

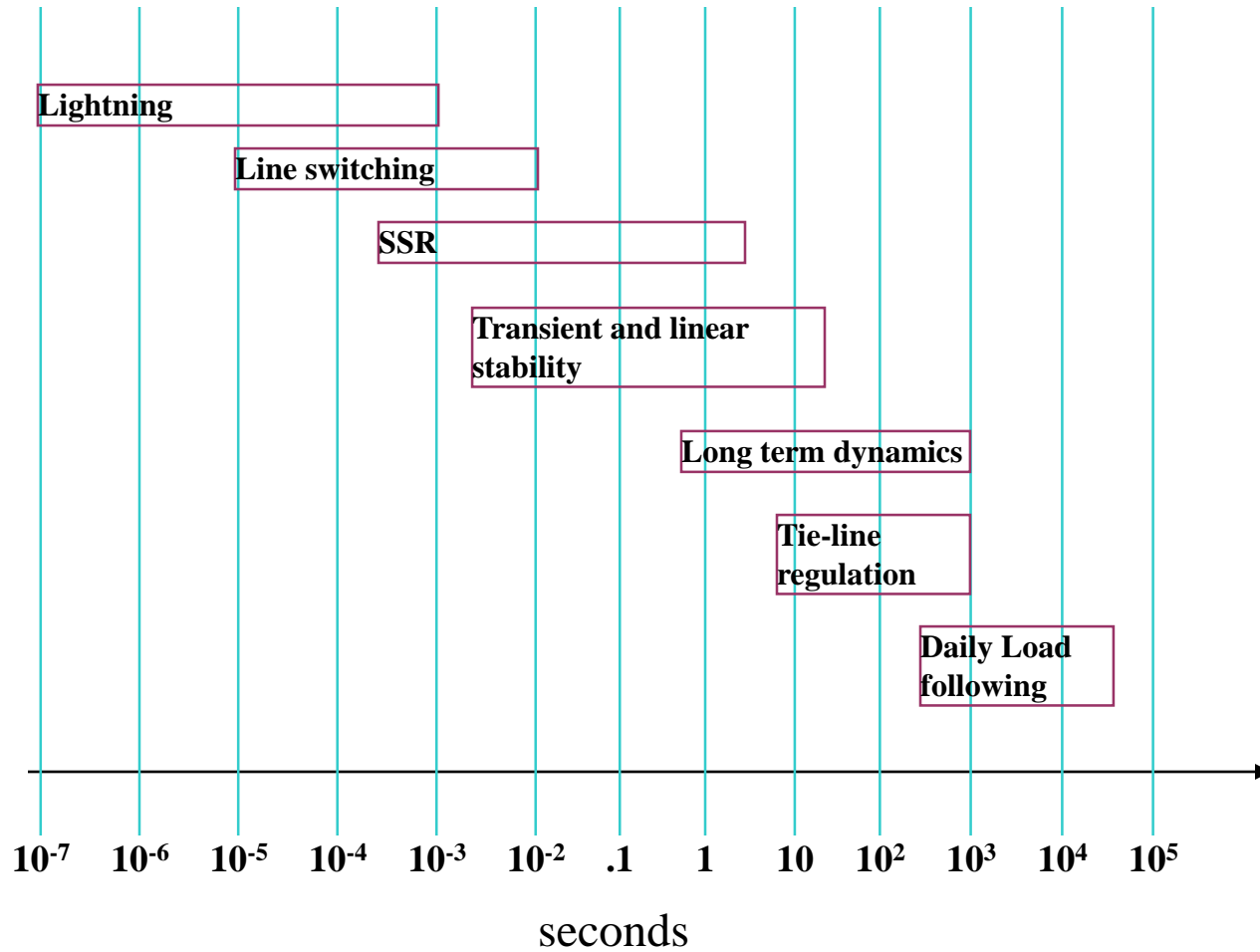
# **Simulation and analysis of power systems**

