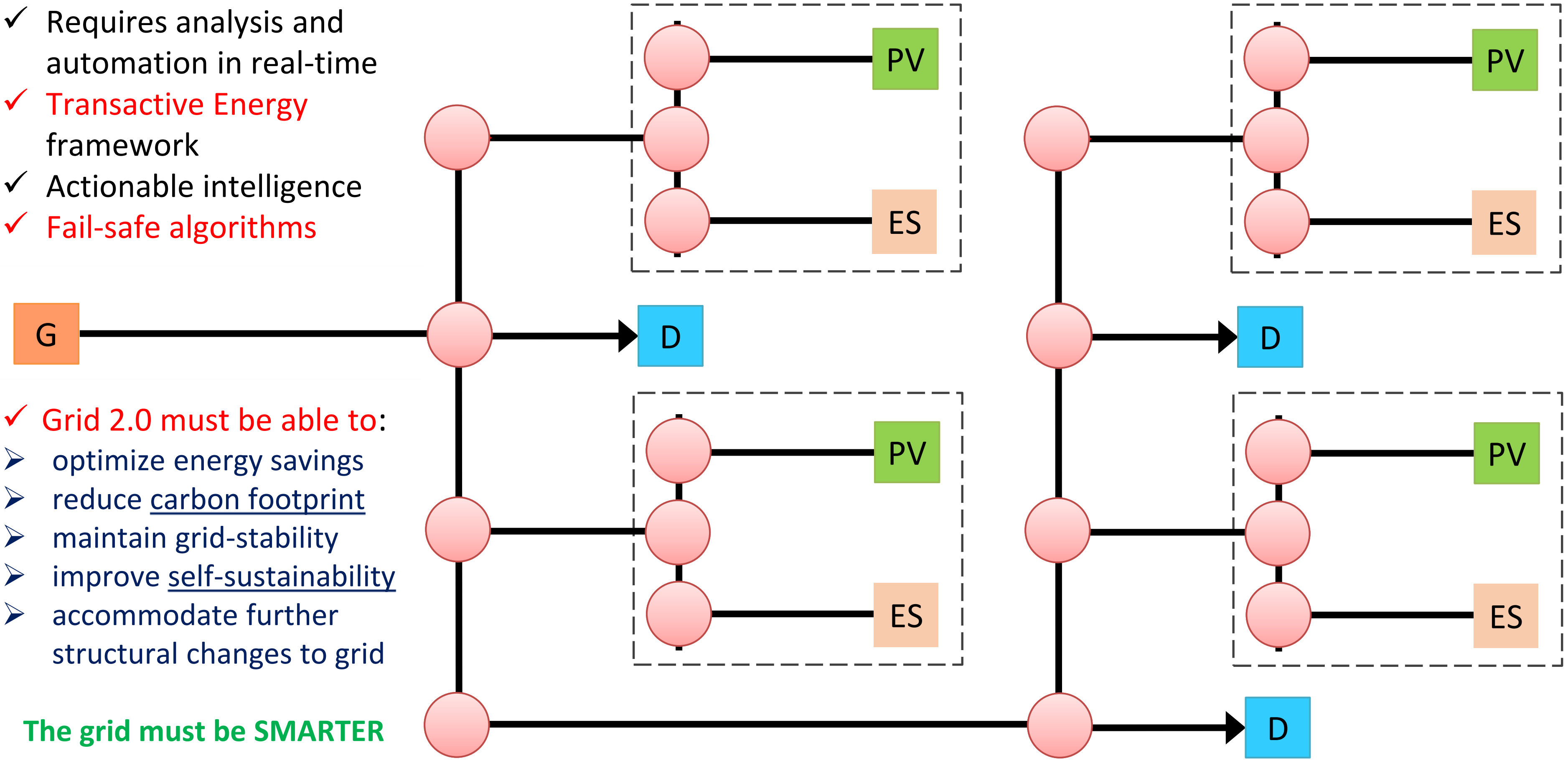
Required Paradigm Shift in Grid's Structure



Real-time Power-Flow Management for Grid 2.0

To be managed by intelligent machines!

- ✓ Requires analysis and automation in real-time
- ✓ Transactive Energy framework
- ✓ Actionable intelligence
- ✓ Fail-safe algorithms



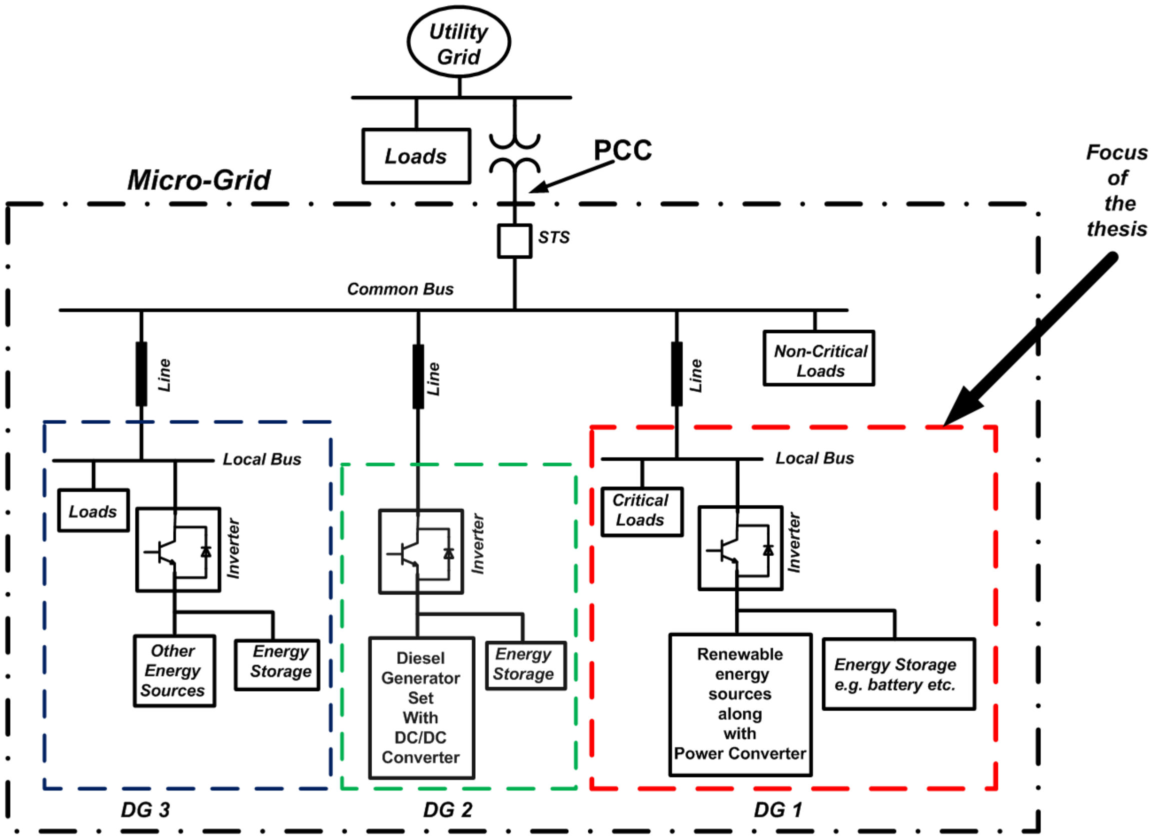
✓ Grid 2.0 must be able to:

- optimize energy savings
- reduce carbon footprint
- maintain grid-stability
- improve self-sustainability
- accommodate further structural changes to grid

The grid must be SMARTER

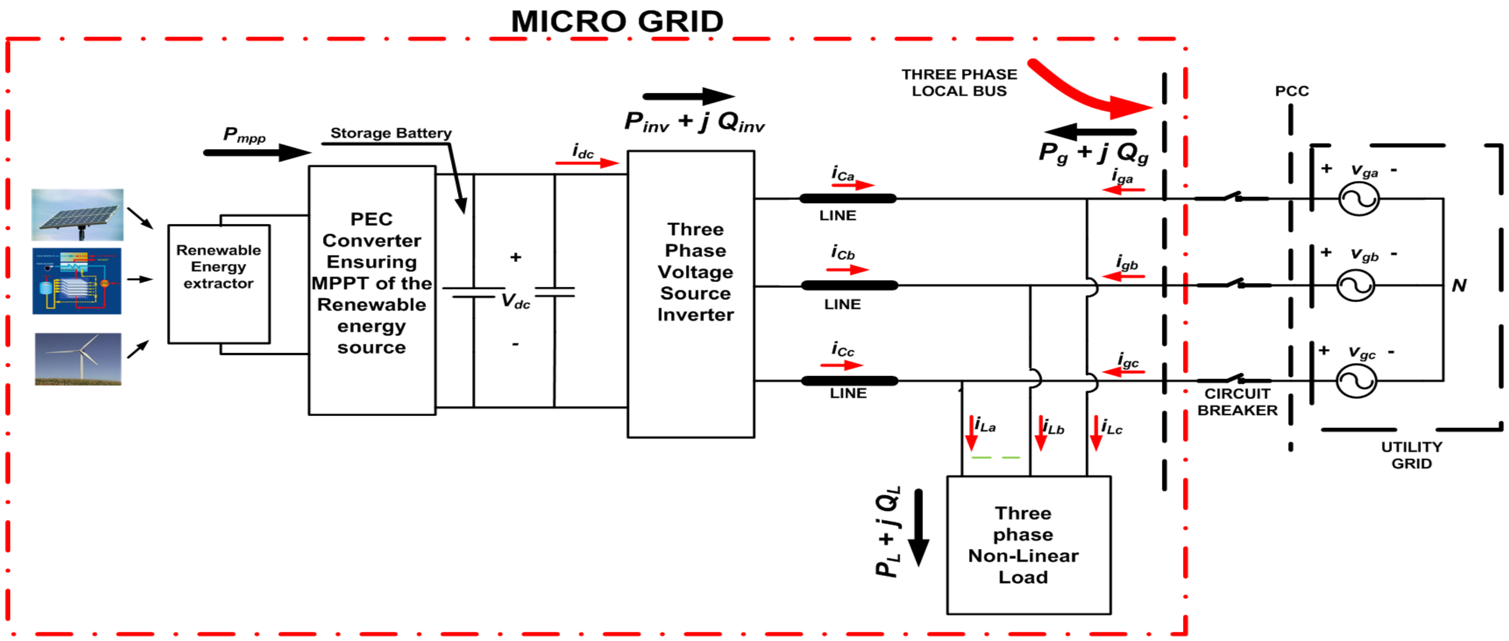
G → Generation　PV → Photovoltaics　D → Demand　ES → Energy Storage

