DOE Transmission Reliability R&D Program

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

ESIG 2023 Spring Technical Workshop

March 28, 2023

Presented by:

Joseph H. Eto, Lawrence Berkeley National Laboratory – jheto@lbl.gov

Project Team:

Frank Tuffner, Pacific Northwest National Laboratory

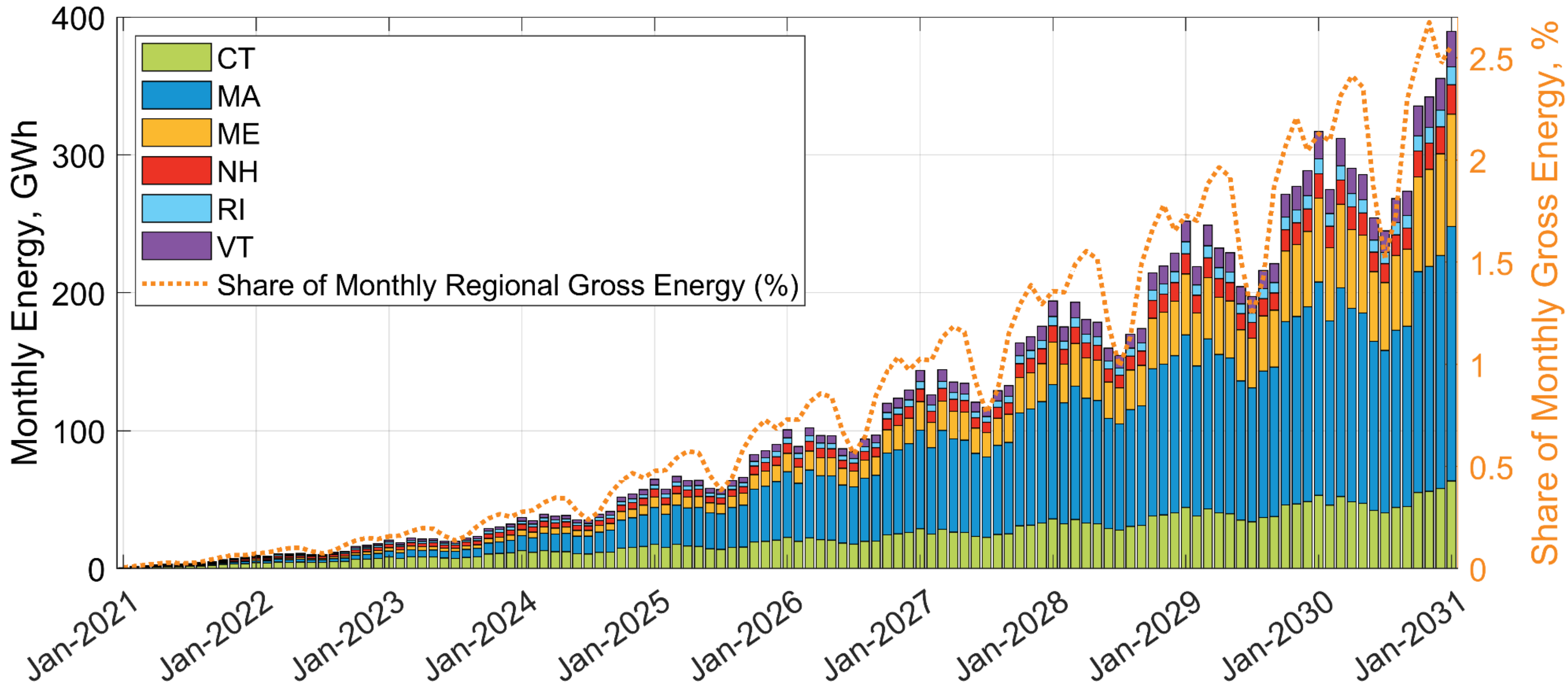
Don Scoffield, Idaho National Laboratory

