Considerations for Modeling Data Centers

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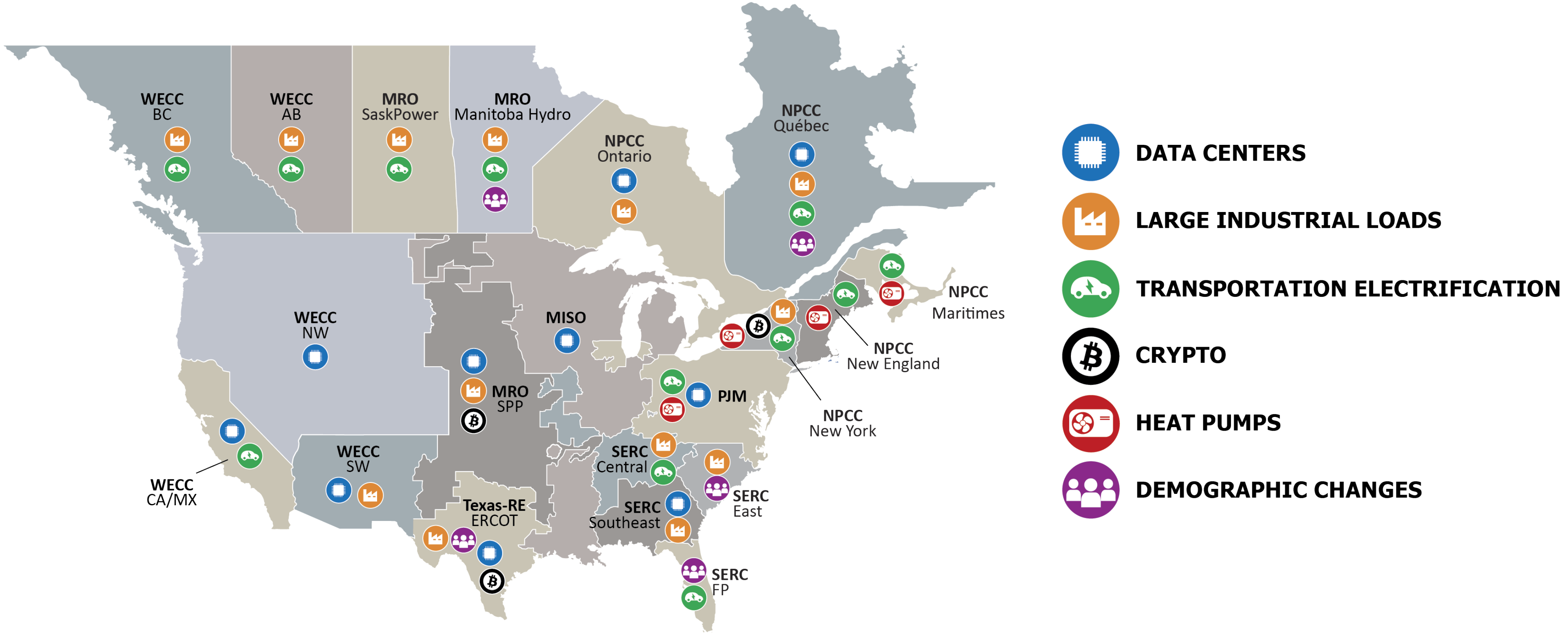
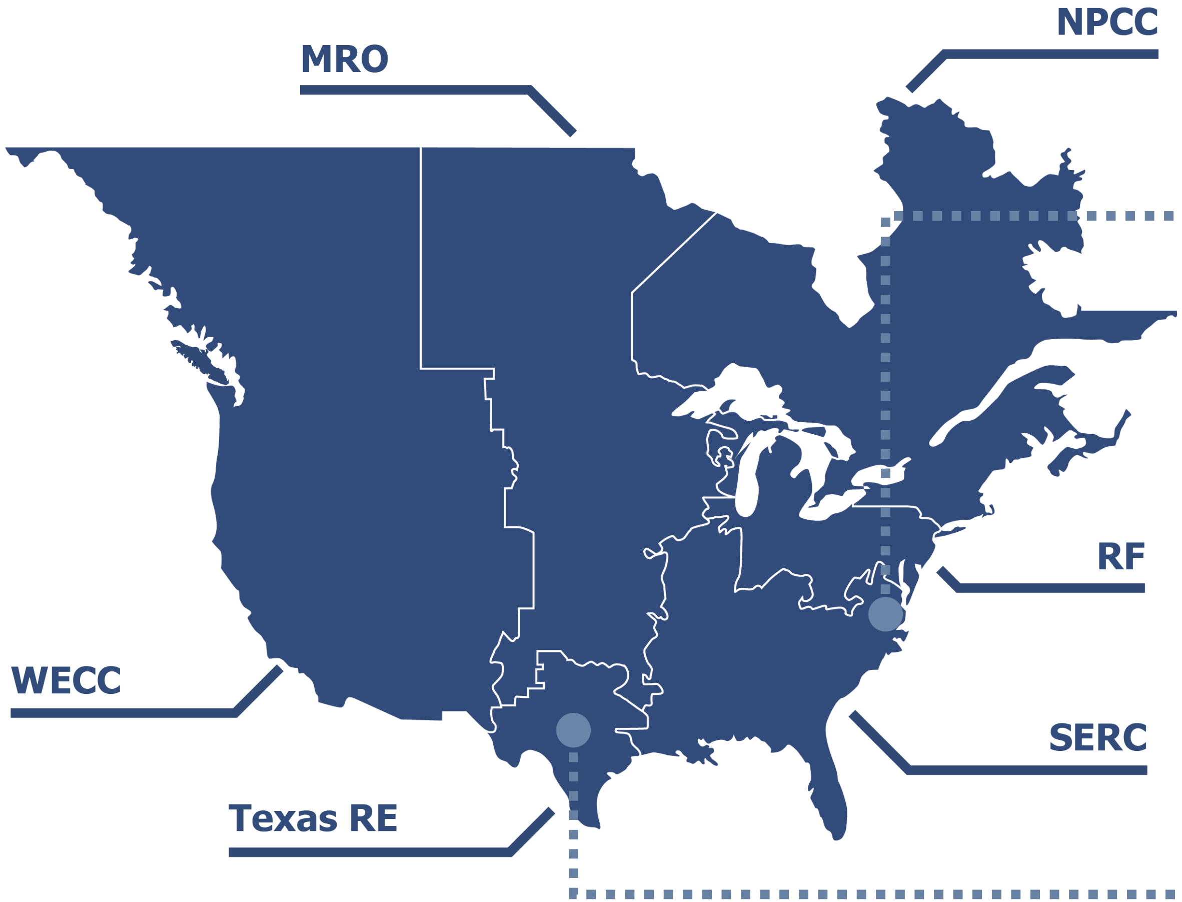
Introduction