Typical multi-bus micro-grid system



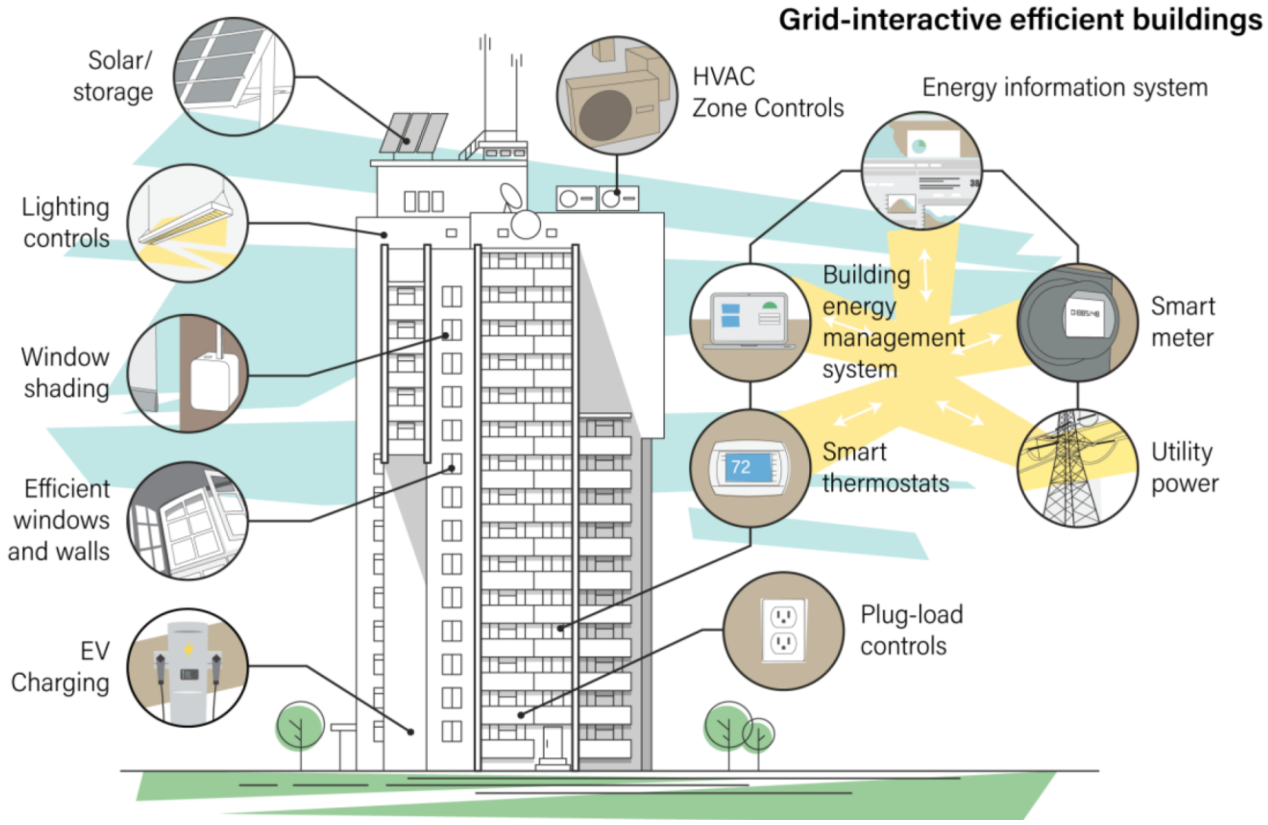
- ***Static Transfer Switch (STS)* on** or **off** defines ***grid connected*** and ***islanded operation***.
- DG1, DG2 and/or DG3 can be fossil fuel based or renewable energy source based generator interfaced to common AC bus using power electronic converters.
- Main concerns of micro-grid research are : ***High band-width active and reactive power flow control*, *THD control of current drawn from common AC bus*, *Load voltage regulation***…etc….

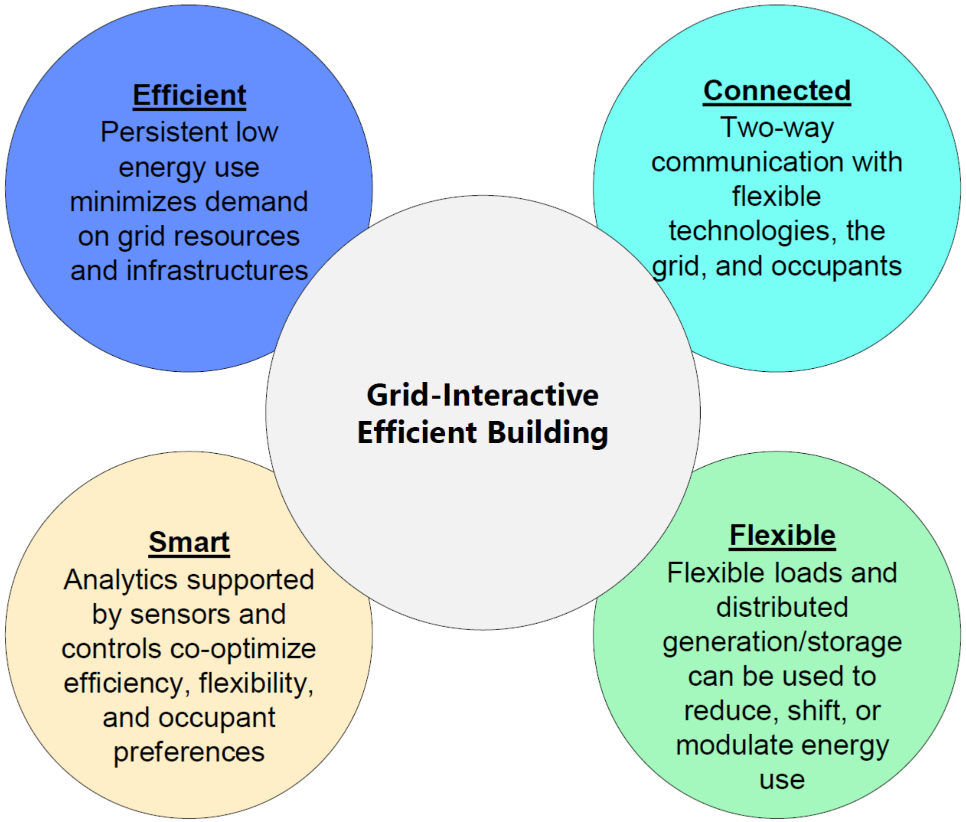
Scheme:



- Total load active power P_L is shared between inverter active power, P_{inv} and grid active power, P_g… i.e. $P_L=P_{inv}+P_g$
- There is a shavings in power consumption from local bus (grid).
- The current drawn local bus is purely sinusoid with DPF=1.
- High-performance non-linear current controller is used for the inverter to perform two actions:
  - Active power flow control
  - THD control of grid current
  - The local bus (grid) voltage can be unbalanced or harmonic contaminated.

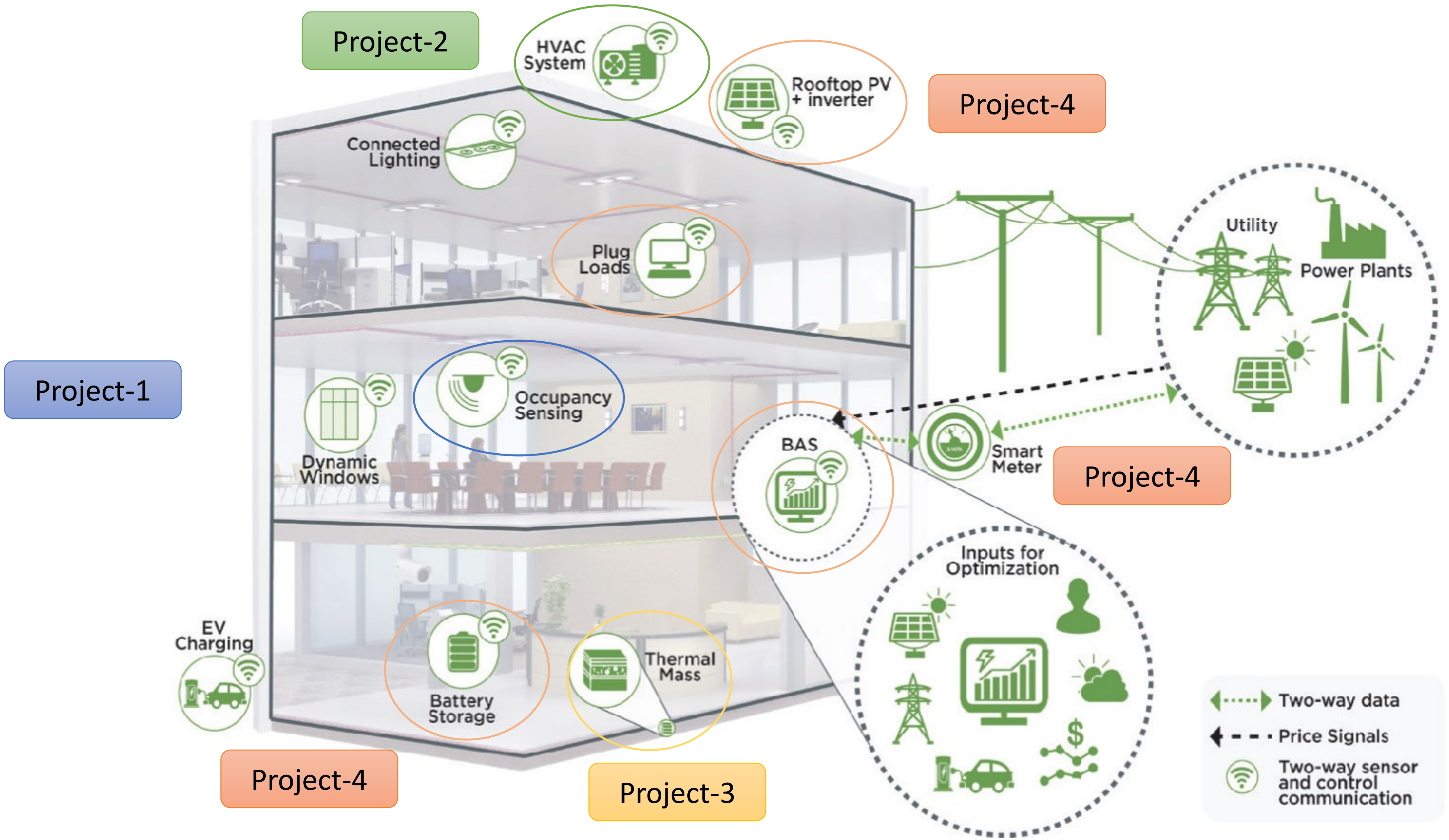
Emerging Concept of Grid Interactive Efficient Buildings





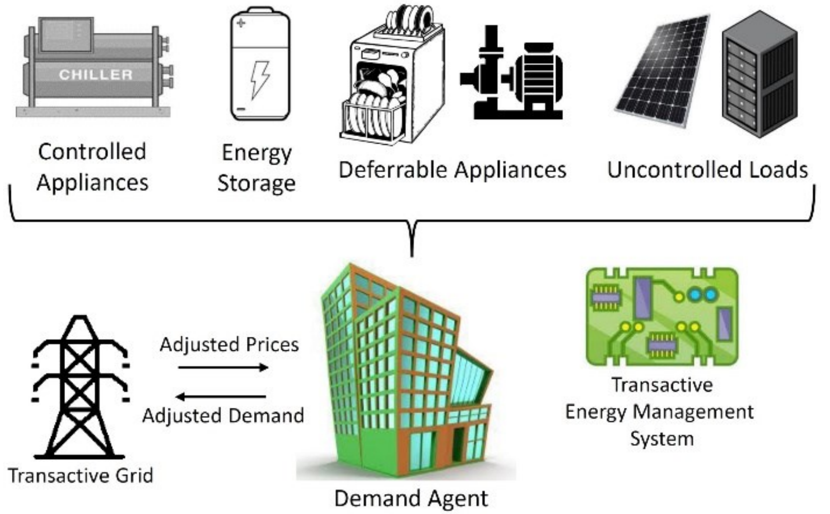
U.S. Department of Energy (DOE), "Grid-interactive Efficient Buildings," 2022.

