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Composite Load Model

High-Level Overview, Benefits, Transition Roadmap and RFP Focus

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Objectives of the Presentation

- Introduction
- Comparing load models: ZIP vs CMLD
- High-Level overview of the CMLD model
- Why choose the Dynamic Load Model?
- Impact of the different load models on system stability
- ISO-NE’s transition to the CMLD model
- Application of CMLD model in the 2025 Longer-Term Transmission RFP

INTRODUCTION

Introduction

- What is electrical load ("load")?
  - Anything that consumes power or current drawn by a device
- Examples of loads include induction motors, lighting, power electronics, thermostatically controlled air conditioners, refrigerators, heating loads, EV charging, data centers, etc.
- Loads are characterized based on the dependency of voltage and frequency
- There are different load models in PSSE, such as the ZIP model (static load model) and the CMLD model (dynamic load model)
- This presentation provides a high-level overview of the CMLD model and ISO-NE's transition to CMLD from ZIP model

COMPARING LOAD MODELS: ZIP VS CMLD

ZIP Load Model

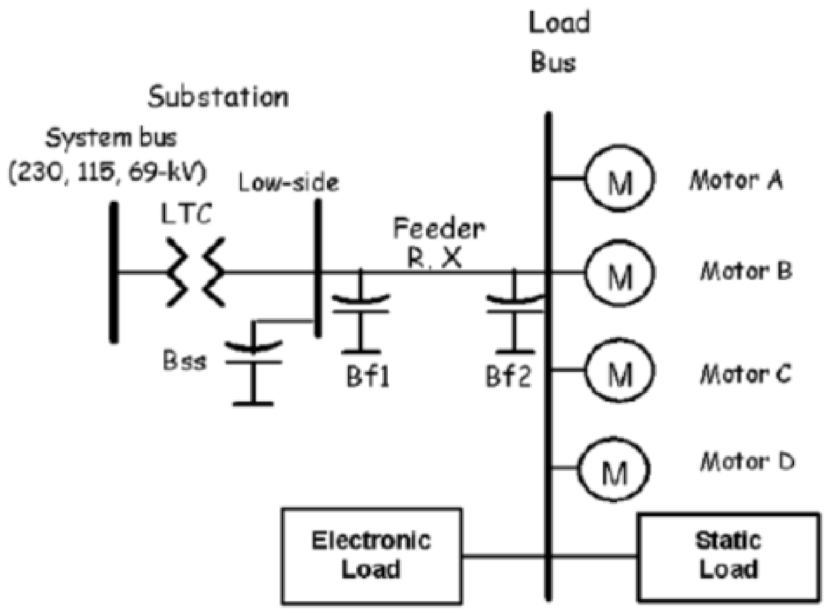
- The ZIP load model is a static load model
  - "ZIP" stands for three components of the load model: constant impedance (Z), constant current (I), and constant power (P)
- Load at any time is represented as a function of voltage magnitude only
- ISO-NE models the loads to be 100% constant impedance, which is the most conservative assumption for angular stability and hence is good for identifying first swing instability

Composite Load Model (CMLD)

- Load composition can vary widely from region to region – For example, Boston city load composition will be different from Western Massachusetts.
- CMLD model captures the aggregate dynamic response of loads
- The model can represent the different types of feeders and compositions of loads
- These different types of loads are usually classified to Motor A, Motor B, Motor C and Motor D loads (details on next slide) in addition to electronic and static loads

CMLD: Overview

Model available in PSSE (CMLDBLU2) has more than 100 parameters



It consists of the following key components:

1. **A distribution substation and feeder equivalent**

2. **Motor A**: 3 phase induction motor driving a relatively low inertia, constant torque type load like positive displacement compressors and pumps

3. **Motor B**: 3 phase induction motor driving a relatively high inertia, variable torque type load like blower fans and large centrifugal compressors

4. **Motor C**: 3 phase induction motor driving a relatively low inertia, variable torque type load small centrifugal pumps

