# DOE Transmission Reliability R&D Program

# Distribution-Level Impacts of Plug-in Electric Vehicle Charging on the Transmission System during Fault Conditions

**DOE Dynamic Load Modeling Working Group**
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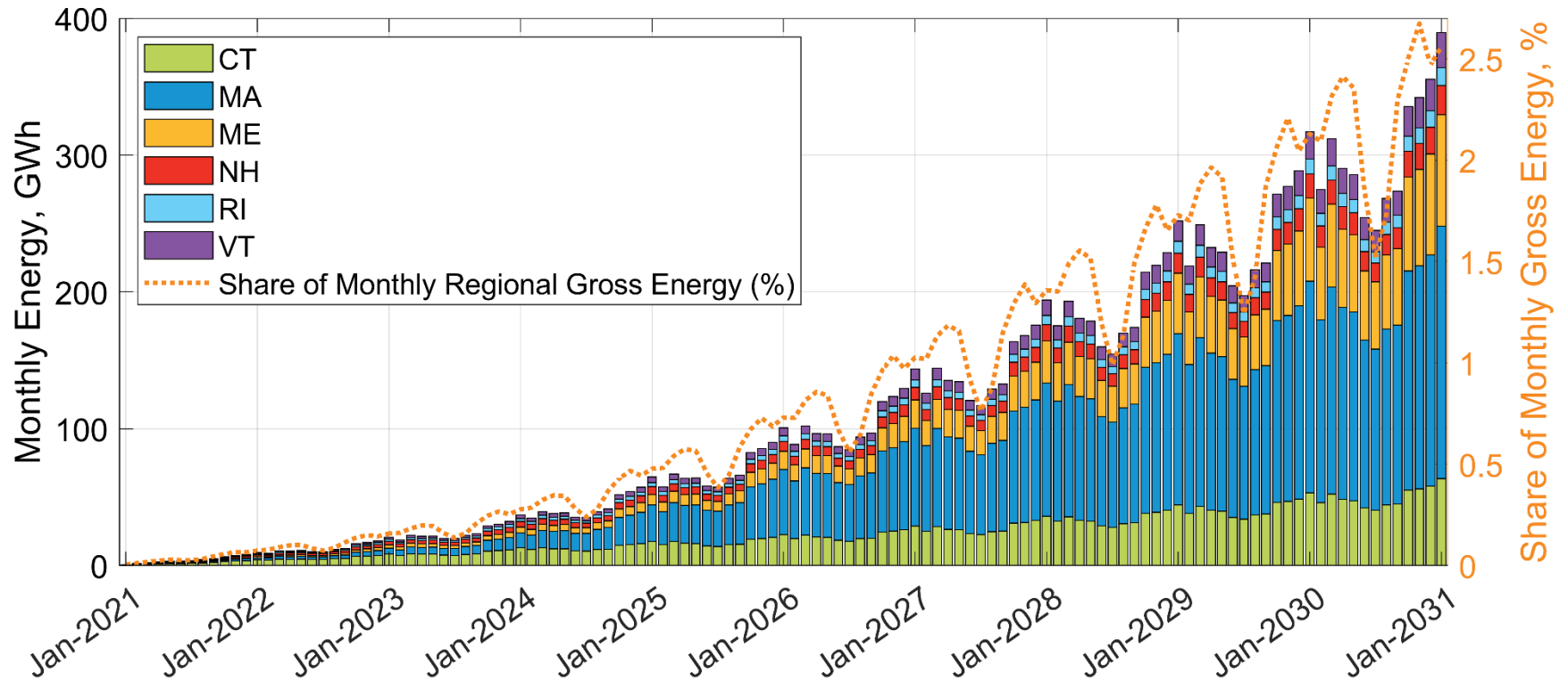
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Ryan Quint, North American Electric Reliability Corporation

# Electricity Consumption by Plug-in Electric Vehicle (PEVs) is Projected to Grow



Source: ISO-NE. 2021 Final Electrification Transportation Forecast

# Study Objectives

To provide engineering counterparts in the PEV and electric vehicle supply equipment industry with insights into the types of PEV charging behaviors that are grid friendly or grid unfriendly during transmission faults

To show the range of grid friendly and grid unfriendly behaviors that currently exist in a selection of PEVs that are in production today

