Real-Time Simulation of Large HVDC-AC Grids

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Presentation Layout:
- Objectives
- Test Systems
- Component and Subsystem Models
  - Wind Power Plant Model
  - AC Network Equivalent Model
  - VSC-HVDC Converter Station Model
- Control Hardware-in-the-loop (CHIL) Structure
- Conclusions
Objectives:

Analysis and performance evaluation of control and protection strategies/algorithms in large HVDC-AC systems.

Analysis of electromagnetic transients (emts)
Tasks:

Development of HVDC-AC grid component models:
  - off-line simulation of emts (0-50kHz)
  - real-time simulation of emts (0-10kHz)

Development of Control-HIL real-time simulation structure for the analysis of emts of large HVDC-AC emts (0-10 kHz)
Test Systems:

- CIGRE VSC-HVDC Grid Test System
- LCC-HVDC Segmented Grid
CIGRE VSC-HVDC Grid Test System

DC Grid Test System
version 2012, March 5
LCC-HVDC Segmented Grid
Component/Subsystem Models:

- **Wind Power Plant (WPP) wide frequency-band (0-50kHz) equivalent model**
  - Type-3 based WPP
  - Type-4 based WPP

- **Frequency-dependent AC-network equivalent model**
  - Single-port (3-phase) equivalent
  - Multi-port (3-phase) equivalent

- **VSC-HVDC converter station model**
  - MMC-HVDC converter station
  - 2-level/3-level VSC-based monopolar and bipolar converter station (with/without transformers)
Proposed Wind Power Plant (WPP) Dynamic Equivalent

(a) PCC

(b) PCC

FDNE Model
DLFE Model

WPP Power System
• FDNE: Frequency-Dependent Network Equivalent of all passive components within the WPP (for example in the frequency range of 0-50 kHz)

  - Two-Layer Network Equivalent Model
  - Modified Two-Layer Network Equivalent model
  - Frequency Scan and Vector Fitting
• LFDE: Low-Frequency Dynamic Equivalent of the aggregated wind units and local controls of wind units and the WPP supervisory control

- Generic Models (WSCC models)
- Vendor Specific Models
- User Defined Models
Structure of the Dynamic Low-Frequency Equivalent (DLFE) Model of a Type-4 WTGs-based WPP
The Supervisory Control Block Structure of the WPP Dynamic Low-Frequency Equivalent Model
Schematic Diagram of the Modified Version of Lake Erie WPP as the Test System
PCC Voltage: L-L-L-G Fault, Fault Clearing, Unsuccessful Reclosure, Fault Clearing
PCC Voltage – VRT

![Graph showing PCC Voltage vs. Time]

- **Detailed Model**
- **Equivalent Model**
- **Grid Code**
Implementation of WPP model in RTDS

PCC Voltage

0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
-1.5
-1
-0.5
0
0.5
1
1.5

0.955 0.96 0.965 0.97 0.975 0.98 0.985
-1.5
-1
-0.5
0
0.5
1
1.5
Frequency Dependent Network Equivalent
Example of Single-port AC-network equivalent model
AC-network equivalent model - Verification

PSCAD/EMTDC

Real-time Simulation
HVDC Converter Station Configurations:
- MMC based HVDC station
- 2-level/3-level VSC-based monopolar/bipolar stations with/without transformer
- (DC/DC converter station?)

HVDC Converter Station Models:
- Fundamental-frequency model
- Dynamic averaged-model (switching function based)
- PMW model (detailed switched model)
RTDS-based Control-HIL Real-Time Simulation of CIGRE HVDC Grid Benchmark

- AC & DC Lines
- Transformers
- T-G Units
- AC CBs
- WPP

(1) Stratix IV FPGA Board
(1) NI-cRIO
(2) Stratix IV FPGA Board
(2) NI-cRIO
(n) Stratix IV FPGA Board
(n) NI-cRIO

External Info & Command

Fast Processor Power Management System
RTDS-Based Control-HIL Structure

RTDS
- Electrical system real-time simulations

cRIO (PXI)
- MMC controller
- DQ-transforms
- Controls
- Determine number of modules to be switched

Stratix IV FPGA Board
- Module Simulations
- Voltage Sorting
- Module Switching Selections

Fiber optics connection

Red: May be removed if fiber optics RIO module is used
Green: May be added if fiber optics RIO module is used
WF 3182
2-Ch Fibre Optic Module
650 nm | 10 Mb/s | 500 m
1 mm POF / 200 um HCS
-40 °C ≤ Ta ≤ 65 °C
Conclusions

• Type-4 and Type-3 WPP s are efficiently and accurately modeled by a reduce-order equivalent for EMT studies.

• The frequency-dependent network-equivalent concept is used for single- and multi-port AC system reduction in large AC-DC systems.

• An RTDS-based augmented structure for Control-HIL of large AC-DC systems is being evaluated.
Future Work

- Development of Type-3 based WPP equivalent model
- Integration of WPP equivalent model in real-time simulation environment
Admittance Magnitudes of the Fitted Equivalent and the Detailed Modeled Passive Network - (a) self admittance, (b) mutual admittance
PCC Voltage, L-G Fault
PCC Voltages: L-L-L-G Fault
PCC Phase-c Voltage, L-L-L-G Fault
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Fast Processor
Power Management System

External Info & Command
Model Verification:

Stratix IV FPGA Board

Control

AC-1 DC AC-2

MMC-based HVDC Station Model

Fundamental Frequency Model

NI-cRIO

AC-1

Stratix IV FPGA Board

RTDS

AC-2

RTDS