SPIDER Modeling Sub-Group
DER Modeling, CAISO Experience

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Presentation Outline

- DER models for power flow and dynamic stability studies
- California ISO studies of DER models, parameters and sensitivities

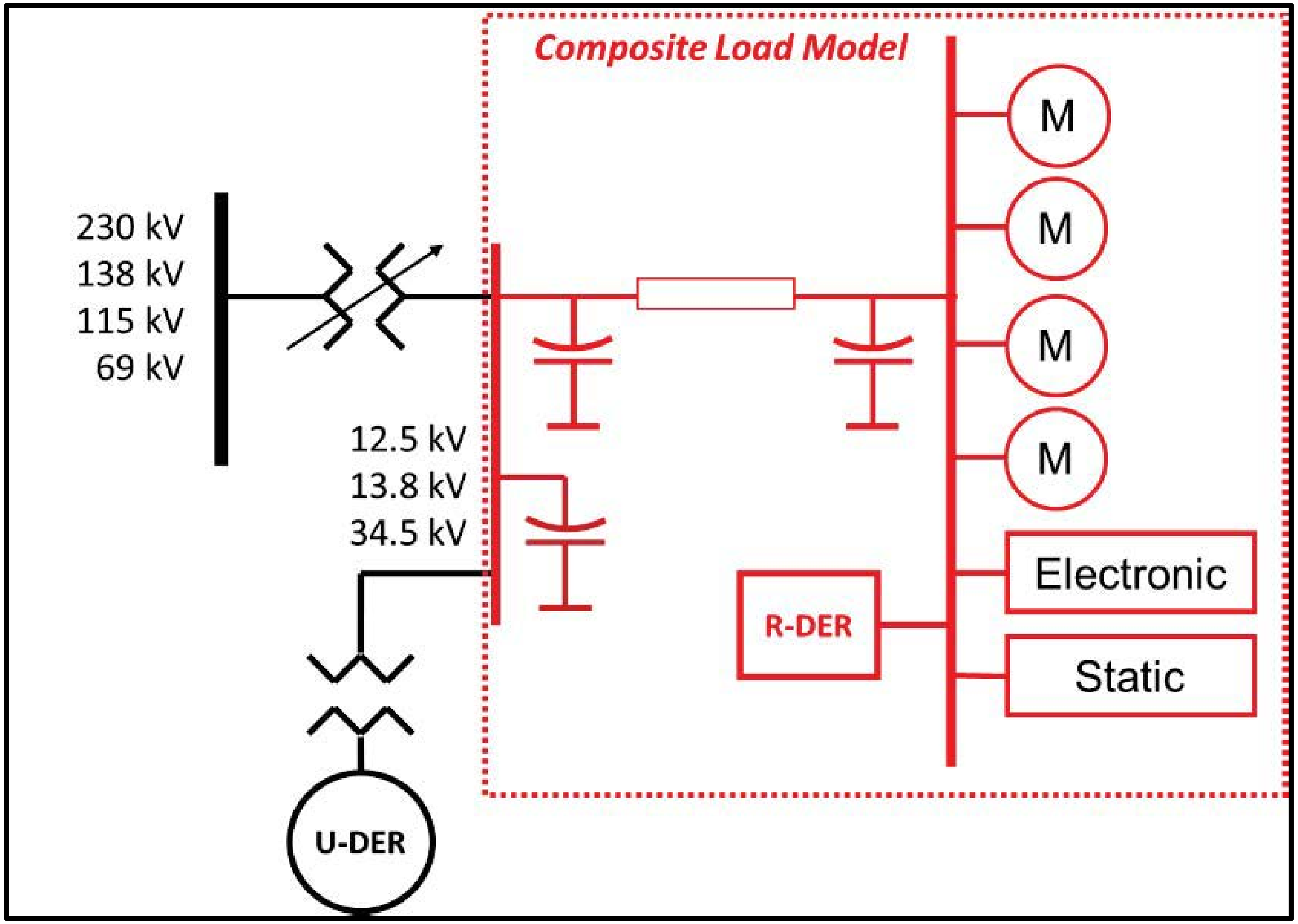
DER Types (NERC Reliability Guideline)

- **Utility-Scale Distributed Energy Resources (U-DER):** directly connected to the distribution bus or through a dedicated, non-load serving feeder. They are three-phase and can range in capacity, for example, from 0.5 to 20 MW
- **Retail-Scale Distributed Energy Resources (R-DER):** offset customer load. Include residential, commercial, and industrial customers. Typically, the residential units are single-phase while the commercial and industrial units can be single- or three-phase facilities.
- Distributed Energy Resources may include:
  - Distributed Generation – in front or behind the meter
  - Energy Efficiency – load modifier embedded in load forecast
  - Demand Response – demand or supply side, can be used as mitigation
  - Energy Storage – can be modeled as aggregated, supply or demand side

CAISO Modeling of Utility Scale and Retail Scale Distributed Energy Resources

- **Supply-side DER** - Utility Scale
  - Resources connected in front of the customer meter
  - Source: PTO Wholesale Distribution Access Tariff (WDAT) and CPUC RPS portfolio
  - Modeled at T/D interface as individual resource
- **Demand-side DER** - Retail Scale (Behind-the-meter Generation)
  - Photovoltaic / Non-photovoltaic
  - Source: Embedded in CEC demand forecast
  - Modeled at T/D interface as aggregated resource (PV only at this time)
  - Behind the Meter solar PV modeled as a part of load

