DIgSILENT Pacific

Power system engineering and software

What future for RMS simulation?

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DIgSILENT Pacific Seminar
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Presentation Overview

- A brief history of power system simulation
- Different types of simulation
- Time domain: RMS vs EMT simulation
- Hybrid RMS/EMT approach
- Stability of grids dominated by inverter based generation

A brief history of power system simulation

Transient Network Analysers

- Electromagnetic transient studies
- Developed late 1930s
- Dominant simulation technique for many years
- Series of inductors wound on magnetic cores to represent transformers, lines, source impedances etc.
- Generators represented as ideal voltage sources behind reactance
- Advantages
    - Simulation in real time – short run time for multiple transient simulations (ms per run)!
    - Computationally stable!
- Disadvantages
    - Relatively inflexible
    - Time consuming setup
    - Limited system size

The Gettysburg Times
Wednesday, February 4, 1953

$400k USD
in 1953
=
$3.86M USD
in 2019

7 FIRMS WILL PUT ANALYZER IN INSTITUTE

Metropolitan Edison Company is one of seven major power companies in Pennsylvania, new Jersey and Delaware which today signed contracts with the Franklin Institute, Philadelphia, for the installation of an A-C network analyzer in the Institute's industrial research laboratories. Announcement of the cooperative venture was made jointly by W. H. Doran, MECO president, and Dr. Henry B. Allen, executive vice president of Franklin Institute.

The analyzer is a $400,000 computing device which solves in a few hours problems which ordinarily would require weeks and even months to solve by paper computation. It is being manufactured by Westinghouse Electric Corporation and will be the largest of its kind ever built.

To Be Put On Roof

Designed to help power companies make careful and detailed plans to meet a constantly growing demand for electricity in factories, in home and on the farm, the network analyzer will be housed in a windowless, special building to be constructed on the roof of the Franklin Institute.

Costs will be shared by the cooperating companies who include: in addition to Metropolitan Edison Company, Atlantic City Electric Company, Philadelphia Electric Company, Pennsylvania Electric Company, Jersey Central Power and Light Company, and Delaware Power and Light Company.

Actually a miniature power system, the A-C network analyzer or calculator is a single phase alternating current network, utilized to represent electric power systems for the purpose of determining load distribution, voltage regulation, short circuit currents, transient stability limitations and other problems. A typical ratio of the power flow in the scaled down model is 100,000 to 1.

Westinghouse AC Network Analyser - Victoria

- Prior to the 1950's, several independent electricity systems serviced Victorian load centres
- Supplied by Westinghouse to State Electricity Commission of Victoria (SECV) in 1950
- Used for development of Victorian power system including the connection between the Latrobe Valley (Yallourn, Morwell and Hazelwood brown coal power stations) and Melbourne, and from Melbourne to NSW (Snowy Mountains Scheme)