Primary Demand Drivers by Assessment Area



NERC's 2024 Long-Term Reliability Assessment

Voltage Sensitive Load Loss Events



EI Data Center Load Loss Events

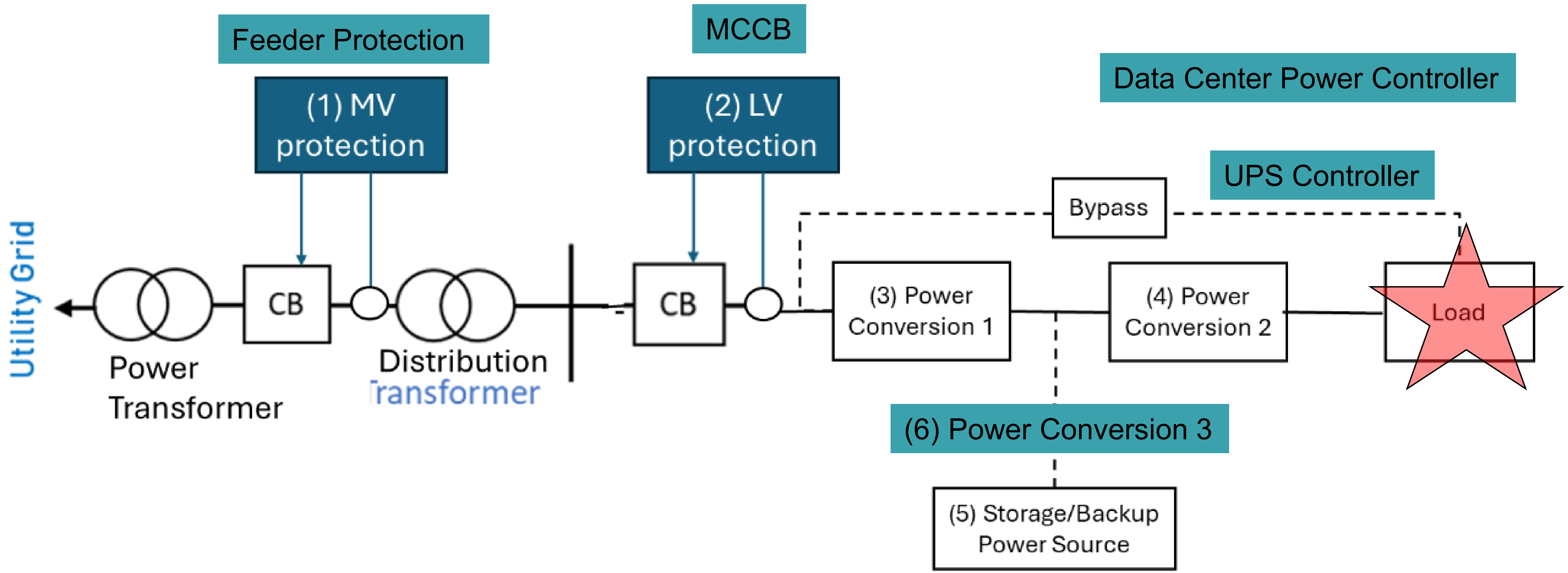
- 1500 MW Load Loss (July 2024)
- 1800 MW Load Loss (February 2025)

ERCOT Crypto Mining Load Loss Events

- 25 Loss Events (November 2023–January 2025)
- 100–400 MW Load Loss

https://www.nerc.com/gov/bot/Agenda%20highlights%20and%20Mintues%202013/Board%20Of%20Trustees%20Open%20Meeting%20Agenda%20Package%20May%208%202025%20Attendees.pdf

Functional overview of a Data Center



- Multiple pieces of equipment that can impact the load response
- Understanding the how and the WHY of Data Center Design and Operation will help improve modeling efforts

Data Center Load Modeling – State of the Art

- Generic Load Models for Data Centers - been developed
- Some open source EMT generic model are available
- Composite Load Model does not have the ability to represent the full set of characteristics of a data center
- Aggregate EV model is been used by some planners to represent the performance of a data center
- Need to build representative models and validate the models with real data (event/test)

Dynamic Models

- CMLD – LMWG 2025 M2 – Disconnection and Pe modeled (VD1, VD2, Frcel)
- Performance Model (LBNL/EPRI-EV) – LMWG 2024 M1 and 3/2025 M1
- Component-level positive sequence Model - LMWG 2025 M1
- EMT Models – LMWG 2025 M2