PNNL-31558

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U.S. DEPARTMENT OF **ENERGY**    Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830
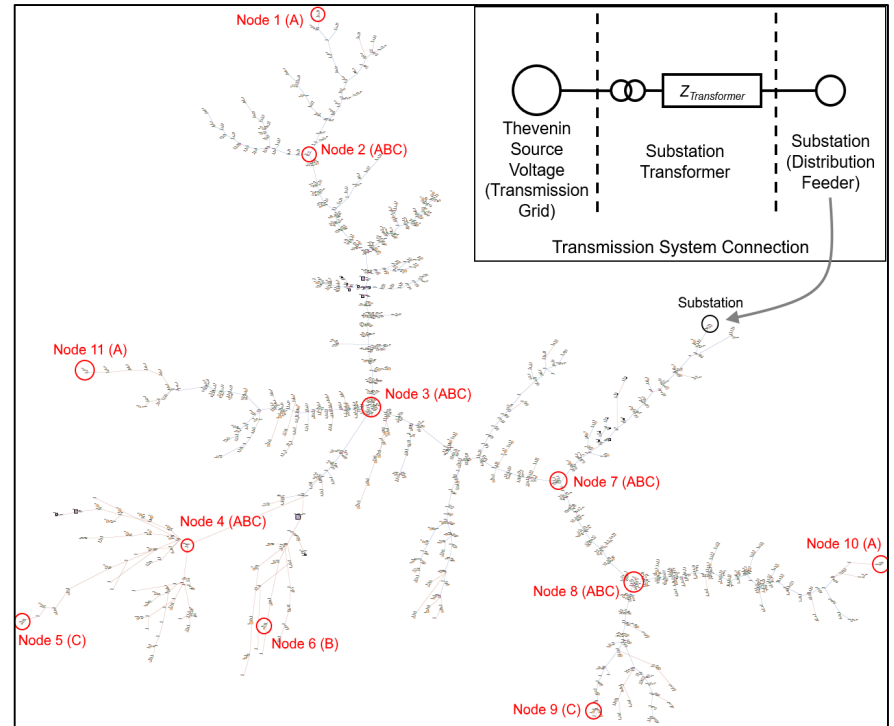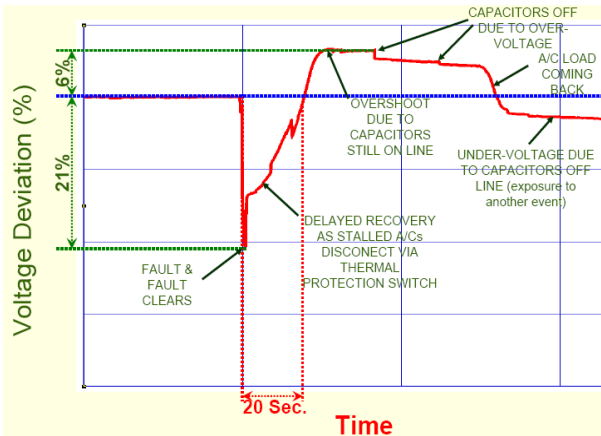
1 Arizona State University
2 Idaho National Laboratory
3 Lawrence Berkeley National Laboratory
4 Bonneville Power Administration
5 North American Electric Reliability Corporation

https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-31558.pdf

# Study Approach

Residential AC stalling (FIDVR) is a known example of a *grid unfriendly* load (http://fidvr.lbl.gov)

This Study examines the impacts of PEV **charging** on FIDVR



PEVs that make FIDVR worse are *grid unfriendly*

PEVs that do not make FIDVR worse are *grid friendly*



Topology and Properties of R1-12.47-1 feeder

| Property | Value |
|---|---|
| Overall Information | |
| Geographic Area | 11.75 square miles |
| Base Load | 5.57 megawatts |
| Load Composition | |
| Residential | 93.4% |
| Commercial | 5.7% |
| Agricultural | 0.9% |
| Distribution Line Lengths | |
| Overhead Line | 14.24 miles |
| Underground Line | 11.35 miles |
| Triplex (service) Line | 3.40 miles |

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# Study Method

The impacts of transmission faults on voltages within the distribution feeder are studied using GridLAB-D

The behavior of single-phase induction motors is represented in GridLAB-D using a dynamic-phasor-based model

The impacts of step changes in distribution voltages on PEV charging are studied using Caldera

Caldera is a model with 4 states and 3 transitions. Parameters were estimated through lab testing of commercially available PEVs (circa 2015 vintage)

Co-simulation of GridLAB-D and Caldera is managed through the HELICS platform
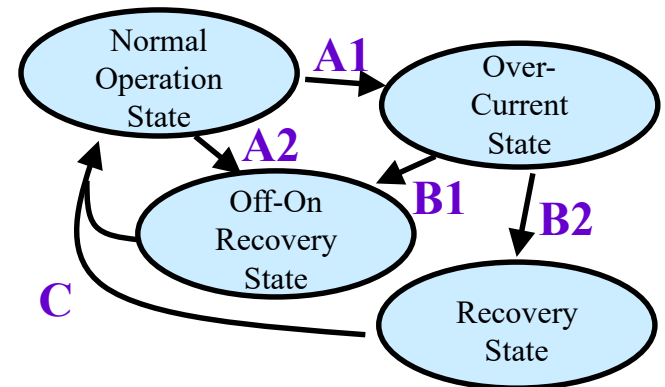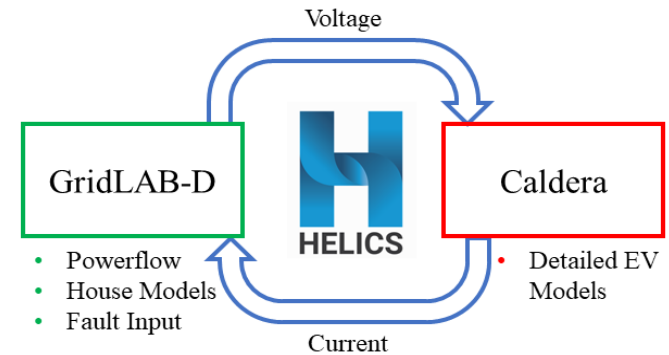
| Step Change in pu Voltage | Probability of Transition A1 | Probability of Transition A2 |
|---|---|---|
| 0.15 | 0.2 | 0 |
| 0.2 | 0.4 | 0 |
| 0.3 | 0.8 | 0 |
| 0.4 | 1 | 0.5 |
| 0.5 | 1 | 1 |

# Baseline FIDVR Results – No PEVs

A range of transmission faults are "played into" GridLAB-D

The number of residential AC units that stall are tabulated (there are a total of 331 residential AC units on this phase of the feeder)

These values represent the baseline against which PEV impacts will be compared

| Depth of Voltage Dip | Duration of Voltage Dip | | | |
|---|---|---|---|---|
| | 5 cycles | 7 cycles | 9 cycles | 12 cycles |
| 0.55 | 0 | 0 | 0 | **272** |
| 0.5 | 0 | 0 | **199** | **331** |
| 0.45 | 0 | 0 | **331** | **331** |