https://collections.museumvictoria.com.au/articles/10181

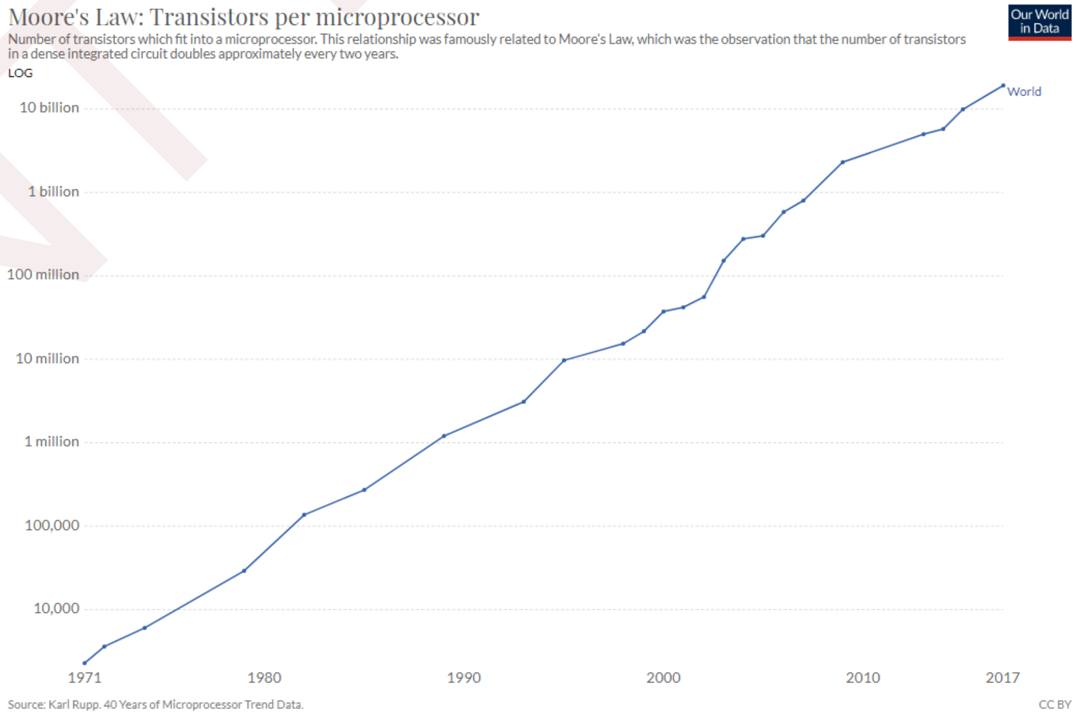
Analogue computer simulation

- Advantages
  - Simultaneous integration of differential equations (digital computers require sequential calculation)

- Disadvantages
  - Was slower than transient network analysers
  - High set up time
  - Algebraic equations requiring loops cannot be solved easily

Digital computer simulation

- Rapid increase in power of digital computers
- Mathematical models of components programmed into a computer
- Models and simulation methods developed and matured over time



https://ourworldindata.org/grapher/transistors-per-microprocessor?time=1971..2017

Different types of simulation

- Balanced and unbalanced load flow
- Short circuit
- Contingency analysis
- Protection system analysis
- Harmonics
- Time domain simulation (RMS and EMT)
- Eigen analysis
- Quasi-dynamic simulation
- Network optimisation:
    - optimal tie open points
    - optimal capacitor placement
    - NPV analysis

Model data

- Detail of data required commensurate with analysis sophistication
  - Unbalanced network analysis requires unbalanced network representation
  - Harmonic analysis requires frequency dependent parameters
  - Protection analysis requires device models and settings
  - Time domain simulation requires controller models
  - NPV analysis requires capital and operational costs

Time domain: RMS vs EMT simulation

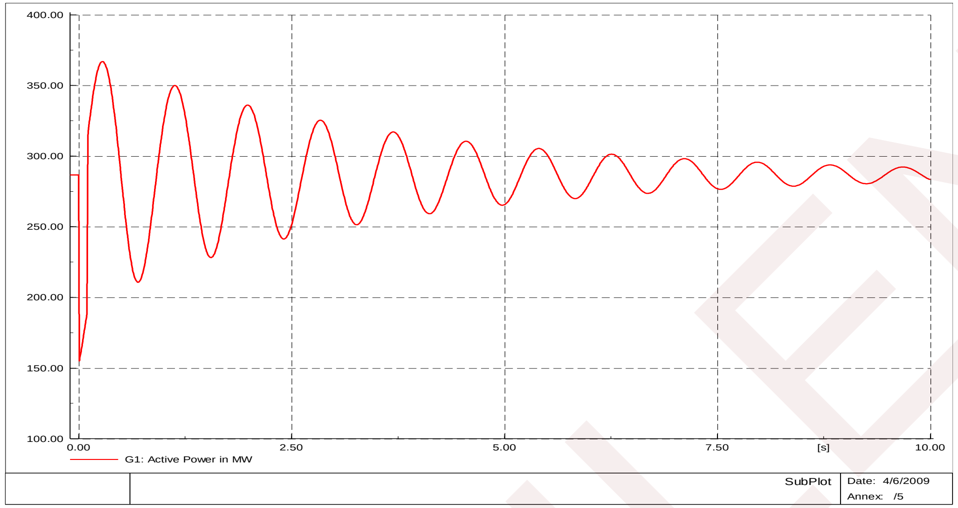
Types of time domain analysis

- RMS (root mean squared) simulations primarily investigate the interaction between the ***electrical*** and ***mechanical*** systems and controllers.
  - Fundamental frequency response only (voltage and current phasors).
  - Typical time frame of interest 0.5-60 seconds.
  - Uses include transient stability, controller design and controller optimisation.