John Undrill, Arizona State University

Dmitry Kosterev, Bonneville Power Administration

Ryan Quint, North American Electric Reliability Corporation

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

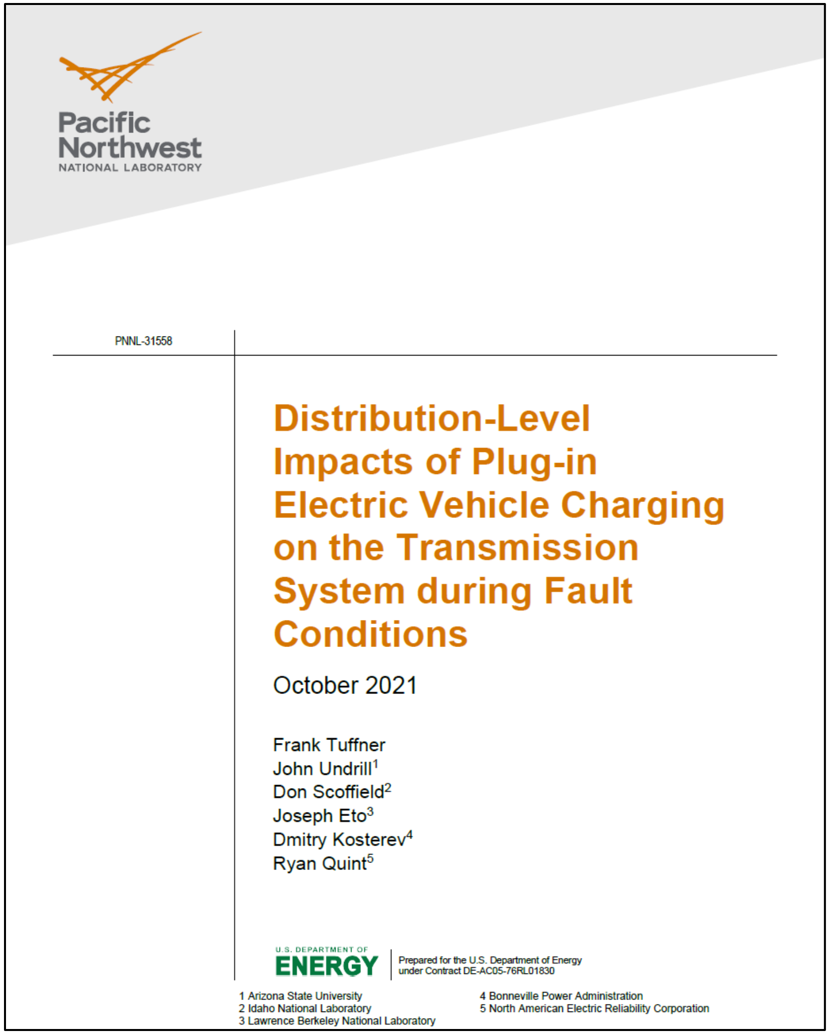


Source: ISO-NE. 2021 Final Electrification Transportation Forecast

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



Pacific Northwest
NATIONAL LABORATORY

PNNL-31558

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

October 2021

Frank Tuffner
John Undrill[1]
Don Scoffield[2]
Joseph Eto[3]
Dmitry Kosterev[4]
Ryan Quint[5]

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

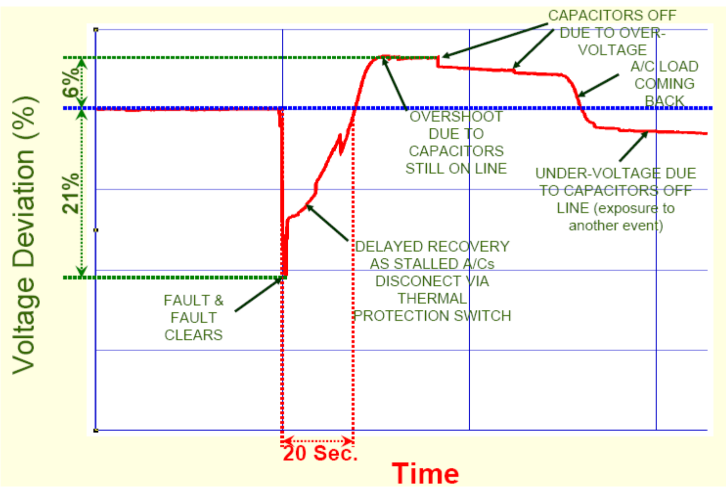
1 Arizona State University
2 Idaho National Laboratory
3 Lawrence Berkeley National Laboratory
4 Bonneville Power Administration
5 North American Electric Reliability Corporation

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

Study Approach

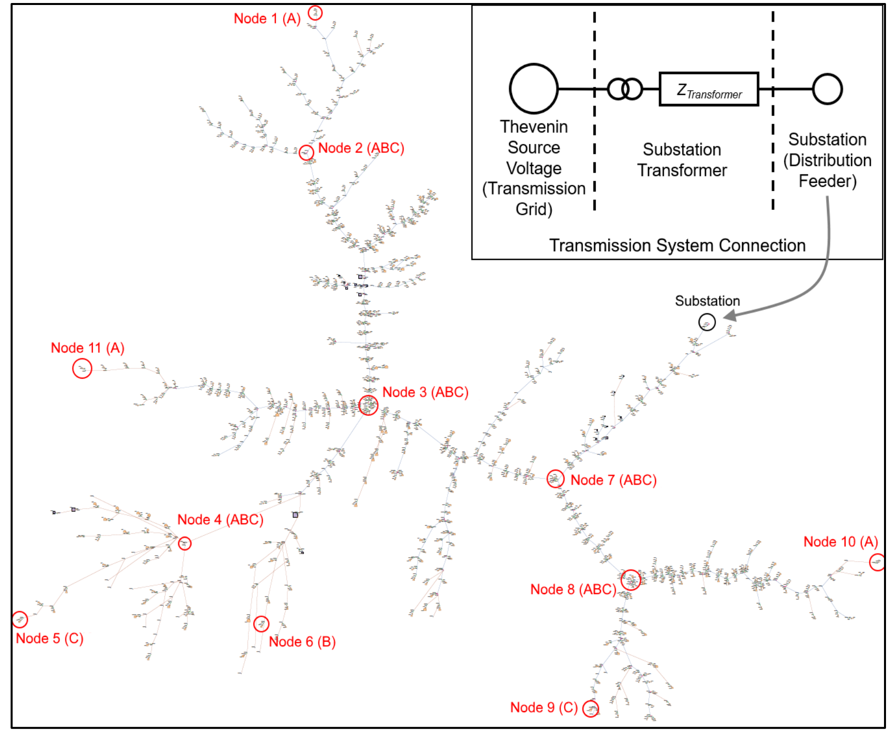
Residential AC stalling (FIDVR) is a known example of a *grid unfriendly* load (http://fidvr.lbl.gov)