Agile, Intelligent, Efficient and Resilient *Connected-Community* of Buildings



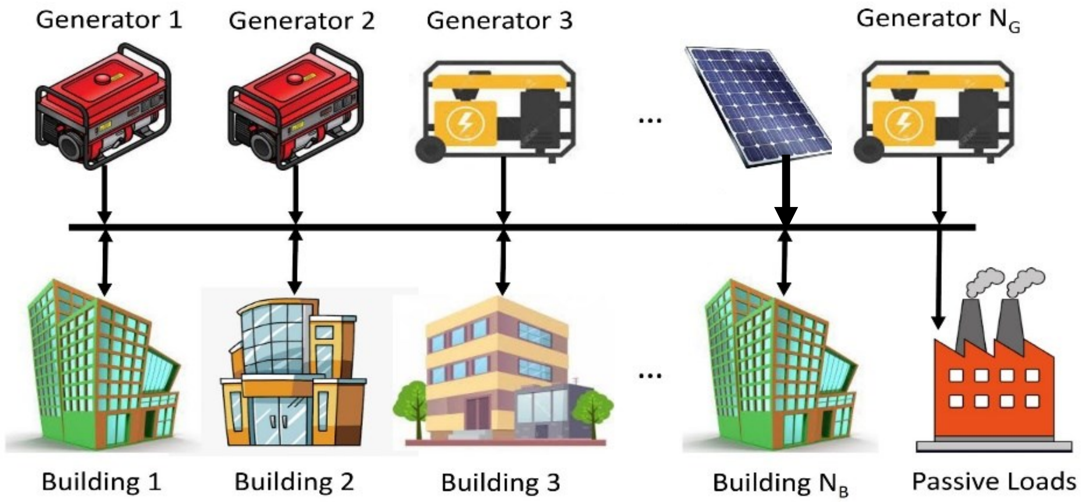
U.S. Department of Energy (DOE), "Grid-interactive Efficient Buildings Whole-Building Controls, Sensors, Modeling, and Analytics," 2019.

Intelligent Grid Interface System for Utility-Customer Power Interaction Control



A prosumer building with electrical resources

Energy Transactions with Grid/Microgrid/Nanogrid



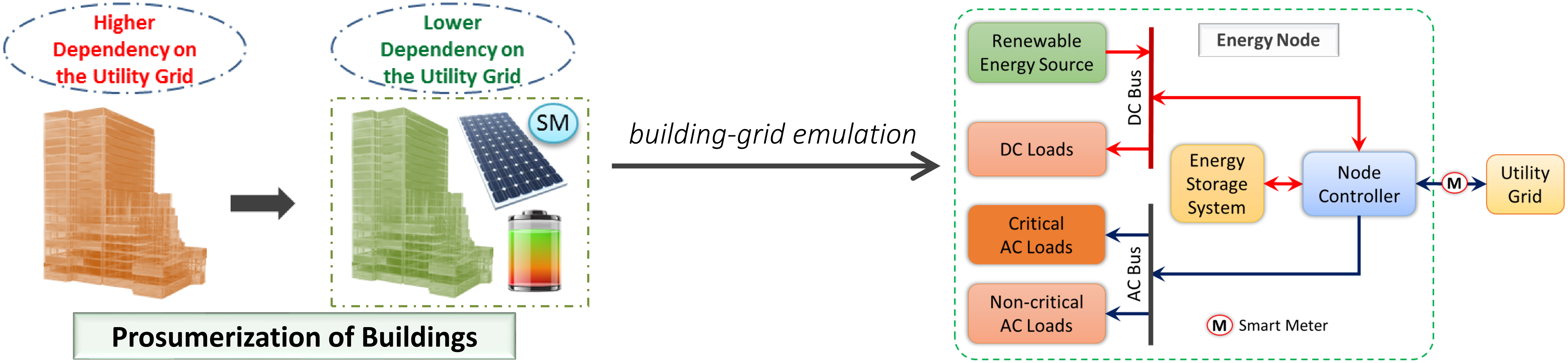
Multiple prosumers connected to grid/microgrid/nanogrid

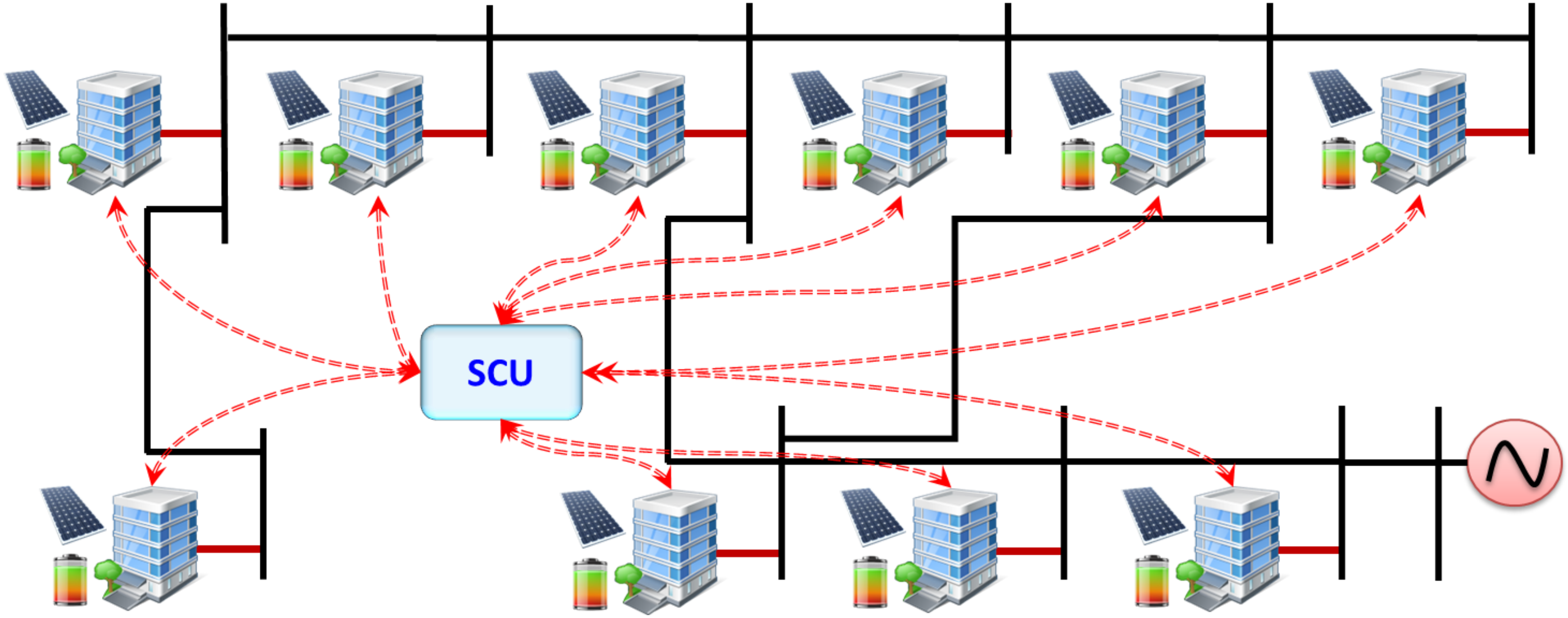
Cross-theme collaboration with Theme-E

SinBerBEST Nanogrid

for building-grid
Building Energy Management Systems (BEMS)

for nanogrid
Transactive Energy Management Systems (TEMS)

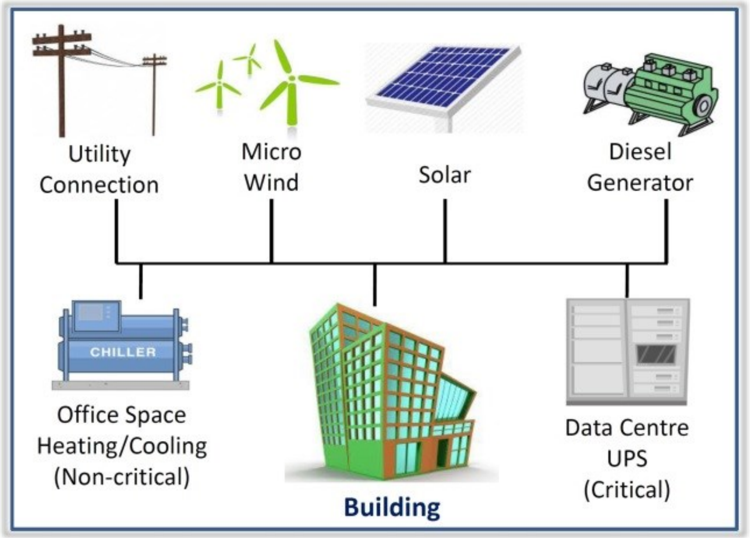




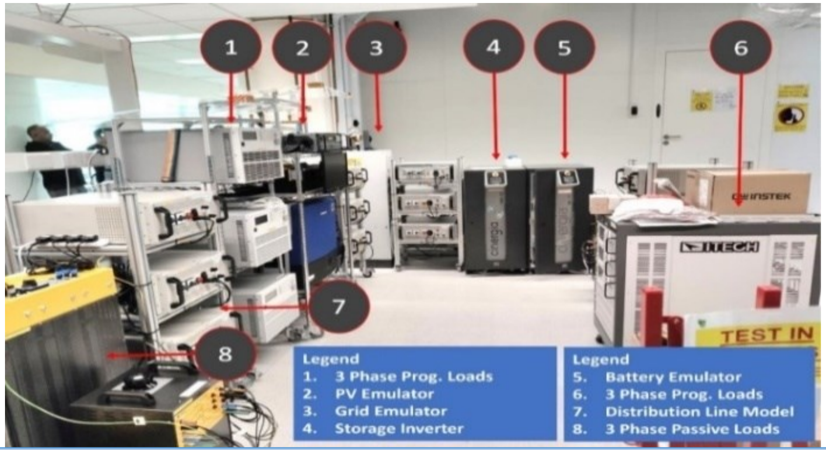
A cluster of energy nodes forms a nanogrid/microgrid depending on cumulative power capability.

Supervisory Control Unit (**SCU**) here is a nanogrid/microgrid control unit.