5. **Motor D**: A performance based algebraic model of a single-phase residential heat ventilation and air-conditioning (HVAC) system

6. **Static load**: The conventional constant impedance (Z), constant current (I) and constant power (P) model; and

7. **Electronic load**

CMLD: Load Composition

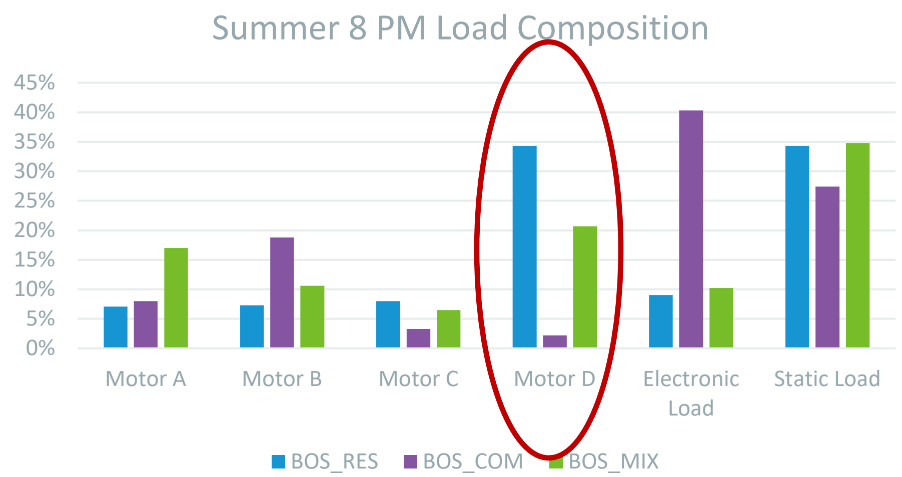
- One of the model inputs is the fractional composition of various load types, such as Motor A, Motor B, etc.
- Load compositions are developed considering factors such as weather, time of day, geographic region, regional industries, and other influencing variables
- Load compositions have been developed based on various data sources including end-user load surveys to gain insight on the types of loads and their breakdown
  - The NERC reliability guideline for developing load composition data explains the process in detail
  - This report sheds more light on the load composition development process in New England

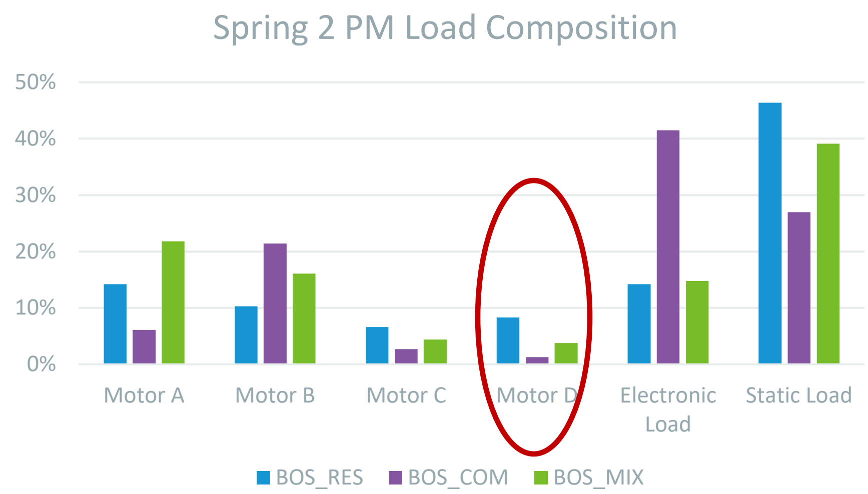
CMLD: Load Composition

- Hourly load composition data is available for three seasons – Spring, Summer, and Winter
  - This is based on a Spring light load day, Summer peak day and Winter peak day respectively which represents the extreme operating conditions such as high load, interface stresses or reduced system inertia
  - Fall typically represents more moderate conditions and is similar to a Spring light load day and hence not included
- Load is categorized geographically to account for weather impacts
  - Geography is represented by assigning each load location to the nearest airport where weather is recorded

CMLD: Load Composition

- Boston load composition is used as an example (below) to demonstrate seasonal variations





- Note the difference in Motor D load (represents the single-phase induction motors, which are common in residential air-conditioning systems) in Summer vs Spring

WHY CHOOSE THE DYNAMIC LOAD MODEL?