Distributed Generation PV Modeling –

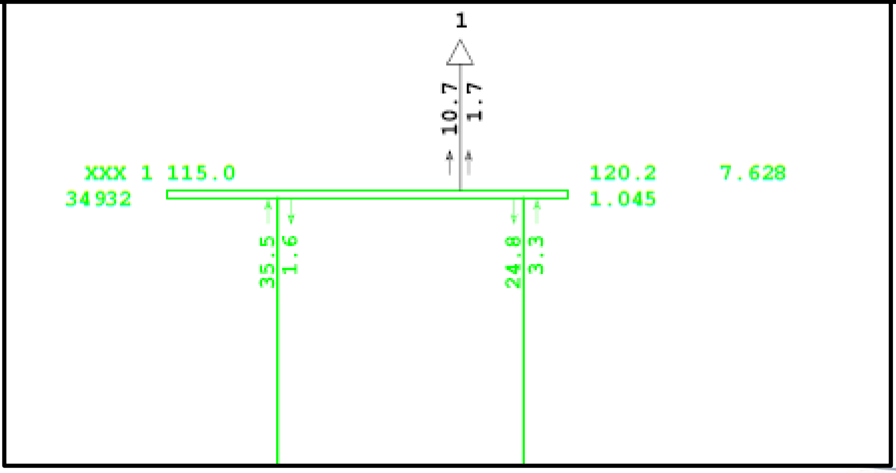


Currently, DER models in dynamic stability exist only for solar PV. Other types of DER are modeled as generators, or as load modifiers

Modeling Behind the Meter DG in Power Flow (GE PSLF)

- Model calculated amounts of BTM-PV at each bus by specifying the P and Q values of the PV as separate entries in the power flow load data, including the following values:
  - Pdg - MW output of distributed generation
  - Qdg - MVAr of distributed generation (sign convention same as generators)
  - Stdg - DG status (1 – on-line)

BUS-NO	NAME	KV	ID	ST	PLOAD	QLOAD	Stdg	Pdgen	Qdgen	AREA	ZONE	PMOTR	QMOTR
34932	XXX 1	115	1	1	11.39	1.69	1	0.69	0	30	315	0	0
34758	XXX 2	115	3	1	1.14	0	1	0.12	0	30	315	0	0
34558	XXX 3	70	2	1	2.05	0	1	0.2	0	30	314	0	0



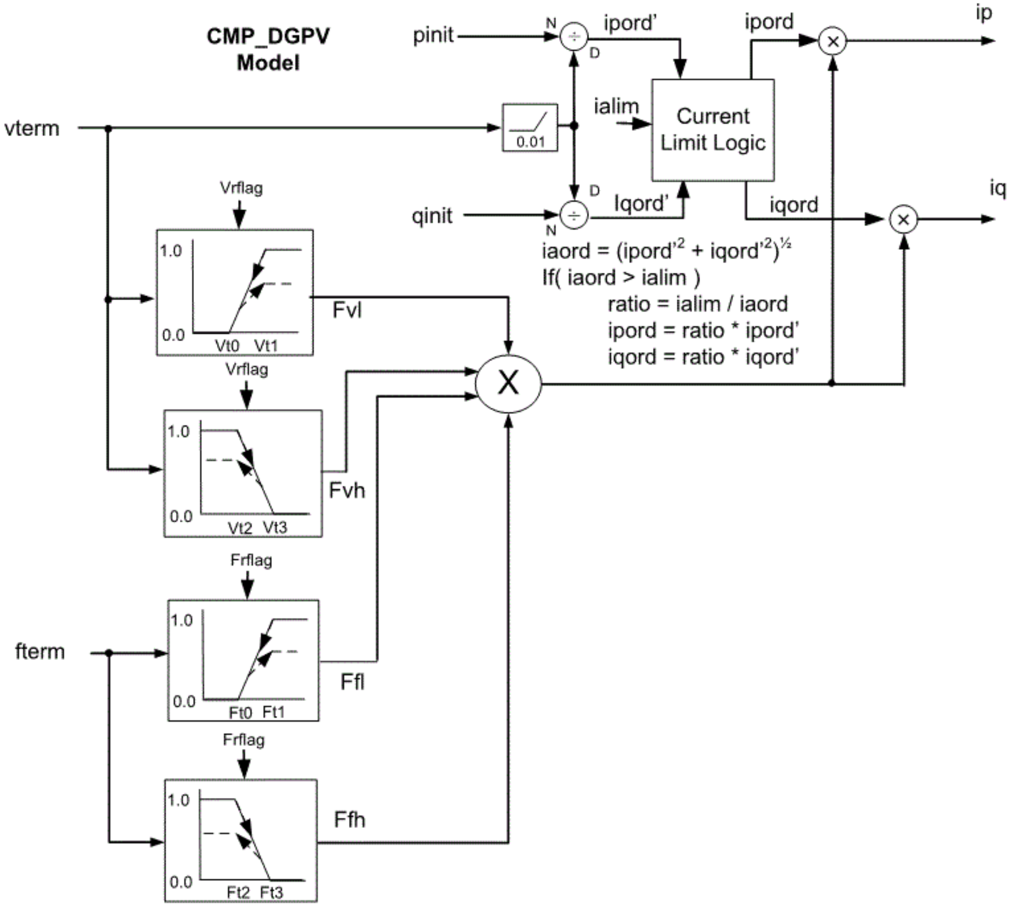
Modeling Retail Scale DER in Dynamic Stability as Part of Load

- When voltage is below specified values, the model trips fractions of each motor, electronic and static load
- The fractions of load that are tripped and voltages at which they are tripped are specified by the user
- Distributed generation was assumed having unity power factor
- DER also have settings at which voltage and frequency they may be tripped or reconnected
- DER solar PV models are simplified compared to the models of large solar PV plants

