Short Circuit Contribution from PV Power Plants

DOE/NREL/SNL Distribution System Modeling Workshop
La Jolla, California, July 27, 2012

Michael Behnke, Principal Engineer
BEW Engineering, a DNV Company

MANAGING RISK

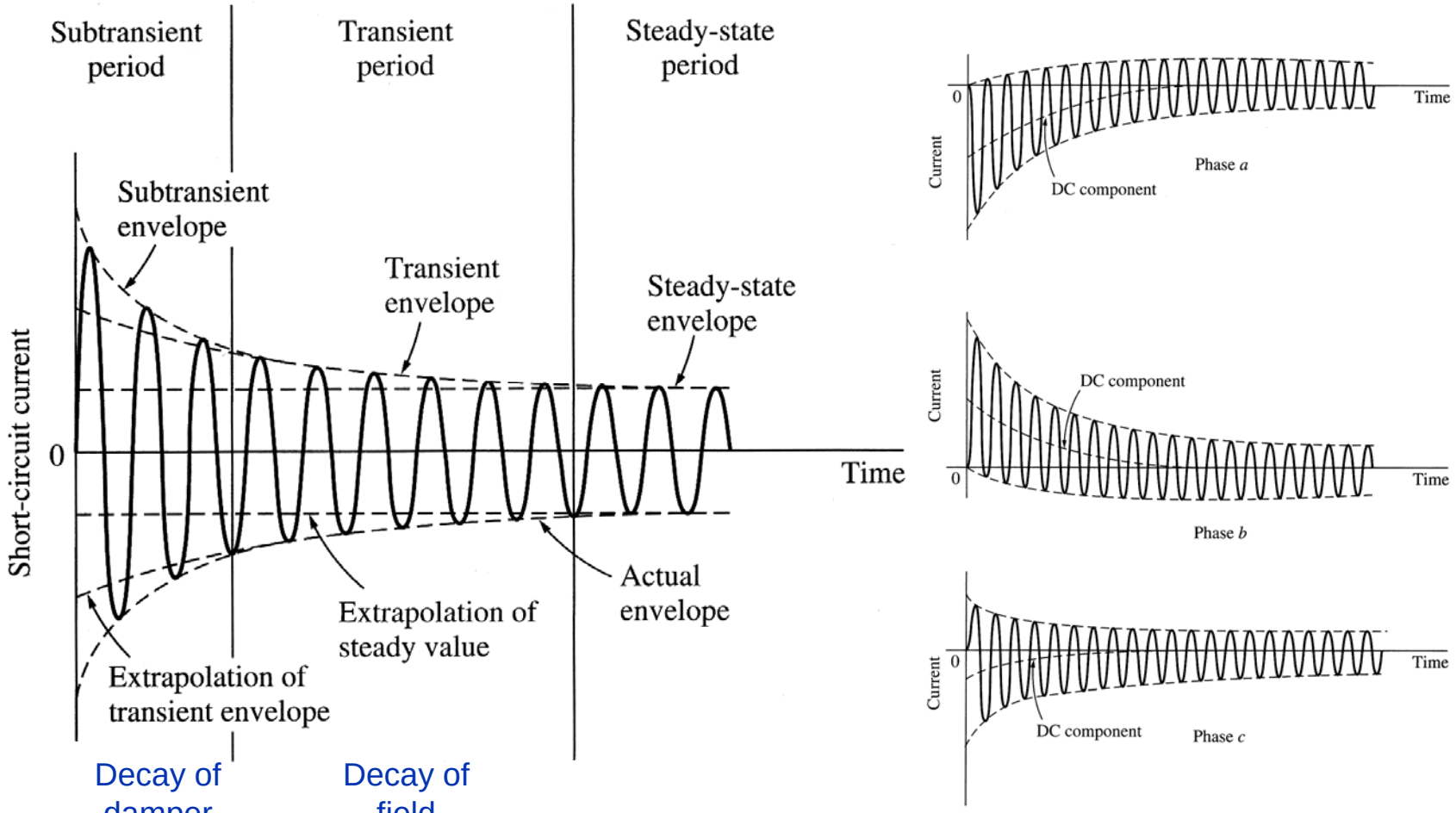
Presentation Outline

- Importance of Short Circuit Analysis in DG Interconnection and Integration
- Synchronous Generator Short Circuit Characteristics
- PV Inverter Short Circuit Characteristics
- Status of Commercial Analysis Tools
- Conclusions

