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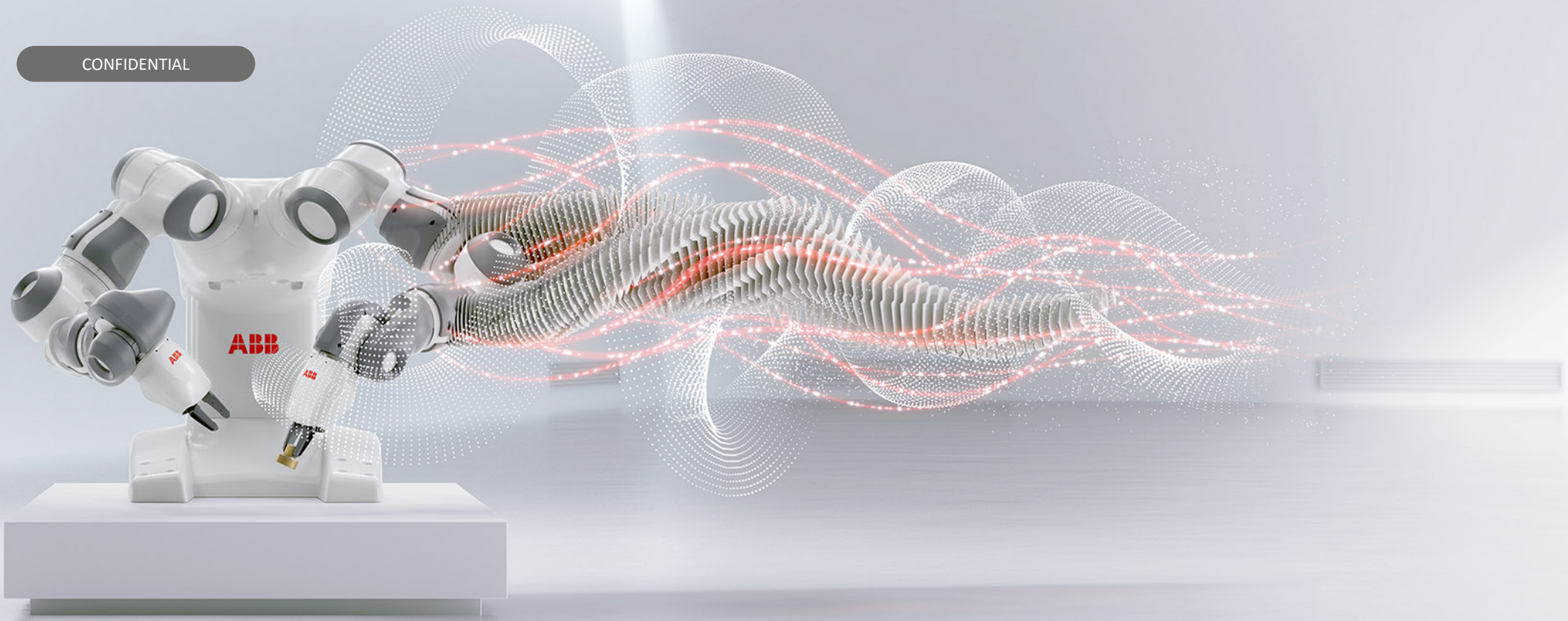

5TH GRID SIMULATOR WORKSHOP, TALLAHASSEE (FL) 15-16.11.2018

ABB Gridsmulator

Grid Simulator Trends

Kai Pietilaeinen

Important notices

This presentation includes forward-looking information and statements including statements concerning the outlook for our businesses. These statements are based on current expectations, estimates and projections about the factors that may affect our future performance, including global economic conditions, and the economic conditions of the regions and industries that are major markets for ABB Ltd. These expectations, estimates and projections are generally identifiable by statements containing words such as “expects,” “believes,” “estimates,” “targets,” “plans,” “outlook” or similar expressions.

There are numerous risks and uncertainties, many of which are beyond our control, that could cause our actual results to differ materially from the forward-looking information and statements made in this presentation and which could affect our ability to achieve any or all of our stated targets. The important factors that could cause such differences include, among others:

- business risks associated with the volatile global economic environment and political conditions
- costs associated with compliance activities
- market acceptance of new products and services
- changes in governmental regulations and currency exchange rates, and
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Although ABB Ltd believes that its expectations reflected in any such forward-looking statement are based upon reasonable assumptions, it can give no assurance that those expectations will be achieved.