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

Study Method

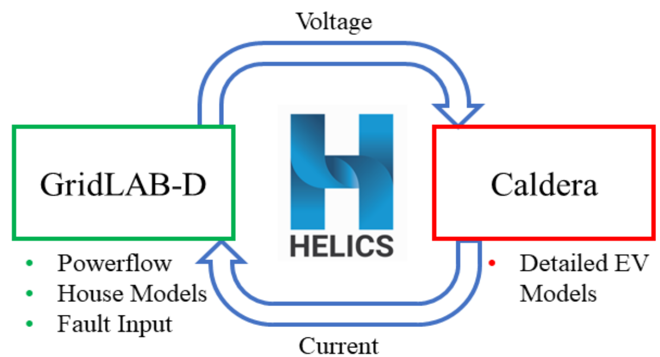
The impacts of transmission faults on voltages within the distribution feeder are studied using GridLAB-D

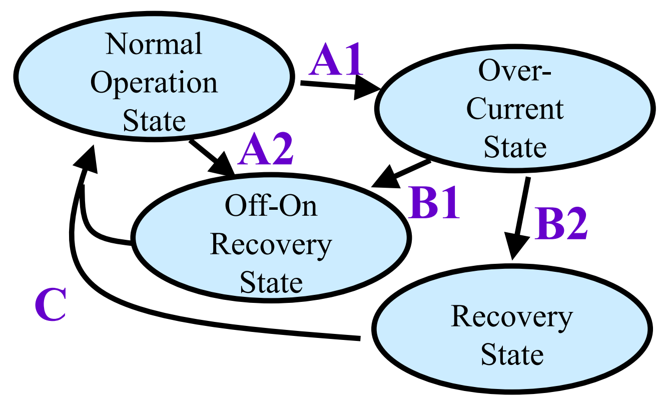
The behavior of single-phase induction motors is represented in GridLAB-D using a dynamic-phasor-based model

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

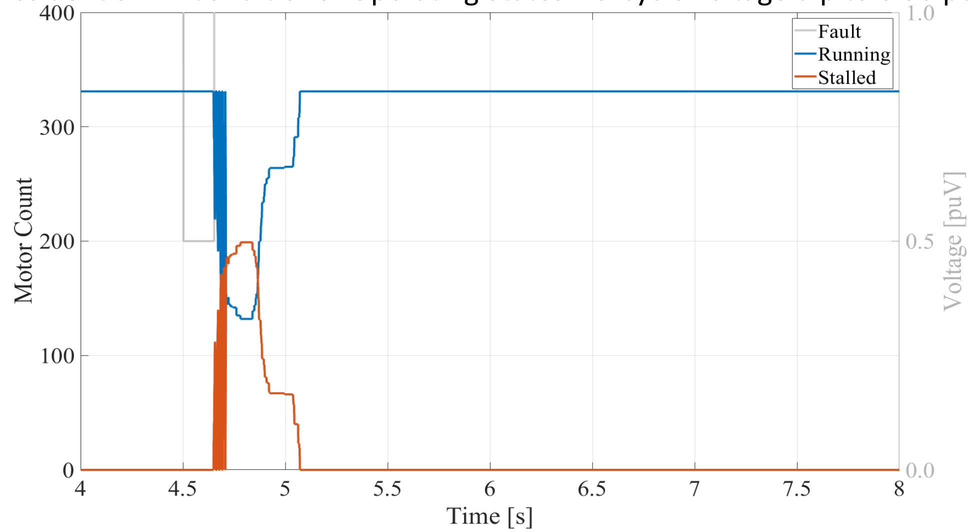
The number of residential AC units that stall are tabulated (there are a total of 331 residential AC units on this phase of the feeder)

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

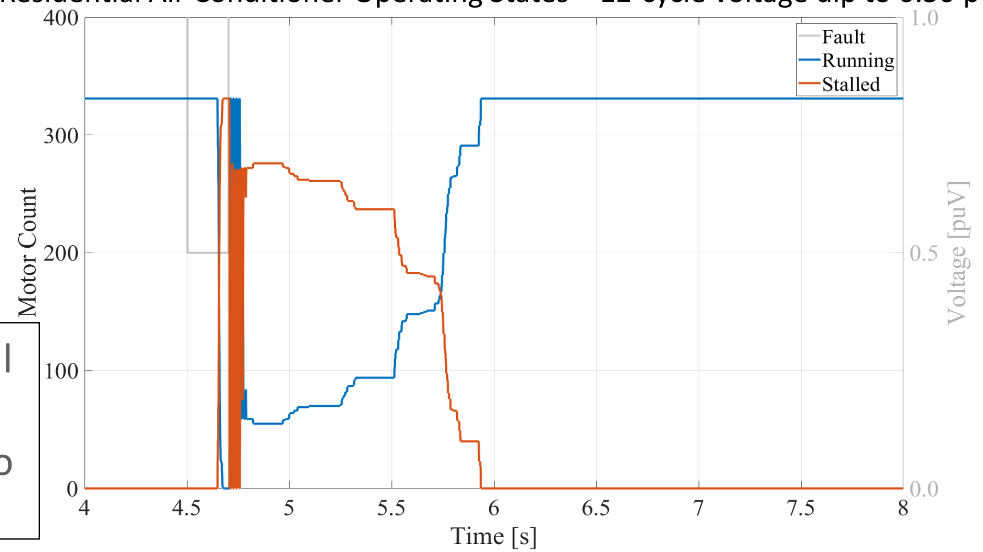
Depth of Voltage Dip	Duration of Voltage Dip			
	5 cycles	7 cycles	9 cycles	12 cycles
0.55	0	0	0	**272**
0.5	0	0	**199**	**331**
0.45	0	0	**331**	**331**