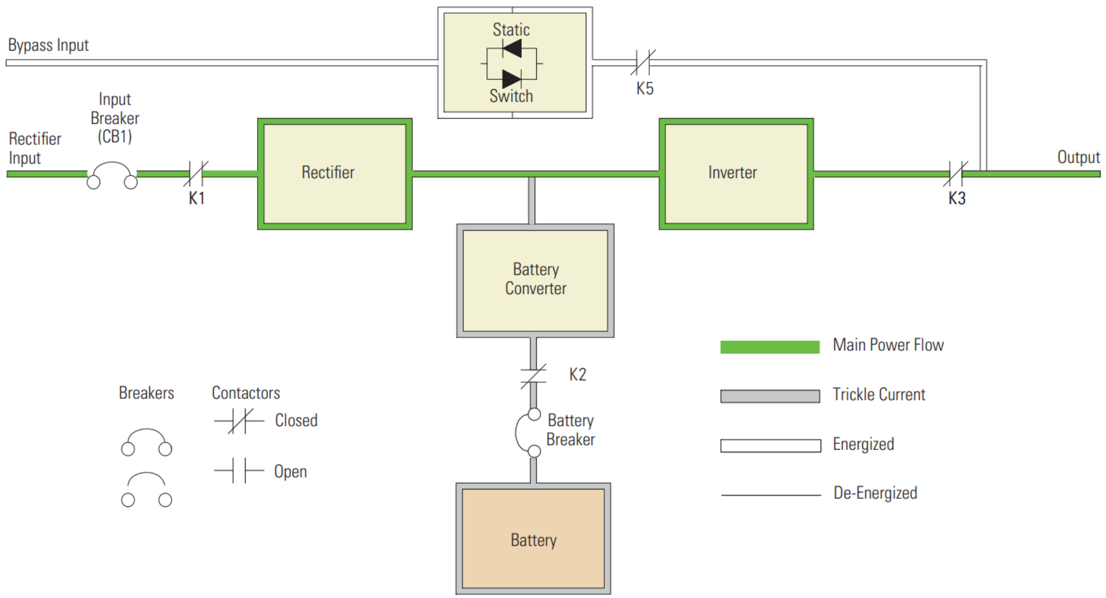
Model Validation

Structure of a Data Center

- Different Architectures but VFI - Double Conversion is dominant
- In-built redundancies (2N+1)
- System Design Margins ~ 0.75
- Rectifier Sizing Considerations
- Loading ~ 0.1
- Unit short circuit contribution ~1.2 pu UL1778
- Other Loads on the feeder
- Implications in Event Analysis for Modeling

[2] UPS Manual Eaton Power Xpert 9395 High Performance (9395P-1200) UPS 1200kVA 1200 kW Installation and Operation manual

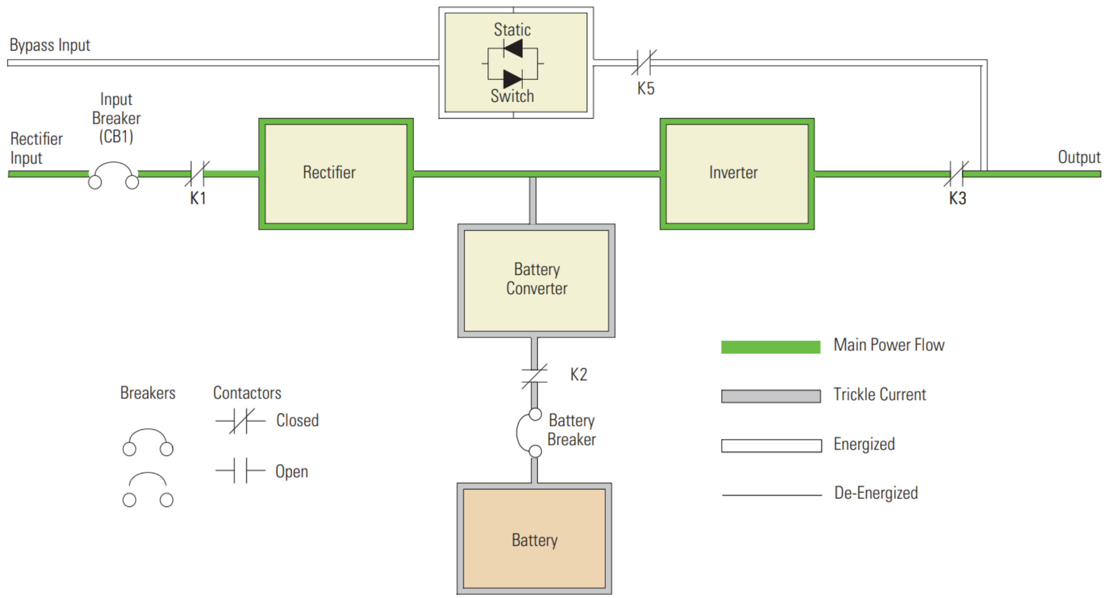
Figure 65. Path of Current Through the UPS in Online Mode



Operational Characteristics of a Data Center

Functional Overview

Figure 65. Path of Current Through the UPS in Online Mode



[2] UPS Manual [Eaton Power Xpert 9395 High Performance (9395P-1200) UPS 1200kVA 1200 kW Installation and Operation manual]

Operation

Operational modes and logic

- Normal mode of Operation
  - Eco
  - Double Conversion
- UPS Unit Controller logic
- Data Center Power Controller Logic