Purpose of Short Circuit Analysis

- Power system faults (short circuit, ground faults) cannot be eliminated
- Utility protection systems must be designed to clear faults through interruption of the source(s) and post-clearing restoration of service to as many customers as possible
- Short circuit analysis aids in achieving these objectives by:
  1. Quantifying the magnitude of fault current through interrupting devices (circuit breaker, fuses, reclosers) to ensure that interrupting capacities are adequate for fault clearance
  2. Providing a basis for protection coordination so that the device(s) that interrupt the fault are the ones that minimize loss of load (selectivity)

Synchronous Generator Short Circuit Characteristics



Source: Chapman, Electric Machinery and Power System Fundamentals, 2002

Synchronous Generator Short Circuit Characteristics

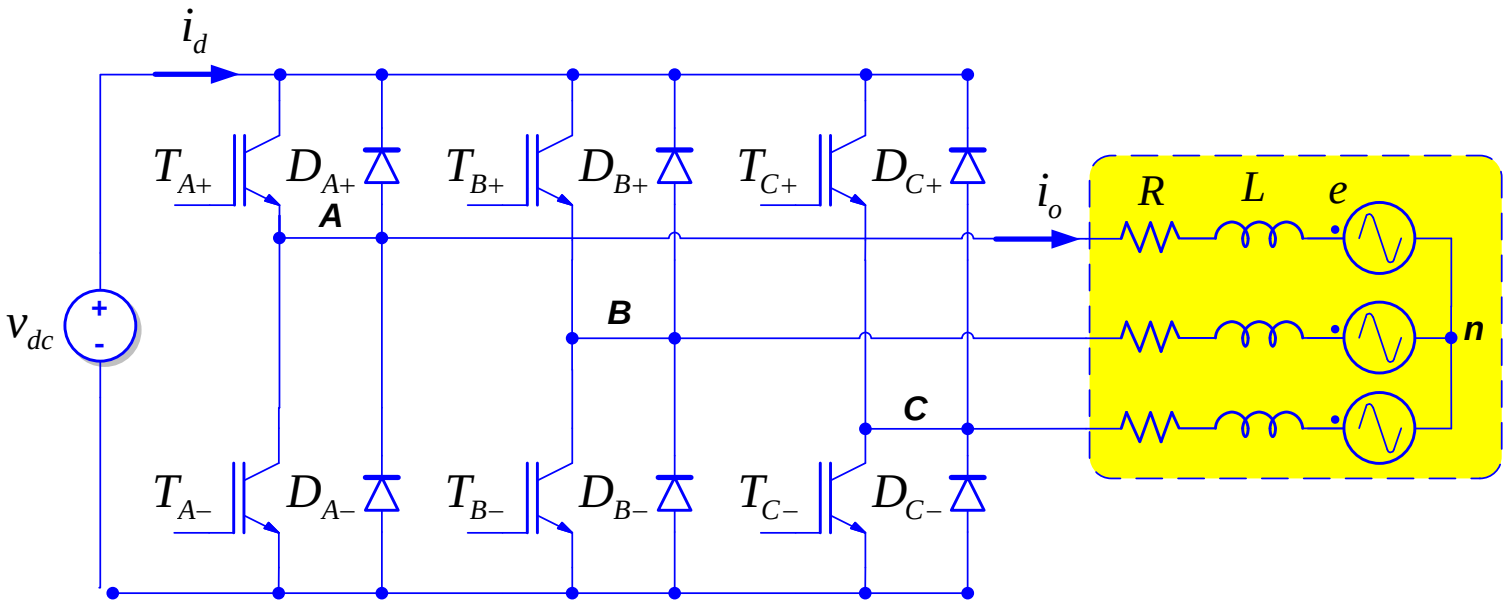
- Time-variant response represented by three separate time-invariant models
- Allows for Thevenin equivalent representation of generator with constant voltage behind appropriate impedance for time period of interest (X”d, X’d, Xd) for balanced faults
- Apply X2 and X0 for unbalanced faults
- Short circuit calculation methods well documented in ANSI and IEC standards

DG Inverter Short Circuit Characteristics

IMPORTANT CAVEAT:

