EMT Simulations are Crucial in Studying Today's Grids: So are Related Education & Training

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Introduction/Context

- Last month I attended the IEEE PES General Meeting
- My interactions/experience reinforced how far apart people within academia are in grasping the need and applicability of EMT tools
- Same goes for need of a common language to bridge between academia and industry
- Specific questions: When/where EMT? Can we learn from past/present practices? What has changed now? How should we proceed with EMT education/training/workforce development?

EMT tools are crucial for studying today's and tomorrow's power grids (specifics to be debated)

When/where EMT? Can we learn from past/present practices?

- A bit of History
- Subsynchronous resonance (SSR) due to series compensation: turbine-generator shaft failure in Mohave, CA in 1970
- Subsynchronous control interactions (SSCI):
  - Torsional mode destabilization by: (a) excitation control involving power systems stabilizer on 555 MVA unit in Lambton, ON in 1969; (b) by speed-governor control in nuclear unit in Ontario Hydro in 1983; (c) in Milton Young generator by interaction with nearby HVdc controls in Square Butt station in ND in 1977
- EMT studies are <u>mandatory today</u> whenever there is a risk of subsynchronous resonance/interaction (SSR/SSI)
- Switchgear and relay vendors routinely use EMT simulations

There is nothing (fundamentally) new under the sun!

When/where EMT? What changed from the past?

- SSRs/SSIs (including with DFIGs): primary local phenomena
- Emerging challenges due to massive IBR penetration:
  - Local: Weak grid subsynchronous oscillations (many all over the world)
  - Wide-area: Forced oscillations (e.g., Jan ‘19 Florida event in EI)
  - Wide-area: Angeles Forest disturbance (and similar events)
  - Wide-area: BESS-PV control interaction in Salt River Project
  - Wide-area: Inter-IBR oscillations involving distant IBRs (academic research)
- Some of these are IBR control and protection (C&P)-induced
- IBR’s inherent dynamics and transient behavior should be better captured
- Possibility of supersynchronous modal interaction in future

Just modeling local regions in EMT may not suffice

What changed & did not change from the past?

- Modeling adequacy question
- We will increasingly need to have higher fidelity IBR models and model of transmission line dynamics for wide-area events/phenomena
- Has phasor/dynamic phasor models lost relevance?
- Adequacy of these options will continue to be evaluated for time-domain studies, control design and root-cause analysis.
- Can we supplement EMT tools for validation/time-domain modeling adequacy study?
- Not likely. All OEMs are using them at component level. How much area for interconnection study is open question. GOs and TPs/PCs need to step in!

Can we take chances with the 'unknown' 'unknowns'?

Training/Education Needs for Different Stakeholder

- Stakeholder dependent
- Original equipment manufacturers (OEMs): routinely uses EMT simulations to validate component-level performance → most employees should have some knowledge
- Planners (TPs/PCs): should have EMT proficient groups (2-5 people?) to cater for phasor-EMT modeling consistency evaluation and interconnection studies if needed
- Generator owners (GOs): same as above (only consistency)
- Consultants: typically have dedicated teams working on EMT simulations

We must start education/workforce training now

Current Workforce & Challenges

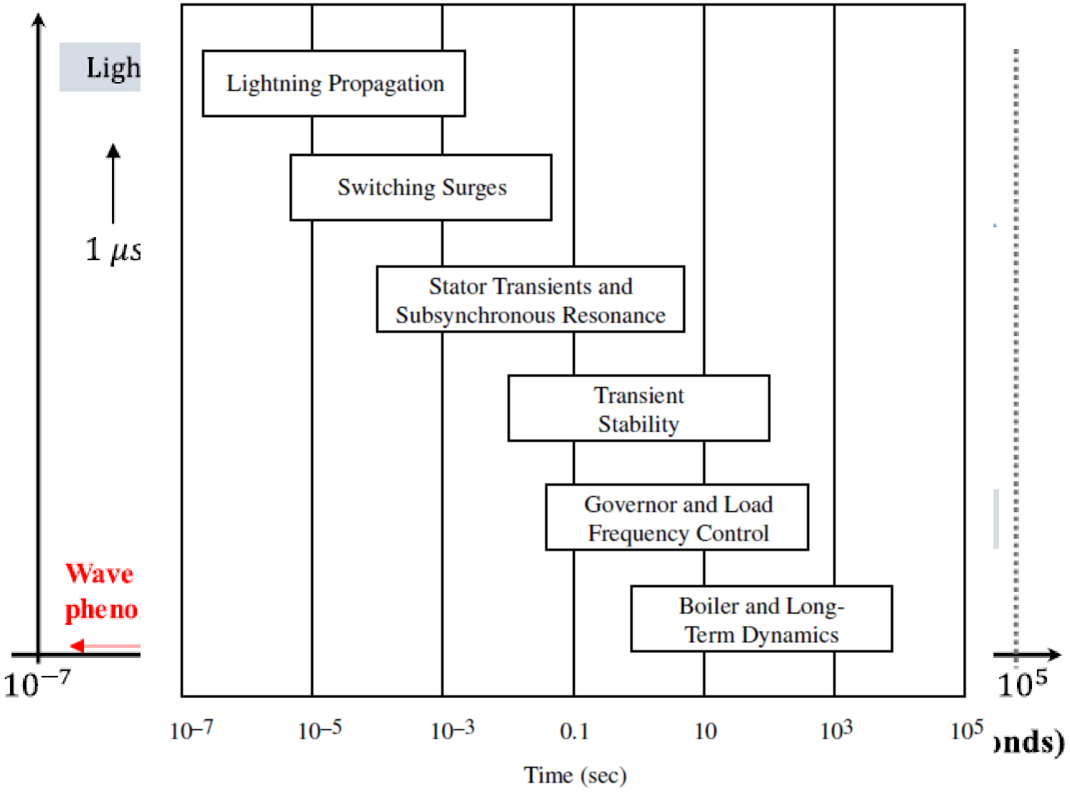

Figure courtesy: [1] Sauer and Pai, 'Power systems dynamics and stability,' 1997. [2] "in Analytic Research Foundations For the Next-Generation Electric Grid." The National Academies Press, WA DC, USA, 2016.