Note: In our simulations, all residential AC units re-accelerate eventually; none remain stalled and trip off due to internal thermal protection



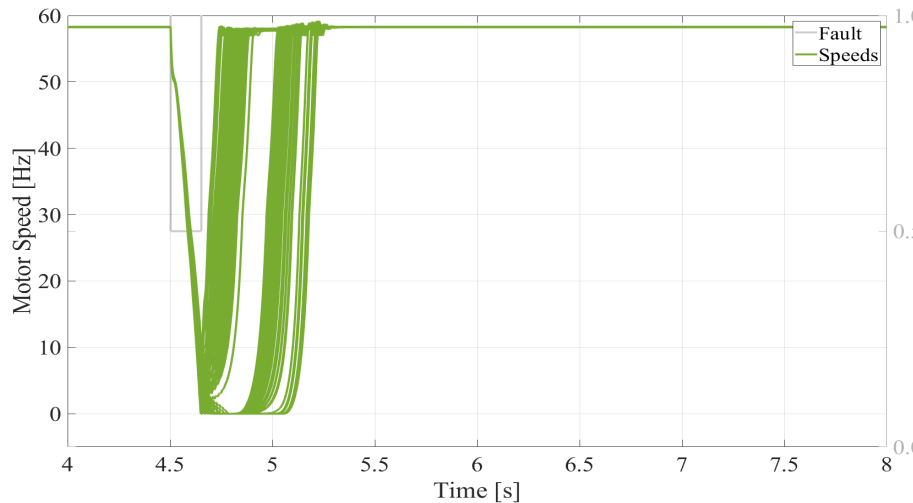Residential Air Conditioner Operating States – 9-cycle voltage dip to 0.50 pu
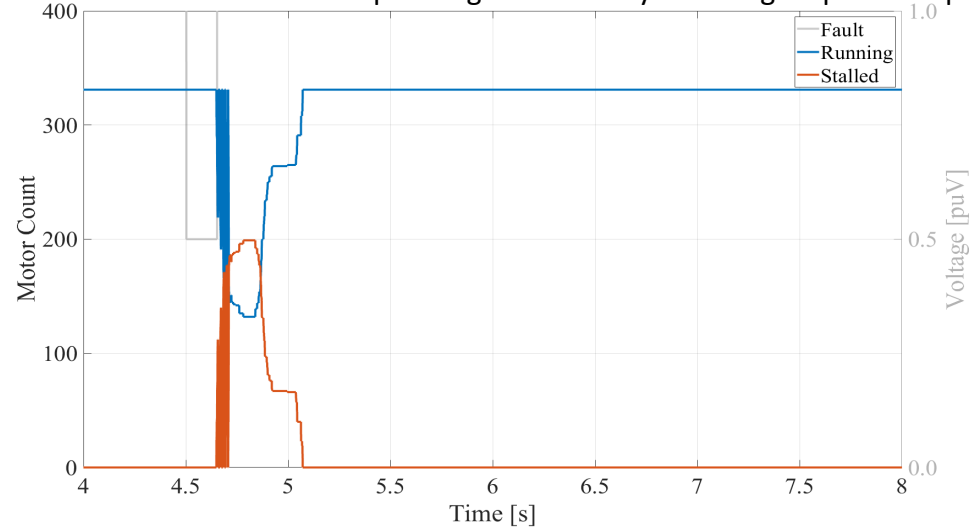


Residential Air Conditioner Operating States – 12-cycle voltage dip to 0.50 pu
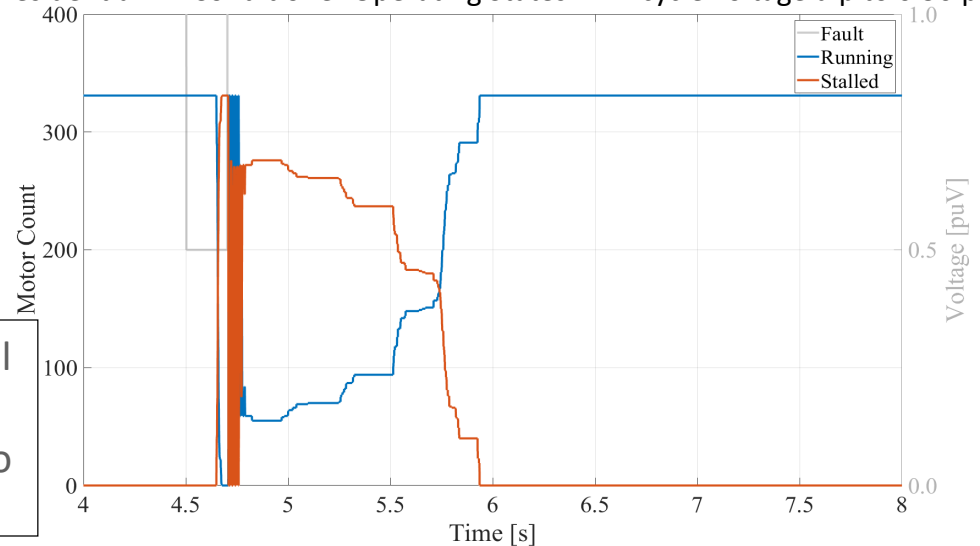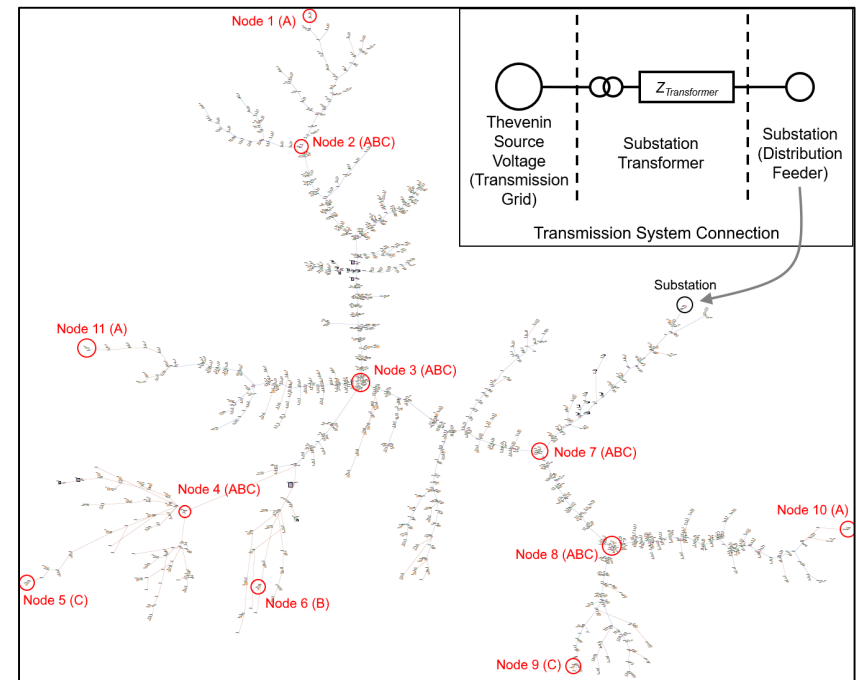
# Baseline Results – No PEVs