Behind the Meter DER in Dynamic Stability (GE PSLF) - as a Part of Load CMPLDWG Model

- DER type – solar PV: 1 – DGPV simplified, 0 – none, 2 – DER_A
- Initial Pdg method : 0) fraction of P load, 1) in MW, 2) **Use P& Q from load table**
- For **DGPV Model:**
  - ✓ Power factor
  - ✓ Current limit, per unit I_{max}
  - ✓ At which voltages and frequencies starts tripping and at which all DG is tripped
  - ✓ Fraction of DG that recovers when voltage or frequency recovers
- For **DER_A Model**
  - ✓ MVA base or load factor
  - ✓ Reference to the record with detailed parameters

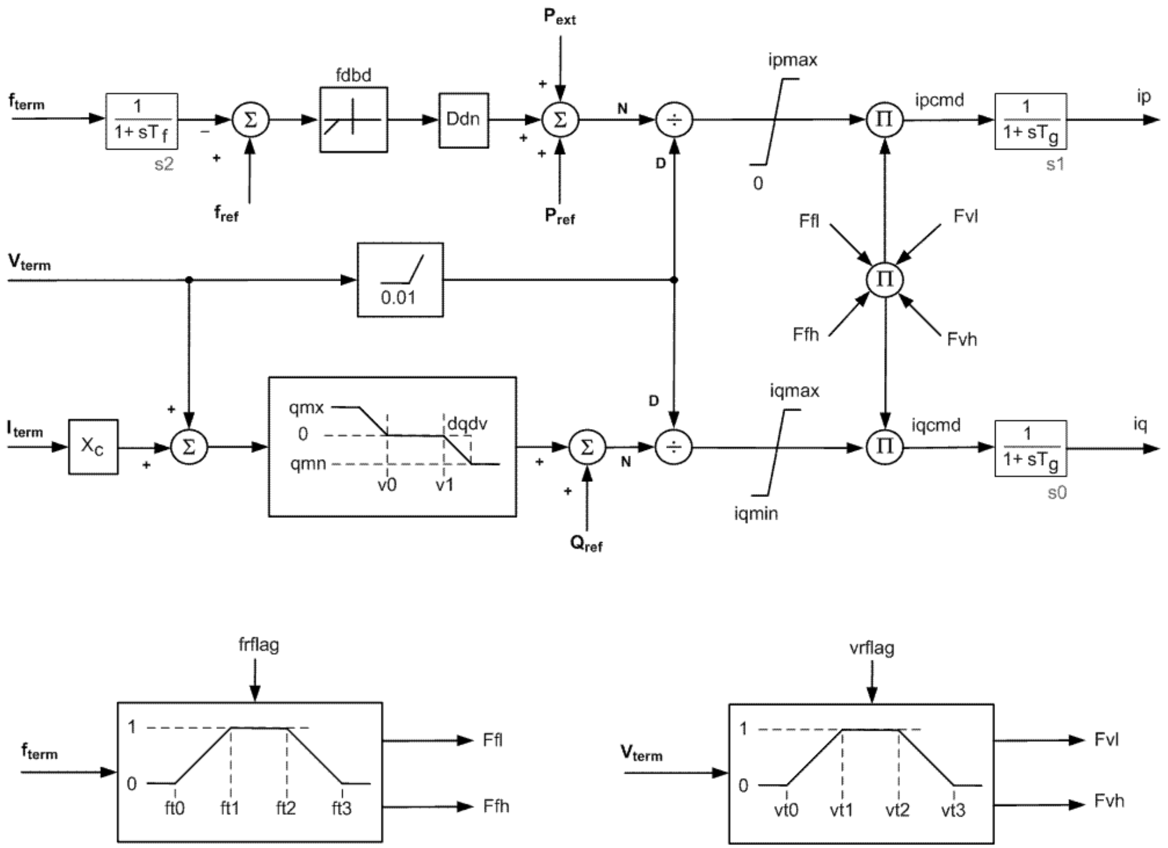
Simplified DER Model as a Part of Composite Load Model (DGPV)



- Currently, in GE PSLF cmpldwg model, only PV can be modeled
- Simplified model
- No time-dependent component
- Similar to PVD1 model, but simplified
- Less options by the user