Interoperability in DER dominated buildings through Testbed Demo

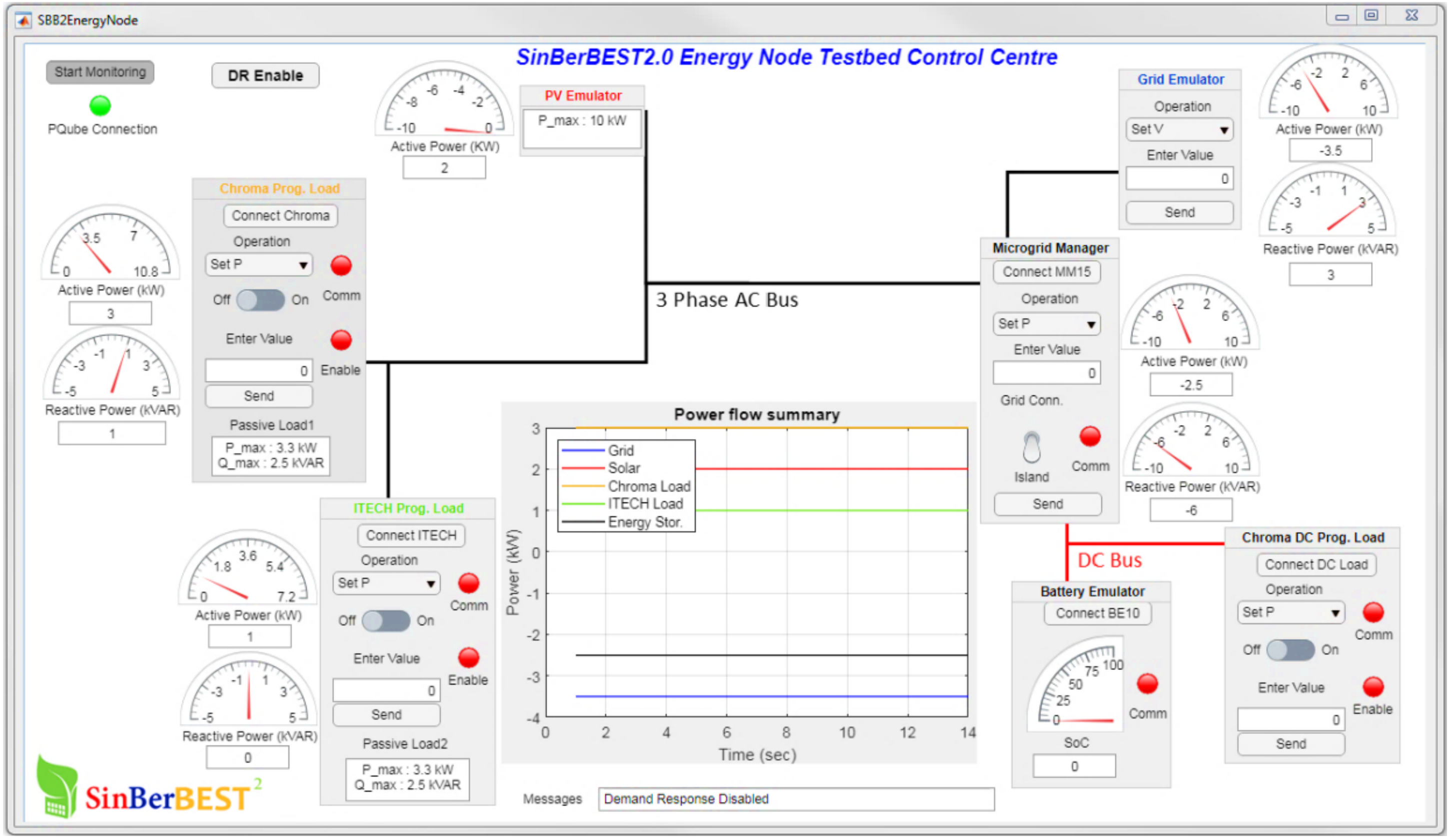


Electrical Resources in Buildings



Setup of the Physical Testbed

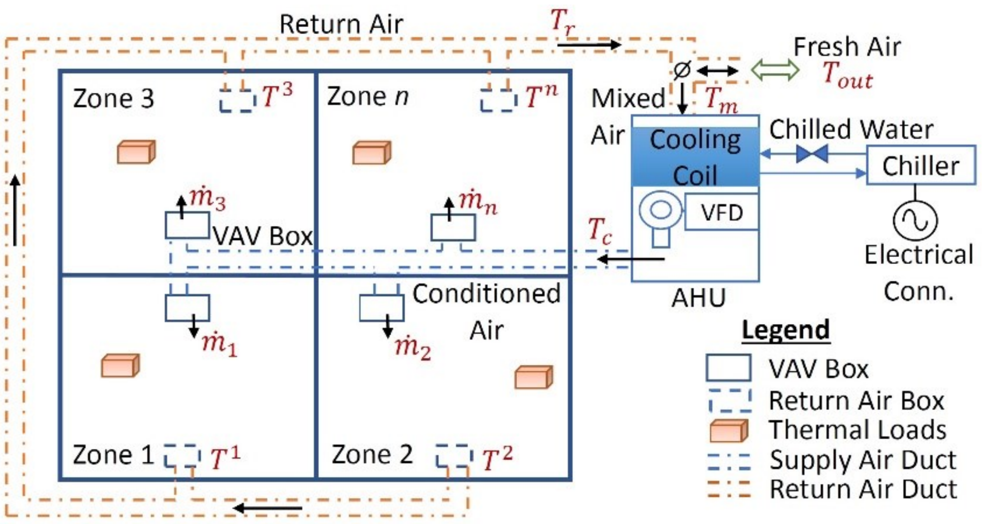
- Development of scalable control strategies for grid participation and enabling interoperability within buildings
- Dashboard developed for coordinated control of the Energy Nodes in nanogrid test-bed



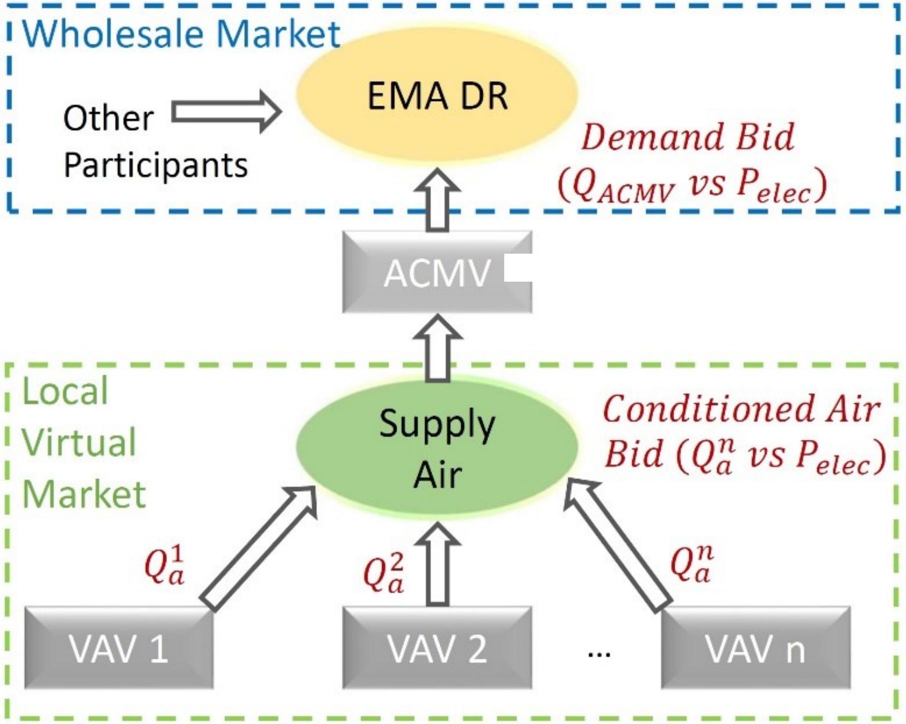
Real-time GUI for Testbed Network Coordination and Interoperability