This presentation contains non-GAAP measures of performance. Definitions of these measures and reconciliations between these measures and their US GAAP counterparts can be found in the ‘Supplemental reconciliations and definitions’ section of “Financial Information” under “Quarterly results and annual reports” on our website at www.abb.com/investorrelations

Topics

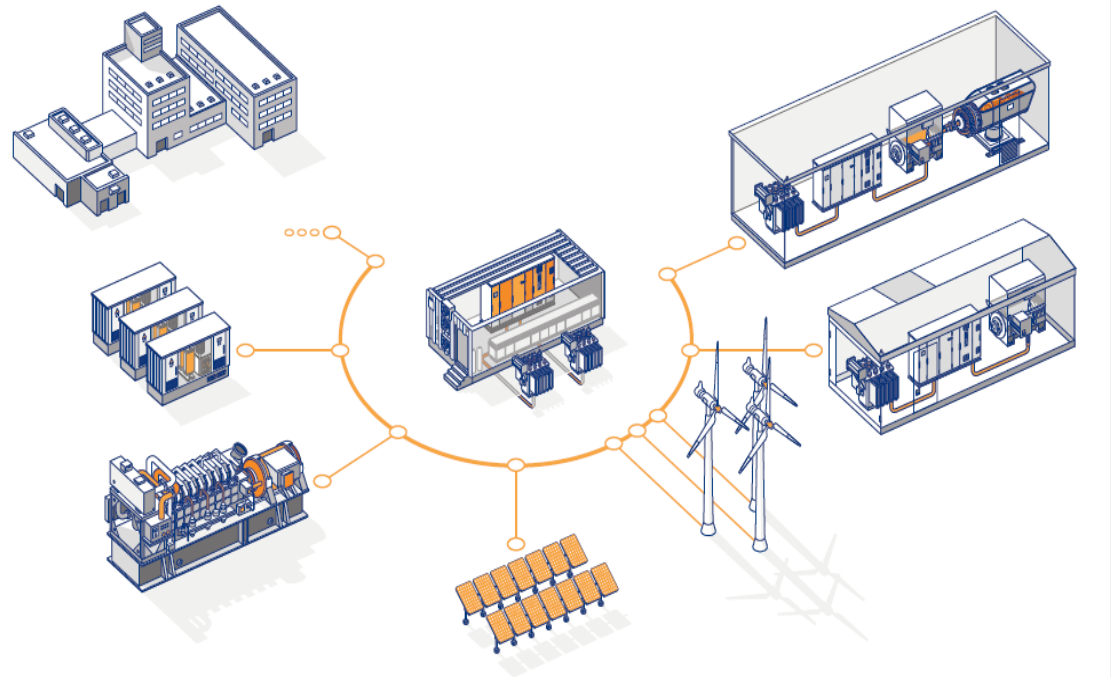
- State of the Art
- Trends
  - Power
  - Grid impedance
  - Bandwidth
  - Mobility
  - Extended Use

A general overview

ABB Grid simulator

Features

- Based on MVD active power electronic
  - Converter, input / output transformers, RC snubber (opt)
- ABB ACS6000 high performance drive
- Arc resistant design
- Any kind of grid code can be simulated and repeated
- 1,2 and 3ph voltage unbalances can be simulated
- Purpose is to test devices to be compliant to grid codes
  - Wind or Tidal Turbines
  - Converter systems
  - PV inverters
  - BESS