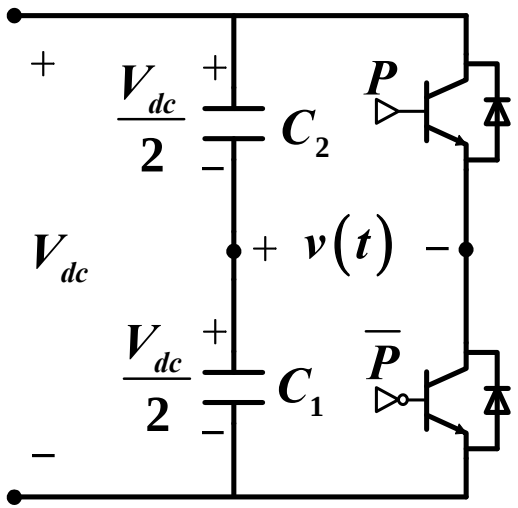
- We will be talking about a certain class of inverters:
  - 3-phase
  - Voltage source topology
  - High-frequency pulse width modulated (PWM)
  - AC current regulated
- This describes nearly all inverter models currently being applied in utility and commercial scale DR
- Some inverters (particularly some PV micro-inverters) do not fall into this class

DG Inverter Short Circuit Characteristics

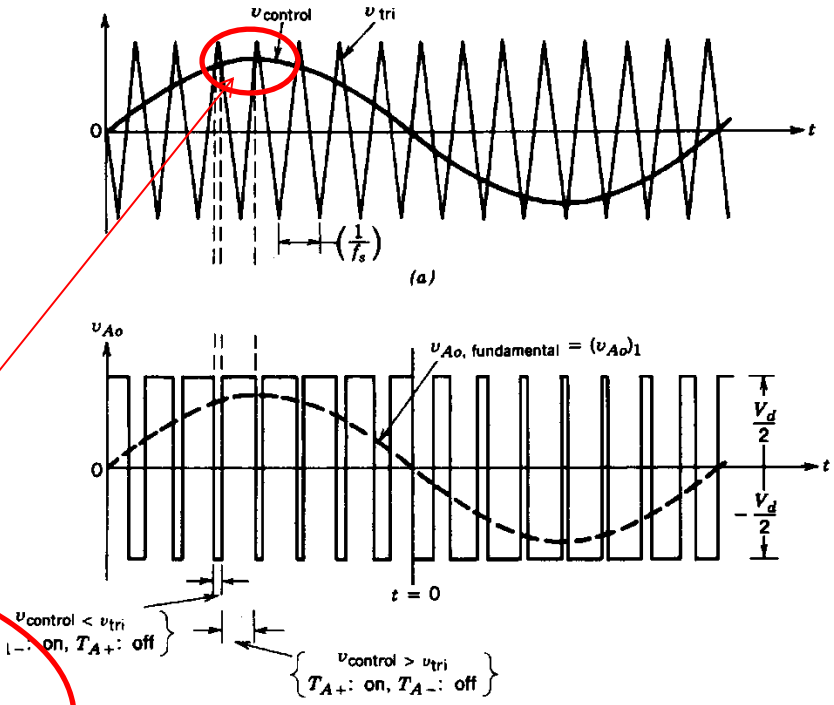


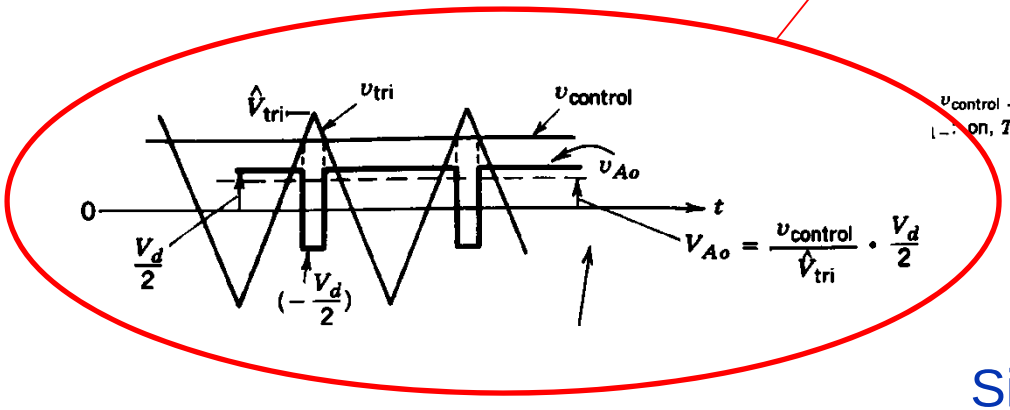
Three-Phase, Two-Level Voltage Source Converter Topology