PVD1 Model – Distributed Solar PV

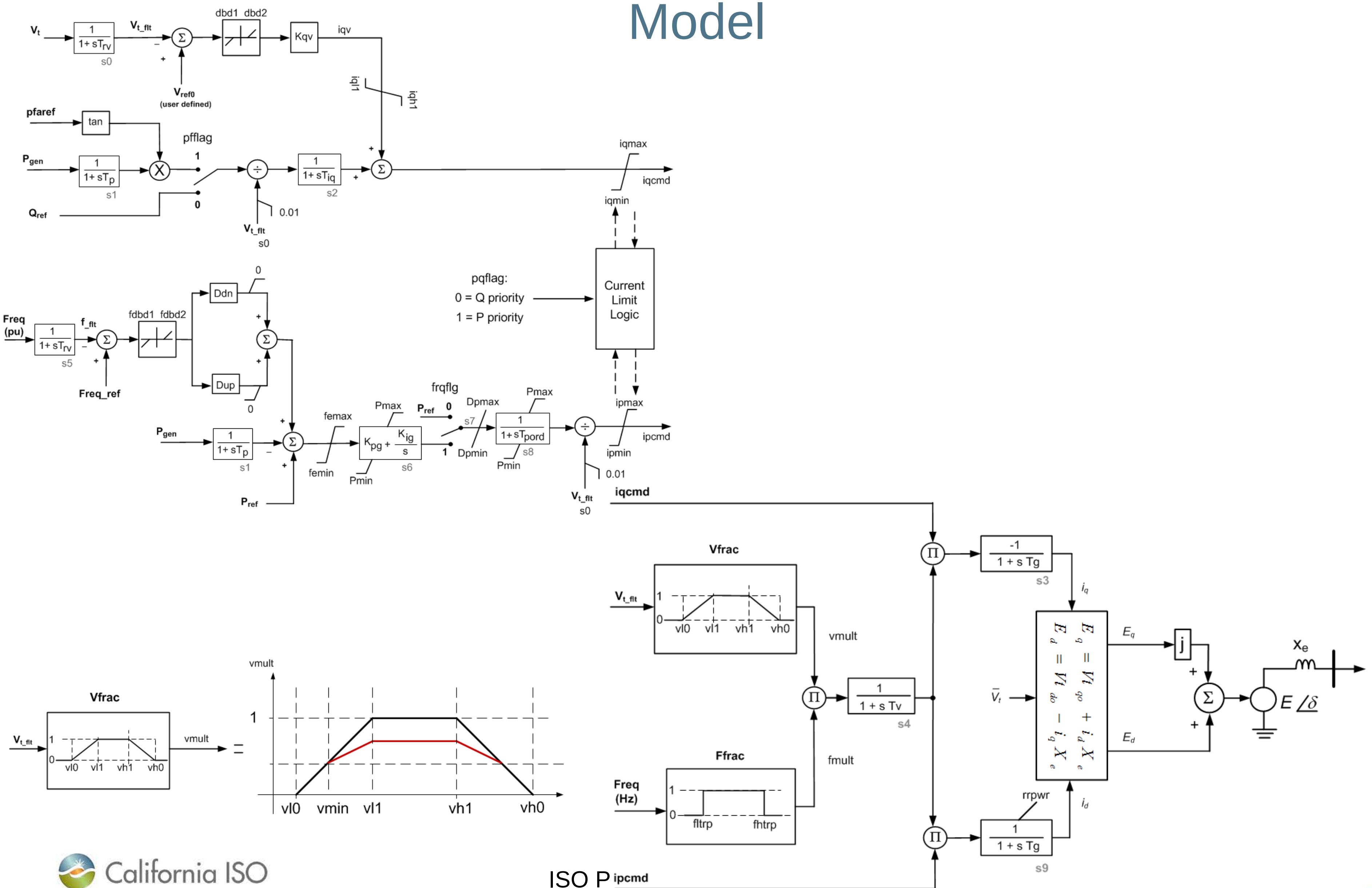
- More detailed model than the DG part of composite load model
- No time-dependent component
- More detailed voltage and frequency tripping response curves
- Reactive or active current priority
- Modeled as generation at power flow buses



More Detailed Model, DER_A

- Reduced version of generic large PV plant model
- Frequency and voltage control emulation, with asymmetric dead-band. The voltage control only allows for proportional control.
- Allows for constant power factor and constant Q-control
- Intended to use as aggregated, allows partial tripping
- Allows for modeling ramp-rate limits on the real-power recovery following a fault or during primary-frequency response, and also models a basic current limit with P/Q priority options
- May also represent battery storage, however without modeling of charge or discharge
- More detailed than DG portion of the cmpldwg model and than PVD1 model, and requires more parameters than these models

DER_A Model Standalone or Part of Composite Load Model



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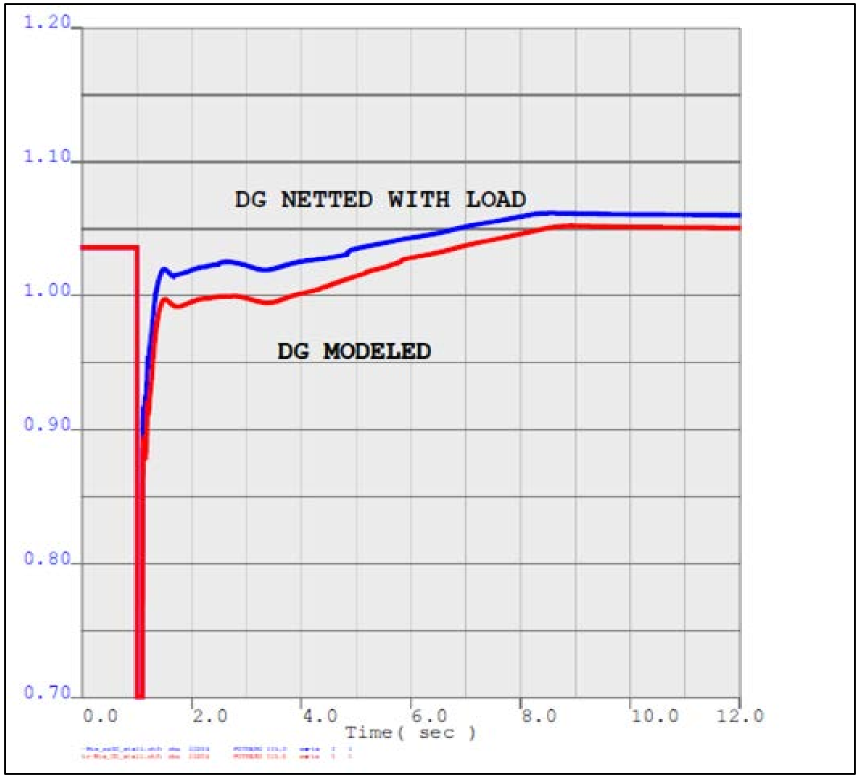
DER_A Model Parameters