Bypass and Eco mode Operation

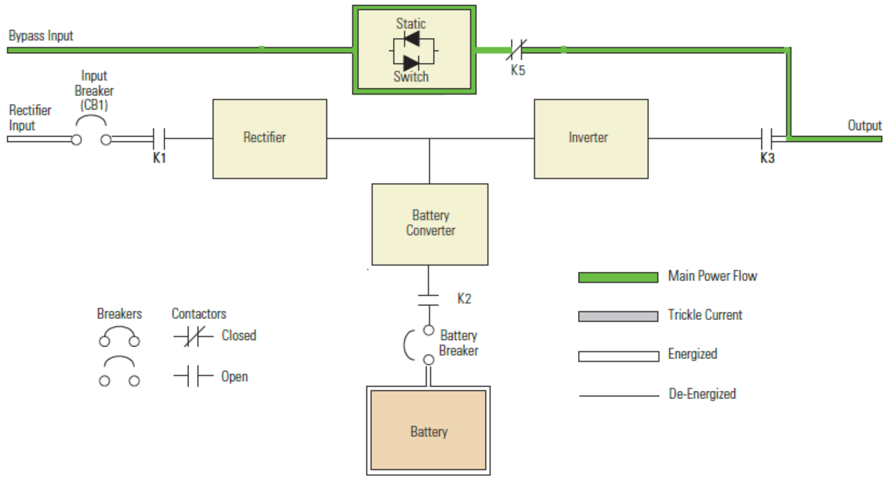
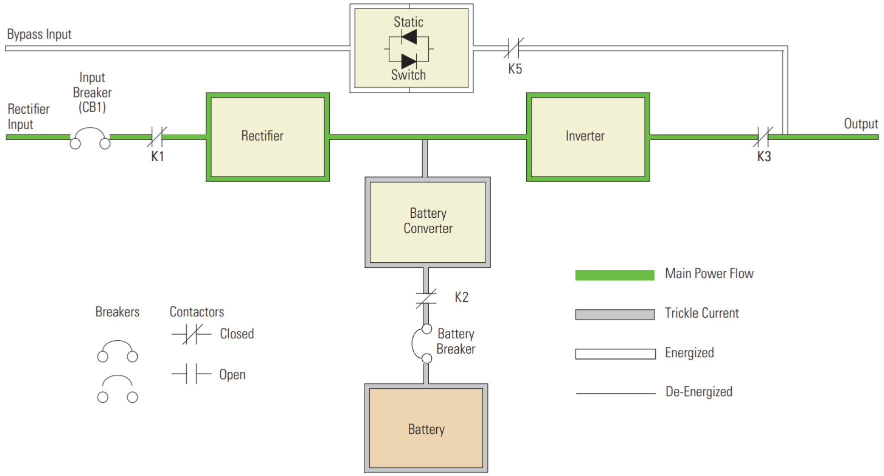


Figure 65. Path of Current Through the UPS in Online Mode



- Operation Mode plays a key role in dynamic Response
- In Eco-mode the Bypass (UL1778) is the main and UPS is the backup
- In Normal (Double-conversion) mode UPS is the main and bypass kicks in if there is a problem in the conversion hardware (or by operator intervention)

[2] UPS Manual Eaton Power Xpert 9395 High Performance (9395P-1200) UPS 1200kVA 1200 kW Installation and Operation manual

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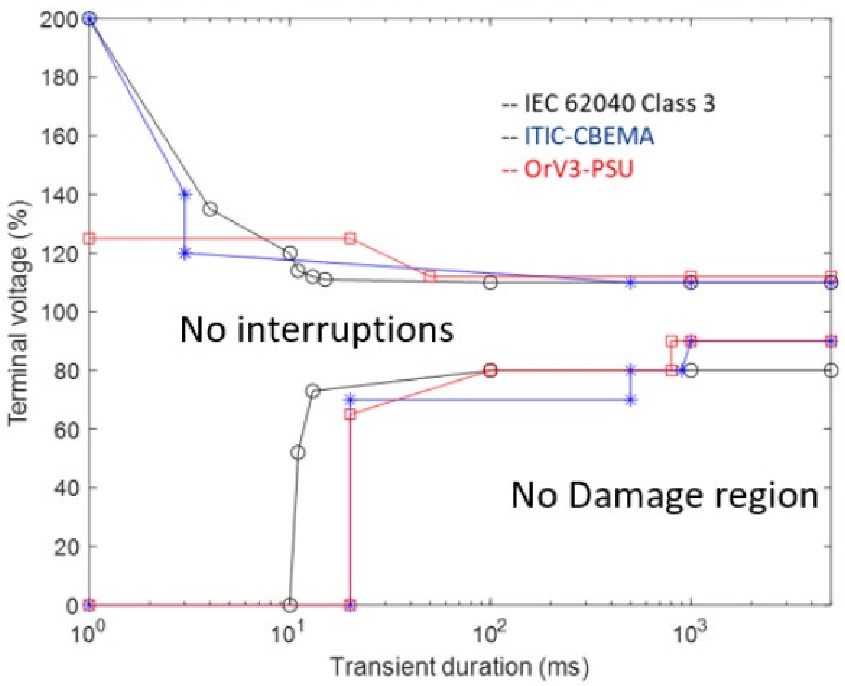
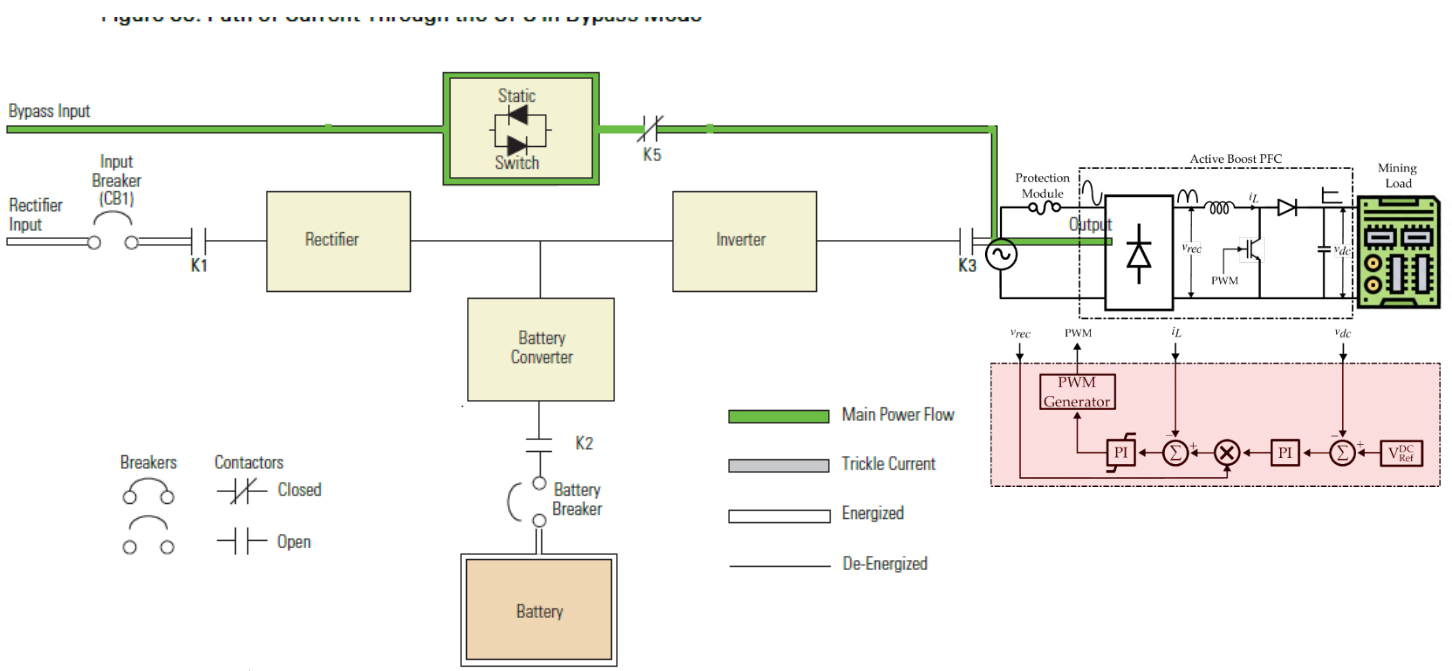
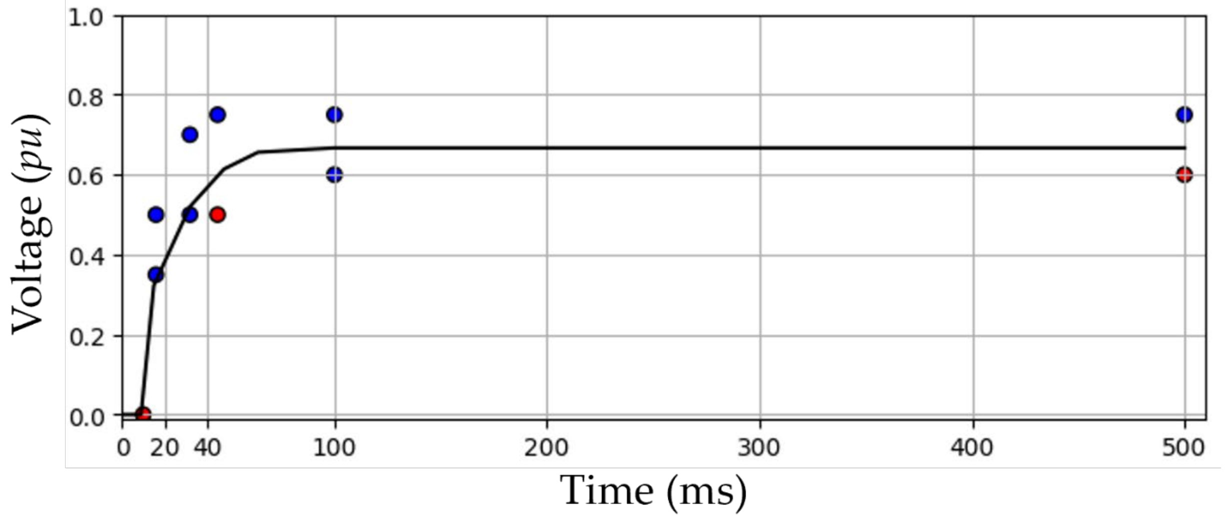
Characteristics of the Bypass mode*