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

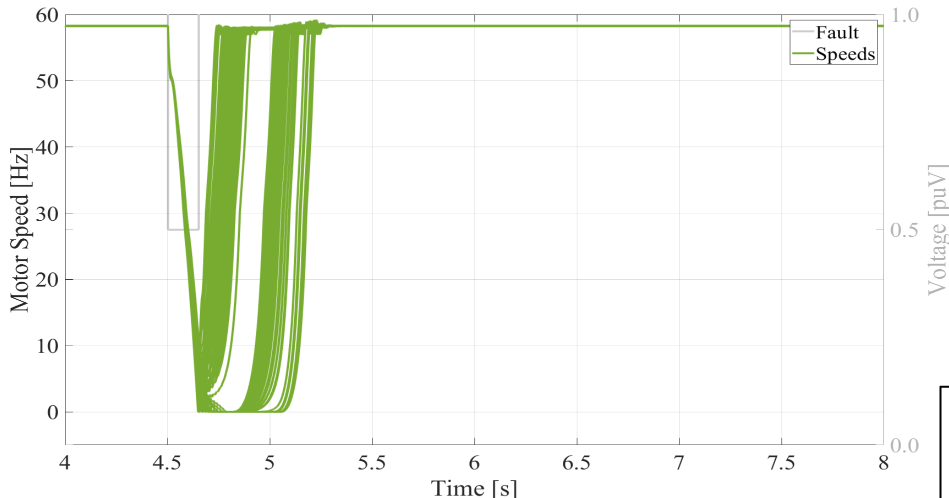


Residential Air Conditioner Operating States – 12-cycle voltage dip to 0.50 pu

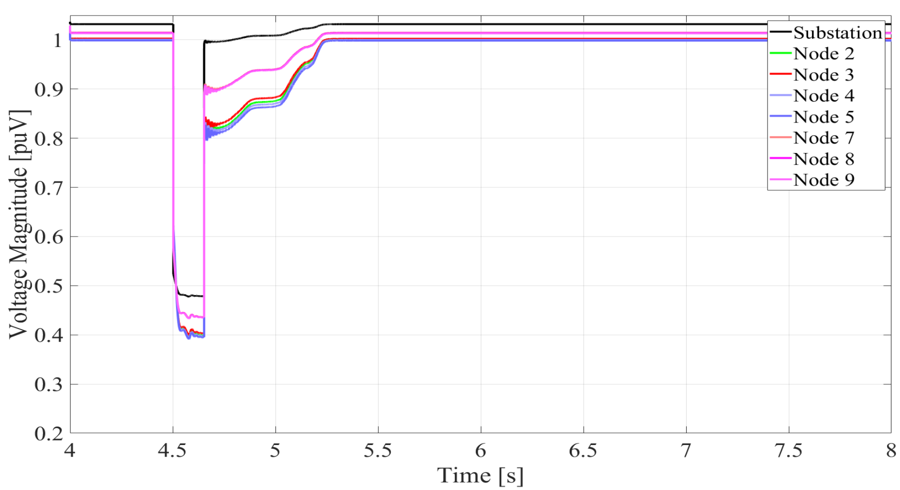


Baseline Results – No PEVs

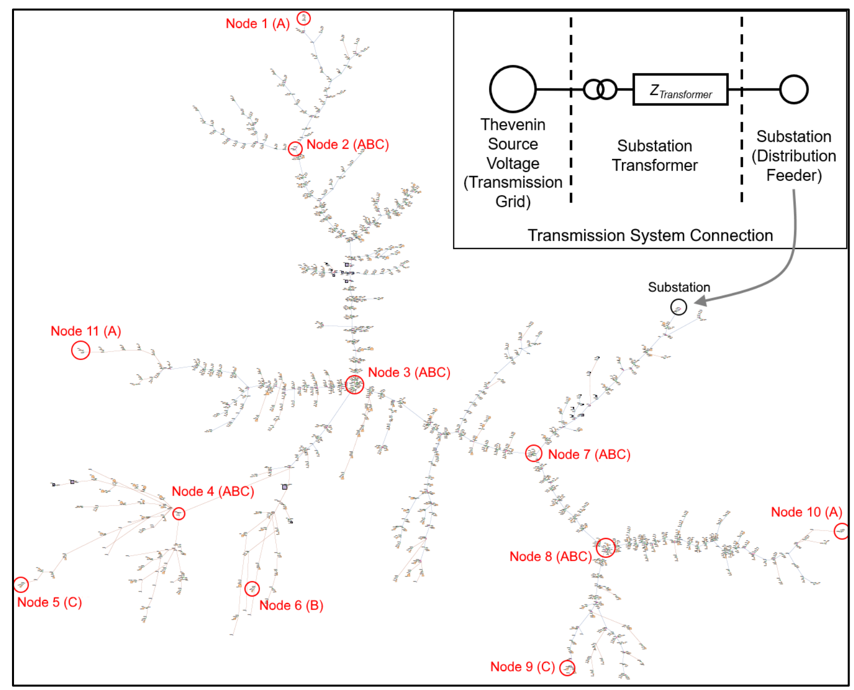
Residential AC Motor Speeds – 9-cycle voltage dip to 0.50 pu