DG Inverter Short Circuit Characteristics



Carrier and Modulating Signals

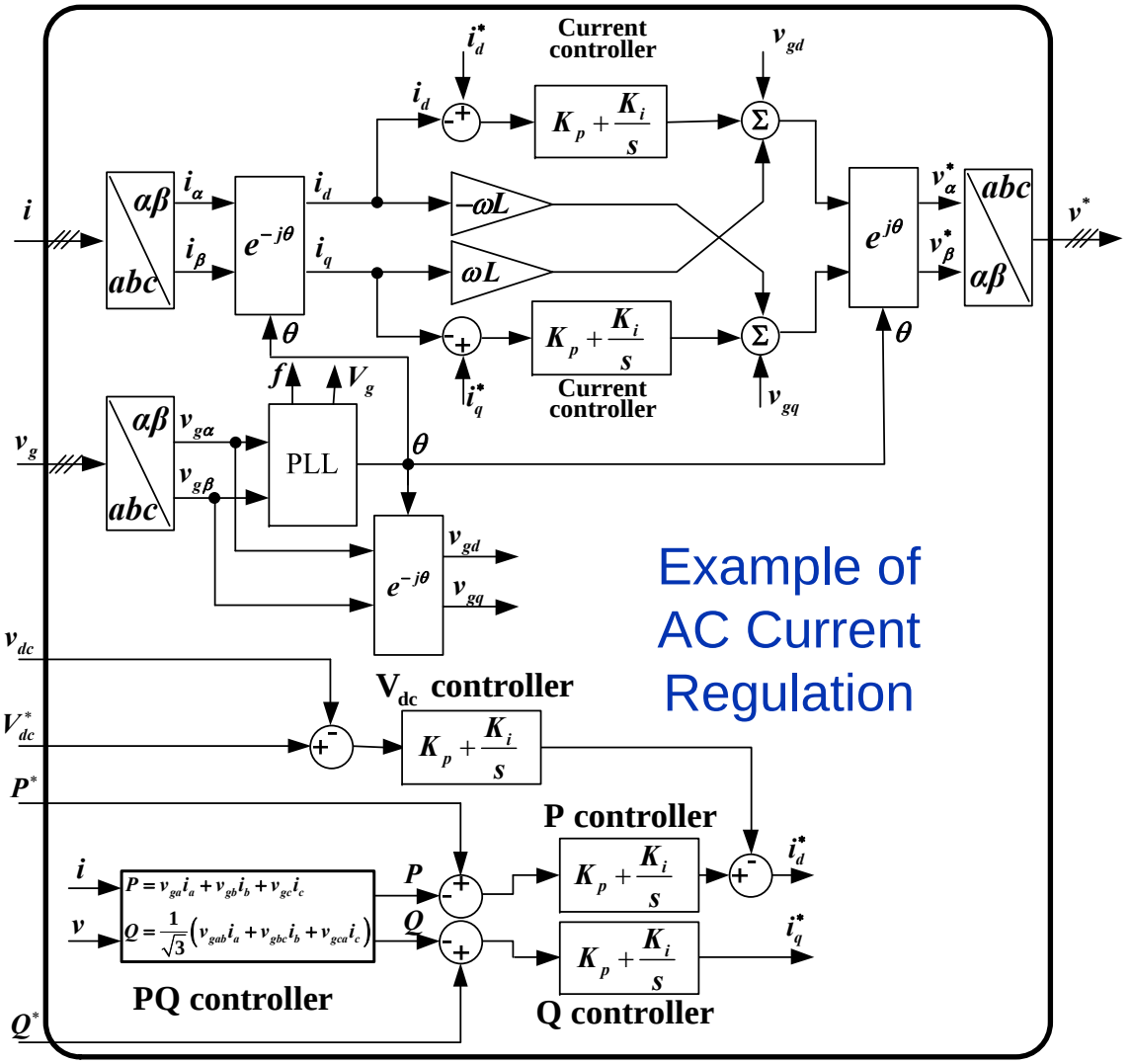




Sinusoidal Pulse Width Modulation

DG Inverter Short Circuit Characteristics

- Modulating signals are generated from AC Current Regulator
- id* and iq* are real and reactive current commands
- High PI gains cause inverter to behave as stiff *current* source