Residential AC Motor Speeds – 9-cycle voltage dip to 0.50 pu



Voltages at Selected Locations – 9-cycle voltage dip to 0.50 pu



The number of residential AC units that stall initially, re-accelerate, or remain stalled depends on the voltage they see, which varies by location within the distribution feeder
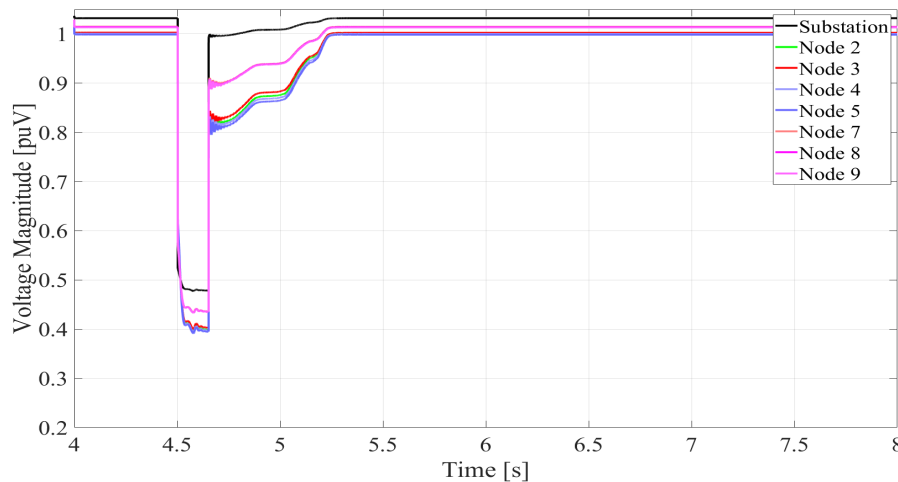
# Impact of PEVs on FIDVR

We now add a single type of PEV to every household within the distribution feeder and re-run the transmission fault scenarios

We tabulate the number of residential AC units that stall initially and also those that remain stalled 2 seconds after the fault has cleared

These values represent the impacts of each type of PEV on FIDVR at two different points in time

We studied six types of PEVs; we normalized their ratings to facilitate comparisons
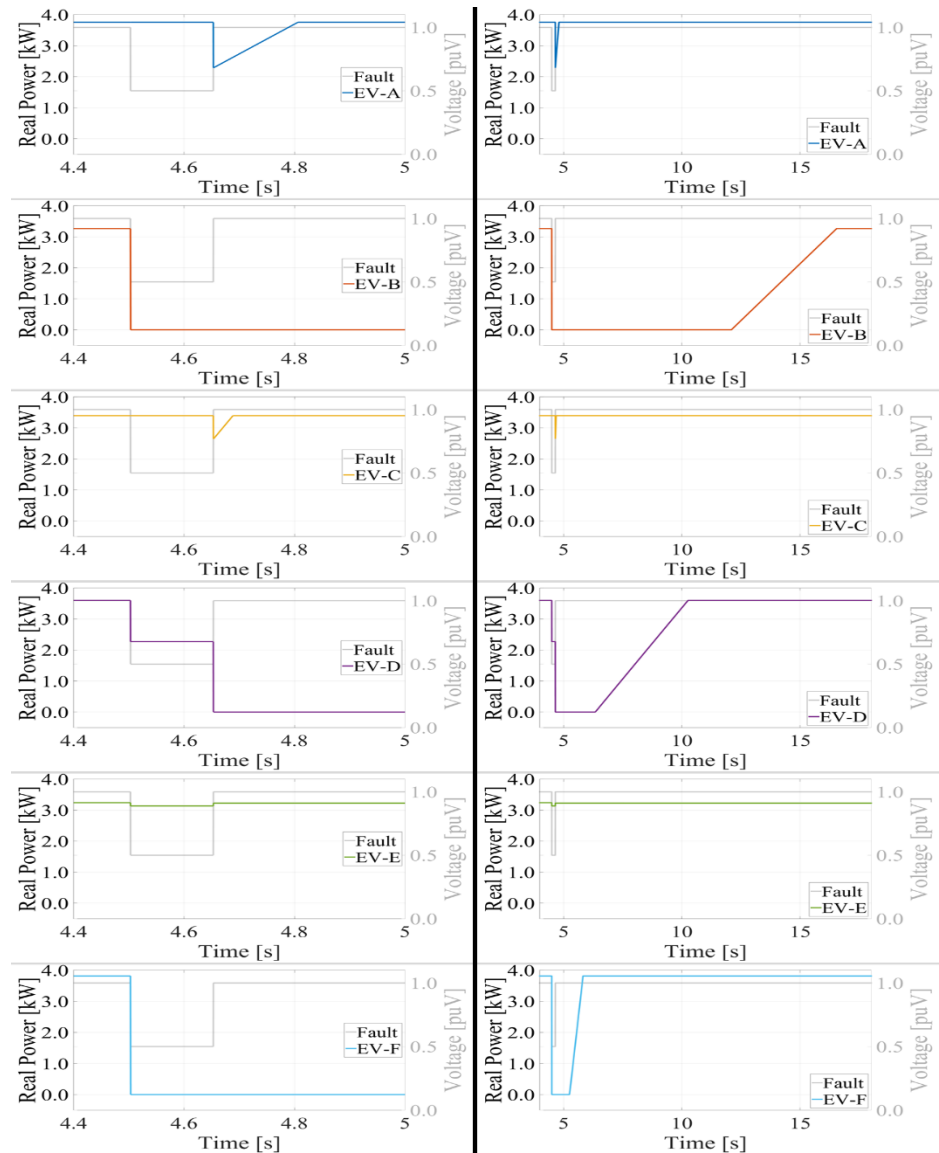
# Effect of PEVs on Initial Number of AC Units that Stall during a Fault