Why Choose the Dynamic Load Model?

- At peak load conditions, about 70% of the load is induction motor loads
- During fault
  - Depressed voltages at the motor terminals
  - Electrical torque is proportional to the square of the voltage, resulting in reduction of torque and consequently slow down of motors
- After fault clearing
  - Partial voltage recovery
  - Slowed motors draw high reactive currents, depressing voltage
  - Motors will reaccelerate to normal speed, if electrical torque>mechanical torque. If not, they will stall/trip

Why Choose the Dynamic Load Model?

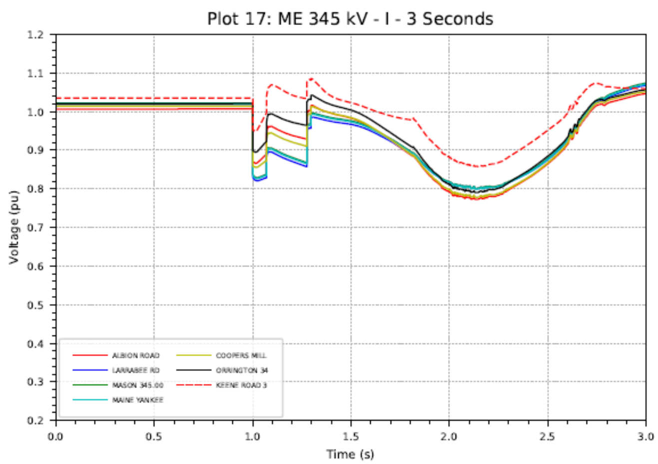
- Closer alignment with actual system dynamics and real-world load behavior
- Advances in computing technology now enables the use of dynamic load models like CMLD
- Dynamic load model is crucial for analyzing first swing angular instability
- Dynamic load model is essential for studying slower stability phenomena such as inter-area oscillations
- A static load model masks the influence of motors on voltage dip and voltage recovery since it cannot capture and reflect the impacts of Fault Induced Delayed Voltage Recovery (FIDVR)

IMPACT OF DIFFERENT LOAD MODELS ON SYSTEM STABILITY

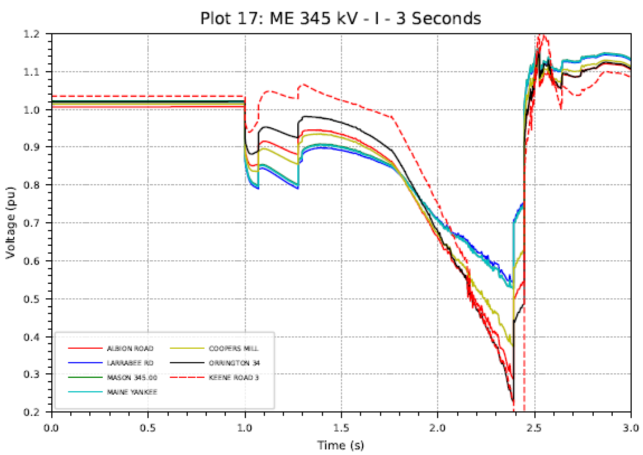
Impact of Load Models on System Stability

- First Swing Voltage Stability Analysis
  - System voltages are depressed in the first angular swing after the fault
  - Power consumed by loads will affect the generator-load imbalance and hence the angular excursion