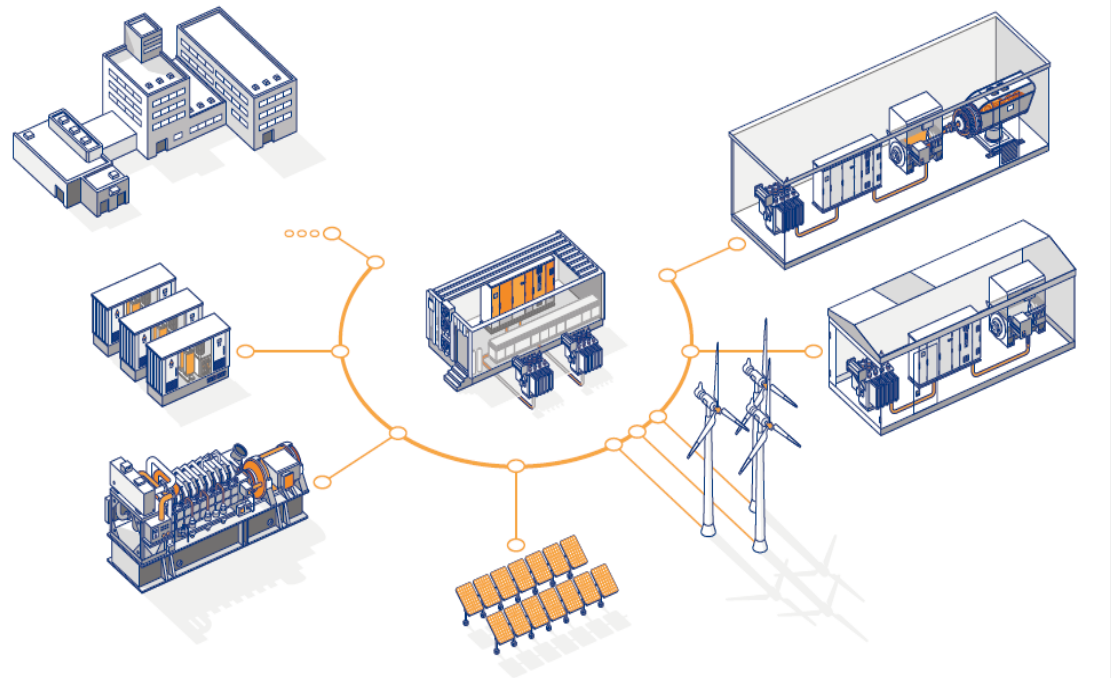


State of the art

ABB Grid Simulator

Features

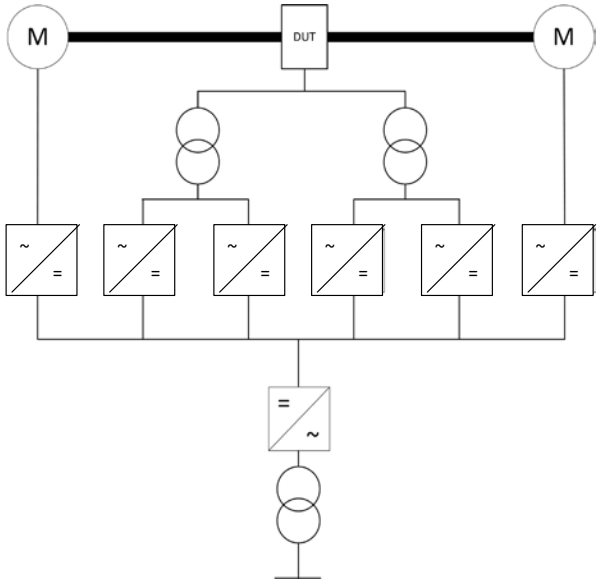
- Power: 15 MW
- Short Circuit power: up to 44 MVA
- Dynamic slew rates up to 20 p.u.
  - Voltage rate of changes down to 1msec
- Combined functionality grid simulator and dynamometer in one lineup
- Independet variation of phase angle, frequency and voltages
- Frequency range: 45-65 Hz (200 Hz)
- Voltage distortion below 1%
- Accurancy (freq and voltage) < 0.1%