Parameter	Description
Trv	transducer time constant (s)
dbd1	lower voltage deadband (pu)
dbd2	upper voltage deadband (pu)
Kqv	proportional voltage control gain (pu/pu)
Vref0	voltage reference set-point (pu)
Tp	transducer time constant (s)
Pflag	1 - constant power factor control, or 0 - for constant Q control
Tiq	Q control time constant (s)
Ddn	frequency control droop gain (down-side)
Dup	frequency control droop gain (up-side)
fdbd1	lower frequency control deadband (pu)
fdbd2	upper frequency control deadband (pu)
femax	frequency control maximum error (pu)
femin	frequency control minimum error (pu)
Pmax	Maximum power (pu)
Pmin	Minimum power (pu)
Freq_flag	1 - frequency control enabled, 0 - frequency control disabled
dPmax	Power ramp rate up (pu/s)
dPmin	Power ramp rate down (pu/s)
Tpord	Power order time constant (s)
Imax	Maximum converter current (pu)
Pqflag	0 - Q priority, 1 - P priority for current limit
vl0	voltage break-point for low voltage cut-out of the inverter
vl1	voltage break-point for low voltage cut-out of the inverter
vh0	voltage break-point for high voltage cut-out of the inverter
vh1	voltage break-point for high voltage cut-out of the inverter
tvl0	voltage break-point for low voltage cut-out timer
tvl1	voltage break-point for low voltage cut-out timer
tvh0	voltage break-point for high voltage cut-out timer
tvh1	voltage break-point for high voltage cut-out timer
Vrfrac	fraction of device that recovers after voltage comes back to within vl1 < V < vh1
fl	frequency break-point for low frequency cut-out of the inverter
fh	frequency break-point for high frequency cut-out of the inverter
tfl	frequency break-point for low frequency cut-out timer
tfh	frequency break-point for high frequency cut-out timer
Tg	Current control time constant
rrpwr	Power rise ramp rate following a fault (pu/s)
Tv	time constant on the output of the voltage/frequency cut-out
genflag	1 - the unit is a generator Ipmin = 0; 2 - the unit is a storage device and Ipmin = - Ipmax

California ISO Studies of the DER Models

- Numerous studies of standalone models and DER as a part of composite load model
- Simplified (PVD1 or DGPV) models, and more detailed (DER_A) models studied
- Some examples:

Voltage at a bus close to a three-phase fault



CAISO Study of Sensitivity of DER parameters for Behind the Meter DER

- Transmission Planning Process (TPP) sensitivity scenario used
  - 2020 summer peak load conditions
  - High renewable penetration
- 230 kV transmission line fault
  - 3-phase fault close to the sending end
- Plots for a 230 kV bus close to the fault, gross load 49 MW, DER 14 MW

Local area	DER installed capacity	DER output
Humboldt	19	19
North Valley	254	252
North Coast/North Bay	388	384
Greater Bay	1323	1310
Total	1965	1946
Central Valley		
Central Coast/Los	1037	1027
Padres	324	321
Kern	431	426
Total	1792	1774
Fresno	920	911
Total (northern California)	4696	4650

System Impact Sensitivities

1. Compare voltage trip settings (CA Rule 21 & IEEE1547)
2. Sensitivity to voltage support (dead-band and gain)
3. Compare increasing recovery percentage (vrfrac) with no voltage support
4. Compare increasing recovery percentage (vrfrac) with voltage support
5. Compare increasing gain
6. Compare Q priority and P priority

Studies of the Sensitivity of DER_A Parameters.

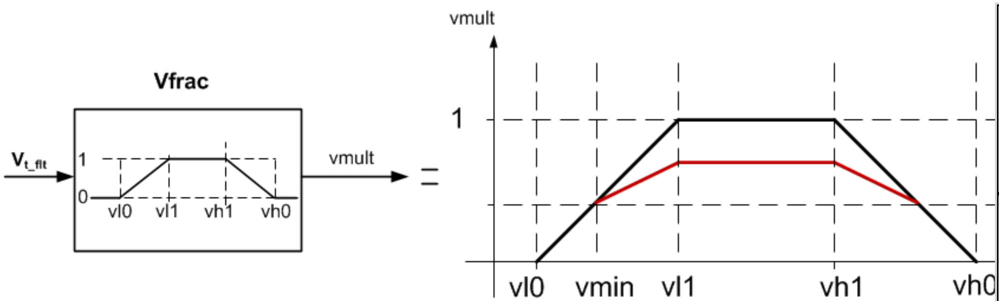
Voltage tripping sensitivity

1. DER is netted with load
2. CA Rule 21 , Voltage tripping

"vl0" 0.50 "vl1" 0.88 "vh0" 1.2 "vh1" 1.1 "tvl0" 0.16 "tvl1" 2.0 "tvh0" 0.16 "tvh1" 1.0 "vrfrac" 0.2