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



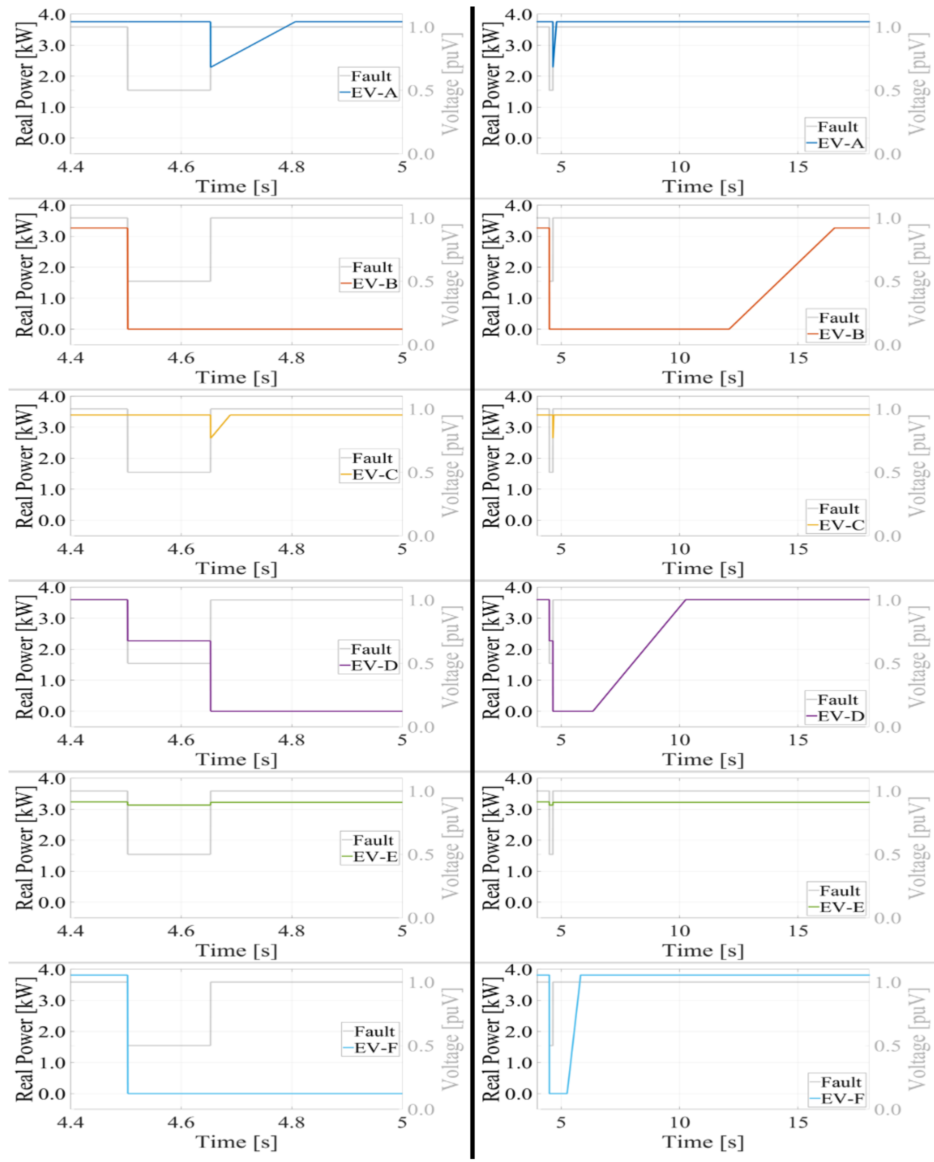
Impact of PEVs on FIDVR

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



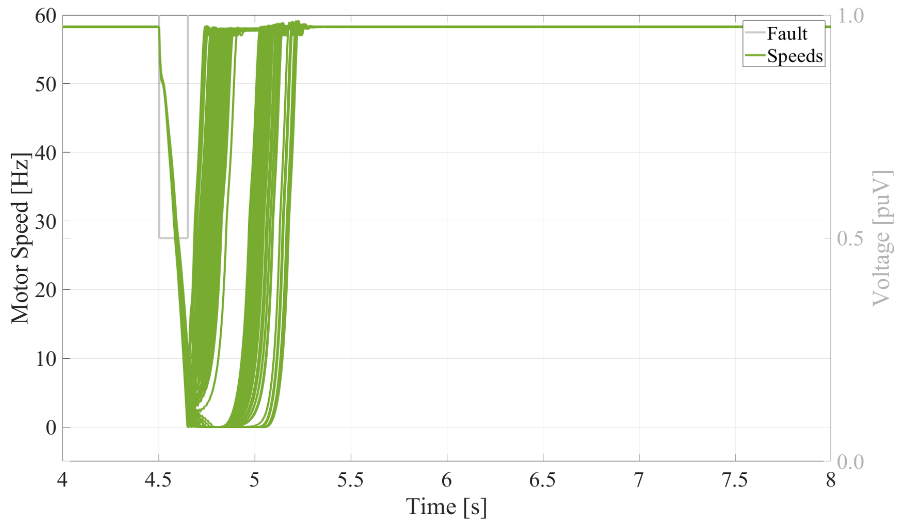
Effect of PEVs on Initial Number of AC Units that Stall during a Fault

