High Frequency Power Electronics at the Grid Edge: Opportunities and Challenges

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High Frequency, miniaturized power electronics for emerging applications

Telecom

Data Center / Point-of-Load

Robotics & Biomedical

HF Grid Interface
Better Power Electronics for Better Power Systems

- **Smaller**: Higher switching frequency
- **Smarter**: Architecture and control
- **More efficient**: New devices and topologies
- **A lot of opportunities at the grid edge**

![Diagram of Smart Grid with Data Center, Smart Home, Solar Inverter, EV Charger]
Why High Frequency Power Electronics?

- Fundamental ways to improve performance and reduce size / cost
- Leveraging wide-band-gap semiconductor devices & magnetics
- “10 years later, probably 5 MHz is not considered HF”?

We will see PV inverters and PFCs running above 5 MHz in 10 years

Thyristor 1950s
BJT 1960s
MOSFET 1990s
GaNFET 2010s

60 Hz 10 kHz 100 kHz 1 MHz 5 MHz ?

Advantages of High Frequency Grid Interface

• Grid-tied power electronics become more “ideal” at higher switching frequencies

• Higher control bandwidth at the edge
  • Edge sensing (impedance measurement)
  • Edge actuation (impedance synthesize)

• Advantages include
  • Faster and more precise control
  • Lower risk of inverter oscillation
  • Faster response to load variation and intermittency
  • Modular design and scalability

A Nano Grid Supported by HF Power Electronics
Challenges of High Frequency Grid Interface

• PWM operation v.s. Resonant operation
• Continuous conduction mode v.s. Discontinuous conduction mode
• Fixed frequency v.s. Variable frequency
• EMI filter design and oscillation problems (non LCL filters)

Will this 5 MHz PFC be compatible with the future grid? What is the grid-interface rule?

• 1MHz-5MHz
• Resonant ZVS DCM
• Variable Frequency

One Possible Architecture of the Future Grid

HV Transmission Line

Medium Voltage, 10 kHz ~ 100 kHz

Solid State Transformer

Energy Storage

Energy Router

Energy Router

Energy Router

Energy Router

Low Voltage, 100 kHz ~ 1MHz

High Frequency Power Electronics at the Grid Edge

- Research Project 1: High Frequency Multiport Grid Interface
- Research Project 2: Low Voltage DC Energy Router in Smart Homes
- Research Project 3: Energy Buffer / Storage and Reactive Power Support

High Frequency MHz level Multiport Grid Interface
Low Voltage DC Energy Router in Smart Homes
Energy Buffer / Storage and Synthetic Impedance
High Frequency Sophisticated Grid Interface Systems

Multiport Energy Management

3 Phase Grid Interface

10 kW, 1 MHz

Smart outlets with multiple voltage modes

High Frequency Grid Interface Power Electronics

Multiway Power Flow and Battery Health Monitoring

On-line High Frequency Grid Impedance Spectroscopy (on-going work)

Power Electronics Building Blocks for Energy Routers

Low Voltage DC Delivery in Smart Homes

400V

AC/DC

Multiport Converter

Smart Outlet

Smart Outlet

Smart Outlet

Smart Outlet

12V~48V

12V~48V

12V~48V

12V~48V

PV

EV

Storage

Multiport Reconfigurable Power Electronics Building Blocks [2, 3]

Energy Buffer, Storage & Reactive Power Support

Stacked Switched Capacitor Energy Buffer Architecture

A grid-interface PV inverter that can perform reactive power compensation with a novel switched-capacitor energy buffer architecture


Other Functions that HF Power Electronics bring

- **PFC Current Shaping**
- **Grid Impedance Measurement**

Systematic modeling and analysis methodologies are still needed. How do we include these into future system operation rules / standards?


Many emerging work on impedance-based stability criteria

Actively “probe” the distribution grid with impedance measurement

Stabilize the grid, damp the oscillation with synthesized impedance

Optimal location of the “sensors” and “actuators”

“Sensing” and “actuating” the grid with large signal synthetic impedances


Data Center as a Testbed for Grid Innovations

Measured low frequency system oscillation in data centers


A Bottom-Up Approach Towards the Smart Grid

Solid State Transformer

Energy Storage

Energy Router

Grid modeling and control

Devices and topologies

Smart Grid

Grid Edge
References