3. Voltage tripping sensitivity (IEEE 1547-2018)

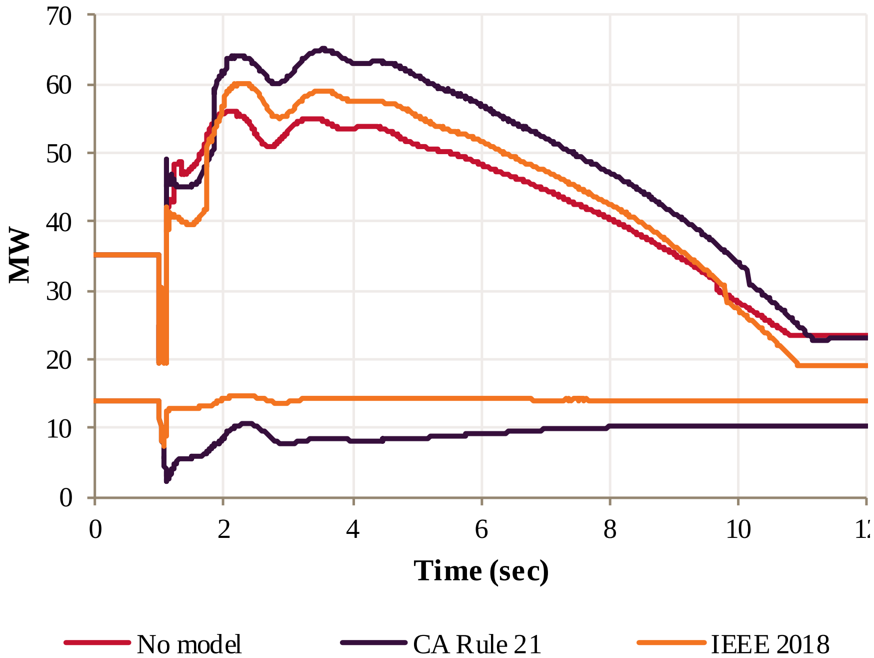
"vl0" 0.44 "vl1" 0.53 "vh0" 1.18 "vh1" 1.1 "tvl0" 0.16 "tvl1" 5.0 "tvh0" 0.16 "tvh1" 1.0 "vrfrac" 0.2



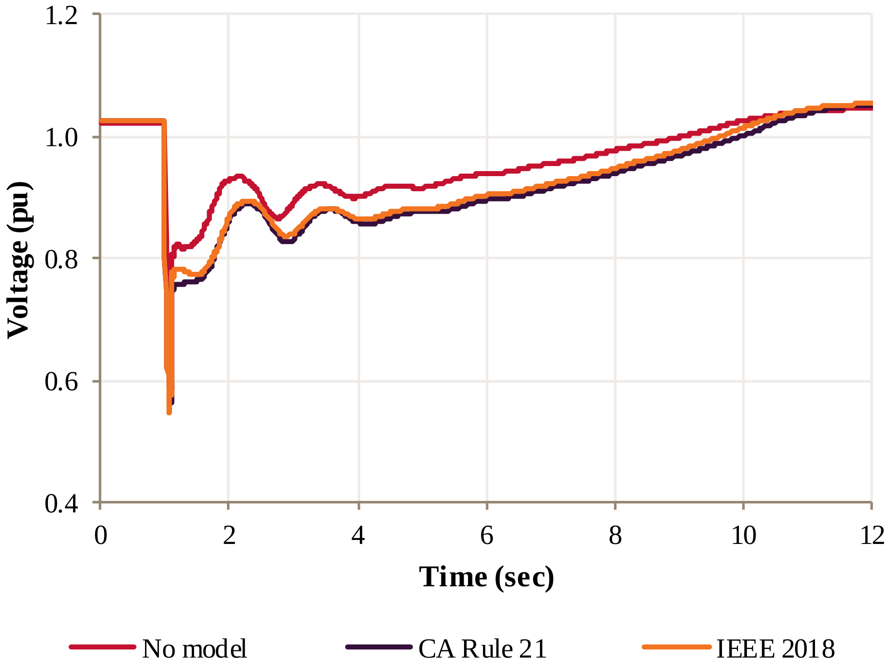
	Absent Model (DER netted)	CA Rule 21 Voltage Trip settings Q Priority	IEEE 1547-2018 Voltage Trip settings Q Priority
Net Load Loss Across Northern California, MW	633	577	852
Loss of Distributed Generation, MW	0	281	25
Loss of Gross Load, MW	633	858	877

Results Comparison – Loss of Load and DER. 230 kV Load Bus Close to the Fault – Trip Voltage Settings

Net Load and DER



Voltage



More DER tripped with Rule 21 because of higher voltage trip settings, thus less net load loss

Less gross load lost with netted DER because gross load included DER

Higher voltage with netted DER, settling voltage the same. DER doesn't provide voltage support

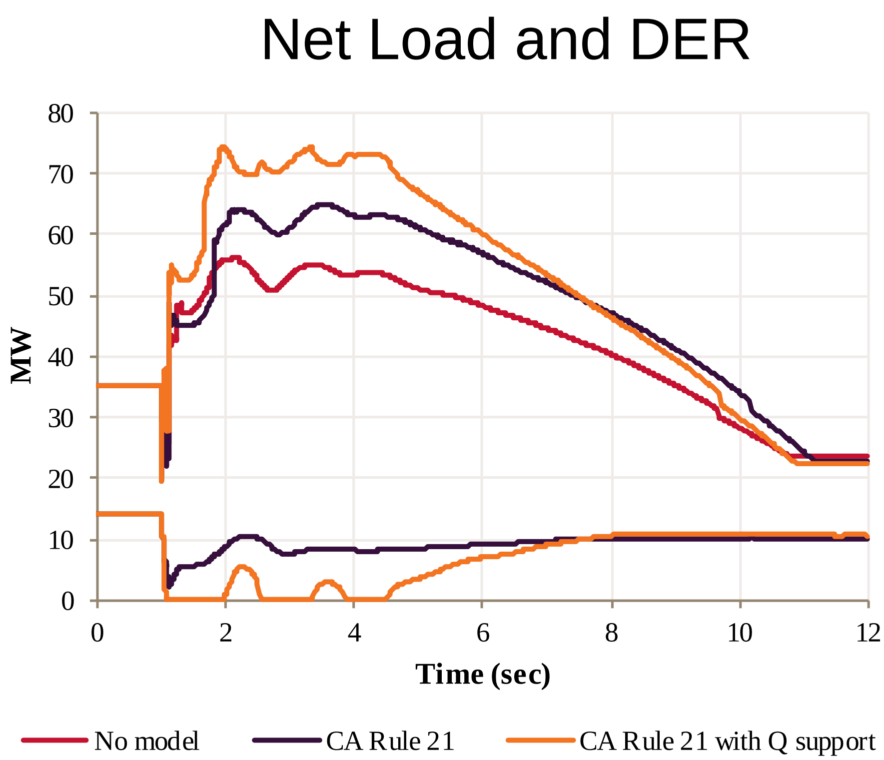
Sensitivity to Voltage Support – Dead-band and Gain. All other parameters as in CA Rule 21

