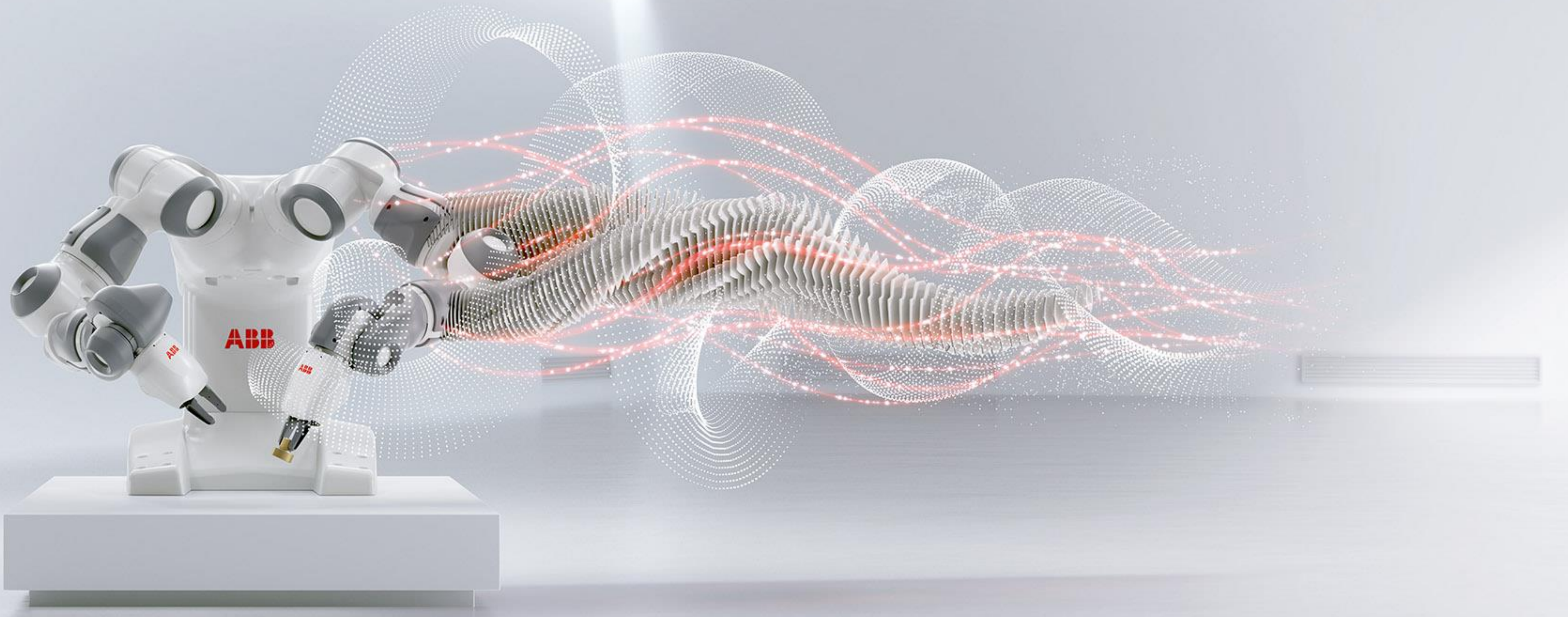


PRESENTATION – 09.11.2022

Determining DUT Thevenin Equivalent Model

6th International Workshop on Grid Simulator Testing, NREL, Golden (USA,CO)

John Eckerle, Kai Pietilaeinen

Topics

- Motivation
- Thevenin Model
- Patent (formula)
- Example (simulation)
- Challenging's
- Summary