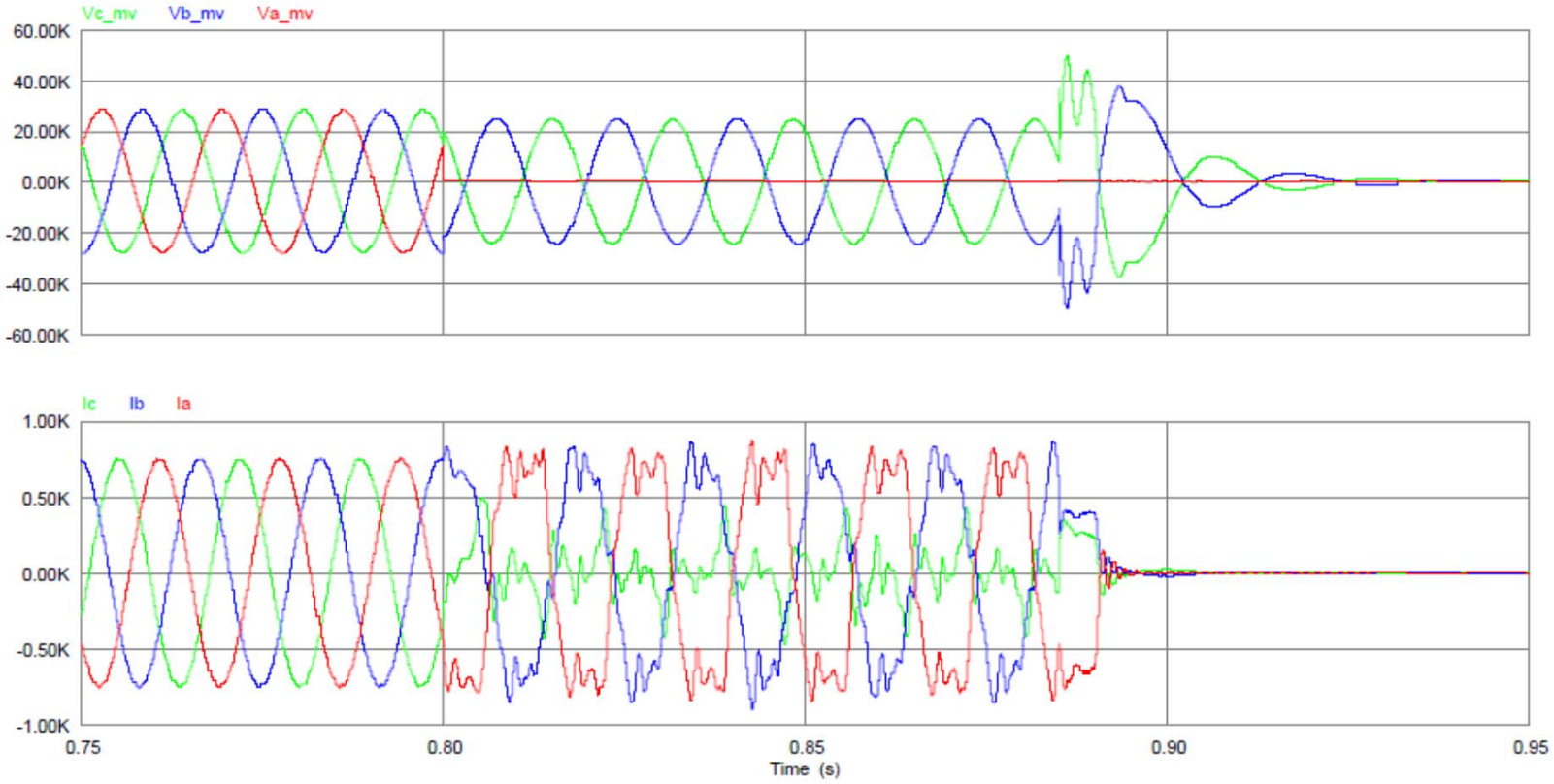


DG Inverter Short Circuit Characteristics

- AC current regulator continues to regulate (and limit) current during fault
- X”d, X’d, Xd, X2 are only meaningful for a single inverter operating point and one single fault location!
- Danger! : Underestimation of fault current contribution is possible with Thevenin representation when impedance is not changed to adapt to fault location
- Line synchronization technique (e.g., PLL implementation) has great impact on unbalanced fault response