| # | Fault Scenario | | Initial Number of Units Stalled (increase/decrease from baseline) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Depth | Duration | EV-A | EV-B | EV-C | EV-D | EV-E | EV-F |
| 1 | 0.55 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0.55 | 7 | 100 | 0 | 72 | 0 | 0 | 0 |
| 3 | 0.55 | 9 | 330 | 0 | 320 | 167 | 309 | 0 |
| 4 | 0.55 | 12 | 59 | -232 | 59 | 59 | 59 | -38 |
| 5 | 0.5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0.5 | 7 | 309 | 0 | 309 | 35 | 260 | 0 |
| 7 | 0.5 | 9 | 132 | -199 | 132 | 132 | 132 | -199 |
| 8 | 0.5 | 12 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0.45 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0.45 | 7 | 302 | -29 | 302 | 280 | 302 | -29 |
| 11 | 0.45 | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0.45 | 12 | 0 | 0 | 0 | 0 | 0 | 0 |

Grid Unfriendly          Grid Friendly
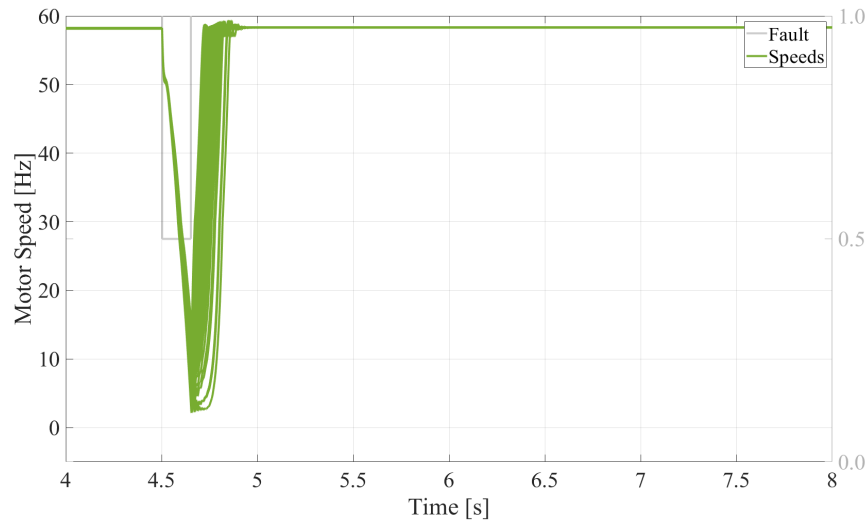
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# EV-B is a Grid Friendly PEV during Faults