[*Presentation by Parag Mitra at LMWG Jan 2025 Meeting titled Building Blocks for Data Center Modeling]

[*Source - Le Xie Presentation at LLTF and publication: Electromagnetic Transient Model of Cryptocurrency Mining Loads for Low-Voltage Ride Through Assessment in Transmission Grids] : https://arxiv.org/pdf/2312.15067v1

Emergency Transfer to Bypass

- POI sees minimal disturbance
- However, post-transition grid disturbance response of the data center will change (IGBT rectifier to SMPS)

[2] Presentation by UPS OEM at LMWG in-person meeting on April 9, 2025 at Austin, Texas (slides shared vis LMWG Listserv)

Double conversion mode

Power Loss

Power Return

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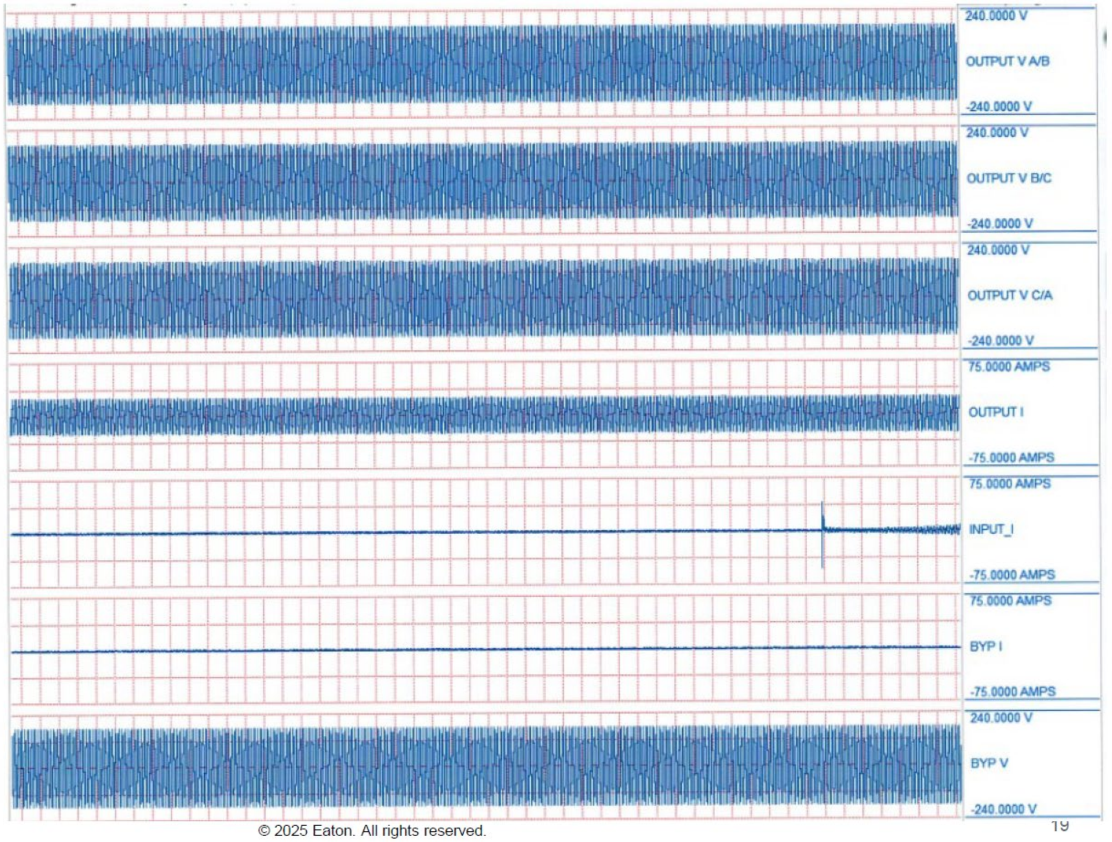
Power Return - Delay