Cross-theme collaboration with Theme-E

Virtual Market based control of ACMV systems



Typical ACMV system schematic

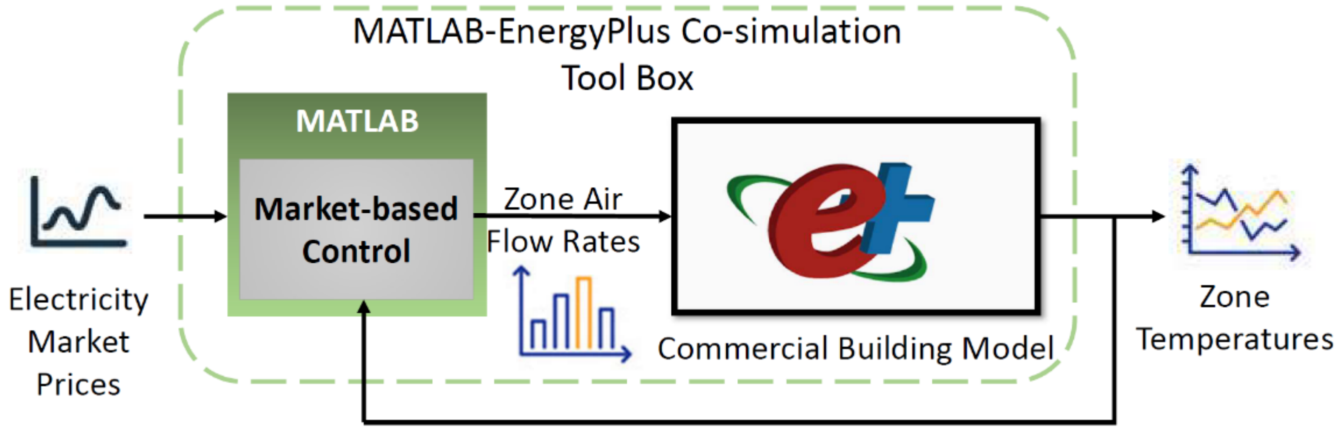


Proposed virtual Transactive Market based control schematic

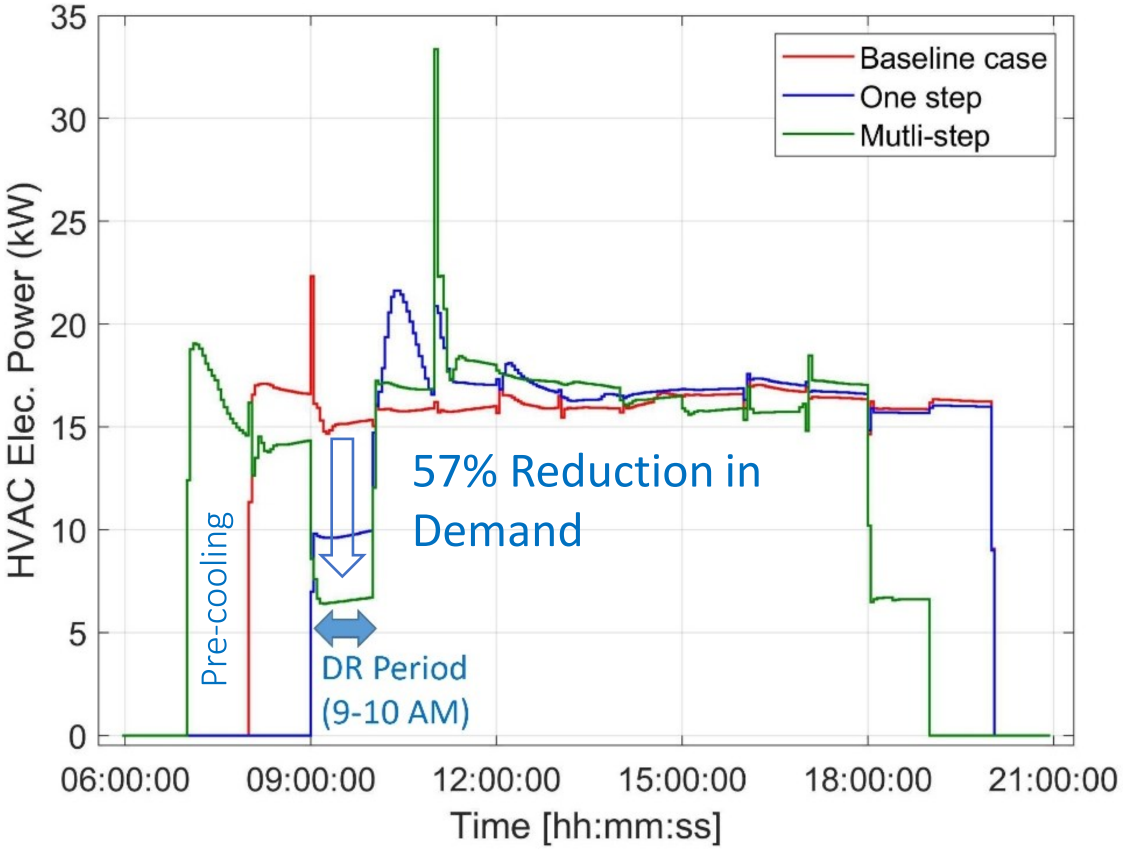
Virtual market-based control with Transactive Energy principles is proposed for air conditioning systems in buildings for participation in Demand Response markets

Virtual Market based control of ACMV systems

Transactive Control of Air Conditioning systems for Demand Response program in Singapore



MATLAB–EnergyPlus co-simulation set up



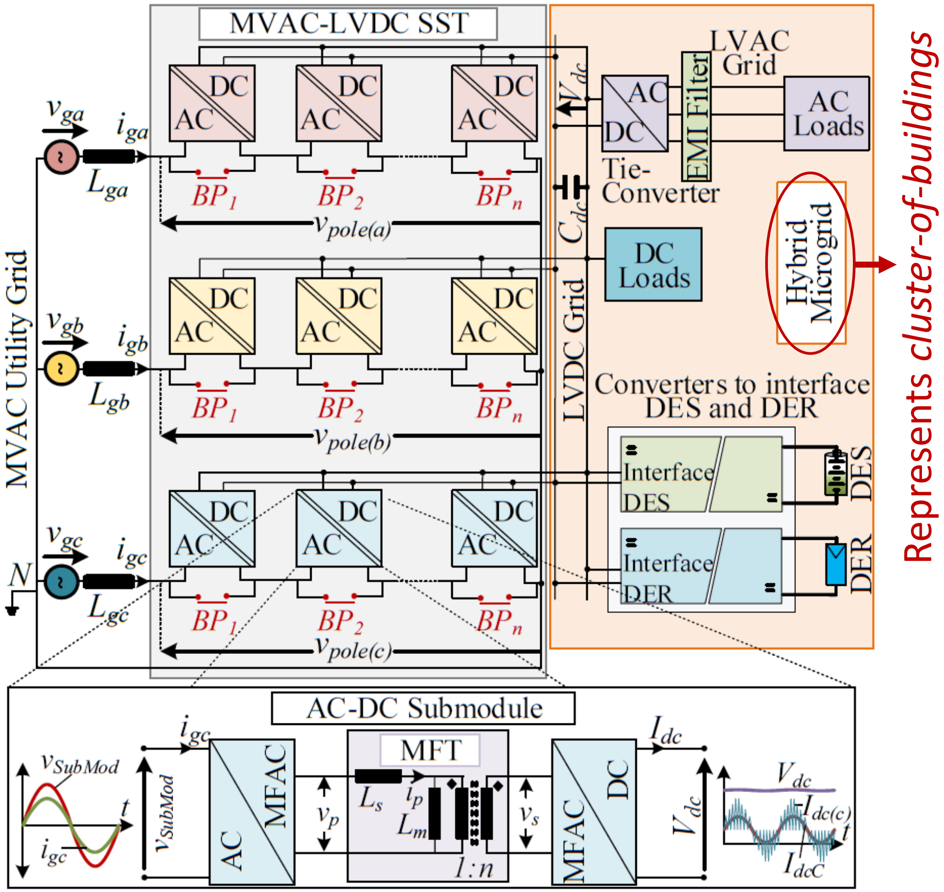
Variation in electricity consumption by the ACMV system

Results

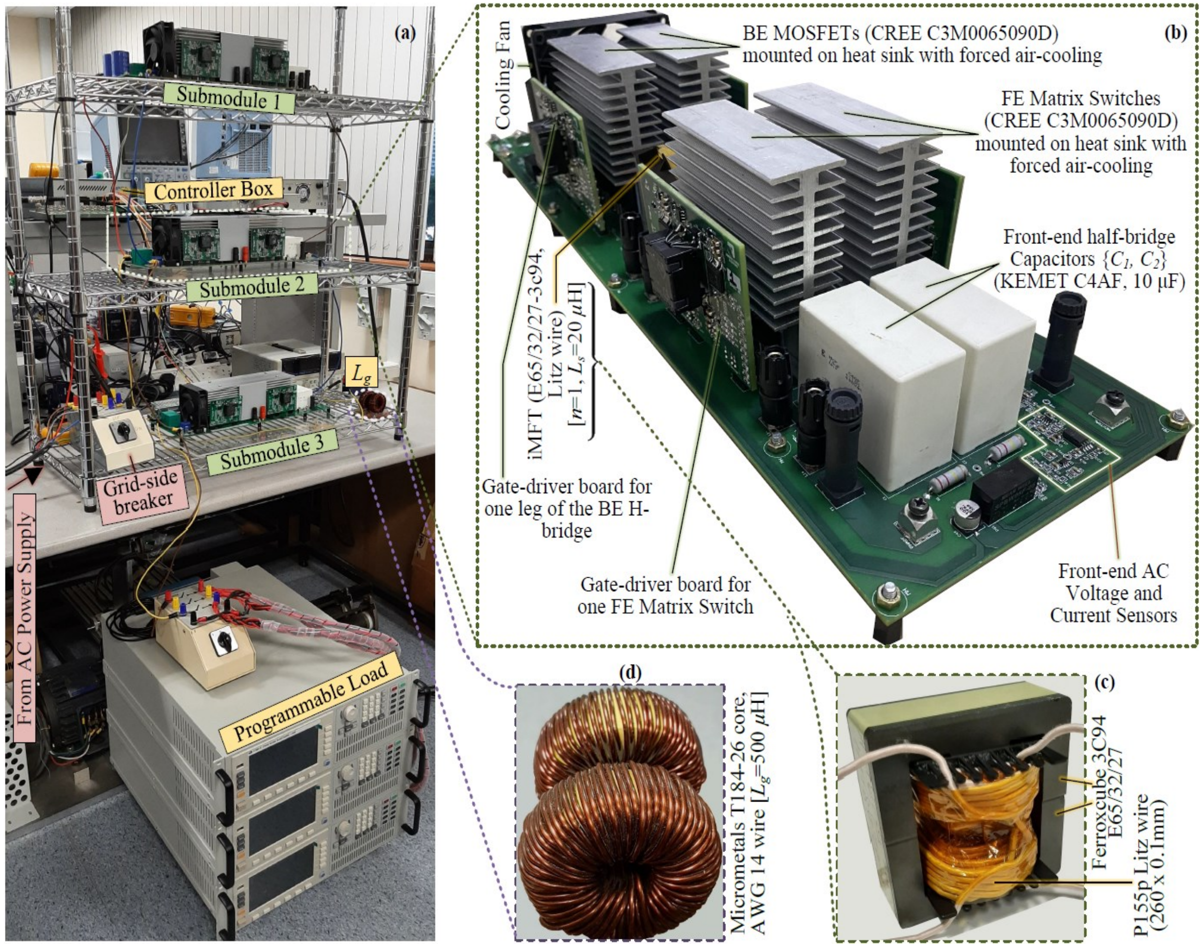
- Novel dynamic programming (DP) approach to utilize the temporal flexibility in cooling demand
- Integration with *EnergyPlus* BEM platform

R. Chandra, K. R. Krishnanand, and S. K. Panda. in Sustainable Energy, Grids and Networks, 2022

High Efficiency and Power Density SST based utility grid interface



MVAC-LVDC interface for integrating renewables and energy storage resources within *cluster-of-buildings*