Motivation

Motivation

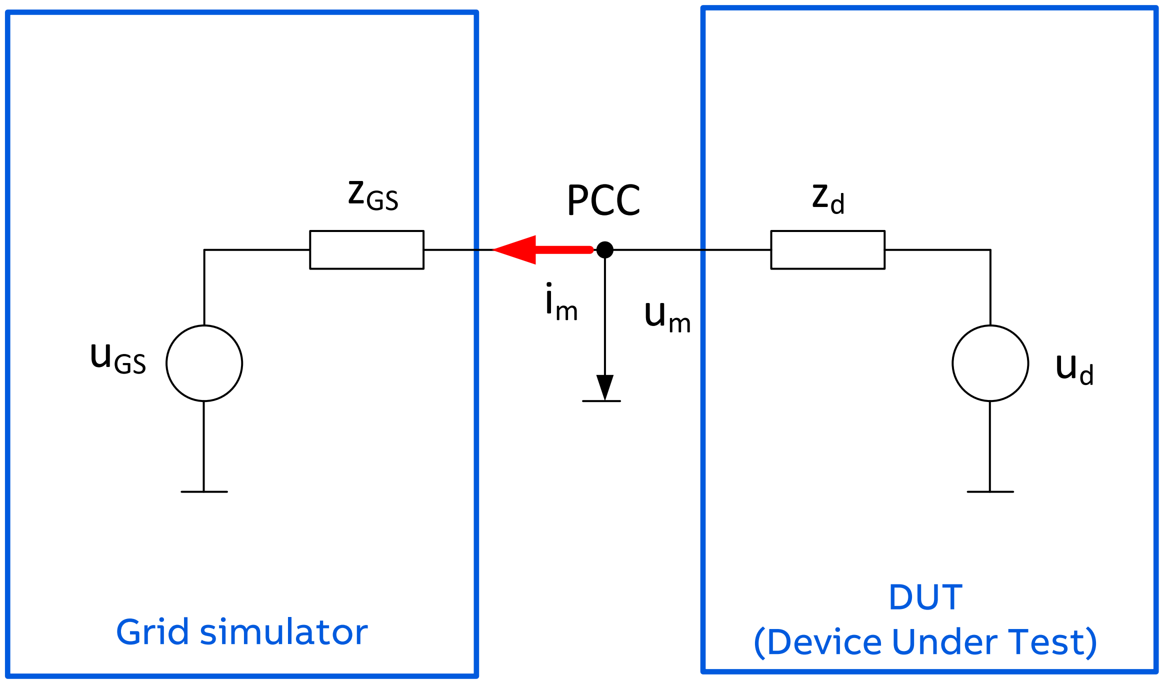
IEC 61400-21-4 Measurement and assessment of electrical characteristics – Wind turbine components and subsystem

Working group topic

- Background voltage distortion elimination of the grid simulator
- Note: Determination of background harmonic voltage distortion IEC 61400-21-1 Annex D.2.6

Grid simulator is

- Decoupled from an unknown network
- Additional possibilities to manipulate a grid.
  - Pulse pattern
  - Filter configuration
  - Transformer configuration
- Is controllable



Thevenin Model

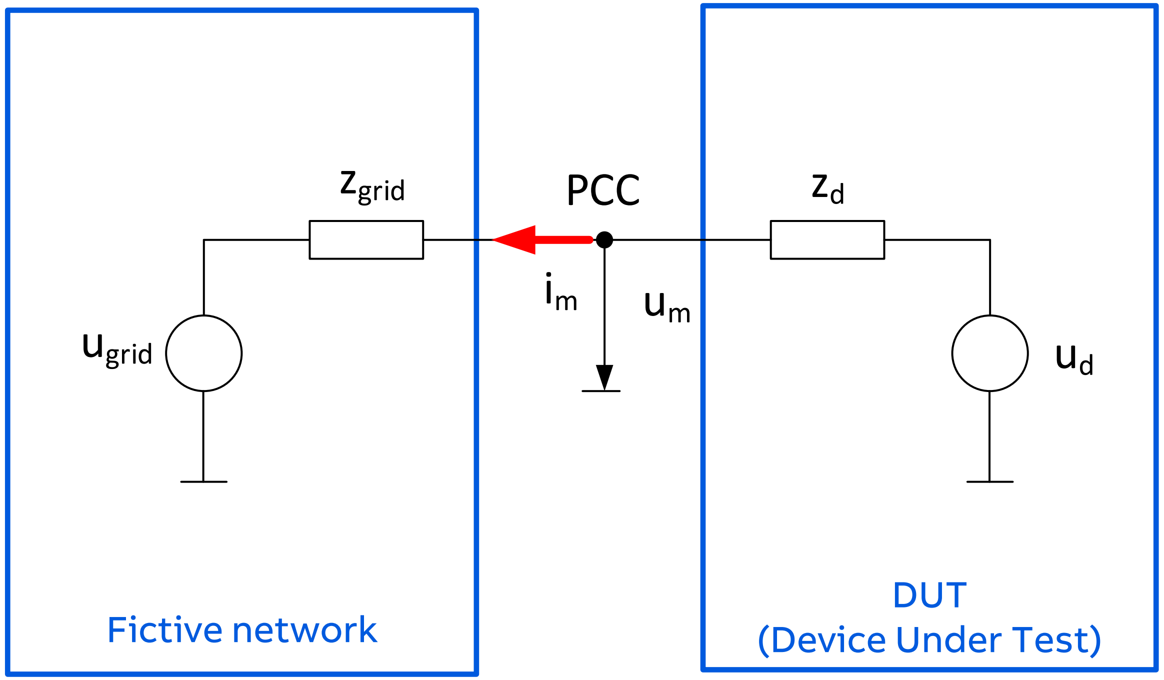
Thevenin model

A DUT Thevenin model defines the harmonics in any network

Working group topic

- The harmonics can be calculated at the PCC for any network impedance (voltage divider zd, zgrid) if the DUT Thevenin model is known