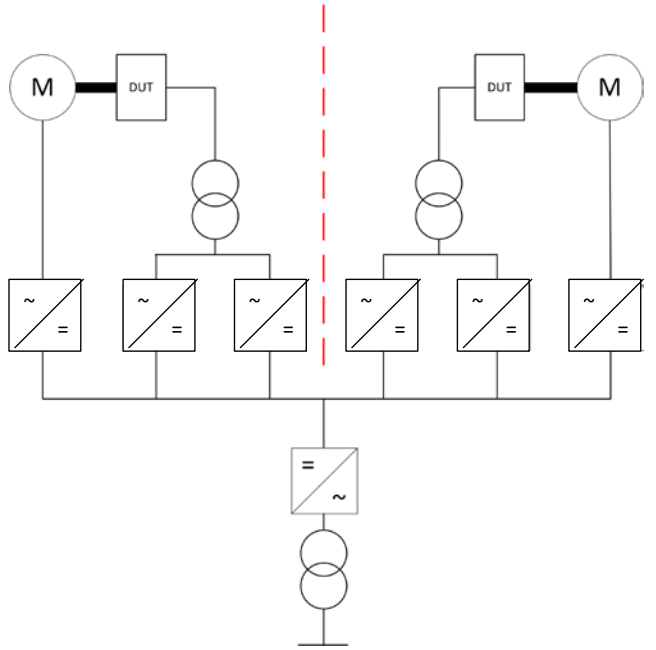
Reconfigurability

ABB Grid Simulator

Example 1



Example 2



One possible configuration among others

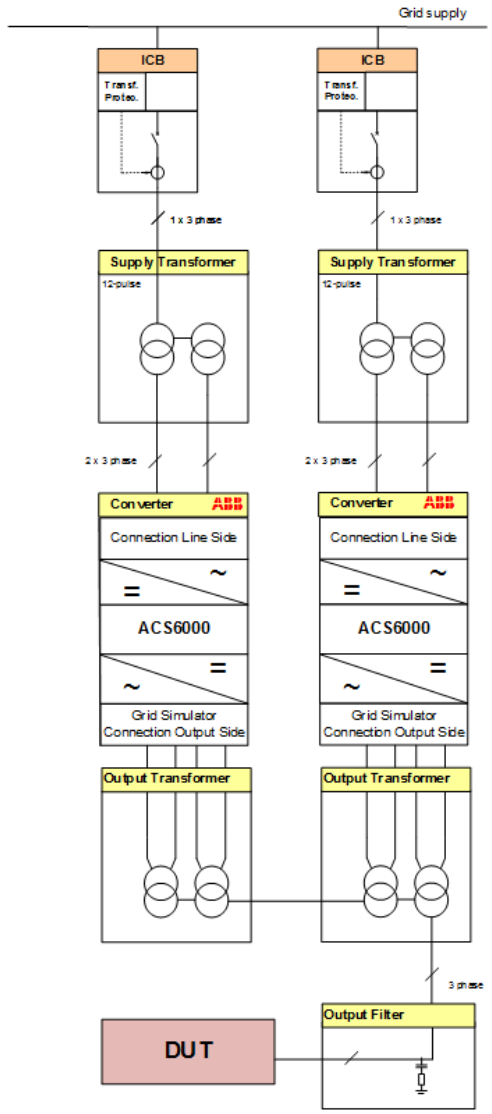
Agenda

- State of the Art
- Trends
  - Power
  - Grid impedance
  - Bandwidth
  - Mobility
  - Extended Use

Power Increase

Power trend is up to 24MW/80MVA

- Turbine has to increase the nominal power to achieve a better LCOE
- Today 12MW turbine is launched
  GE- Haliade-X
- Grid simulator has to be prepared for future turbine development



Grid Impedance

Virtual short circuit emulating

The transformer voltage drop (u_d) at a weak network is simulated by the controlled output voltage (U_{PCC})

Point of common coupling voltage phasor at PEGS:

$$\overline{u_{PCC}} = \overline{u_r} + \overline{i_0} \cdot \overline{z_d}$$

Where Zd is first order

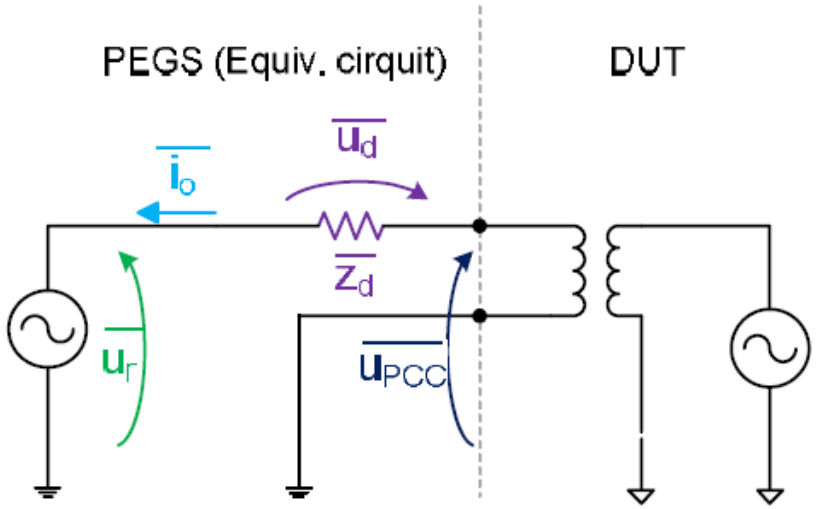
Possible extension to higher order transfer function