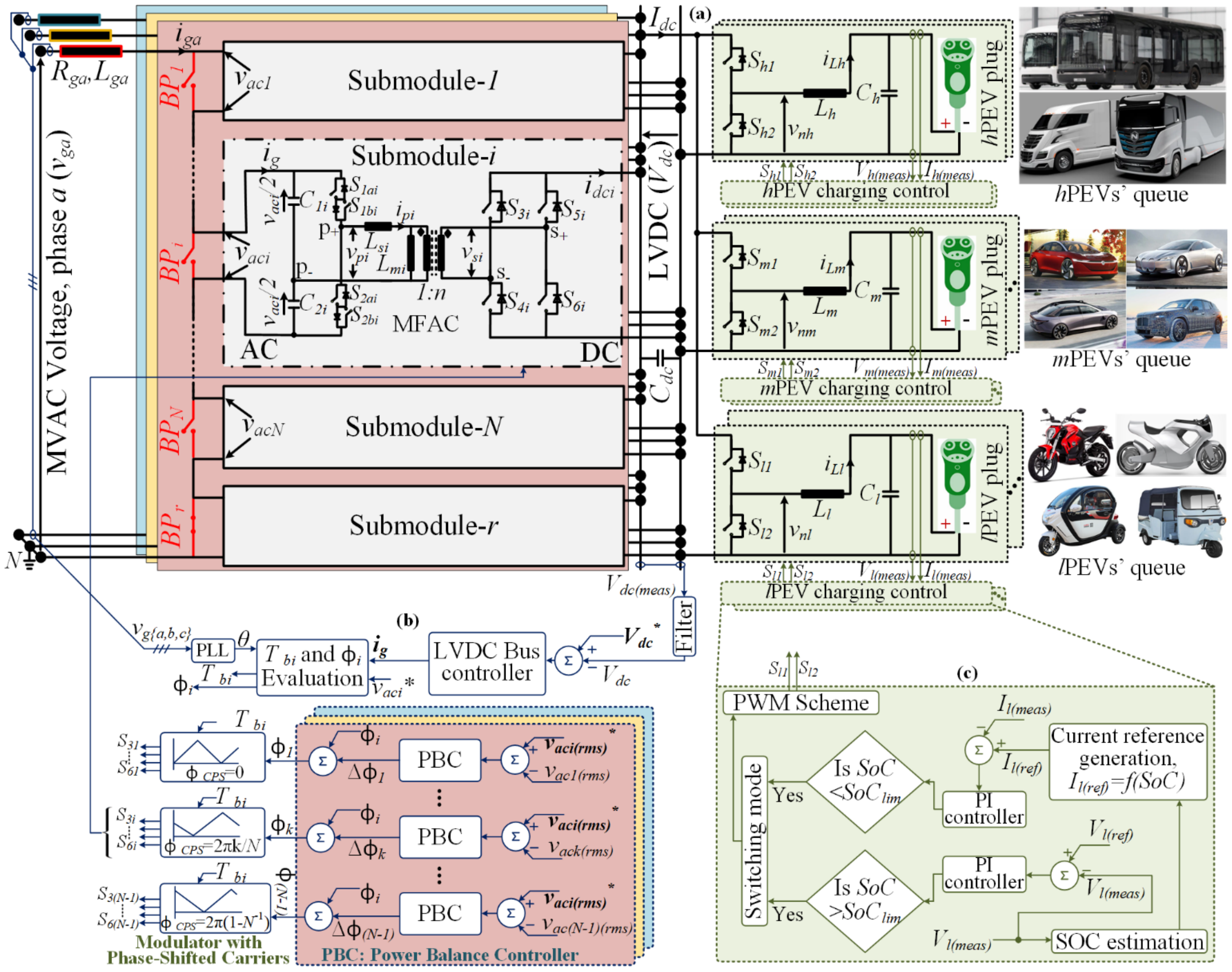


Scaled-down laboratory level prototype

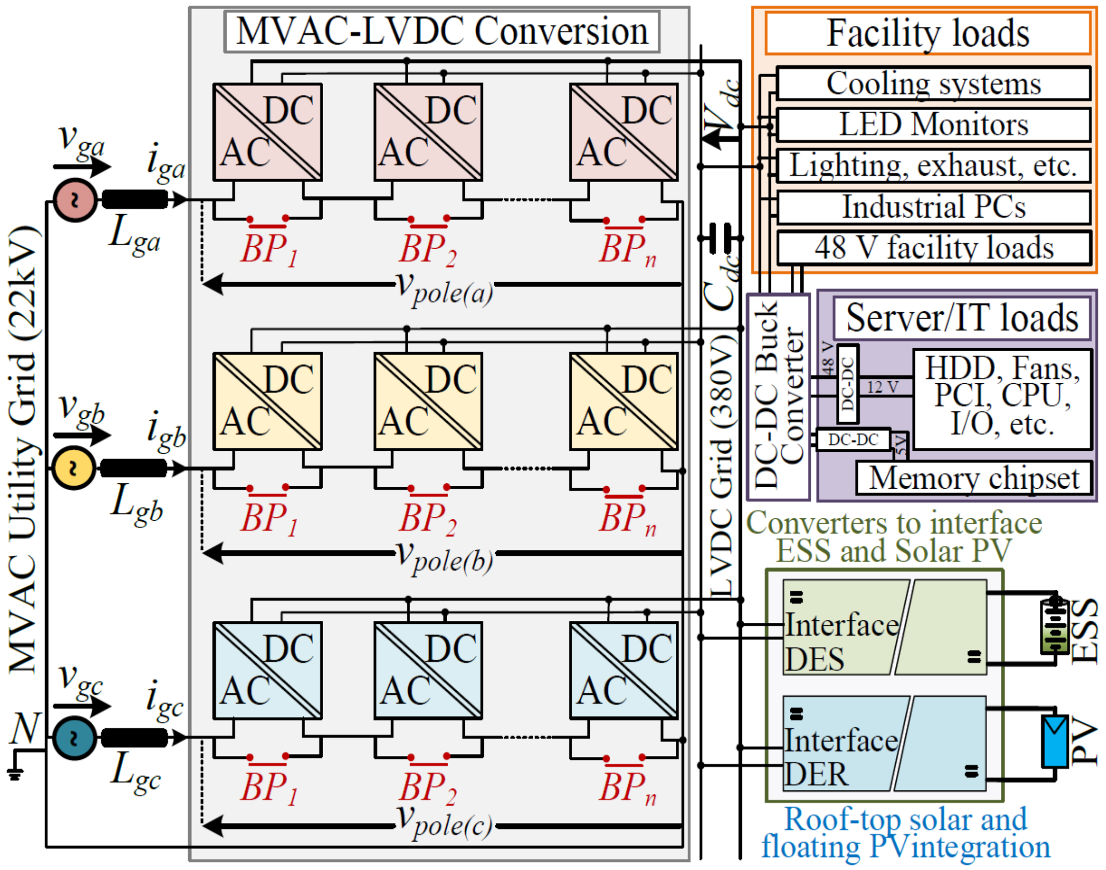
- Efficiency ~ 96% and power density ~ 3 kVA/L

J. Saha, N.B.Y. Gorla, and S. K. Panda. in IEEE Journal of Emerging and Selected Topics in Power Electronics, 2021

Emerging Applications of SST based utility grid interface

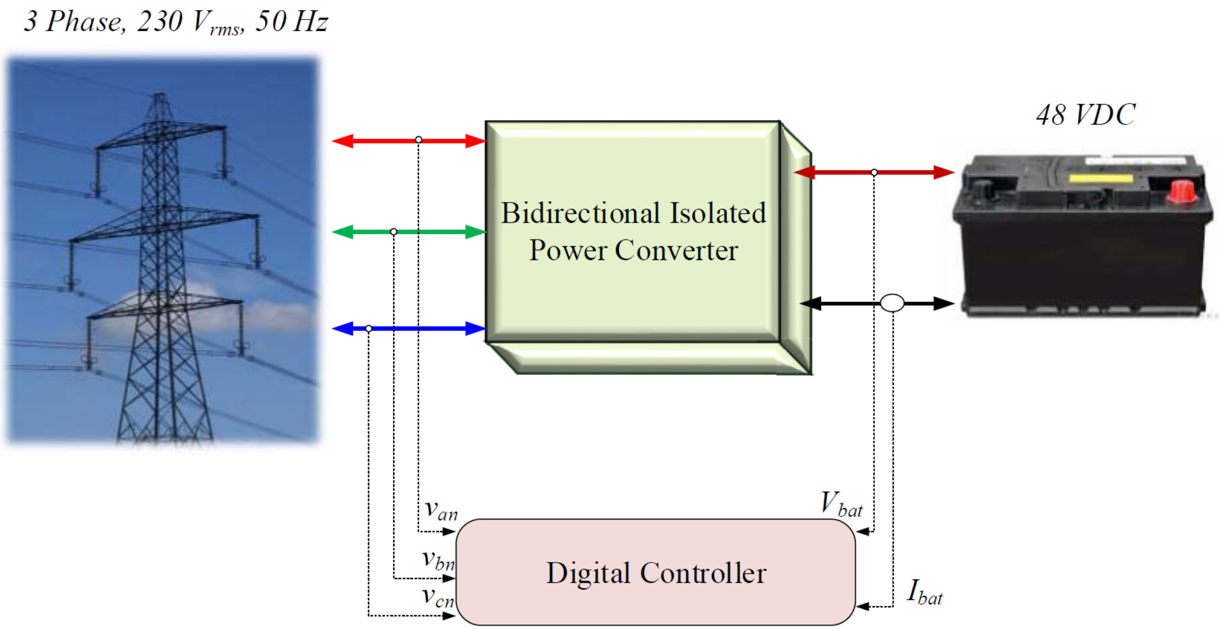


Schematic of MV grid-connected bidirectional fast-charging station

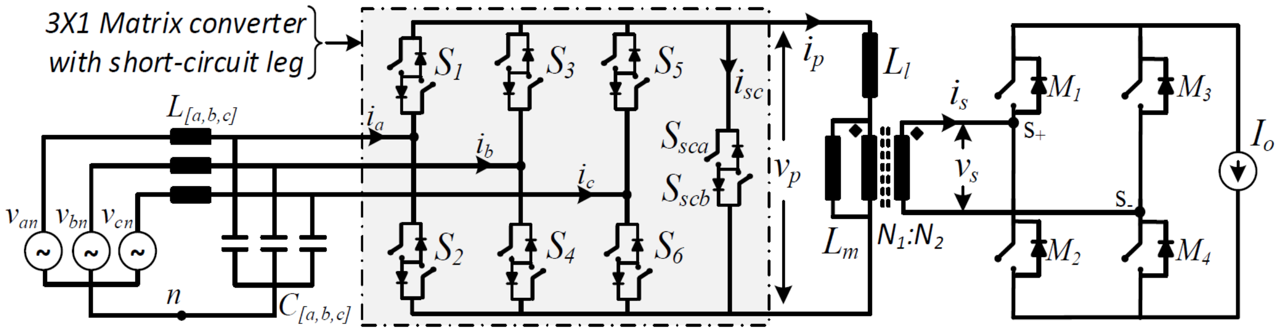


Schematic of MVAC-LVDC conversion stage for MV grid-interfacing of DC based data-centre distribution grid.