Residential AC Motor Speeds **No PEV** – 9-cycle voltage dip to 0.50 pu
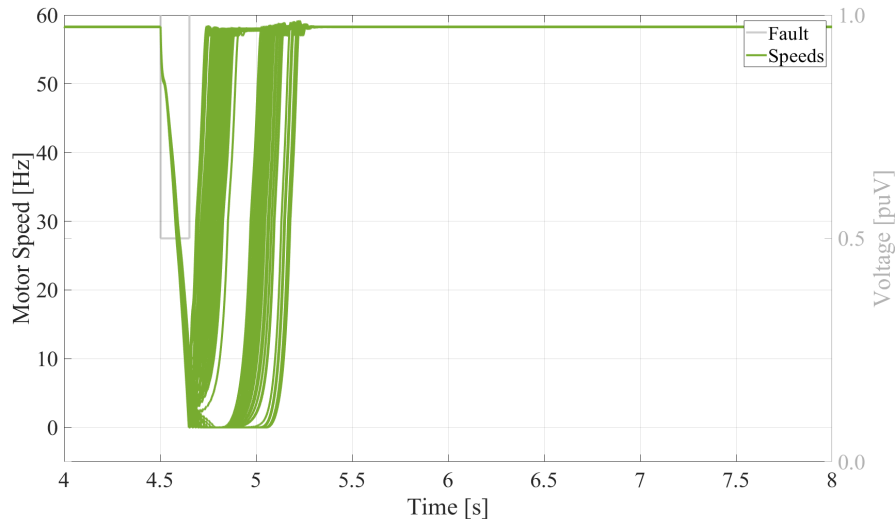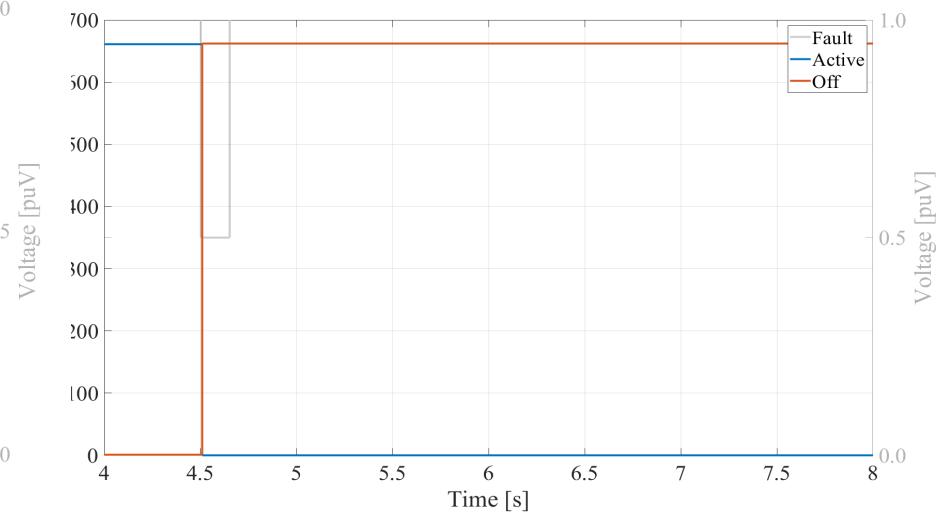


EV-B is grid friendly because it ceases consuming current at the onset of the fault

By taking PEV load off the distribution feeder, residential AC units are able to re-accelerate more quickly

Residential AC Motor Speeds **with EV-B** – 9-cycle voltage dip to 0.50 pu



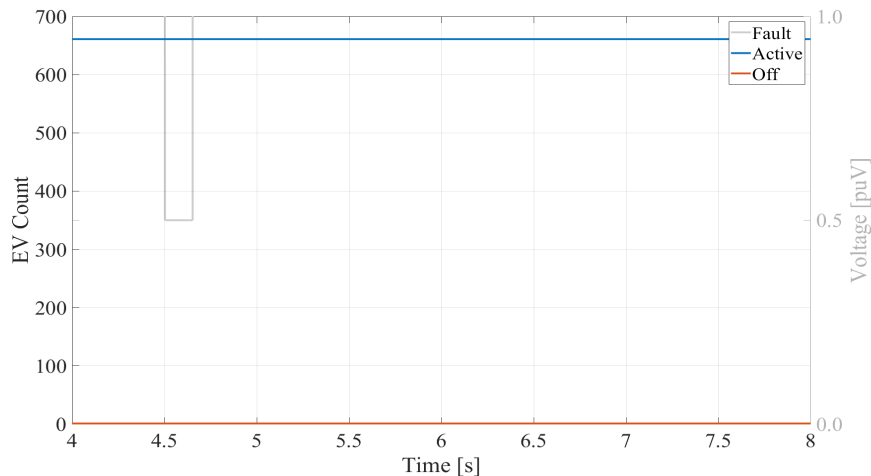Operating States of **EV-B** – 9-cycle voltage dip to 0.50 pu

# EV-A is a <span style="color:red">Grid Unfriendly</span> PEV during Faults

EV-A is grid unfriendly because it does not cease consuming current at the onset of and through the duration of the fault

By keeping PEV load on the distribution feeder, residential AC units are not able to re-accelerate
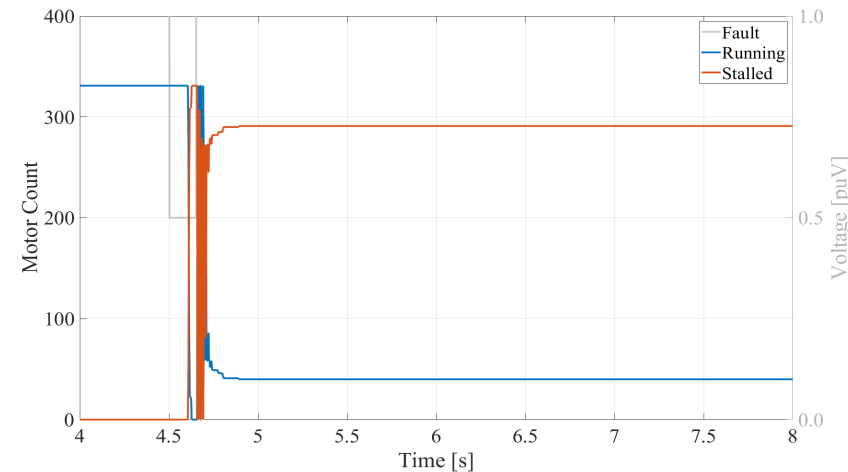
Residential AC Motor Operating States **No PEV** – 9-cycle voltage dip to 0.50 pu