$$u_{PCC} = u_d \frac{z_{grid}}{z_{grid} + z_d}$$



©ABB

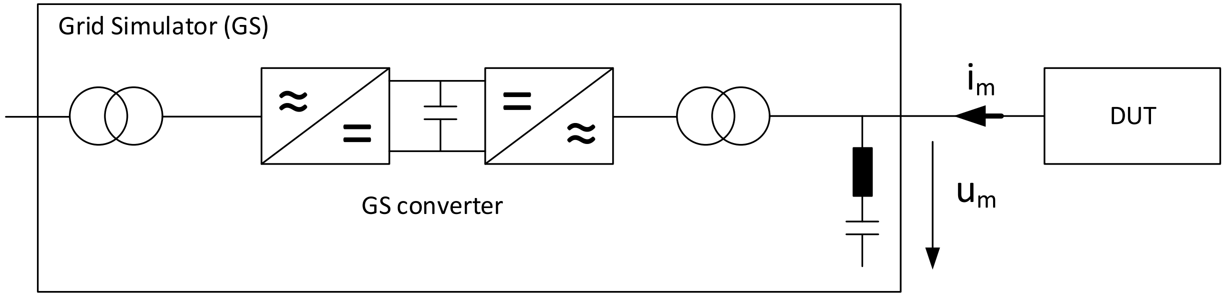
ABB Patent

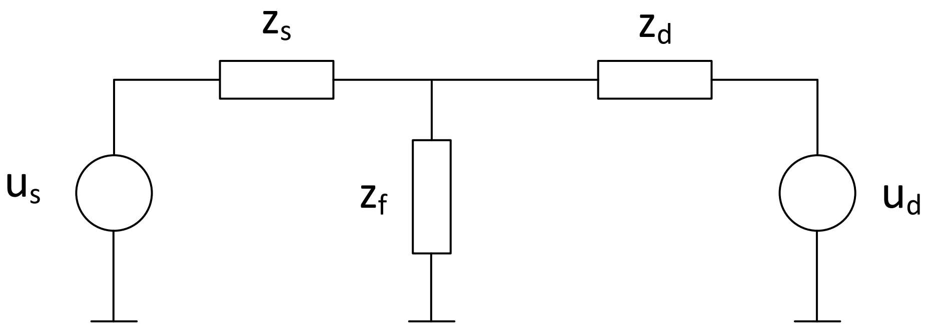
EP 3 828 557 A1

Determining Thevenin Equivalent Model for a Converter

Formula for the Thevenin model based on **patent EP 3 828 557 A1**

A simplified Thevenin model is used – u_d and z_d of the DUT can be calculated based on (2) different measurements





$$u_d = \frac{i_{m1} \cdot u_{m2} - i_{m2} \cdot u_{m1}}{i_{m1} - i_{m2}}$$

$$z_d = \frac{u_{m2} - u_{m1}}{i_{m1} - i_{m2}}$$

The unknown parameter u_d and z_d are calculated by different Kirchhoff's equations with different transformer impedances (z_{s1} and z_{s2}), different filter impedances (z_{f1} and z_{f2}) or voltages (u_{s1} and u_{s2})