	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 (EV-A, EV-C, EV-D, EV-E) Grid Friendly (EV-B, EV-F)

EV-B is a Grid Friendly PEV during Faults

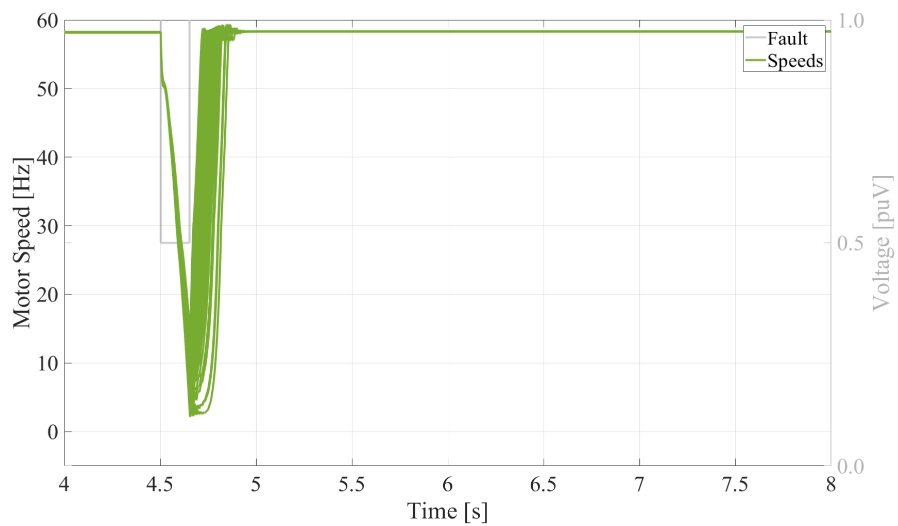
Residential AC Motor Speeds **No PEV** – 9-cycle voltage dip to 0.50 pu



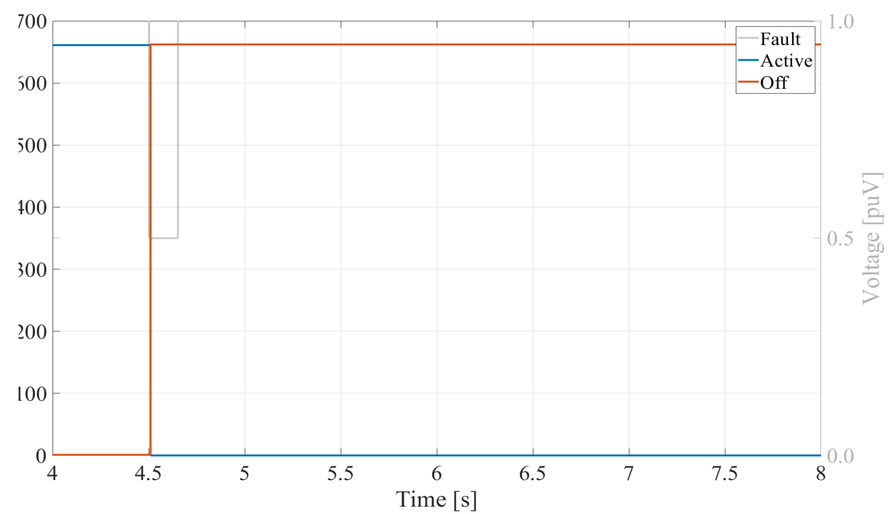
EV-B is grid friendly because it ceases consuming current at the onset of the fault