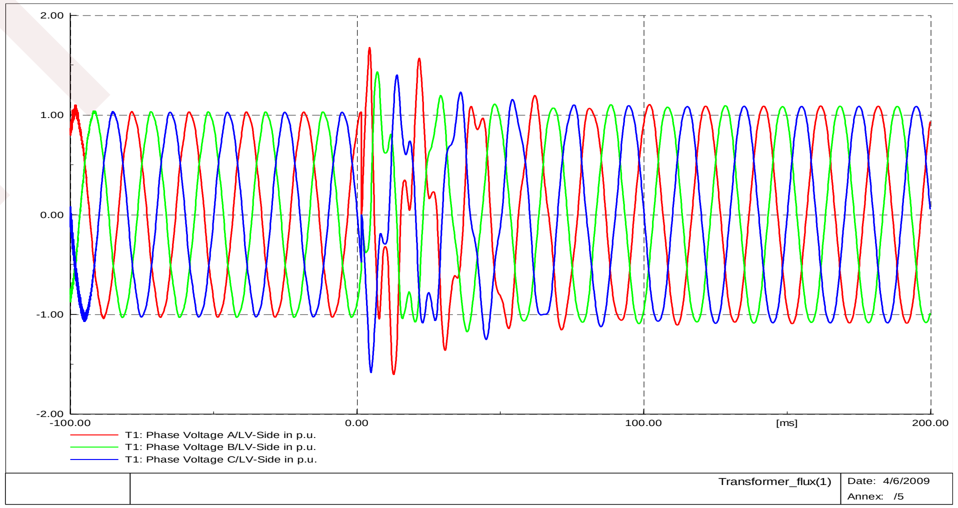
- EMT (electro-magnetic transients) also consider the interaction between ***electrical*** and ***magnetic*** phenomena.
  - Full sinusoidal representation of three phase voltage and current.
  - Historically:
    - typical time frame of interest is 20 ms – 1 second.
    - uses include insulation co-ordination, capacitor inrush, transformer inrush and wind-farm fault ride through.
  - Recently EMT simulation used to examine transient stability over longer durations (0.5-60 seconds) due to the proliferation of inverter based generation

Time domain: RMS vs EMT simulation

- The choice of simulation method depends on the phenomena that is being investigated and/or the level of detail required in the analysis.



RMS simulation



EMT simulation

Time domain: RMS vs EMT simulation

- Iterative procedure to solve AC and DC load flows at any given time point (algebraic equations), along with the solution for dynamic model state variables (differential equations)

- RMS simulation
  - Steady-state, symmetrical (balanced) or three-phase (unbalanced) representation of the passive electrical network