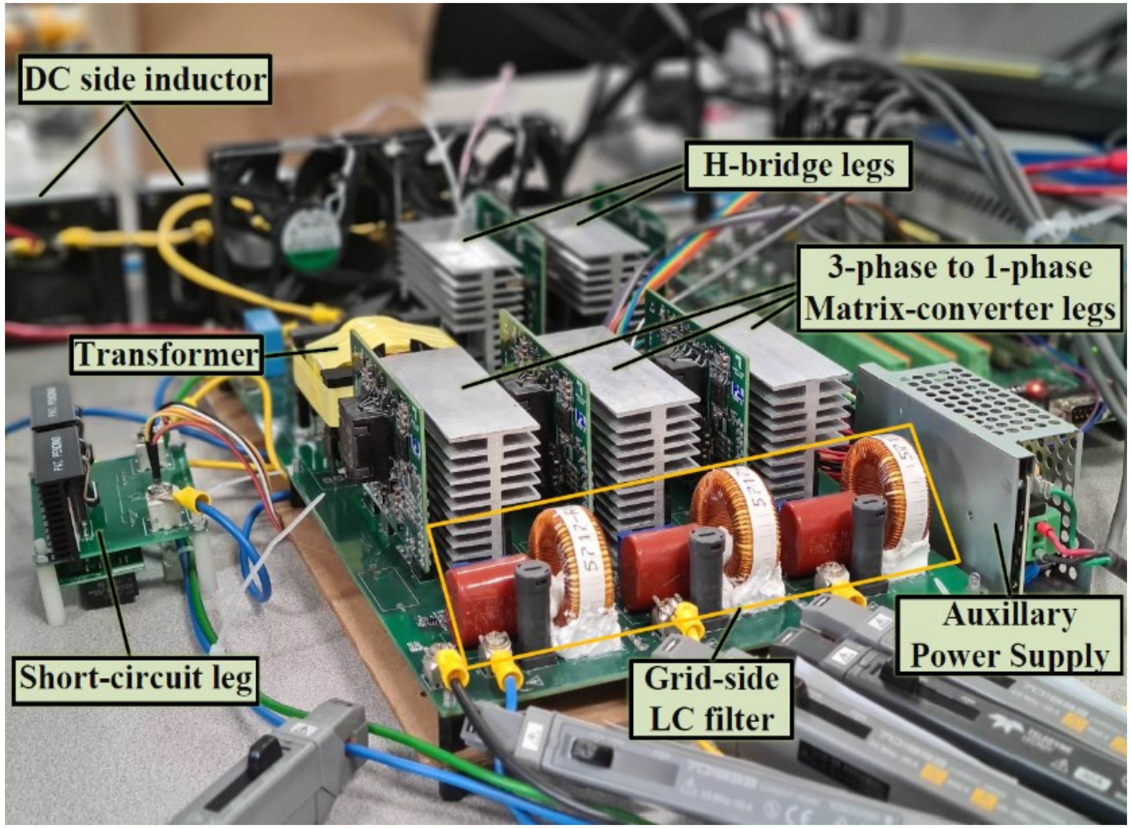
Matrix-based Compact and Efficient BESS interfacing converter



Schematic of the bidirectional isolated power conversion

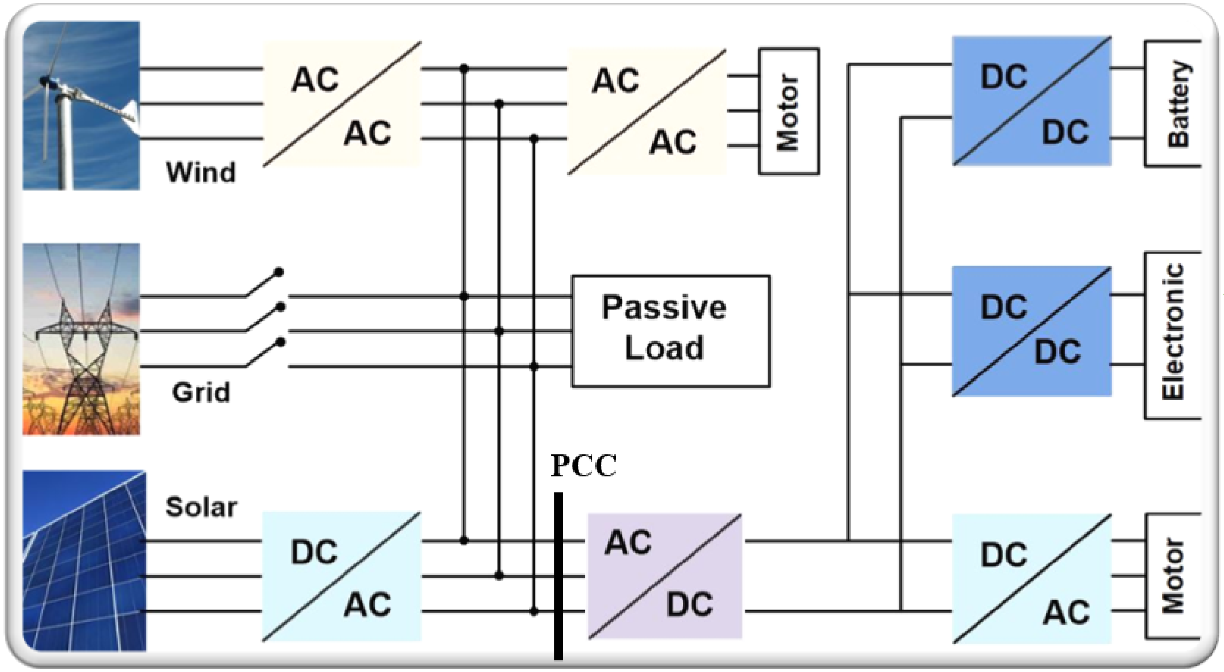


Circuit diagram of the proposed bidirectional isolated matrix-based AC-DC power converter for integration of battery storage

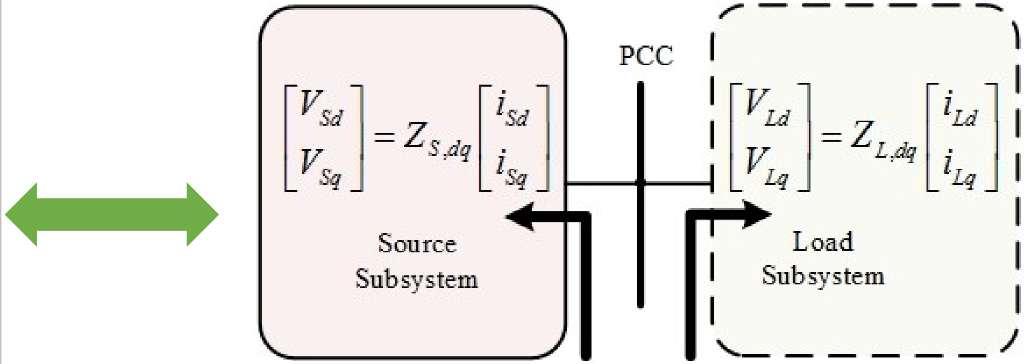


2 kW experimental prototype of the proposed 3-phase bidirectional matrix-based AC-DC power converter

Real-time Grid Impedance Measurement for Adaptive Control



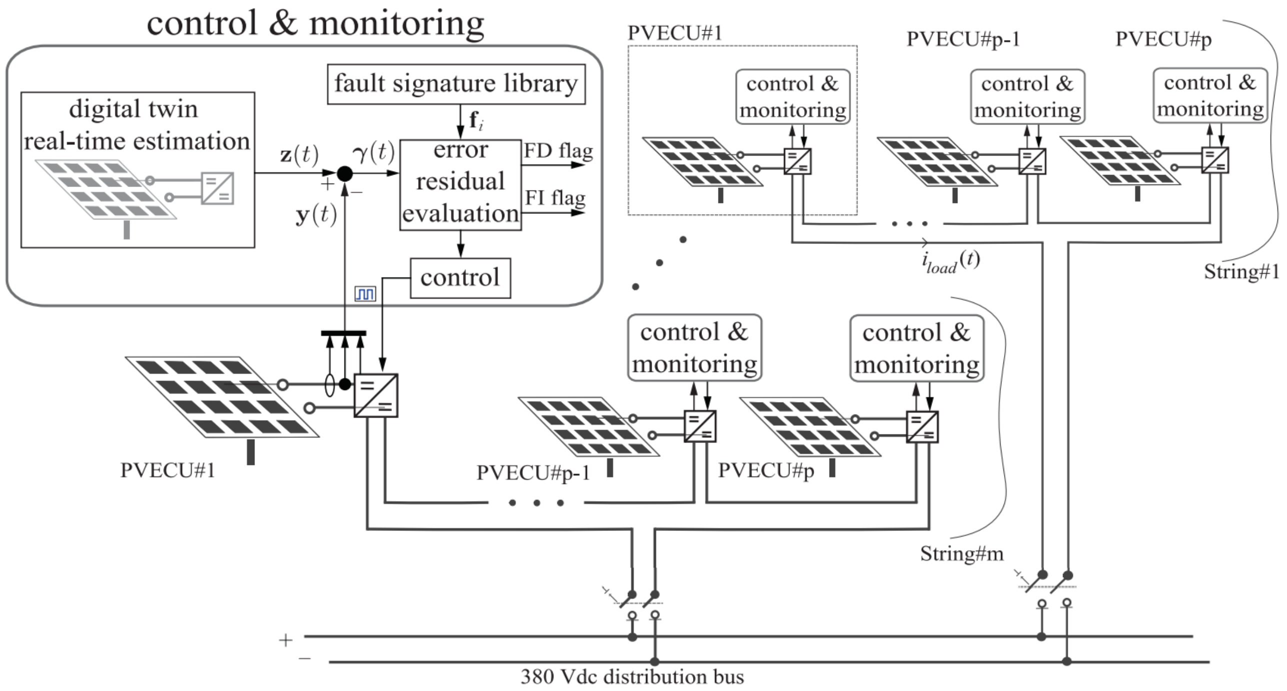
A power electronics based Microgrid



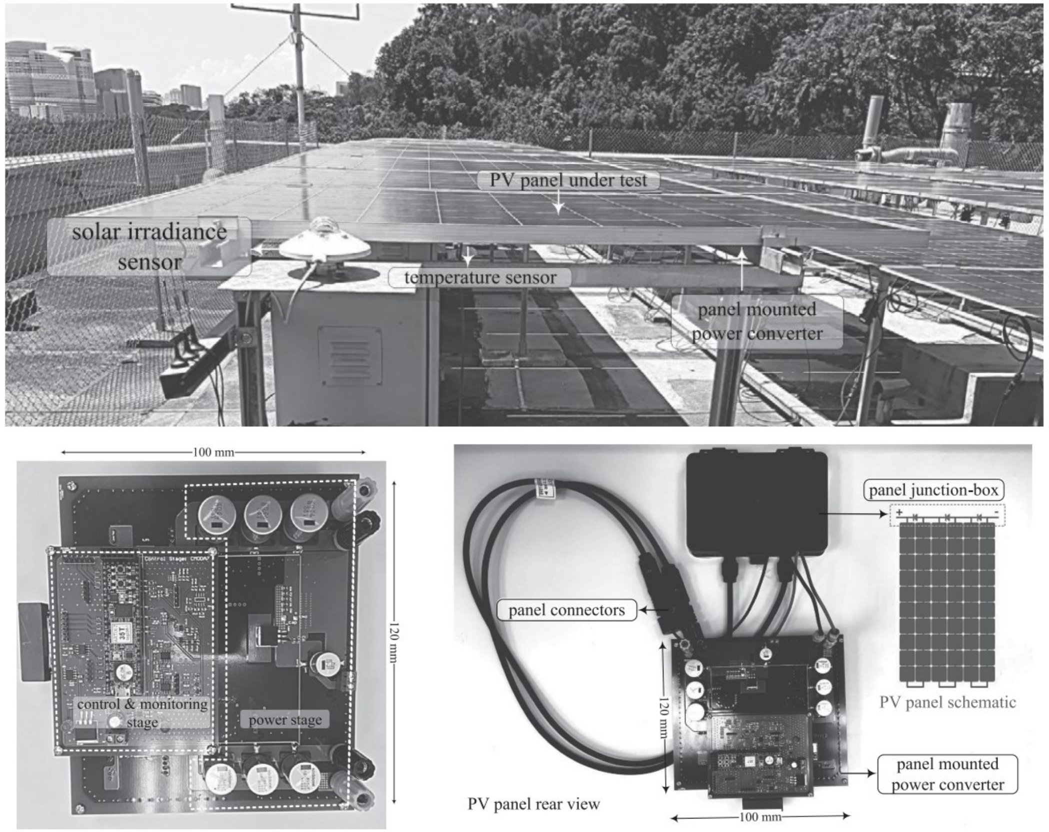
Representation of Microgrid system with
Source and load sub systems

- In Microgrid applications, the DES are connected through an inverter and it is typically controlled as a current source
- Important concern for grid-connected inverter: effects of grid impedance on inverter control performance and stability.
- High grid impedance can destabilize the inverter current control loop and lead to sustained harmonic resonance or other instability problems
- Real-time grid impedance measurement is compulsory for adaptive control of Inverter for improved stability.

