# Introduction

The objective of this work item is to develop a curated repository of modeling and study references related to Electromagnetic Transient (EMT) modeling and analysis for power electronics and Inverter Based Resources (IBRs) which power system engineers can use to learn the theory, mechanics, and application of performing EMT studies for IBR interconnection. EMT modeling and simulations date back to the late 1960s and were commercialized in the 1970s and 1980s. EMT studies have historically been focused on unbalanced conditions, high frequency transients, lightning protection, ferro-resonance, harmonics, black start studies, and other phenomena.[[1]](#footnote-1) However, as the penetration of inverter-based resources (and distributed energy resources) continues to grow, EMT modeling and studies have become increasingly necessary to help ensure reliable operation of the BPS. The following is a list of the most notable drivers for performing EMT studies to study BPS-connected inverter-based resources (IBR):[[2]](#footnote-2),[[3]](#footnote-3)

* Integration of inverter-based resources into low system strength networks
* Sub-synchronous control interactions (plant-to-grid)
* Inverter-based resource controls interactions (plant-to-plant and within the plant)
* Inverter-based resource controls stability (large and small disturbance)
* Benchmarking and verifying RMS positive sequence dynamic models
* Inverter-based resource frequency and voltage ride-through capability and performance
  + Poor ride-through performance identified in recent disturbance reports due to instantaneous inverter ac overcurrent and overvoltage protection, inverter dc-bus unbalance protection, unbalance current protection
* Inverter-based resource short-circuit current analysis
* Majority of grid faults are unbalanced faults
* Potential misoperation of protection system
* Power quality studies (e.g., harmonics, rapid voltage change)[[4]](#footnote-4)
* Plant startup studies
* Black start and system restoration studies
* Verification of IEEE 2800-20228 performance requirements[[5]](#footnote-5)

Industry experience thus far has shown that developing EMT models and executing EMT studies is not an easy task. The purpose of this reliability guideline is to provide industry with recommendations for actions to take to prepare for current and future study needs. The need for EMT studies to assess BPS reliability is expected to grow exponentially in the coming years based on planned projects in the interconnection queues.5 Industry will need to act quickly to develop the skills, processes, tools, infrastructure, and capabilities to perform these studies effectively and efficiently.

# Outline of EMT Modeling Resources Repository

Links are maintained in the spreadsheet *EMTTF\_References.xlsm*. Please use the GitHub issue reporting mechanism to suggest updates or new references.

**Theoretical Background**

1. Electromagnetic Transient Theory
2. Behavior of Power Electronic Devices and IBRs
3. EMT Software Tool-Specific Training

**Application Examples**

1. EMT Modeling and Performance Assessment of Inverter-Based Resources
   1. Device Level Modeling and Validation
   2. Plant Level Modeling and Validation
2. EMT System Impact Studies
   1. Development of EMT Network Models
   2. Automation of EMT Studies
   3. Post-processing of results
3. Case Studies

# White Papers

The NERC Work Item 3 team is preparing three white papers for the repository.

## Annotated Bibliography

Introduction with suggested readings/reading order for various audiences/use cases: which walks a reader through the compiled resources. E.g., if you are getting started on EMT simulations you should have a background in EMT Theory. To achieve this you can review X, Y, and Z

## Differences between Positive Sequence Dynamic and EMT Tools

Very important to have a balanced viewpoint:

1. Commentary on limitations/behavior of library models vs user models
2. If you only look at positive sequence phasor domain what might you be missing? How do you know? When you go to EMT, what is different and what is similar? Select topics:
3. Synchronous Machines:
   1. General control systems are the same (Exciter, governor, PSS)
   2. In EMT you can capture the impact of point-on-wave phenomena, DC offsets, zero miss effect
   3. In EMT domain you can observe shaft torsional interactions (e.g., SSR)

## EMT Modeling of Bulk Power Systems

With EMT studies, there is not always a one size fits all representation for modeling general power system equipment. Many of the commercially available tools which are used for automated creation of EMT models have a default method of modeling equipment and will generate a usable model. For example, these tools will typically import steady-state and dynamics data from a phasor domain tool and will generate a EMT model that can run time domain simulations at a given simulation time-step. However, because of limitations of data available in the source databases, such models will not include many system modeling details that are typically important for EMT level simulation, such as:

* Correct zero sequence impedance of transmission lines or cables
* Frequency dependent impedance of transmission lines or cables
* Mutual coupling between transmission lines
* Transformer winding configuration and grounding information
* Transformer saturation characteristics
* Custom or user-defined representation for load or generation

It is necessary for the study engineer to ensure that power system equipment is modeled appropriately for the phenomena of interest under evaluation. Providing a complete and detailed discussion on power system modeling for EMT is outside the scope of this document.

Topics to cover include:

1. Real code models for IBRs
2. Resources for obtaining “missing” EMT model data e.g.,
3. Transformer winding configuration and grounding information
4. Transformer saturation characteristics
5. What are rules of thumb/guidance for determining saturation characteristics? (e.g., selection of knee point, selection of excitation current, selection of air-core reactance)
6. When and why is the missing data important? For example, when do you need frequency dependent transmission lines?

1. <https://emp.lbl.gov/queues> [↑](#footnote-ref-1)
2. <https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Item_4a._Integrating%20_Inverter-Based_Resources_into_Low_Short_Circuit_Strength_Systems_-_2017-11-08-FINAL.pdf> [↑](#footnote-ref-2)
3. <https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline-EMT_Modeling_and_Simulations.pdf> [↑](#footnote-ref-3)
4. Some equipment manufacturers can do harmonics analysis using their EMT models while others cannot because component-level hardware irregularities cannot be captured in the model. TPs and PCs should work with GOs and the equipment manufacturers to ensure that appropriate models are used for each type of study. [↑](#footnote-ref-4)
5. <https://standards.ieee.org/ieee/2800/10453/> [↑](#footnote-ref-5)