Power Return - Ramp



[2] Presentation by UPS OEM at LMWG in-person meeting on April 9, 2025 at Austin, Texas (slides shared vis LMWG Listserv)

Delay (0.68s to 3s)+ Ramp (1s-30s |0 to P_rated)

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*~Other Characteristics

- DC Bus – ride through faults < ¼ cycle
- Power factor < 0.98
- Vss_min~0.8 pu
- Vss_max~1.15 pu
- I_input<1.2 pu
- Fss_max=60.6 Hz
- Fss_min =59.4 Hz (High tolerance)
- Walk-in – (1-30) s
- Manual Lockout – more than 3 power quality events within 10 minutes~
- MV Protection and Control will also play a major role

[2] UPS Manual Eaton Power Xpert 9395 High Performance (9395P-1200) UPS 1200kVA 1200 kW Installation and Operation manual

[3] UPS Manual - G9400 Series UPS | Power Electronics | Toshiba International Corporation

Table 3–6 Specifications

Rated Output kVA	1,050	1,400	1,750
Rated Output kW	1,050	1,400	1,750
AC INPUT			
Configuration	3 phase, 3 wire		
Voltage	400 / 415 V +15% to -20%		
Frequency	50 / 60 Hz ±10%		
Reflected Current THD	5% typ. at 100% load		
Walk-In Function*	Factory set at 10 seconds (Programmable in 1 second increments from 1 to 30 seconds)		

Rectifier/charger input:

1. Nominal three-phase input voltage: 480 VAC:

   3-wire plus ground input (grounded wye source or high resistance ground (HRG) source required)

   Separate inputs for each UPM are optional

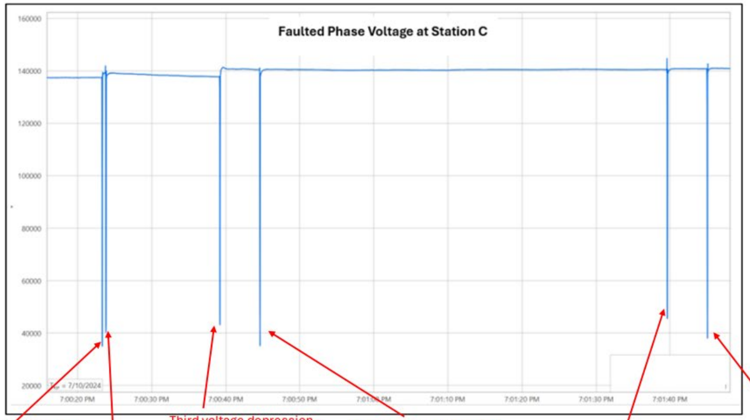
2. Operating input voltage range: +10 percent, -15 percent of average nominal input voltage without battery discharge; Voltage tolerance, partial load: -30 percent of nominal voltage without discharging the battery at loads less than 85 percent.
3. Operating input frequency range shall be 45 to 65Hz.
4. Input power factor 0.99 typical load.
5. Normal input current limit: the UPS shall have the following programmable input current limit settings while operating in normal mode:
   a) Rectifier/ input current limit shall be adjustable from 100 to 115 percent of full load input current.
   b) Battery charger current limit shall be adjustable from 0 to 120 amps DC per UPM. With decreased load, maximum charge current per UPM is 120A. Charge capability drops to zero with input line at minus 15% of nominal voltage at full load

If the UPS transfers to Bypass mode from Online mode due to any reason other than operator intervention, the UPS automatically attempts to transfer back to Online mode (up to three times within a ten minute period). The fourth transfer locks the critical load to the bypass source and requires operator intervention to transfer.

The distributed bypass system can be transferred from Online mode to Bypass mode manually. However, the distributed bypass system automatically switches to Bypass mode whenever the UPSs can no longer supply the critical load. If the distributed bypass system transfers to Bypass mode from Online mode due to an output voltage deviation, the distributed bypass system automatically attempts to return to Online mode (up to three times within a 10–minute period). After three transfer attempts or an overload, the system locks the critical load to the bypass source and requires operator intervention to transfer.

Bypass mode is a normal operating mode, not an alarm condition. However, if the distributed bypass system is unable to return to Online mode following an automatic transfer to Bypass mode, an alarm condition is recorded.