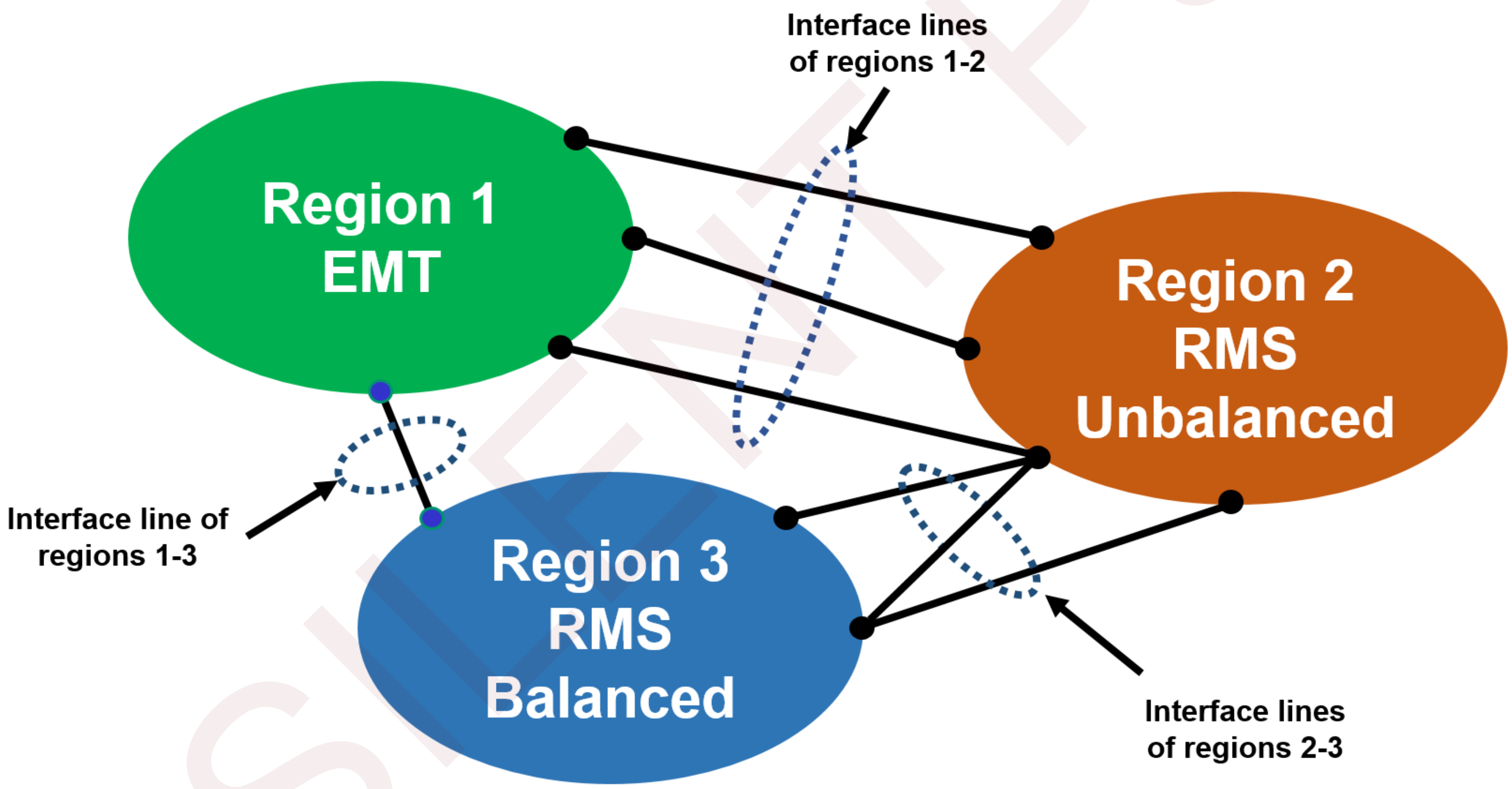
- EMT simulation
  - Dynamic behaviour of passive network elements is also taken into account
  - The integration step size has to be significantly smaller than in the case of a steady-state representation and as a result, the calculation time increases

RMS-EMT co-simulation

- The objective of RMS-EMT co-simulation is to bring the best of the two worlds (EMT, RMS) together:
  - RMS analysis works on fundamental frequency (e.g. 50 Hz), faster and main focus is on electro-mechanical dynamics only
  - EMT analysis works on instantaneous values, slower (for smaller time steps) and can examine the electro-magnetic transient effects

- The general implementation of RMS-EMT co-simulation is to let each computation task carried out independently in each time step and feedback the other task with new results at the end of each time step