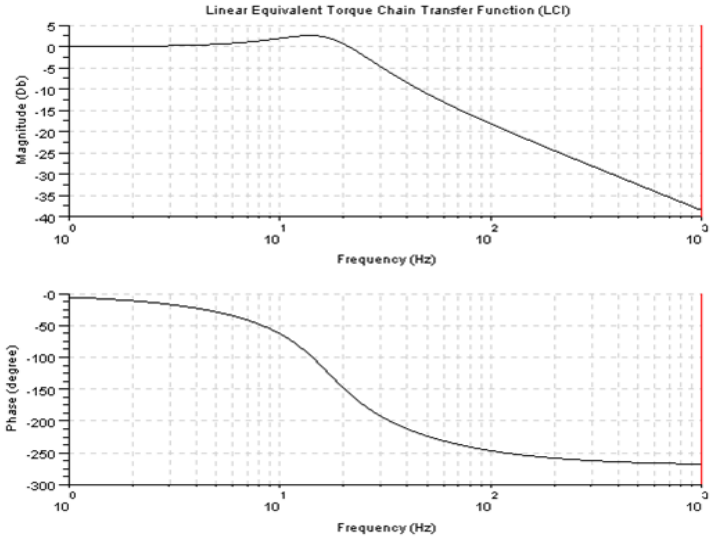
$$K(s) = \frac{-\tau_d/2\,\omega^2 s + \omega^2}{s^2 + 2\zeta\omega s + \omega^2}$$

τ = 0 (dead times are modelled separately in Simulink)

ω = 2*pi*100

ζ = 0.7



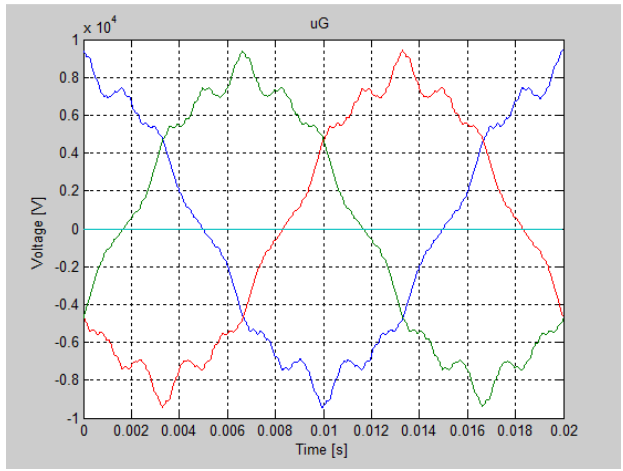


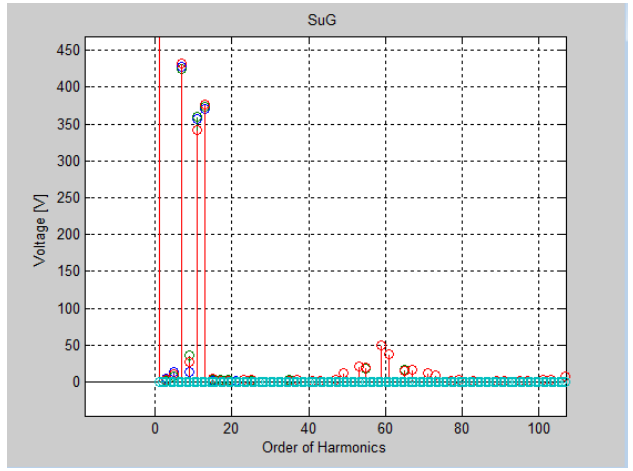
Bandwith

For stability test

Evolution

- Harmonic injection to test the stability of the DUT
- Today up to 25th harmonic injection
- Future higher band with is required
  - 1.5 kHz (25th harmonic injection) for 60 Hz application
  - 3.0 kHz (50th harmonic injection) for 60 Hz application
  - 6.0 kHz (100th harmonic injection) for 60 Hz application