Load loss event – 1500 MW load loss



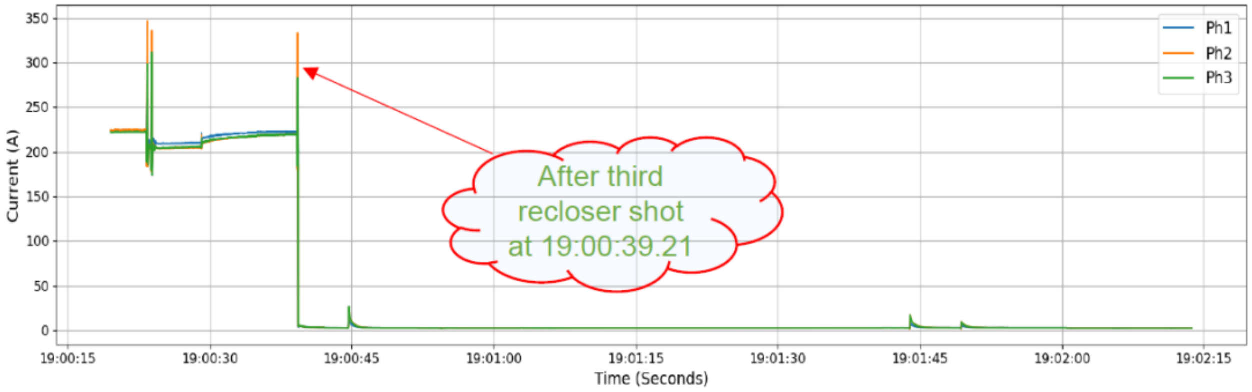


Figure 10: Voltage Disturbance Counting Scheme Load Characteristic

Table 1: Voltage Depression Times and Durations

		Voltage Depression Time (hh:mm:ss.msec)	Voltage Depression Duration (milliseconds)
Voltage Depression 1	Initial Fault (arrestor failure)	19:00:23.351	42
Voltage Depression 2	Instantaneous and simultaneous automatic reclose at both terminals	19:00:23.883	66
Voltage Depression 3	2nd Automatic reclose at terminal A	19:00:39.211	58
Voltage Depression 4	2nd automatic reclose at terminal B	19:00:44.630	50
Voltage Depression 5	3rd automatic reclose at terminal A	19:01:39.600	66
Voltage Depression 6	3rd automatic reclose at terminal B	19:01:45.016	59

Need to simulate Utility Protection + Local MV Controls

https://www.nerc.com/pa/rrm/ea/Documents/Incident_Review_Large_Load_Loss.pdf

Load Modeling

- Facility interconnection studies
- Interconnection wide studies
- Special studies for data center performance evaluation

Gaps and Challenges

- Successful model building efforts will require collaboration between OEMs, facility architects and the Utility industry
- Performance models are approximations of Component based models
- The developed models should be validated with real data
  - EMT Models validated with real data
  - PSPD Models benchmarked against EMT models
- Significant gap in model validation using real data

NERC LMWG Activities

- Join the LMWG and attend and Present your work in LMWG meetings – https://www.nerc.com/comm/RSTC/Pages/LMWG.aspx
- Load Modeling Workshop - October 20
- Volunteer to author the NERC Data Center Technical Reference – Contact LMWG Coordinator

Discussion

Appendix

References

[1] Sun, Jingjing, et al. "Development of a converter-based data center power emulator." *2021 IEEE Applied Power Electronics Conference and Exposition (APEC)*. IEEE, 2021.

[2] UPS Manual Eaton Power Xpert 9395 High Performance (9395P-1200) UPS 1200kVA 1200 kW Installation and Operation manual

[3] UPS Manual - G9400 Series UPS | Power Electronics | Toshiba International Corporation

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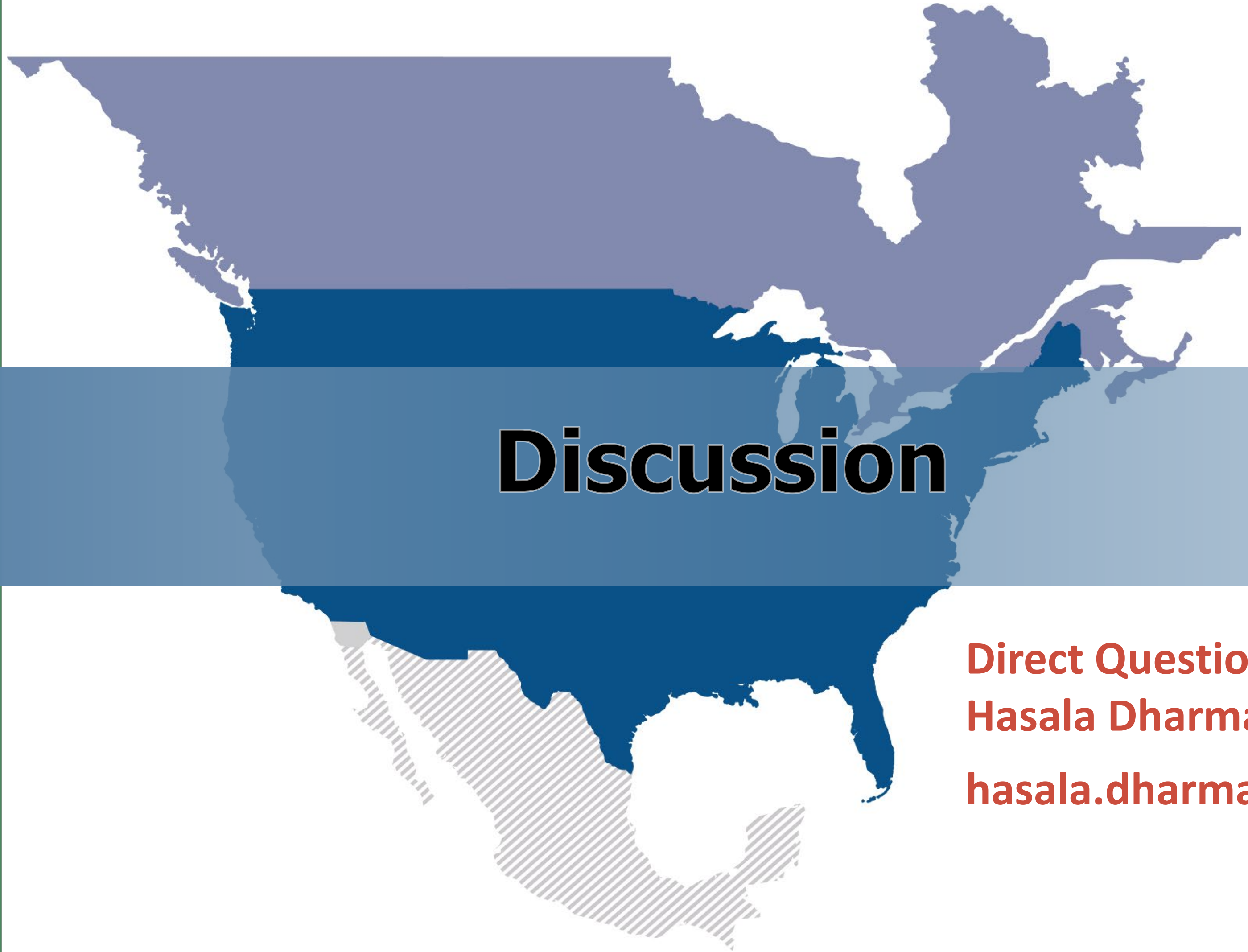
LMWG Activities