Hybrid RMS/EMT approach

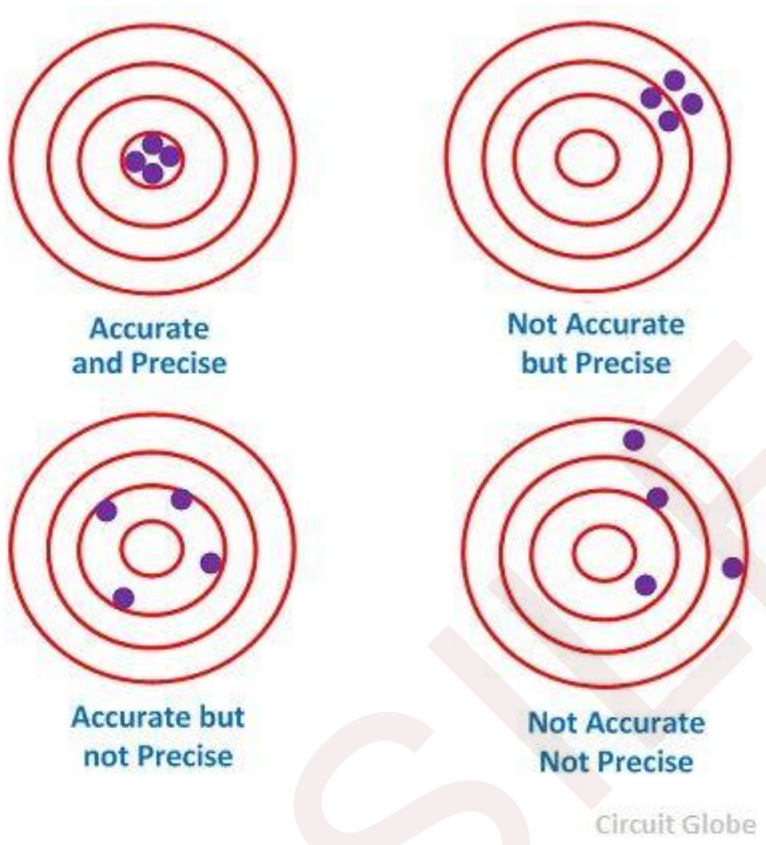


Hybrid RMS/EMT approach

- Definition of regions allows for calculation parallelisation
- Takes advantage of modern multicore processing
- Efficiency benefit in RMS simulation of slow moving phenomena with more detailed EMT simulation of faster transient phenomena