## **Steady-State and Transients**

### **Software tools**

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# Power System Phenomenon



# Software tools

- Short-circuit
  - Based on sequence networks
  - Fundamental frequency
- Power-flow (Load-flow): operating conditions
  - Positive sequence network
  - Fundamental frequency linear network
- Transient stability (electromechanical transients)
  - Positive sequence network
  - Phase domain linear network model, fundamental frequency
  - Time-domain solution of machine equations
- Harmonic analysis
  - Representation of harmonic sources
  - Propagation of harmonics
  - Linear, multiphase network
  - Nonlinearities can be included: harmonic coupling
- EMTP (electromagnetic transients)
  - Wideband, ultimate precision
  - Detailed time-domain analysis
  - Harmonic analysis, power quality
  - Nonlinear network
  - Includes load-flow and steady-state solutions
- Matlab
  - General purpose environment, support tool, separate modeling
  - Not for large scale problems

# Fundamental notions

- Balanced network analysis, fundamental frequency
  - Traditional power system analysis methods
  - Linear network conditions
- Multiphase network analysis
  - Phase domain
  - Circuit based
- Steady-state analysis
  - Phasors, linear or nonlinear conditions
  - Generation and propagation of harmonics
- Time-domain analysis
  - Samples, oscilloscope
  - Transient conditions leading into steady-state
  - Harmonics
  - May start from existing steady-state
- Time-domain steady-state condition
  - Fundamental frequency waveforms
  - Harmonics: Fourier series in steady-state

# Short-circuit analysis methods

- Based on sequence networks
- Assumes balanced networks
- Assumes linear networks
- X/R ratio usage for setting breakers
- Multiple fault calculations
  - Symmetric faults
  - Non-symmetric faults
  - Many automatic features
- Limitations
  - Sequence networks
  - When coupling between sequence networks
  - Linear

# Harmonic analysis

- Generation and propagation of harmonics
- Steady-state computations
  - Harmonic source models
    - Independent sources based on device type
    - Does not account for harmonic coupling
  - Network models, may account for harmonics
  - Some models have frequency dependent parameters
- Contingency methods
  - Impedance scan at the point of connection
- Harmonic Power-Flow
  - Iterative methods
  - Capable of accounting for harmonic coupling between sources
  - Capable of accounting for voltage dependency of harmonic sources

# Time-domain methods

- Phase-domain solution
- Waveform based solution
  - Transients
  - Steady-state
- No limitations (in principles)
- Account for:
  - Nonlinearities
  - Extremely detailed models
  - Frequency dependence of component parameters
  - Propagation on transmission lines

# Other methods

- SPICE-type
- Saber
- Electronic industry
- Mixed Technology system simulation
- Mixed engineering domains
- Finite elements methods
- Maxwell equations