U.S. DEPARTMENT OF ENERGY



Discussion

Direct Questions to NERC LMWG Staff Coordinator – Hasala Dharmawardena

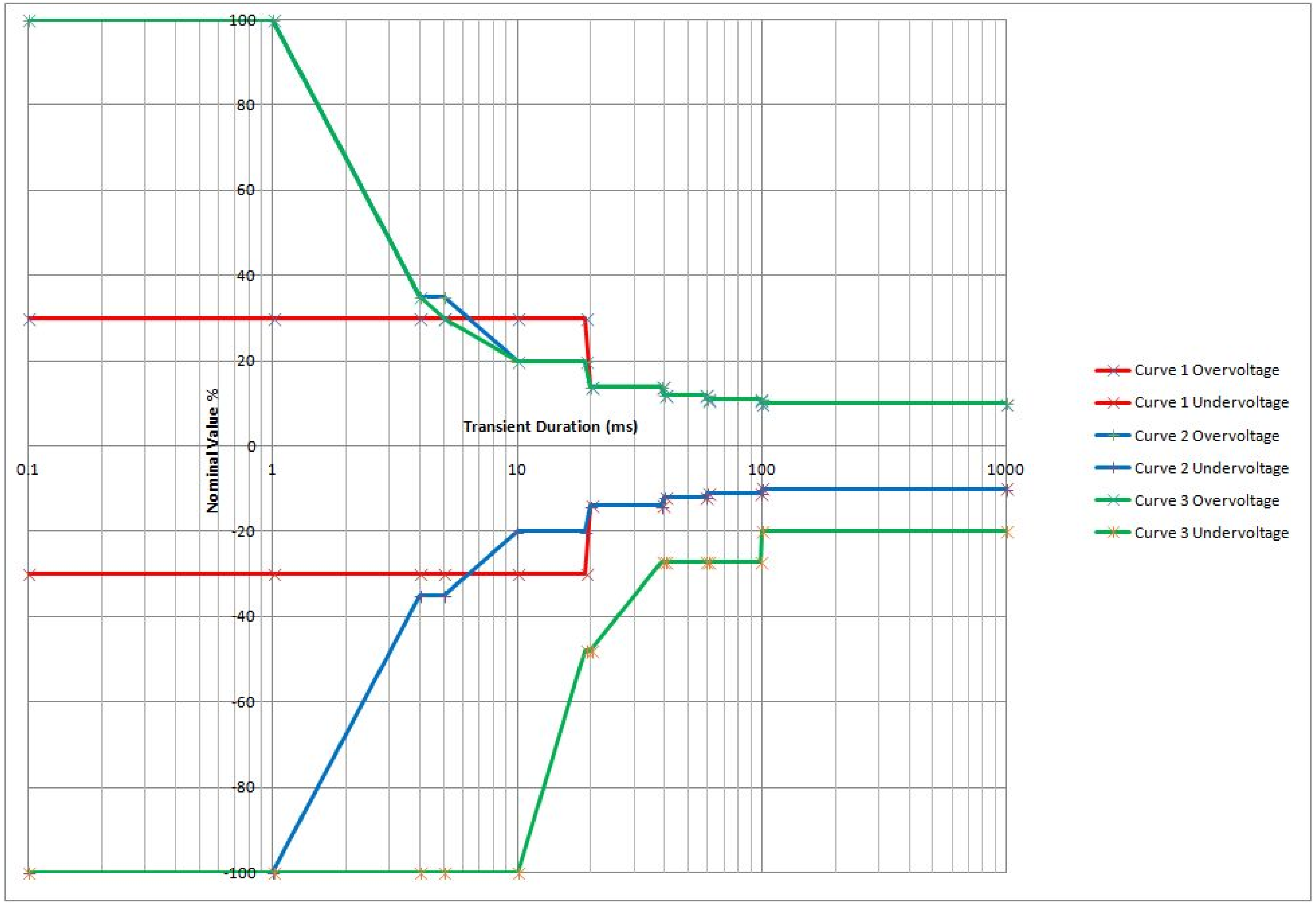
hasala.dharmawardena@nerc.net

Next Meetings

Future Meetings

Date	Time	Location
Tuesday, July 15, 2025	12:30 -4:30 p.m. Eastern	Teleconference
Tuesday, November 18, 2025	12:30 -4:30 p.m. Eastern	Teleconference

UPS End Goal – Uninterrupted (conditioned) Power to the IT Load



Source - UPS Classification to EN62040-3 - Uninterruptible Power Systems

- CBEMA/ITIC Curves defines how the IT Load power supply should ride through
- Minimum functional specification that need to be met by the UPS on the converter side to ensure power supply to the IT Load
- Should not be translated as ride through curve for the data center