Operating States of **EV-A** – 9-cycle voltage dip to 0.50 pu
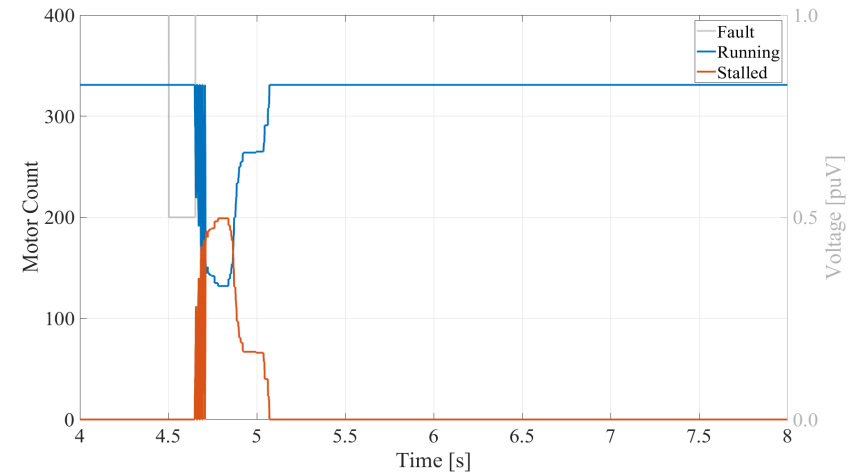


Residential AC Motor Operating States **with EV-A** – 9-cycle voltage dip to 0.50 pu

# Effect of PEVs on Number of AC Units that Remain Stalled 2 seconds after Fault has Cleared

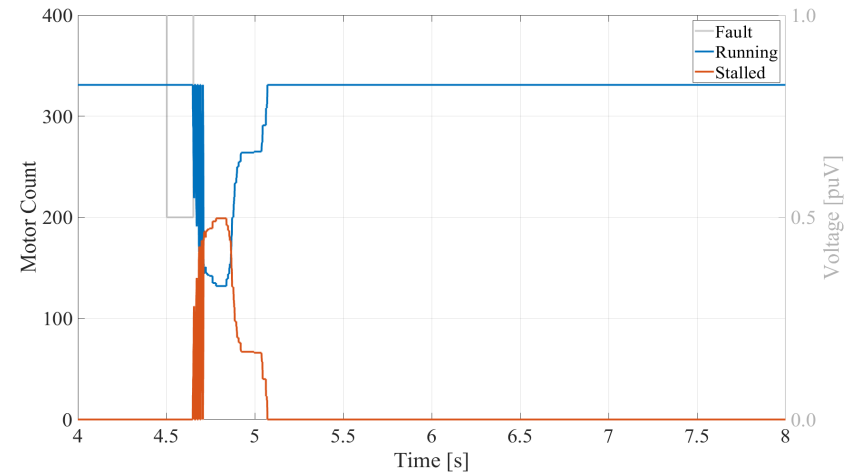| | Fault Scenario | | Number of Units Stalled at $T_{Fault}$+2.0s (increase/decrease from baseline) | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| # | Depth | Duration | EV-A | EV-B | EV-C | EV-D | EV-E | EV-F |
| 1 | 0.55 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0.55 | 7 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0.55 | 9 | 291 | 0 | 307 | 0 | 300 | 0 |
| 4 | 0.55 | 12 | 291 | 0 | 307 | 0 | 303 | 0 |
| 5 | 0.5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0.5 | 7 | 272 | 0 | 295 | 0 | 256 | 0 |
| 7 | 0.5 | 9 | 291 | 0 | 307 | 0 | 300 | 0 |
| 8 | 0.5 | 12 | 291 | 0 | 305 | 0 | 300 | 0 |
| 9 | 0.45 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0.45 | 7 | 297 | 0 | 301 | 0 | 295 | 0 |
| 11 | 0.45 | 9 | 303 | 0 | 307 | 0 | 300 | 0 |
| 12 | 0.45 | 12 | 307 | 0 | 307 | 0 | 300 | 0 |

Grid Unfriendly    Grid Friendly

# EV-D was a Grid Unfriendly PEV during the Fault, but was Grid Friendly after the Fault

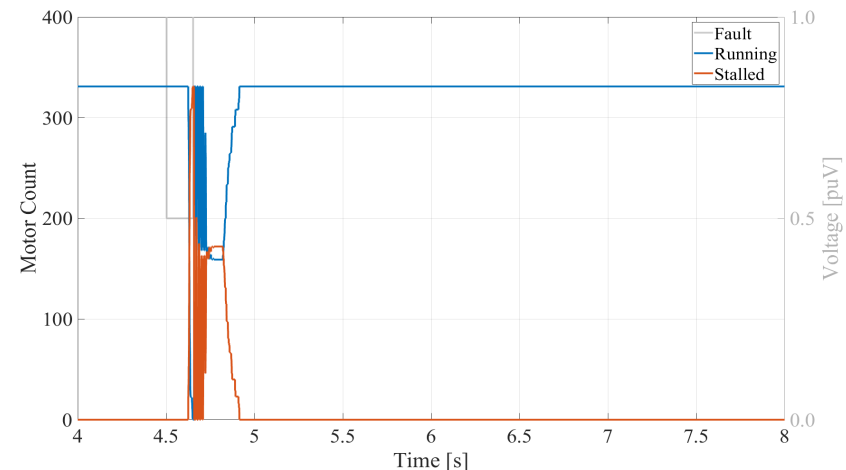EV-D was grid unfriendly because it did not cease consuming current at through the duration of the fault