Demonstration – RMS/EMT hybrid

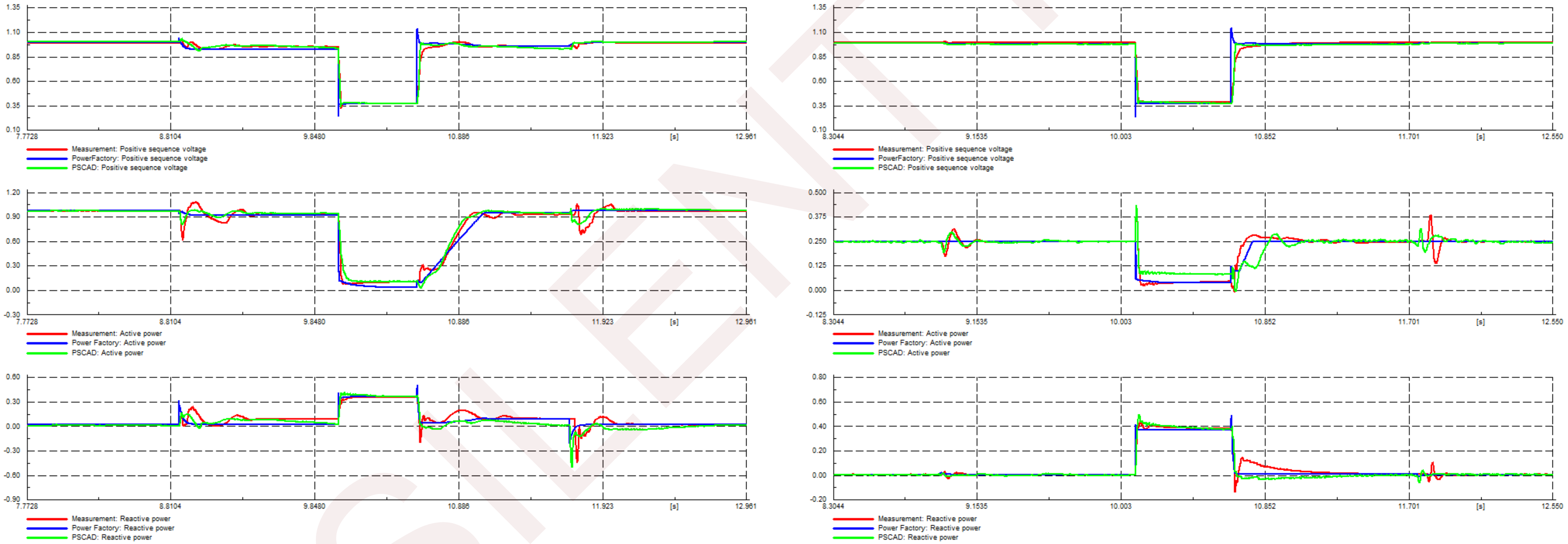
Accuracy vs precision



- Both EMT and RMS models are only models that will always respond slightly different from the reality.
- Both EMT and RMS models should be validated. It cannot be assumed that an EMT model is less or more accurate than an RMS model.
- Because EMT models consider higher frequency phenomena, it is generally more difficult to validate other than in a laboratory environment

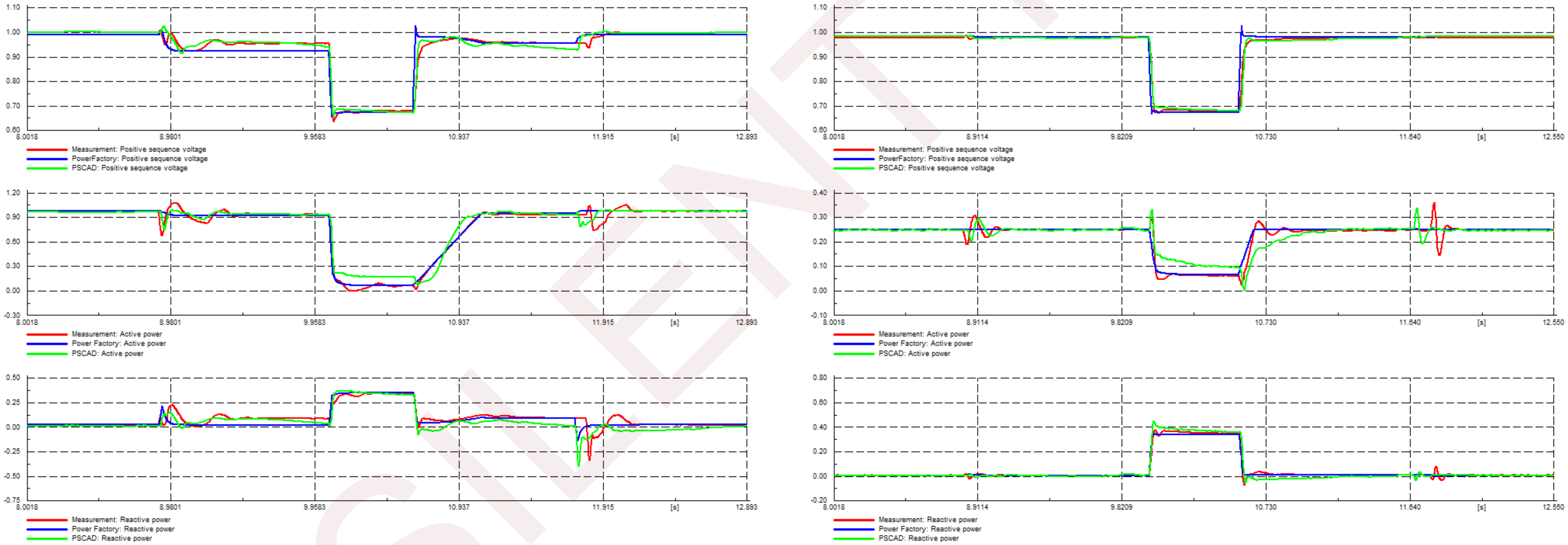
https://circuitglobe.com/accuracy-and-precision.html

Unbalanced RMS and EMT models vs measurement



Symmetrical faults

Unbalanced RMS and EMT models vs measurement



Asymmetrical faults

Discussion

- Unbalanced RMS model can accurately represent the main behaviours of non-synchronous generators at the system fundamental frequency.
- EMT model is not necessarily more accurate. It can show more detailed responses and can **possibly** be more accurate but at the expenses of computing time and resource, higher development and maintenance cost, higher modelling complexity and dependencies. It is often encrypted/blackboxed due to IP concerns and hence more difficult to use and debug.
- Models are subjected to the level of details, modelling quality and accuracy as well as mistakes.
- Models should be validated against measurement to confirm the accuracy of the models for a specific study objective.