ZIP



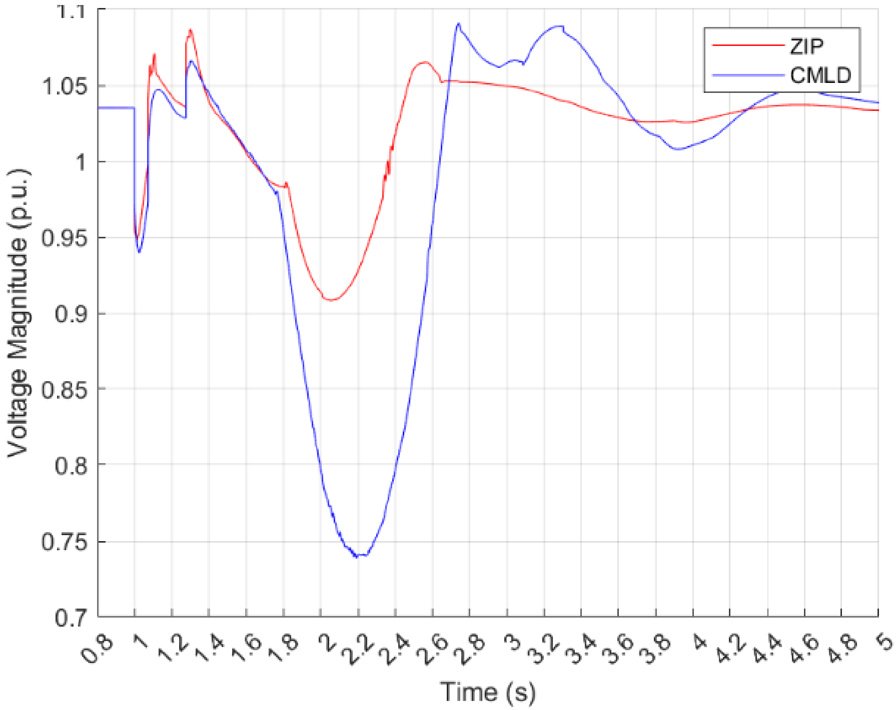
CMLD



Impact of Load Models on System Stability

- Comparison of voltage plots for the ZIP and CMLD models under identical transfer levels

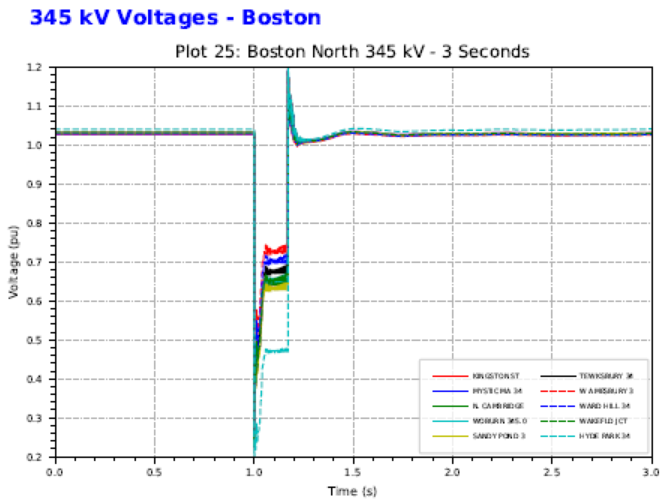
Voltage at a 345 kV bus in Maine



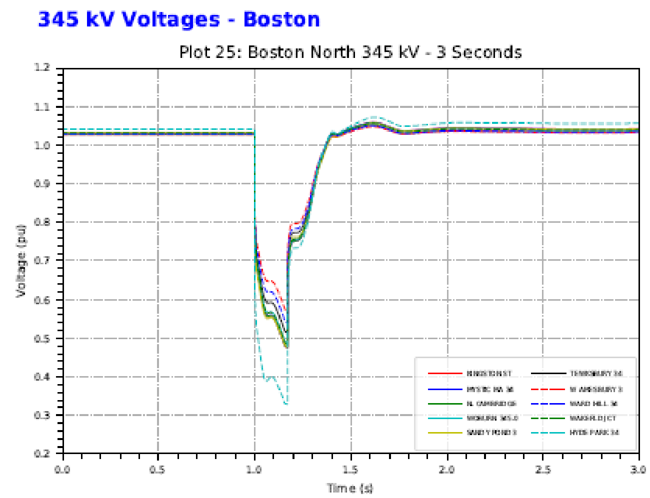
Impact of Load Models on System Stability