Digital Twin approach for fault diagnosis in Solar PV Systems

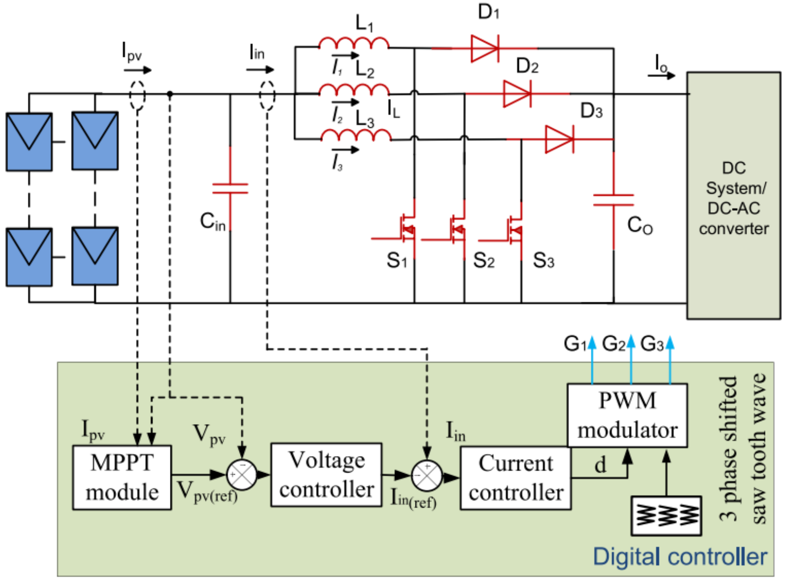


An overview of a digital twin approach for fault diagnosis of the complete Distributed Solar PV system

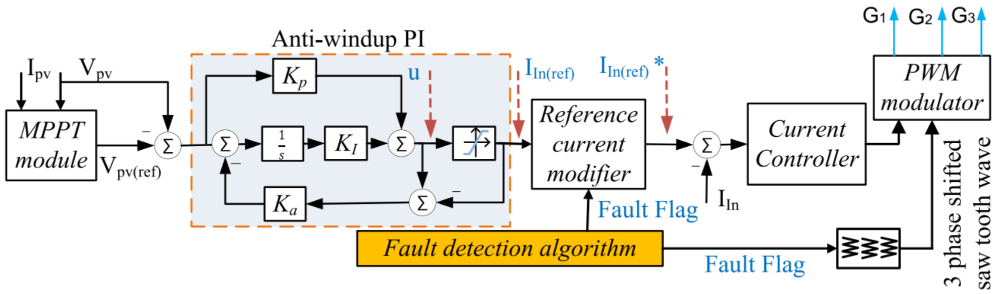


The PV energy conversion system in field used for conducting outdoor field experiments

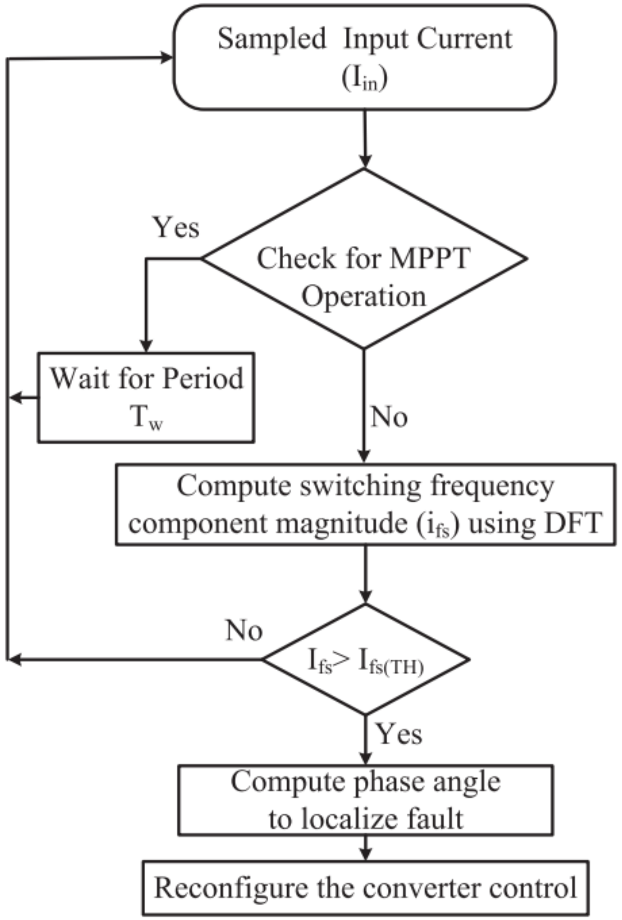
Fault Diagnosis and Post-fault Reconfiguration scheme for Interleaved Boost Converter (commonly used for solar PV systems)



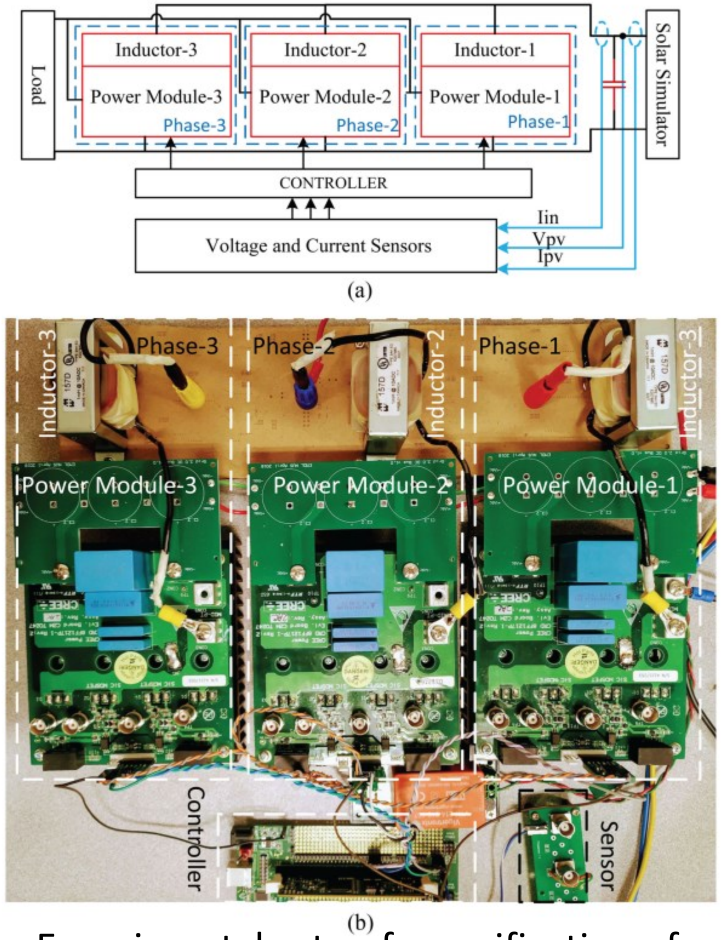
Inter-leaved boost converter



Modified controller for inter-leaved boost converter



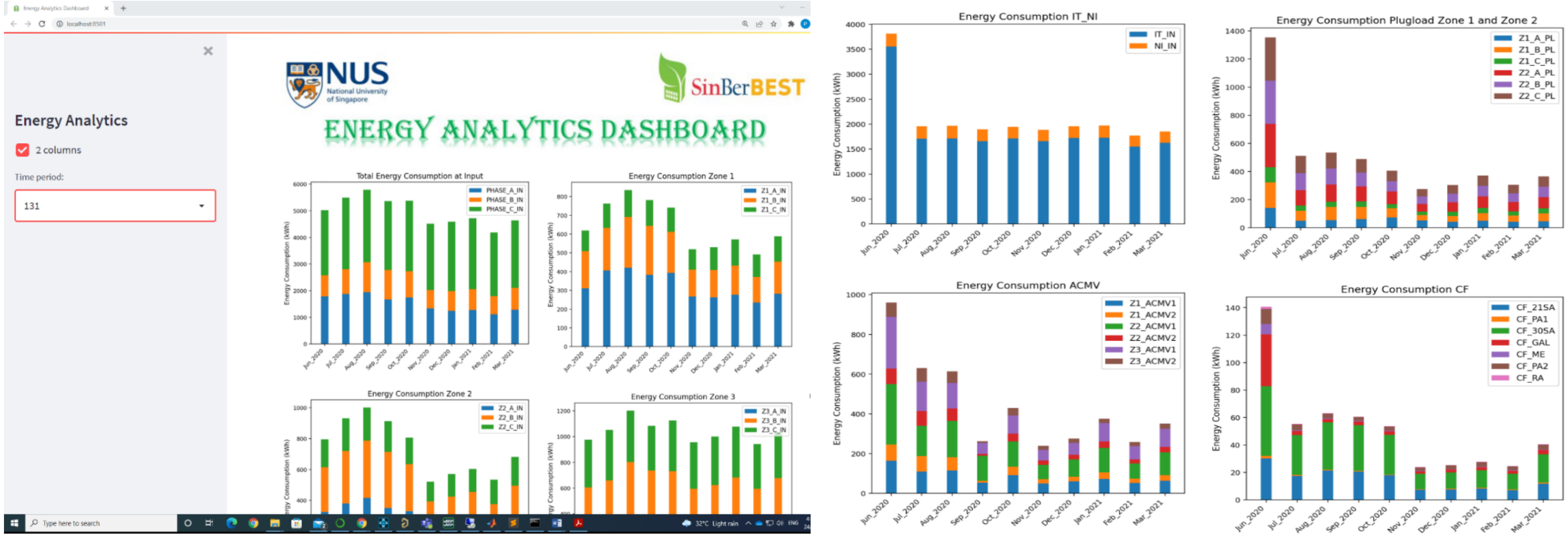
Proposed fault detection, identification, and reconfiguration algorithm



Experimental setup for verification of proposed approach

Energy Analytics in a DER rich Grid-interactive-building

Building Energy Analytics - Monitoring



Python-based Energy Analytics Dashboard Using Real Data from Living Lab

- Three-phase energy consumption at the input and identification of unbalanced loading
- Energy consumption according to load types, identification of abnormal energy consumption, detect anomalies and provide corrective suggestions if necessary

K.R. Krishnanand, D.C. Hoang, M.Gupta and S. K. Panda. in IEEE Transactions on Industry Applications, 2020

THANK YOU