Automation bias

GPS Tracking Disaster: Japanese Tourists Drive Straight into the Pacific

By **Akiko Fujita** March 16, 2012

https://abcnews.go.com/blogs/headlines/2012/03/gps-tracking-disaster-japanese-tourists-drive-straight-into-the-pacific

Stability of grids dominated by inverter based generation

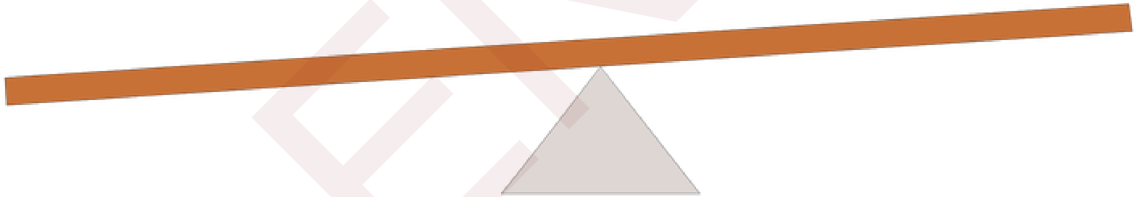
Inverter dominated grids

- Increasing levels of renewables resulting in system dynamics more and more dominated by inverter based generation
- Renewable technologies currently deployed will shape the dynamic grid behaviour for the next 5-10 years
- Most commercially available solar and wind inverters utilise grid-following control strategies
- Grid-following controls
  - Current injection based on PI characteristic
  - Works as long as the grid can absorb the current
  - Unstable under weak grid conditions
- Growing demand for grid-forming controls
  - Basically generators that can operate in a stable fashion within an integrated grid
  - Synchronous condensers exhibit grid-forming characteristics

System strength evaluation

- Grid forming characteristics
  - Conventional steam, gas, hydro turbine generators
  - Synchronous condensers

- Grid following characteristics
  - Solar and wind turbine inverters (current state of the art)



System strength evaluation

- Preliminary Impact Assessment – hand calculation of SCR and equivalent SCR calculation
- Full Impact Assessment – Transient stability EMT simulation of a significant region of the grid

Converter control strategies

- Grid-following converter control – state-of-the-art
  - Voltage oriented vector current control – synchronisation via phase-locked loop (PLL)
  - Slow outer loop P/Q controller
  - Fast inner loop current controller

- Grid-leading converter control
  - Fixed frequency (internal oscillator)
  - Small island and offshore grids (e.g. HVDC offshore wind farm)

- Grid-forming converter control
  - Ability to synchronise with other converters or generators
  - Several different strategies proposed

Definition of grid forming

- From a recent paper presented at the Wind Integration Conference 2019

  Only the control designs of power electronic generating units which show a strong initial response on changes in terminal voltage magnitude and phase angle can supply the system with high penetration of power electronics in a satisfactory manner