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

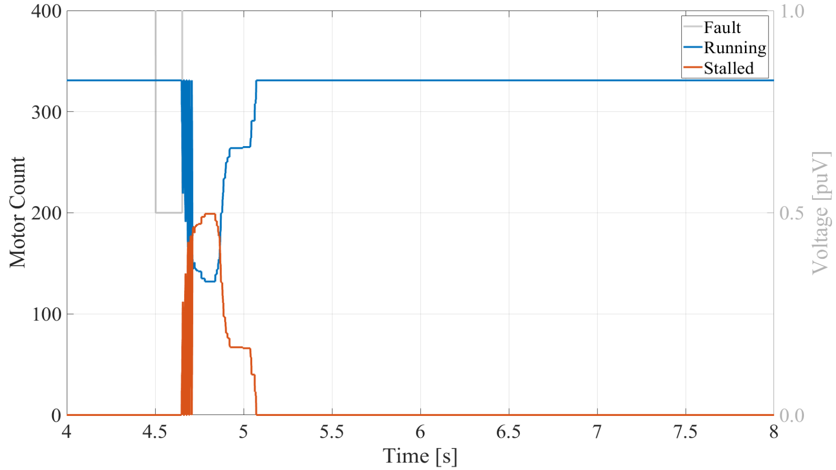


EV-A is a Grid Unfriendly PEV during Faults

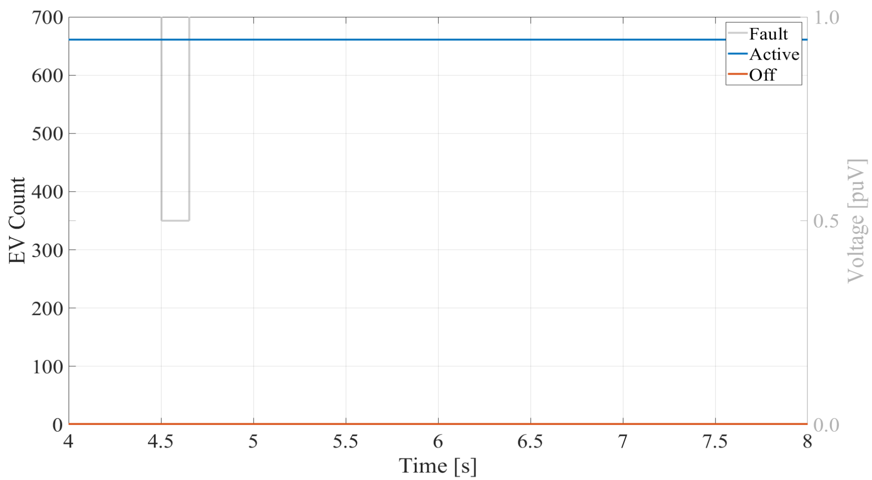
EV-A is grid unfriendly because it does not cease consuming current at the onset of and through the duration of the fault

By keeping PEV load on the distribution feeder, residential AC units are not able to re-accelerate

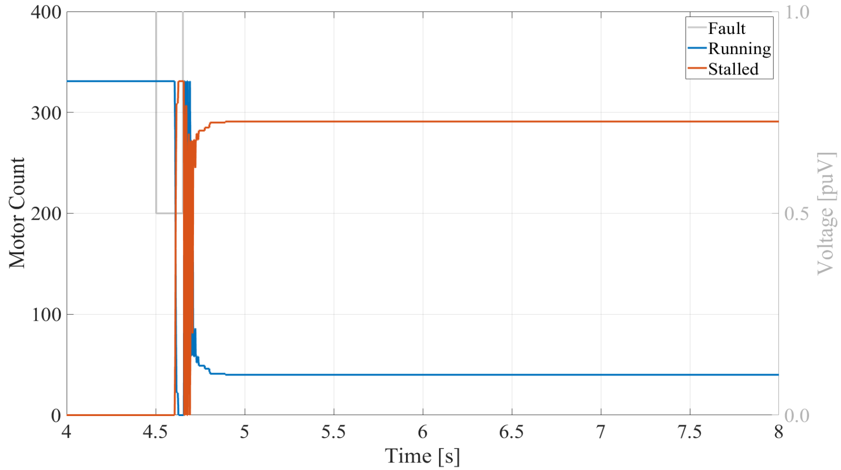
Residential AC Motor Operating States **No PEV** – 9-cycle voltage dip to 0.50 pu



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

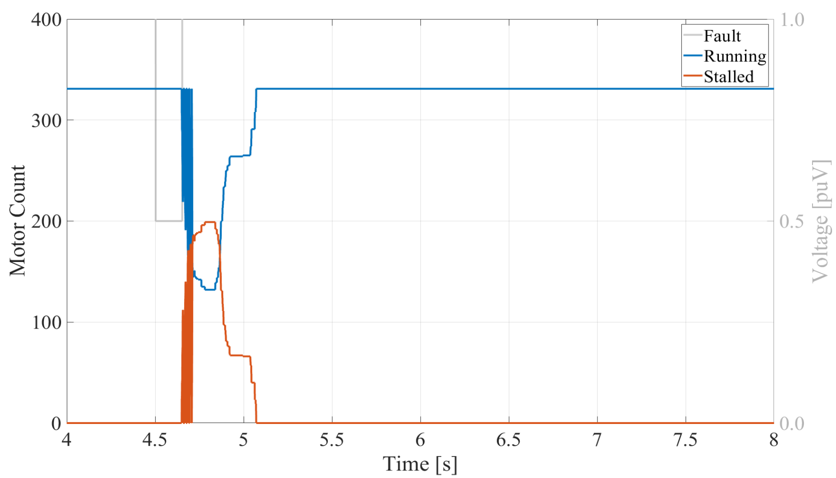
EV-D was a Grid Unfriendly PEV during the Fault, but was Grid Friendly after the Fault

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

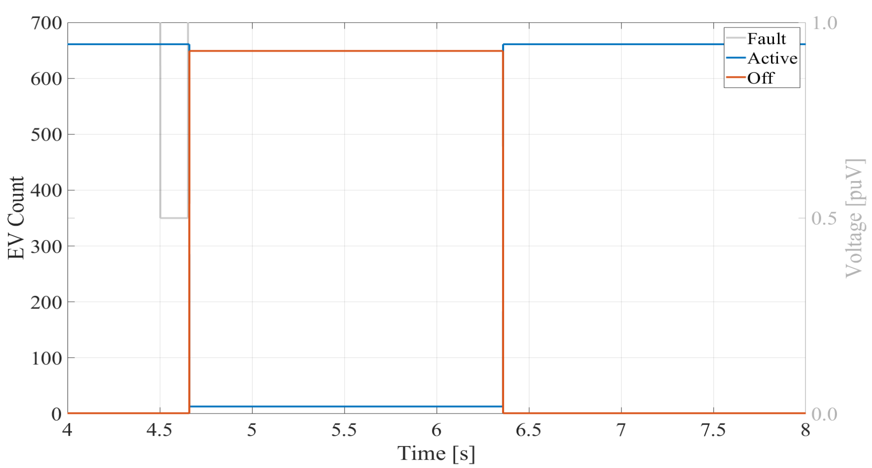
EV-D became grid friendly because it ceased consuming current after the fault