7th, 11th and 13th harmonic injection as an example

Mobility

For installed turbine test

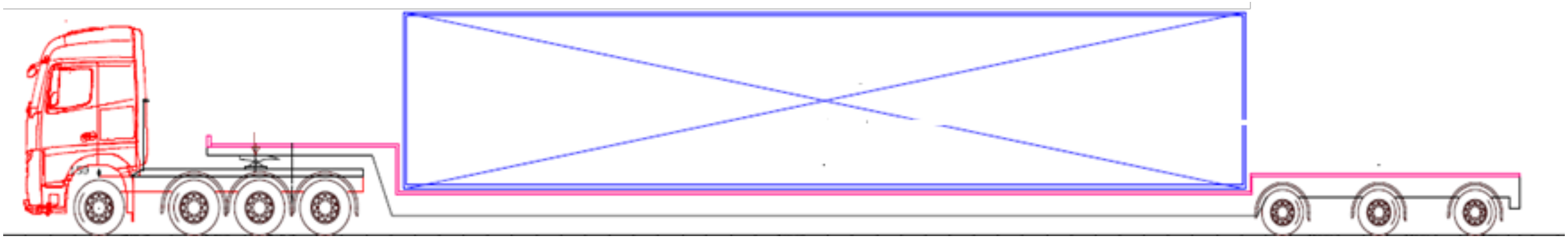
Motivator

- A test at an installed turbine should also be considered
- A complete test at the turbine is a customer request
- Extended functionality compared to passive setup