- How fast?
  - Within the first quarter period

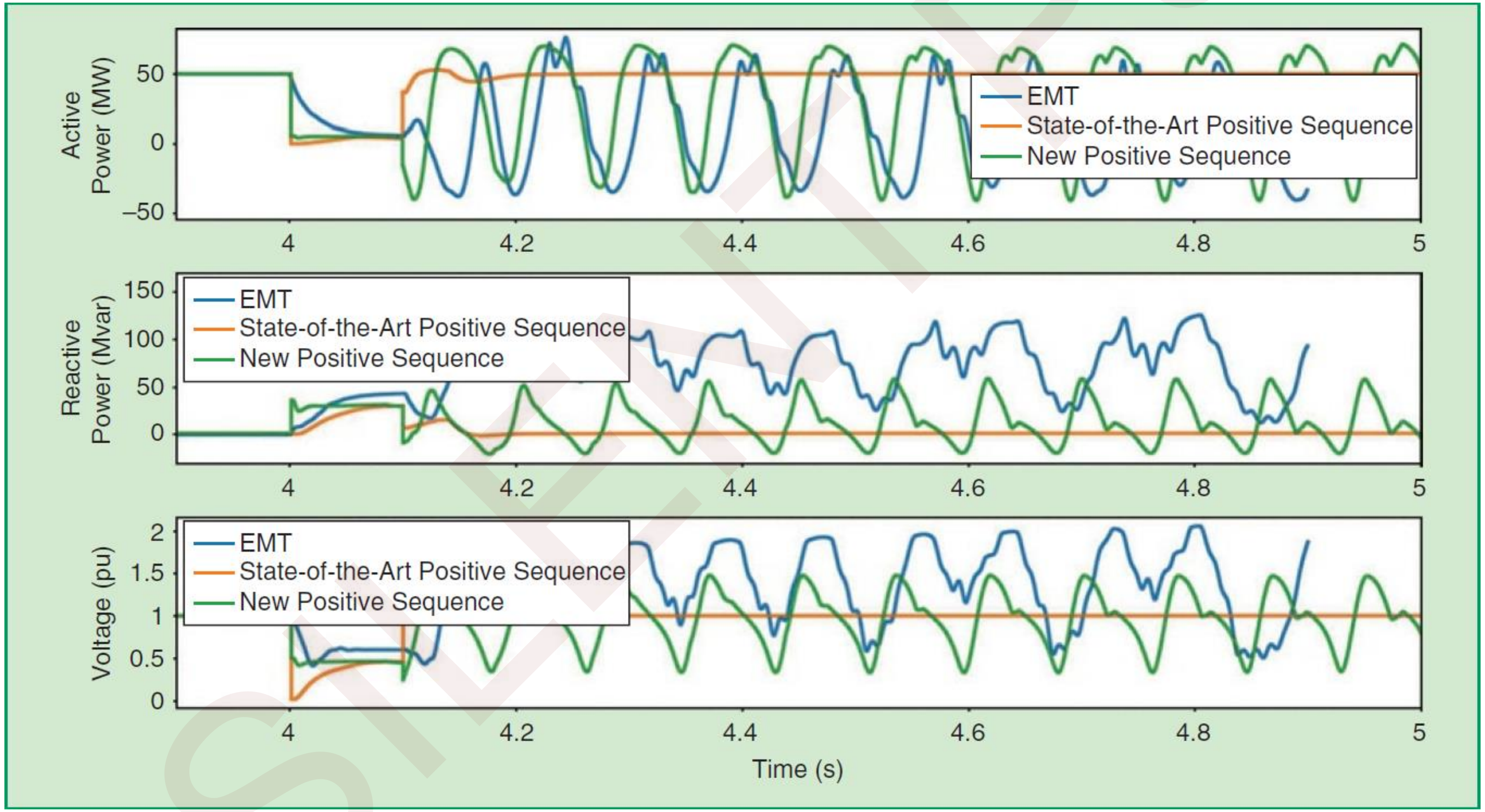
- What is considered strong?

- Testing of grid forming capability can be done by applying steps in voltage magnitude as well as in voltage phase angle at the devices terminals

B. Weise, A. Korai, A. Constantin: Comparison of Selected Grid-Forming Converter Control Strategies for Use in Power Electronic Dominated Power Systems – 18th international wind integration workshop, Dublin, Ireland – 16-18 October 2019

Demonstration – inverter dominated grid

New positive sequence RMS



J. Matevosyan, B. Badradeh, T. Prevost, et al.: Grid-Forming Inverters. IEEE Power and Energy magazine. Vol 17 Num 6. Nov/Dec 2019

Conclusion

- What is the future for RMS simulation?
  - No future – EMT everything?
  - Hybrid RMS/EMT?
  - Grid code / technical rules change to ensure sufficient grid forming capability?
  - New positive sequence RMS models?

Thank you!

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