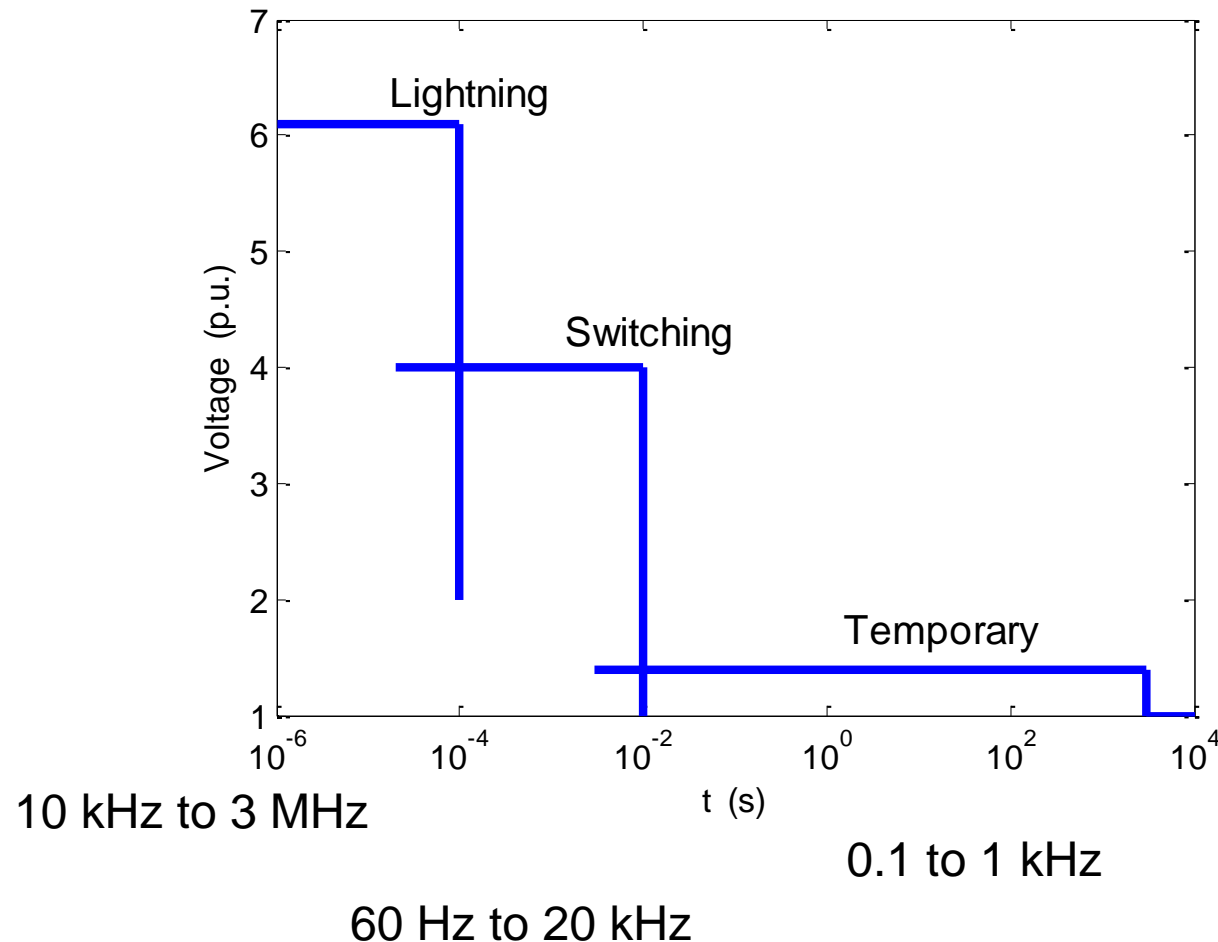
# EMTP: Electromagnetic Transients

- [www.emtp-software.com](http://www.emtp-software.com) (EMTP-RV)
- Electromagnetic Transients Program
  - For computing Power System Transients
  - For computing electrical circuit transients
  - Non-real-time application
- Comparison with real-time applications
  - Designed for highest precision within available mathematical capabilities and within available data
  - Designed for wideband analysis: within model mathematics, no limitations in time-step, computer limitations in precision
- History
  - **Old EMTP**: research program, started in the 80s, DCG-EMTP
  - Has triggered many developments in the field of transients
  - Widely used commercial products (EMTP type) in chronological order: EMTP-RV, EMTDC, ATP
- **IPST conference**
  - International Power Systems Transients conference
  - [www.ipstconf.org](http://www.ipstconf.org)