- **Good reasons** for a mobile grid simulator

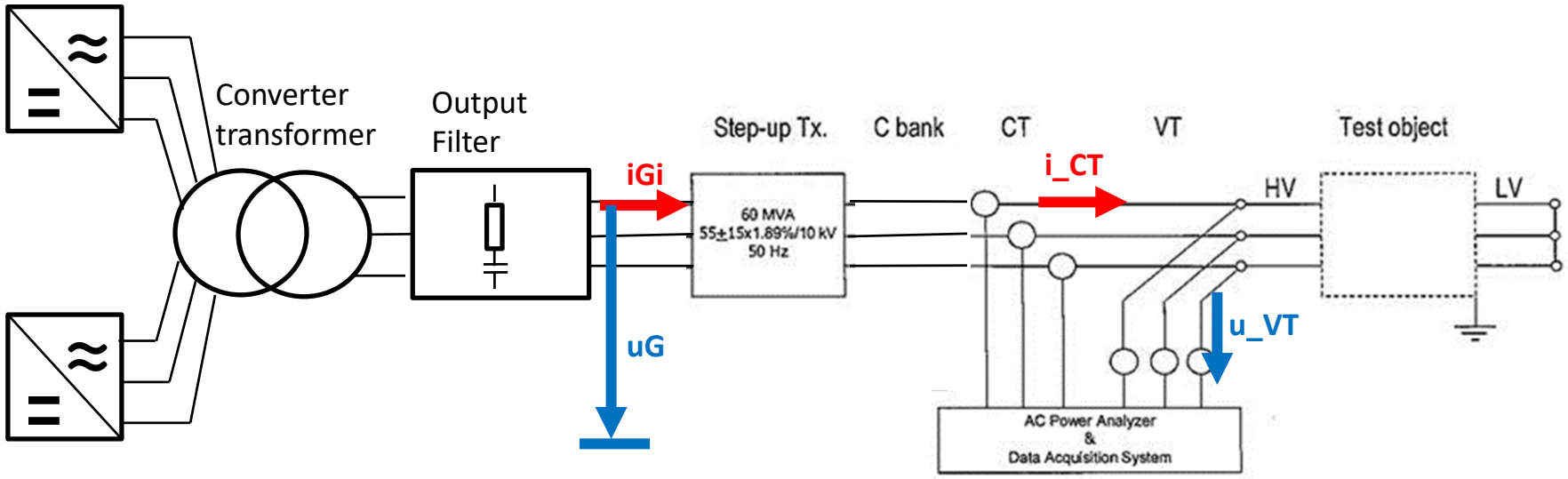
Challenges

- Multiple trucks
- Setting up the system at site
- Skilled personnel



Extended Use

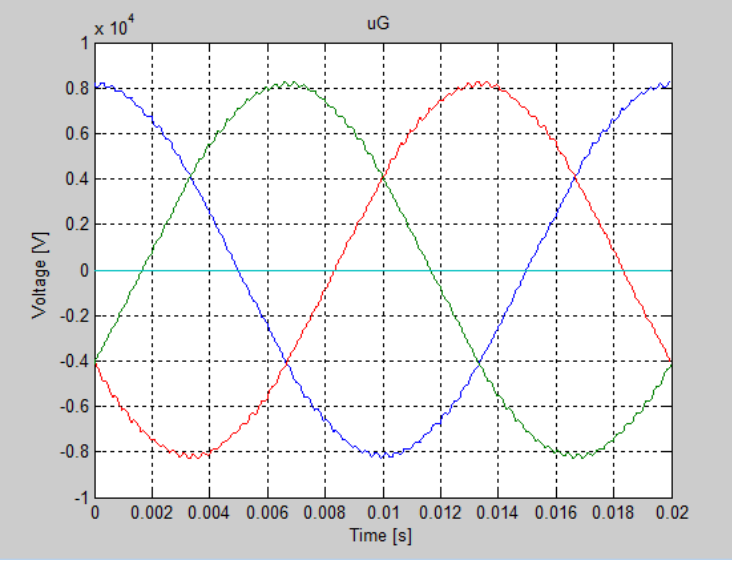
Component Testing



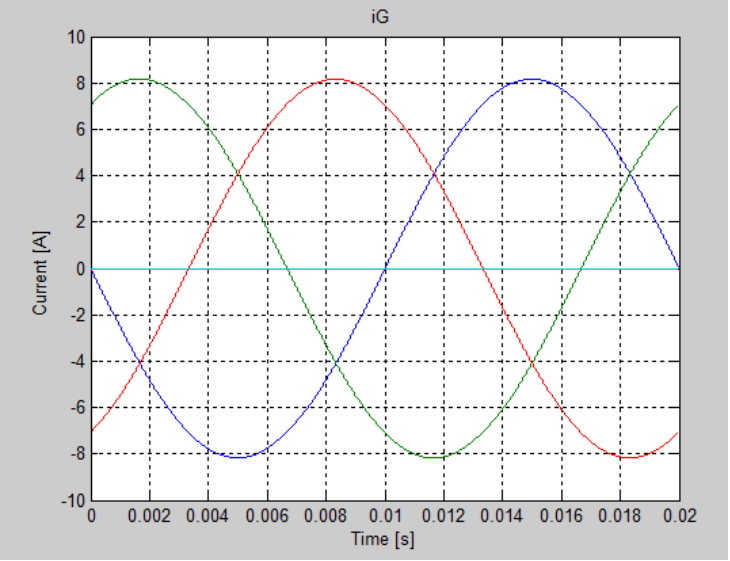
Extended Use

Component Testing, 50 Hz