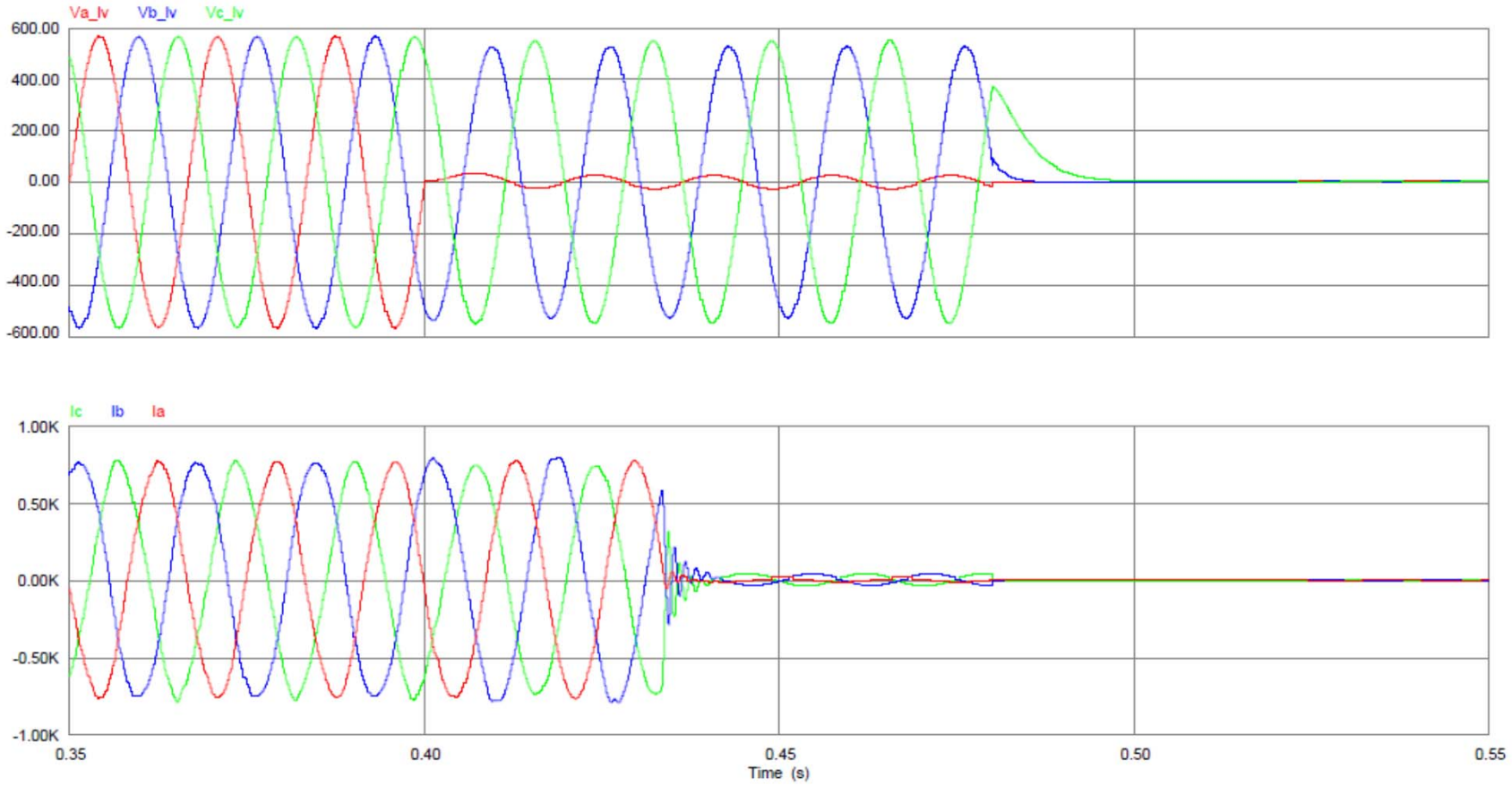
DG Inverter Short Circuit Characteristics

Response to unbalanced faults: Manufacturer #1



DG Inverter Short Circuit Characteristics

Response to unbalanced faults: Manufacturer #2



Status of Commercial Analysis Tools

- Disclaimer: these comments are general in nature are not directed at any particular software vendors' products
- Approaches to modeling current-regulated inverters:

1. None (far most common)
   - No option for user but Thevenin generator model
   - What to do?
     a. For balanced faults, use X" = $1/I_{sc}$ (***Careful !!!***), or
     b. Manually iterate Thevenin impedance, voltage or both to achieve I_{sc}
     c. For unbalanced faults?