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

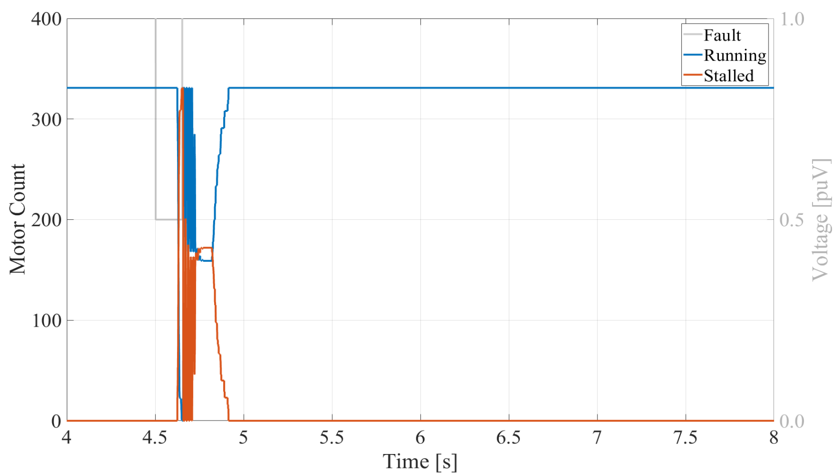
Residential AC Motor Operating States **No PEV** – 9-cycle voltage dip to 0.50 pu



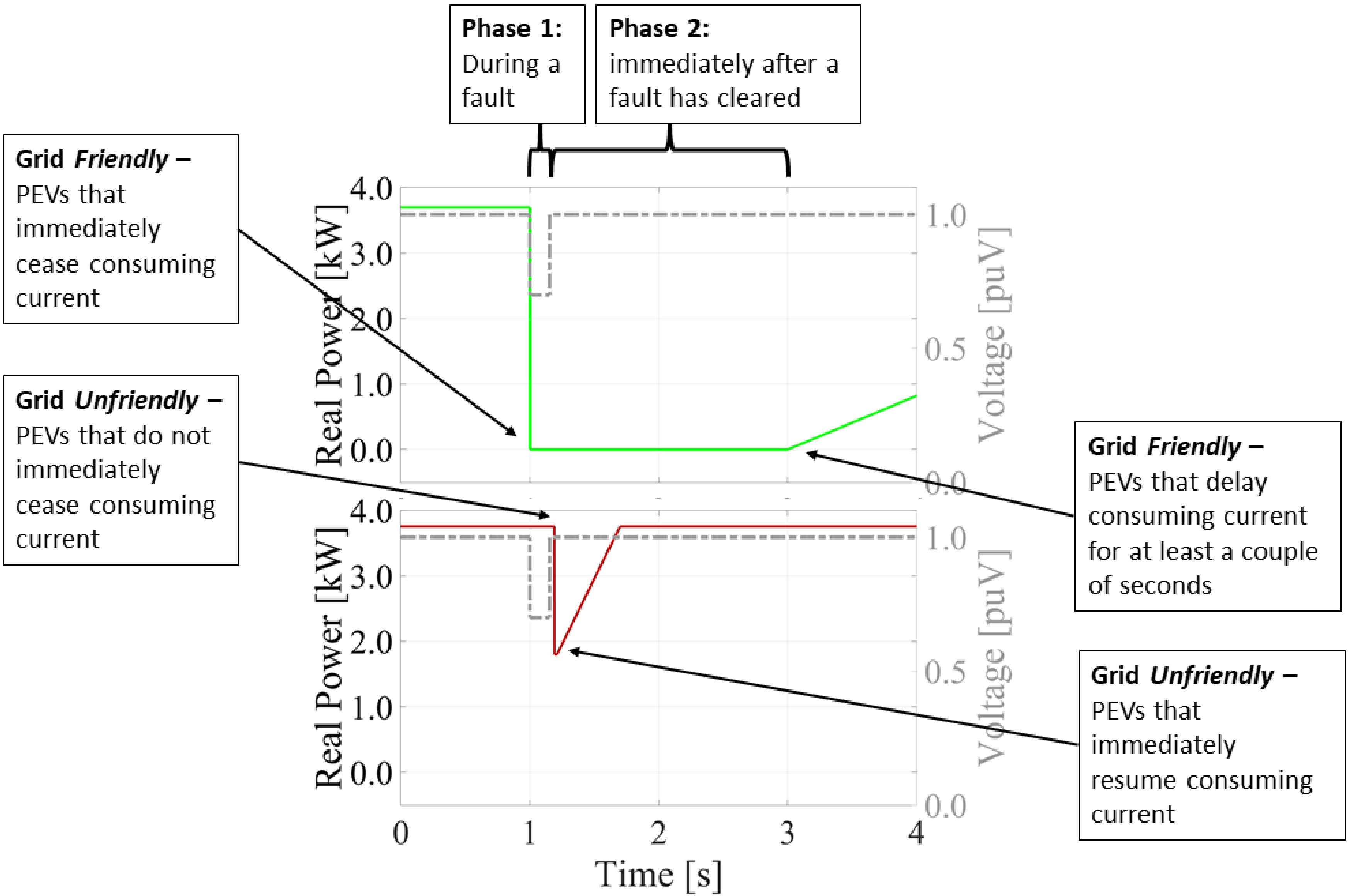
Operating States of **EV-D** – 9-cycle voltage dip to 0.50 pu



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