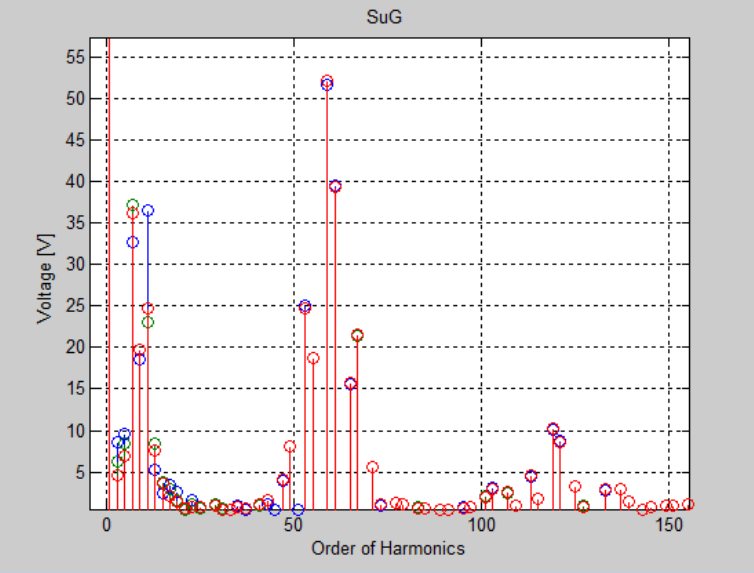
Voltage



Current



Spectrum

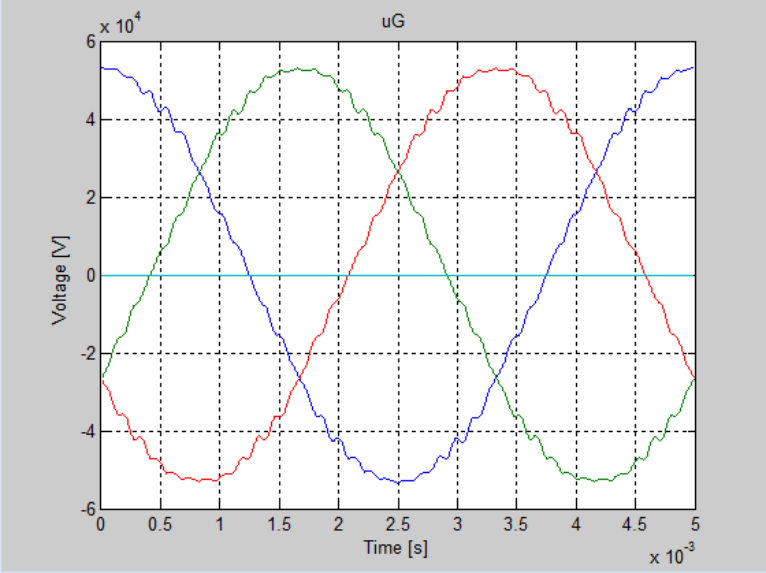


THDi <1%, THDv<1.5%

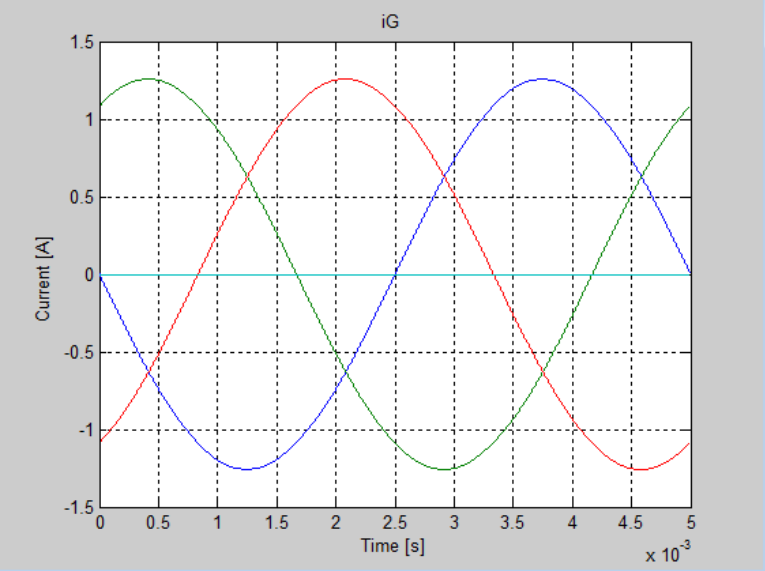
Extended Use

Component Testing, 200Hz

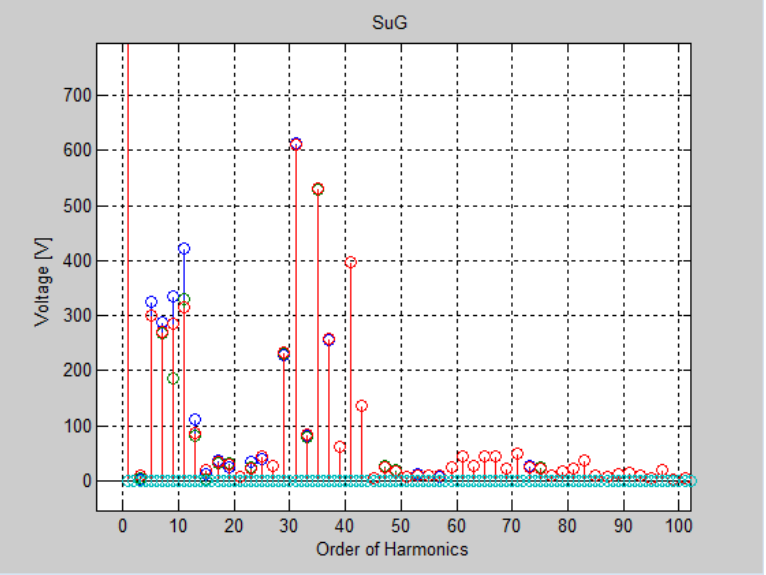
Voltage



Current



Spectrum



THDi <1%, THDv<3%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