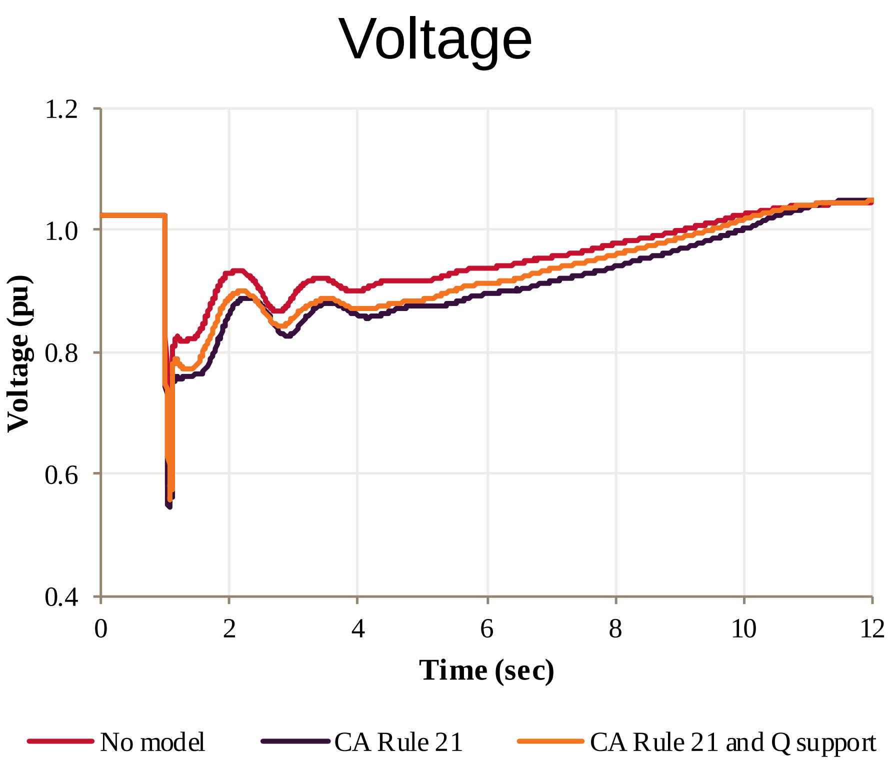
	Absent Model (DER netted)	Gain=0 deadband=+/-99 vfrac = 0.2 Q Priority	Gain = 6 deadband = +/-0.02 vrfrac = 0.2 Q Priority
Net Load Loss Across Northern California, MW	633	577	541
Loss of Distributed Generation, MW	0	281	233
Loss of Gross Load, MW	633	858	774

With voltage regulation:

- Less DER loss
- Higher gross load loss close to the fault, depends on type of load
- Net and gross load loss is less with voltage regulation because of higher voltage

DER_A Sensitivity to Voltage Support – Dead-band and Gain





- Settling load and DER approximately the same
- In short time load with Q support higher because less DER loss

- Higher voltage with netted DER
- Higher transient voltage with Q support
- Settling voltage the same

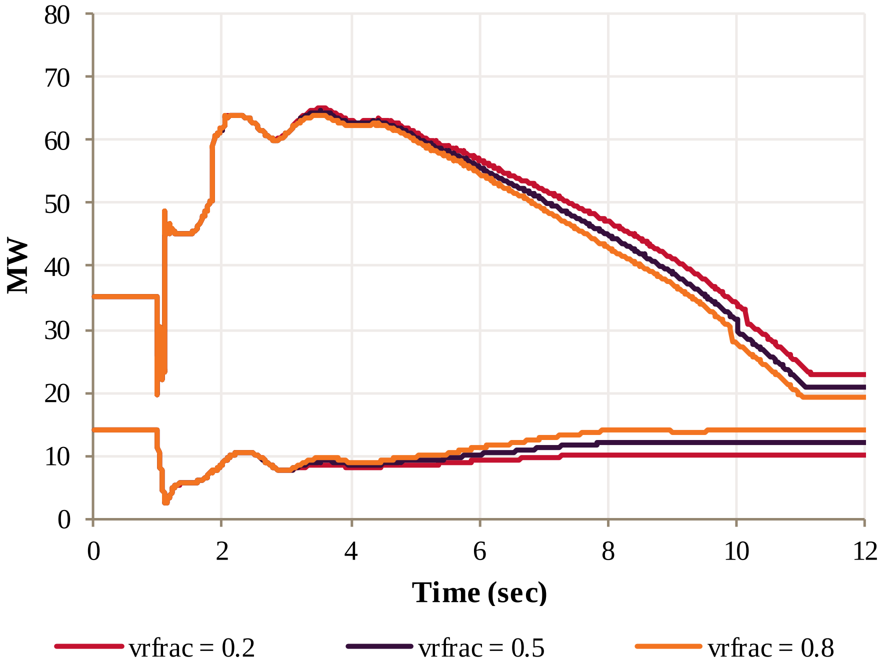
Sensitivity to Increasing DER Recovery (vrfrac). No Voltage Support