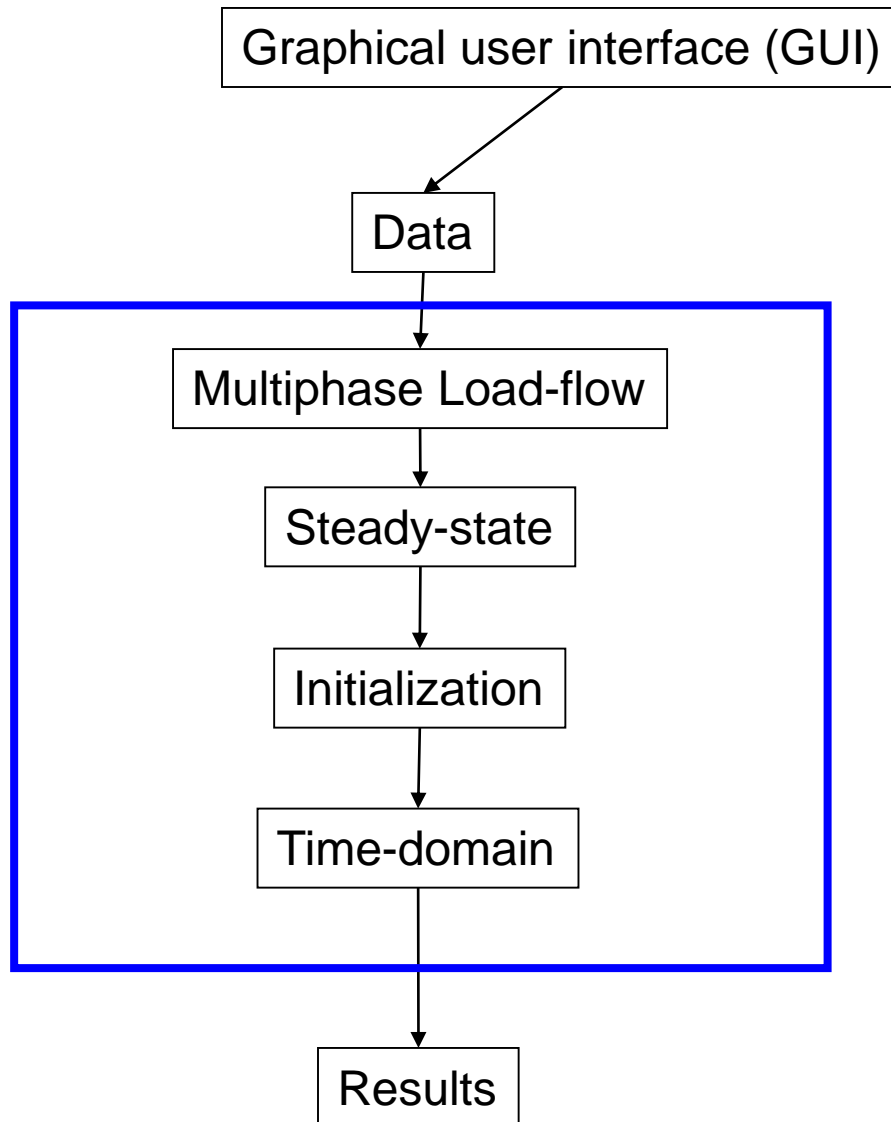
# Field of EMTP applications

- **General purpose circuit analysis tool:** wideband, from steady-state to time-domain
- **Simulate and analyze power system transients**
- **Power system design tool**
- **Detailed simulation and analysis of large scale electrical systems**
- **Network analysis:** network separation, power quality, geomagnetic storm, interaction between compensation and control components, wind generation
- **Synchronous machines:** SSR, auto-excitation, control
- **Multiterminal HVDC systems**
- **Power electronics:** compensators
- **Series compensation:** MOV energy absorption, short-circuit conditions, network interaction
- **Transmission line systems:** insulation coordination, switching, design, wideband line and cable models
- **Switchgear:** TRV, shunt compensation, current chopping, delayed-current zero conditions
- **Protection:** power oscillations, saturation problems, surge arrester influences
- **Detailed transient stability analysis:** more and more
- **May save millions in design and operation!**

# Range of Transient phenomenon



# EMTP-RV modules



# Ultimate Simulation Tool