Status quo:

- GOs and TPs/PCs typically used to phasor-based analysis
- Fundamental knowledge of IBRs maybe lacking
- Usage of EMT and phasor-based models used to be highly distinct

Need of the present and future:

- Usage of EMT and phasor may significantly overlap: needs knowledge of both domains

Current Approach: EMT Training/Education

- Some of the relevant courses or curriculum that exist to teach EMT in a few US universities today
- Grad-level *Power Systems Transients* course:
  - Typically includes EMT theory and EMT applications like switching, insulation coordination
  - In some cases, include power electronic converter modeling
  - Uses EMT tools like EMTP, PSCAD, Matlab/Simscape for hands on simulation experience in projects and homeworks
- Typical text books:
  - Allan Greenwood, Electrical Transients in Power Systems, John Wiley
  - Lou van der Sluis, Transients in Power Systems, Wiley, 2002. (eBook)
  - H.W. Dommel, "EMTP Theory Book", 1987.

Current Approach: EMT Training/Education

- Some of the relevant courses or curriculum that exist to teach EMT in a few US universities today
- Grad-level *Power Systems Digital Relaying* course:
  - Typically includes digital filter-based relay algorithm basics, and into to relay hardware
  - Uses EMT tools like EMTP, PSCAD, Matlab/Simscape for hands on simulation experience in projects and homeworks
- Typical text books:
  - Anderson, P.M., Power System Protection, IEEE Press, New York, 1999.
  - Blackburn, J.L., Applied Protective Relaying, Westinghouse Electric Corporation, New York, 1982.

Current Approach: EMT Training/Education

- Some of the relevant courses or curriculum that exist to teach EMT in many US universities today
- UG/Grad-level *Power Electronics* courses:
  - These could include a wide-ranging topics on power electronics
  - Uses EMT tools like SPICE, PSPICE, Matlab/Simscape for hands on simulation experience in projects and homeworks
- Typical text books:
  - Depends on the topic of the course (e.g., HVdc, FACTS, AC-DC converter, DC-DC converter, motor drives, renewable generators, etc.)

Gaps & Challenges: EMT Training/Education

- Challenge 1: imbalance between Power Systems (little EMT) & Power Electronics curriculum (must have EMT)
- Challenge 2: hard to teach in UG level as significant background needed
- Challenge 3: holistic, integrative first principle-based teaching is absent when comes to systems side where application of EMT models depends engineering judgement
- Challenge 4: IBR-specific courses are less common than general power electronics courses
- Challenge 4: some important theories are still being developed like steady-state short circuit fault analysis of inverter-based resources and modeling adequacy of IBR-dominated grids

Power electronics majors can readily join OEMs, but EMT expertise in Power systems major is far less common!

Next Steps: EMT Training/Education

Framework	Time-domain validation	Sensitivity analysis	Multi-rate simulation	Control design, root-cause analysis, short circuit ratio and stability analysis	Simulation time	Maturity of tools
EMT						R&D
Phasor						

- EMT gives highest possible accuracy, but is not a design framework
- Potential new tool: Dynamic phasor
- Linearizable dynamic phasor and phasor frameworks are better suited for control design and root-cause analysis
- First principles-driven understanding should be emphasized in curriculum

Next Steps: EMT Training/Education

- <u>Holistic approach:</u> needed to bridge power electronics application to power systems
- <u>Two-pronged approach</u>:
  - Update/introduce undergrad/grad courses
  - Update/introduce professional training courses
- Typical grad courses are hands-on research-based: Homeworks & projects demand use of EMT tools and research-driven learning.
- Engage DOE for funding development of course modules with input from stakeholders

Upgrading existing courses and adding new courses needed

Next Steps: EMT Training/Education

- Example 1: Power Systems Dynamics, Stability, and Controls:
  - Currently synchronous machine-focused, which should remain
  - Need to add a second course with complete focus on IBRs
  - In alternate form, these two can be merged into a single course
- Example 2: Power Systems Transients:
  - Currently heavily focused on switching/lightning/insulation coordination
  - Should balance this with power electronics-related modules
- Example 3: Protection of IBR-dominated Power Systems:
  - Need to introduce new course (e.g., special studies course) that relies on research papers

More IBRs and EMT focus for Power Systems courses!

Next Steps: EMT Training/Education

- Example 4: Advanced UG-level power electronics course:
  - Currently may have non-real time EMT simulation in HWs
  - Should introduce a lab module involving real-time simulation
- Example 5: IBR-focused Grad-level power electronics course:
  - Currently limited focus on specific IBR applications and also represent the rest of the grid using Thevenin's equivalent
  - Should introduce/upgrade course with more IBR focus
  - Introduce notions of realistic representation of grid model to the extent possible
  - Introduce real-time simulator-related course project

More IBR focus and 'systems' level perspective in Power Electronics courses!