Grid Interactive Power Converter Controls and their Fault Ride-Through Capability

Abstract: In the recent decade, we have seen an unprecedented growth of renewable generation and we are experiencing a changeover from the traditional model of centralized generation to a mix of centralized and distributed generation in the power grid. Integration of local generation, load and/or storage molds is currently finding widespread applications in large scale data centers, renewable energy integrations, electric ships, and commercial/industrial buildings bringing the benefits of high efficiency, power quality, flexibility, stability, and reliability. There is also the recent increase in the adoption of electric vehicles, consumer electronics, and computing. Power electronics is the key technology that connects modern customers with utility by enabling distributed generation, microgrids as well as the integration of this new class of loads. The interfacing power electronics converters are embedded with advanced controls, and are often capable of collaborative operation in a networked scenario.

Significant advances have been made in recent years by both academia and industry to achieve low and medium voltage interconnection between utility and customers through wide bandgap power devices, innovative converter topologies, and soft switching techniques. Robust controllability, flexibility of operation, reliability and lower operating cost have been the major driving factor behind the adoption of these power electronics enabled technologies. To achieve such level of robustness and reliability in microgrids and in networked power electronics systems, controls play a key role where they are implemented in a hierarchical manner starting from local power converter controls to primary to secondary and to tertiary levels. The primary controls are responsible for power sharing among multiple sources and stability of the system, while secondary and tertiary controls are for retaining nominal operation through energy management and economic optimization. The control challenges are immense both due to interaction among the power electronics converters and the intermittency of the renewables. As the power electronic converters are actively controlled units, they introduce highly nonlinear and time varying dynamics and the interaction among different units may lead to instability in interconnected systems. Much of the existing autonomous and distributed control in power systems relies on temporal and spatial decoupling among the phenomena being controlled. A system with multiple power electronics converters is bound to be affected by the faster switching surge dynamics to slower frequency control both qualitatively (novel dynamics) and quantitatively (many more components). In that aspect, despite substantial efforts put forth by both academia and the industry, fault ride-through (FRT) of inverter based resources (IBRs), particularly for grid forming (GFM) controls, remains an open research question. The underlying synchronization mechanism employed during fault and the real and reactive power output as a consequence, plays a vital role in the stability of the associated grid, especially after fault clearing.

This tutorial on grid interactive inverters is designed to cover the components, system architectures and controls, ancillary services and grid support, and customer interactions and benefits in the context of microgrids and networked power electronics based systems. This tutorial is organized into four parts: Part I provides a review of basic components of microgrid and distributed generation in a modern power system; Part II presents motivation, system architecture, and control objectives for residential and commercial systems; Part III covers the two dominant strategies, namely, grid-following (GFL) and grid-forming (GFM) control, for IBRs; Part IV highlights the need for in-the-loop modelling and simulation for both IBR development and interconnection studies; and Part V presents the challenges and recent advances on fault ride-through (FRT) control solutions for IBRs to augment grid support under various transients. Finally we will conclude with some thoughts on trends into the future for widespread industrial adoption.

Outline of Tutorial:

1. <u>Modern Power Electronics based Power Systems (20 mins)</u>
    a. Distributed Generation
    b. Power Electronic Interfaced Loads (including EV Charging Stations)
    c. Power Converters used in Power Systems
    d. Microgrids; Residential and Commercial: Data centers, hospitals, universities

2. <u>System Architecture and Control Objectives (40 mins)</u>
    a. Residential customer
        i. Hardware configuration (single black box for PV, battery, and Load)
        ii. Control strategies benefiting customers
    b. Commercial customer including system operators
        i. System hardware architecture
        ii. Motivation (Customer) - reduced peak demand charges, increased reliability & resiliency (less outages & black-start), leverage time of use rate
        iii. Motivation (System operator) – renewable integration (greener and cheaper), manage intermittency of renewables (peak shaving), reliability and resiliency
        iv. Control objectives – voltage and frequency stability of the grid with large number of distributed resources with reduced inertia
        v. Additional objectives – safety concerns (Islanding detection, anti-islanding), power quality, black-start, and grid re-synchronization transition

3. <u>Control of Networked Power Electronics Systems (30 min)</u>
    i. Generic Inverter Based Resource (IBR) Control Structure
    ii. Bandwidth limits and harmonic resonance instabilities
    iii. Grid-following (GFL) vs grid-forming (GFM) controls:
        - Different ways to provide synthetic inertia, frequency & voltage regulation support
    iv. Interconnection strengths & heavy IBR penetration

4. <u>In-the-Loop Modeling and Simulation of IBR Controllers (20 min)</u>
    a. Need in development environments
    b. Need in interconnection studies
    c. UNIFI SIL example with 3-phase VSI
    d. IBR Simulation in an IEEE bus system

5. <u>Inverter Fault Ride Through (70 min)</u>
    a. Terminal response to faults by GFL & GFM IBRs
    b. Weak Grids & Power Flow constraints: Fault ride-through (FRT) under low- vs heavy IBR penetration scenarios
    c. What it means to be GFM under current constraints
    d. Wish-list for ideal FRT by IBRs
    e. Large signal Analysis: Symmetric and Asymmetric faults
    f. Double Synchronous FRT controller
    GFM nature retaining FRT controller

Presenter Biographies:

Prof. Iqbal Husain is the Director of the Future Renewable Electric Energy Delivery and Management (FREEDM) Engineering Research Center and the ABB Distinguished Professor at North Carolina State University where he joined in Fall 2011. Prior to coming to NC State he was serving as a faculty member at the University of Akron, Ohio was also a visiting Professor at Oregon State University. Prof. Husain also served as the Director of Power Electronics for the PowerAmerica Institute at NC State. He is the recipient of a Fulbright Scholar Award with the help of which he engaged for research and extension with Universities in Australia. He received the B.Sc. degree from Bangladesh University of Engineering and Technology, Bangladesh, and the M.S. and Ph.D. degrees from Texas A&M University, College Station, Texas.

Prof. Husain's research interests are in the areas of control and modeling of electrical drives, design of electric machines, inverters for distributed power generation, inverter controls for grid synchronization, and modeling and control of electric and hybrid vehicle systems. The primary application of Prof. Husain's work is in the automotive, aerospace, and renewable energy industries.

Prof. Husain is a Fellow of the IEEE, and also, is the past Editor-in-Chief of the IEEE Electrification Magazine. He received the 2022 IEEE-IAS Outstanding Achievement Award in recognition of outstanding contributions in the application of electricity to industry, 2022 Alcoa Foundation Distinguished Engineering Research Award, 2006 SAE Vincent Bendix Automotive Electronics Engineering Award, the 2004 College of Engineering Outstanding Researcher Award, the 2000 IEEE Third Millennium Medal, the 1998 IEEE-IAS Outstanding Young Member award, and several IEEE-IAS prize paper awards.

M A Awal received his Ph.D. degree in Electrical Engineering from North Carolina State University (NCSU), Raleigh, NC, USA, in 2020. He is currently working as a Sr. Controls Engineer at EPC Power Corporation focusing on utility scale grid-interactive power converters. He also serves as an Adjunct Assistant Professor at the FREEDM NSF Research Center, NCSU. Prior to joining EPC Power, he was serving as a Sr. Controls Engineer in the medium voltage (MV) R&D team at Danfoss Drives, specializing in MV power conversion systems for very high-power industrial drives and electrification applications.

His research interests include design and control of power electronics converters and systems with applications to reduced-inertia networks, grid interfaces, energy storage systems, variable speed drives, and electric automotive systems.