ECCE 2014 Tutorial Proposal

1. Title of Tutorial

Impedance-Based Modeling and Analysis of Three-Phase Grid-Connected Converters

2. Abstract

Three-phase PWM converters have been used as front-end rectifiers for motor drives, UPS, telecom power supplies, and other three-phase loads. An increasing number of such converters are also used as inverters to integrate wind, solar and other distributed energy sources into the power grid, as well as to replace conventional line-commutated converters in HVDC, FACTS and other power system applications. Operation and control performance of such grid-connected converters are strongly influenced by the grid. A wind or solar inverter, for example, may become unstable when connected to a weak grid that has high impedance. A converter may also form resonance with the grid impedance, producing high harmonics that deteriorate grid power quality, trig converter and grid protection functions, and cause physical damages to the converter and other devices in the grid.

Impedance-based methods have been used extensively to study stability and dynamic performance of dc power systems. An early application is dc-dc converter control instability in the presence of input EMI filters: The ratio of the filter output impedance to the converter input impedance must satisfy the Nyquist criterion in order for the converter control to remain stable when the filter is added. In principle, the same method can be applied to converters interfacing with ac power systems. However, the time-varying (sinusoidal) operation trajectory of such a converter makes it mathematically difficult to develop its impedance models by conventional small-signal analysis. Additionally, the method cannot be directly applied to three-phase converters due to the mutual coupling among three phases (when there is no neutral connection, as is usually the case.)

This tutorial introduces impedance-based modeling and analysis methods for converters connected to the ac power grid, with a focus on three-phase PWM inverters and rectifiers. After a review of the general impedance-based analysis technique, modeling and control of three-phase converters in the dq reference frame will be presented. An averaged model in the dq frame permits direct linearization under balanced conditions, and the resulting dq impedance matrix can be used in conjunction with the generalized Nyquist criterion to determine converter stability in the present of grid impedance. The generalized Nyquist criterion, however, is difficult to apply and doesn't lend itself well to practical design. To overcome these limitations, a new method combining harmonic linearization with symmetrical component analysis is presented for three-phase converters. In this approach, a three-phase converter is modeled by positive-sequence and negative-sequence impedances, and converter-grid interactions are studied using a positive-sequence and a negative-sequence equivalent circuit that are uncoupled from each other, such that the conventional Nyquist criterion can be applied. Applications of the method in such practical problems as converter control instability under weak grid conditions and harmonic resonance between the converter and the grid will be presented. Practical methods to measure three-phase converter and grid impedances are also presented, and the possibility to develop adaptive control for solar and wind inverters based on real-time measurement of the gird impedance is discussed.

3. Outline of Tutorial

- Introduction
  - Converter-Grid Interactions – Examples
  - Impedance-Based System Stability Analysis
  - Stability Criterion for Current-Source Systems
  - Application: Single-Phase Inverter-Grid Resonance
- Three-Phase Converters and Analysis in the DQ Reference Frame
  - Basic Control and Reduced-Order Modeling
  - Current Control in DQ Reference Frame
  - Impedance Modeling in the DQ Reference Frame
  - Generalized Nyquist Criterion and Applications
- Sequence Impedance Modeling and Analysis
  - Harmonic Linearization and Symmetrical Component Analysis
  - Example – PFC with DQ Current Control
  - Modeling Nonlinear Circuits and Functions
  - Sequence Impedance Measurement
- Grid-Connected Inverter Analysis and Control
  - Grid-Connected Inverter Applications and Control Functions
  - Phase Locked Loop and Inverter Output Impedance
  - Harmonic Resonance and Its Analysis and Mitigation
  - Effects and Online Measurement of Grid Impedance

4. Lead Instructor

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5. Other Instructor – None

6. Instructor Bio

Dr. Sun joined the faculty of Rensselaer Polytechnic Institute in 2002, where he is currently a Professor in the Department of Electrical, Computer, and Systems Engineering. He is also the

Director of New York State Center for Future Energy Systems (CFES). His research interests are in the general area of power electronics and energy conversion, with an emphasis on modeling, control, and different applications including renewable energy, power systems and aerospace. He has published more than 50 papers and presented three tutorials on impedance-based modeling and analysis of power electronic circuits and systems.

Dr. Sun received his PhD from the University of Paderborn in Germany. Prior to joining RPI, he spent five years working at the Advanced Technology Center of Rockwell Collins, and was a Post-Doc Fellow at Georgia Tech from 1996 to 1997. He was the Editor-in-Chief of IEEE Power Electronics Letters from 2008 to January 2014, and is currently the Treasurer of the IEEE Power Electronics Society (PELS).