OK for one generator, but for dozens?

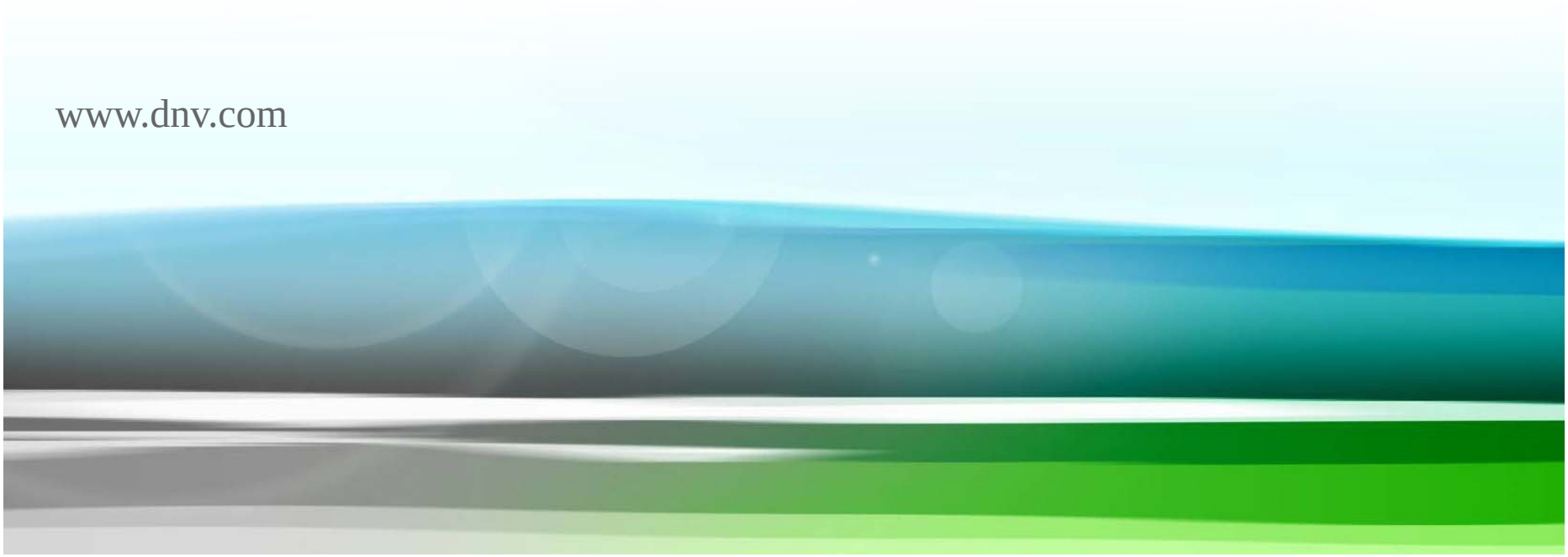
2. Iterative solution
   - Automates manual process above, can work well for balanced faults
   - Provide user means to scale negative sequence current relative to positive sequence current (but without user guidance) for unbalanced faults

Conclusions

- Inability to properly model inverter-based generation in utility industry tools ***will*** drive penetration limits as utilities feel increasingly exposed on system protection issues
- No relevant industry standards (IEEE, ANSI, IEC) currently exist
- Commercial software packages are based on inapt Thevenin generator models (though some vendors are making initial attempts at more suitable representation in an uncoordinated way)
- New computational methods are necessary
- Generalizations about unbalanced fault response are difficult due to manufacturer specific controls implementation
- Consensus standard is badly needed, could be led by third party (DOE with National Labs) and include key stakeholders:
  - Utility Protection Engineers
  - DG Inverter Manufacturers
  - Software Vendors

Safeguarding life, property and the environment

www.dnv.com



MANAGING RISK