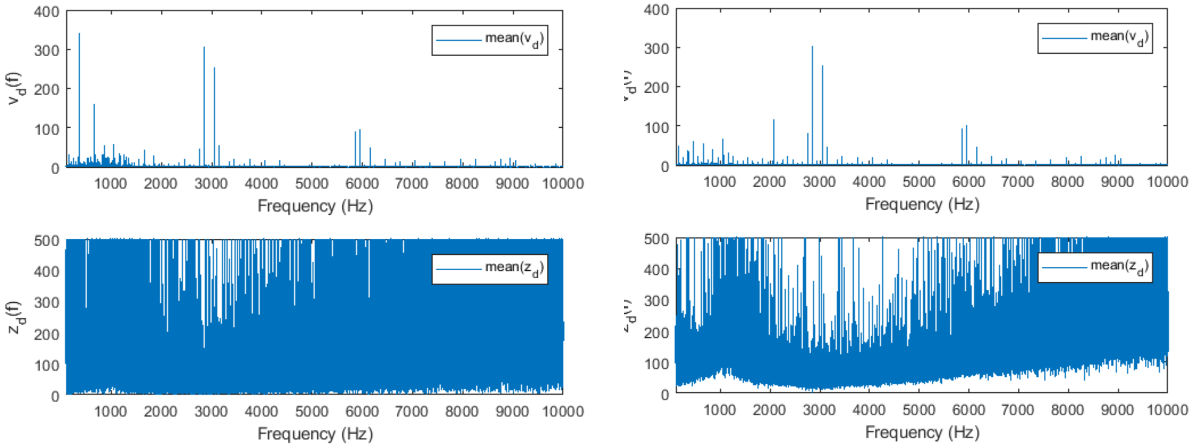
Verification

Verification

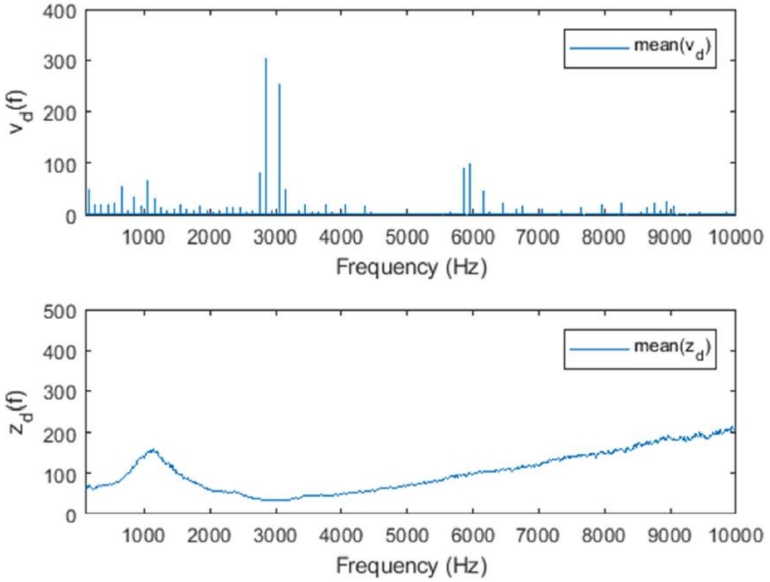
Based on simulation results

DUT Thevenin model can be determined

- Carrier frequency of the grid simulator: 3.6kHz
- Carrier frequency of the DUT: 2.95 kHz
- Measurement analyze based on 5 different filter capacitances -> 10 different combination



- Using statistical methods
  Outlier detection and filtering (minimization of noise)
  Butterworth filtering to smoothen the impedance curve