- Motors in CMLD model provide voltage support <u>during the fault</u>, particularly in scenarios with reduced synchronous generation, such as during daytime minimum load conditions

<u>ZIP</u>



<u>CMLD</u>

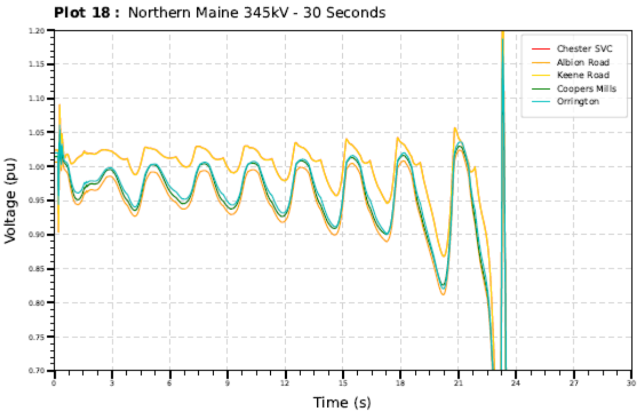


Impact of Load Models on System Stability

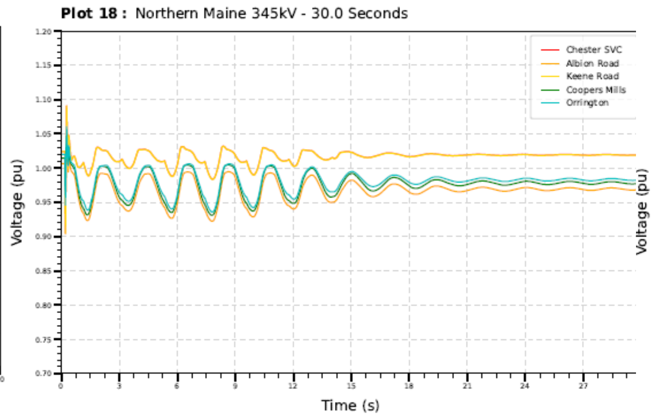
- The following plots demonstrate how the CMLD model enhances the damping performance with summer load composition while showing diminished performance using spring load composition

Difference in damping performance with ZIP and CMLD at light load levels

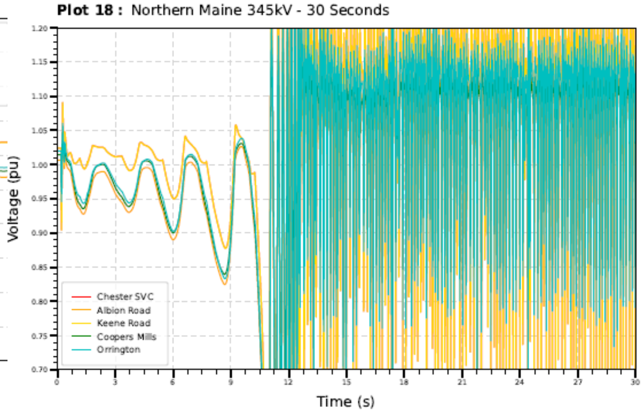
ZIP



CMLD – Summer 2 PM



CMLD – Spring 2 PM



Impact of Load Models on System Stability

- Induction motors tend to draw more reactive power as voltage drops, which is not captured in ZIP load models
- ZIP model's limitations in capturing the load dynamic behavior limits its accuracy in representing the voltage stability during transient events
- Delayed voltage recovery can potentially cause more DERs to trip – an effect that is not captured in the ZIP model
- CMLD model shows improved system performance in some scenarios which will be missed with ZIP model
- Benchmarking indicates that system performance with the CMLD model aligns more closely with real-world behavior than the ZIP model – more details to follow