EV-D became grid friendly because it ceased consuming current after the fault

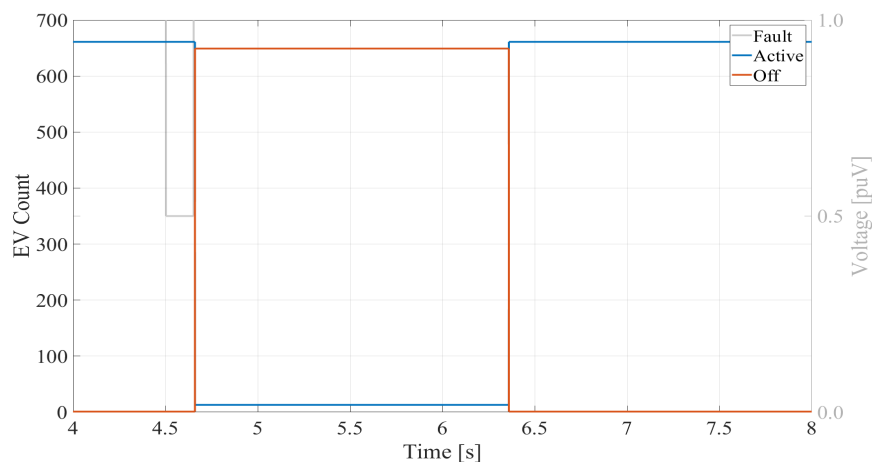By taking PEV load off the distribution feeder, residential AC units were able to re-accelerate

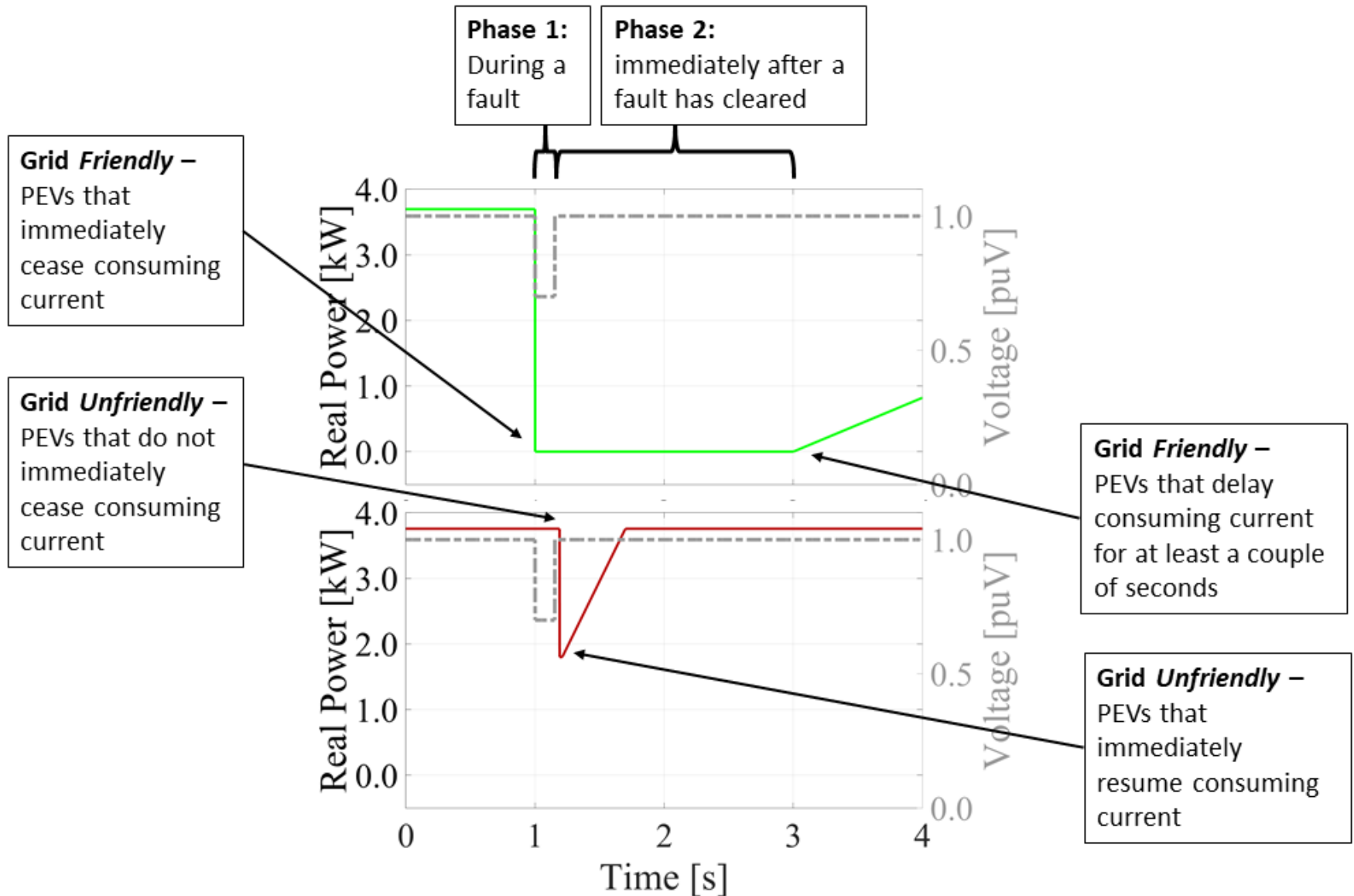Residential AC Motor Operating States **No PEV** – 9-cycle voltage dip to 0.50 pu



Operating States of **EV-D** – 9-cycle voltage dip to 0.50 pu



Residential AC Motor Operating States **with EV-D** – 9-cycle voltage dip to 0.50 pu

# Grid Friendly and Grid Unfriendly PEV Behaviors

# Next Steps

Present and discuss findings with engineering counterparts in the PEV and electric vehicle supply equipment industry

Explore opportunities to develop standards (IEEE and SAE) that establish technical performance requirements and testing protocols for electronically-coupled end-use loads connected to the grid through power electronic interfaces

Demonstrate the usefulness of study approaches such as these for supporting enhancements to the composite load model to better capture the diversity and growth in power electronic loads