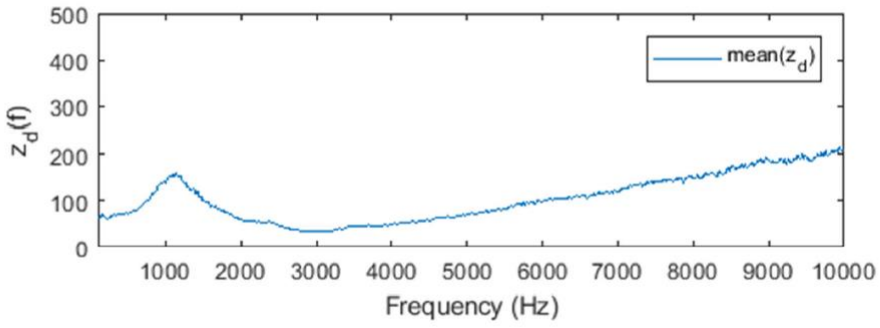
©ABB

Additional verification

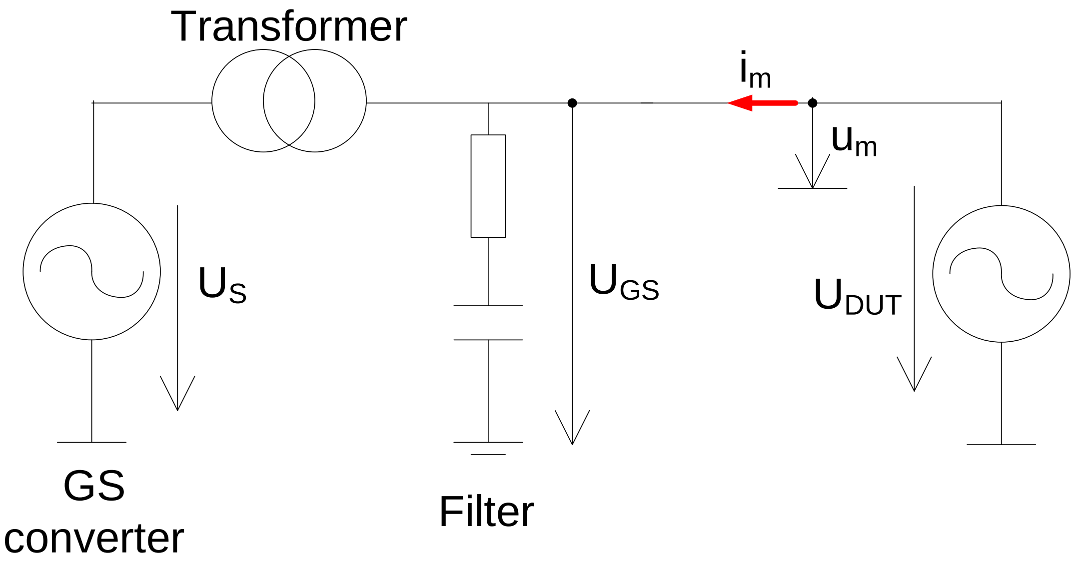
Frequency sweep

Frequency sweep with monoharmonic injection

- The impedance can be also measured by a frequency sweep
- The frequency range is limited by the switching frequency and filter.
- Below 2 kHz the Thevenin impedance is mostly defined by control and filter design of the DUT
- In the high frequency range the Thevenin impedance is normally inductive



- $U_{GS} = U(f_0) + U_h(f_i)$



Challenges

Challenges

Measurement & Data analysis / Thevenin impedance evaluation

Measurement Sensors - State of the art

Voltage sensor

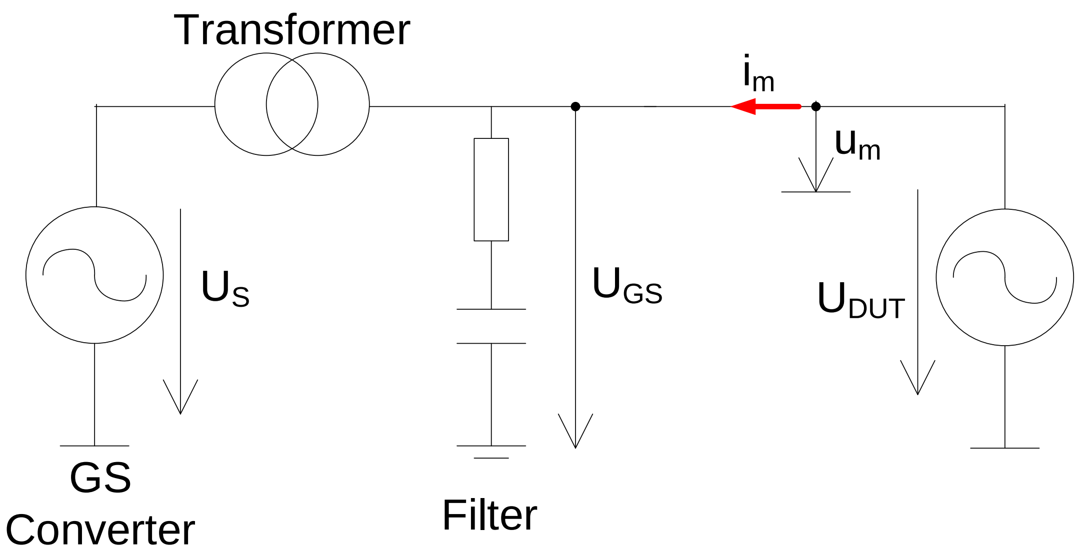
- Bandwidth up to 14 MHz (60 kV)
- Rise time: 25 ns

Current sensor

- Measuring range ± 8000 A
- Bandwidth up to 100 kHz
- Linearity error: 7ppm
- Offset current: 11 ppm
- DC – 10Hz accuracy: 23ppm
- AC max gain error (10Hz…1kHz): 0.05%

Impedance curve: Alternative with frequency sweep

Frequency sweep (FS), $U_{GS} = U(f_0) + U_h(f_i)$



©ABB

Summary

Summary

Determining DUT Thevenin Equivalent Model

This Thevenin parameters determining is applicable

- The formula based on different measurement points doesn't need any information about grid simulator and DUT
- The influence for harmonic distortion of the grid simulator can be eliminated by the proposed formula
- The power quality of DUT can be defined by measurement with the proposed method
- Thevenin voltage source can easily analyzed as shown by the simulation example
- Higher number of experiments improves the quality of the Thevenin parameter calculation.
- Thevenin impedance is more difficult but possible. There are alternative ways to do this (for example frequency sweep)
- Grid simulator and measurement sensors are available on the market

- The patent is not blocked

Patent declarations:

- License 1:
  Patent holder prepared to grant a free of charge license

©ABB

ABB