ISO-NE'S TRANSITION TO THE CMLD MODEL

ISO-NE’s Transition to CMLD: Benchmarking

- Benchmarking two real events with CMLD load model reinforced our confidence in the CMLD model performance
- Benchmarking indicates that system performance with the CMLD model aligns more closely with real-world behavior than the ZIP model
- Further, it was confirmed that not using CMLD model could potentially lead to missing some problems
- A brief description of two benchmarking events and an overview of the results from one of the events is presented in the following slides

ISO-NE's Transition to CMLD: Benchmarking

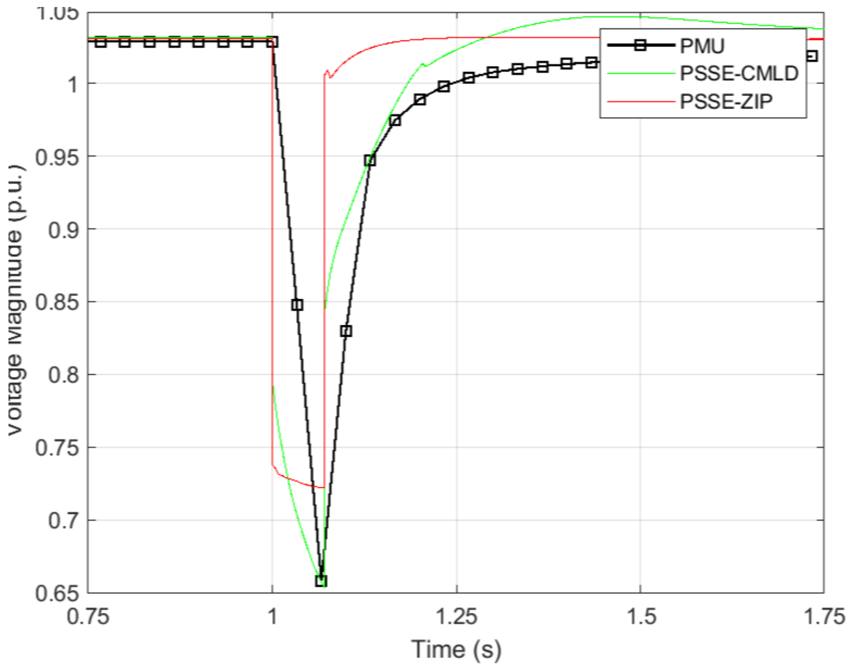
- Event 1: Brief description
  - An unbalanced fault occurred on a 115 kV transmission line in SEMA (South-Eastern Massachusetts) at 03:27 PM EST
  - The fault occurred on a hot day (highest temperature was around 89°F), similar to the Summer High Renewables scenario in Transmission Planning studies
  - This testing also included full modeling of DERs with dynamic models (Total load will be affected by DER tripping along with CMLD load loss)
- Event 2: Brief description
  - A balanced fault (3 phase fault with very little impedance) occurred on a 345 kV transmission line in SEMA on a mild summer day at 8:00 PM EST
  - This was perfect for benchmarking the load model since the event happened in the late evening hours when there will not be any interaction with DERs, which can in turn affect the gross load

ISO-NE's Transition to CMLD: Benchmarking

- Event 1: Benchmarking Results
  - Fault recreation with CMLD model shows good alignment with the voltage depression and voltage recovery with the PMU measurements, unlike the fault recreation with ZIP model, which completely misses the delay in voltage recovery after the fault is cleared
  - Since the DER trip settings are based on the voltage depression and the time of recovery, CMLD model is important to capture the DER behaviors more accurately

- Event 1: Plot Comparison

The black line shows the voltage at the nearest 345 kV bus based on PMU measurements (sampling rate 30 data points/second)

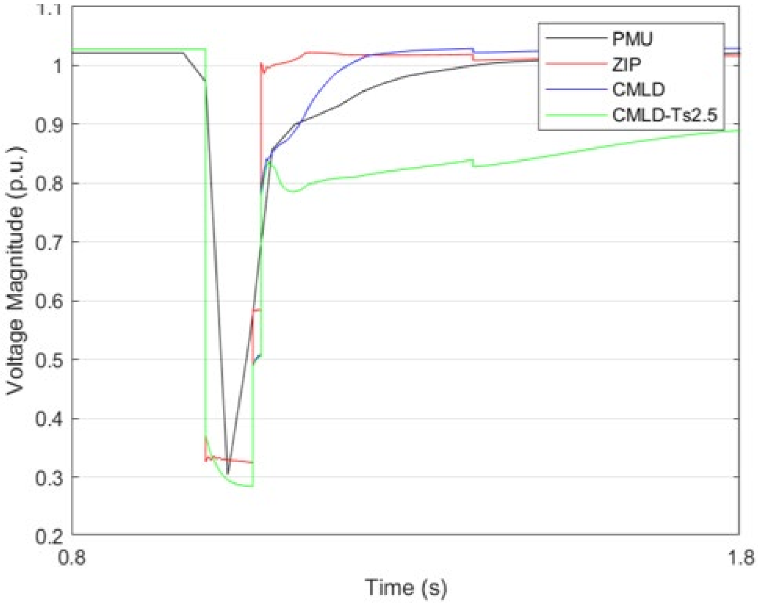


ISO-NE's Transition to CMLD: Benchmarking

- Event 2: Benchmarking Results
  - Results with CMLD model is significantly closer to the PMU data compared to the ZIP model
  - This event is ideal for benchmarking the CMLD model because the event happened in the late evening hours, when interactions with DERs are minimal
  - During the event, ISO-NE loads dropped by about 500 MW which is captured with the CMLD approximately, but completely missed with the ZIP model

- Event 2: Plot Comparison

The black line shows the voltage at the nearest 345 kV bus based on PMU measurements (sampling rate 30 data points/second)



CMLD-Ts2.5 in the plot legend represents another sensitivity that ISO-NE tested but decided to not pursue

ISO-NE's Transition to CMLD: Adoption

- CMLD model has already been used in major studies such as
  - Compliance studies like NERC TPL-001-5, where it is stipulated by NERC (Requirement R.2.4.1 shown below) to use an appropriate model to simulate the dynamic behavior of loads

    R.2.4.1 System peak Load levels shall include a Load model which represents the expected dynamic behavior of Loads that could impact the study area, considering the behavior of induction motor Loads. An aggregate System Load model which represents the overall dynamic behavior of the Load is acceptable.
  - NPCC Directory #1 Area Transmission Review
  - Maine Transfer Limit Analysis presented at the 2024 June and December PAC meetings

ISO-NE’s Transition to CMLD: The Look-Ahead

- Different groups at ISO-NE have started using CMLD model such as System Operations
- Looking ahead, we plan to extend the use of CMLD model to all Transmission Planning studies such as
  - Needs Assessments and Solution Studies
  - Longer-Term Transmission Studies (when stability analysis is required)
  - RFPs for competitive transmission solicitation
  - Other compliance and reliability studies

APPLICATION OF CMLD MODEL IN THE 2025 LONGER-TERM TRANSMISSION RFP

Application of CMLD Model in the RFP

- ISO-NE will publish the cases (.sav) and the snapshot files (.snp) with the CMLD model integrated
- Along with these files, a user-defined model (.dll) will also be included to report the CMLD load loss by airport codes and load types specific to ISO-NE loads

Application of CMLD Model in the RFP

- Increased computation time is possible with CMLD model, especially for extreme faults causing system instability
- For such faults, system instability can be detected the first few seconds of the simulation, eliminating the need to complete the full 30-second simulation

Questions