	Gain=0 deadband=+/-99 vfrac = 0.2 Q Priority	Gain = 0 deadband = +/-99 vrfrac = 0.5 Q Priority	Gain = 0 deadband = +/-99 vrfrac = 0.8 Q Priority
Net Load Loss Across Northern California, MW	577	683	771
Loss of Distributed Generation, MW	281	185	97
Loss of Gross Load, MW	858	867	868

- Less DER loss with higher DER percentage that recovers
- Thus, higher net load loss
- Gross load loss approximately the same

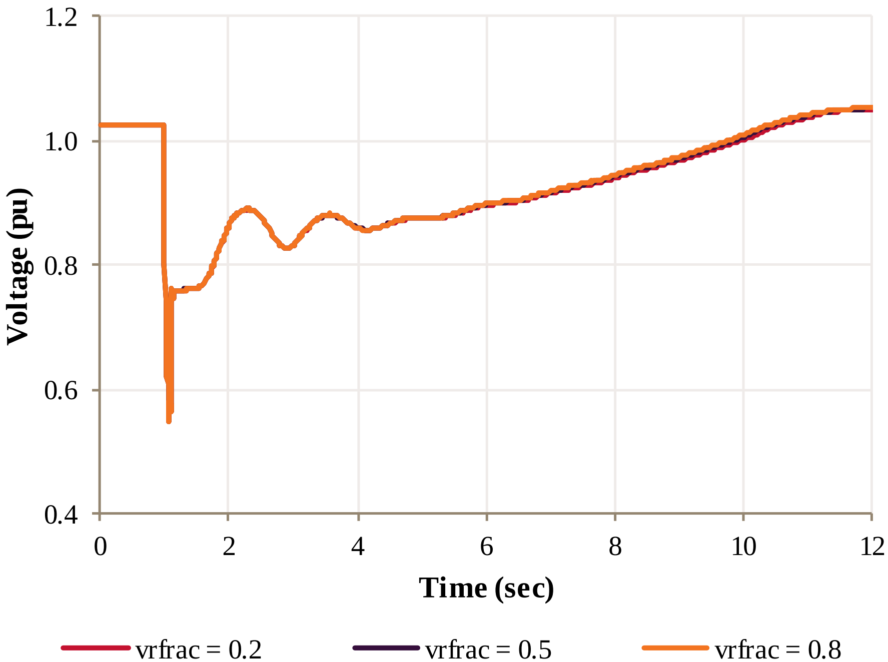
Sensitivity to Increasing DER Recovery (vrfrac). No Voltage Support

Net Load and DER



Net load higher with less DER portion that recovers

Voltage



Voltage the same

Sensitivity to Increasing DER Recovery (vrfrac) with Voltage Support

	Gain = 6 deadband = +/- 0.02 vrfrac = 0.2 Q Priority	Gain = 6 deadband = +/- 0.02 vrfrac = 0.5 Q Priority	Gain = 6 deadband = +/- 0.02 vrfrac = 0.8 Q Priority
Net Load Loss Across Northern California, MW	541	626	698
Loss of Distributed Generation, MW	233	150	85
Loss of Gross Load, MW	774	777	783

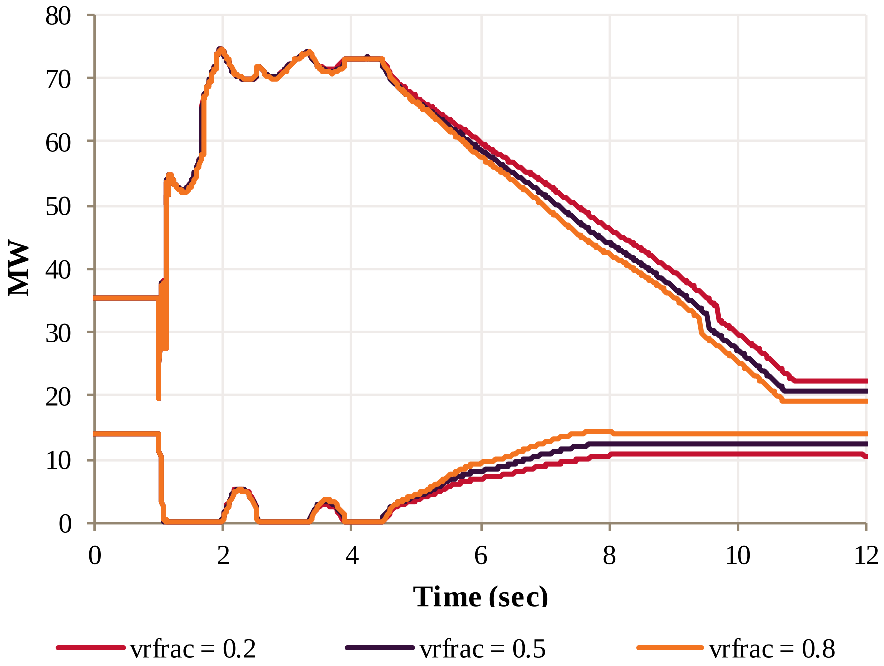
Compare with same, but without voltage support

	Gain=0 deadband=+/-99 vfrac = 0.2 Q Priority	Gain = 0 deadband = +/- 99 vrfrac = 0.5 Q Priority	Gain = 0 deadband = +/- 99 vrfrac = 0.8 Q Priority
Net Load Loss Across Northern California, MW	577	683	771
Loss of Distributed Generation, MW	281	185	97
Loss of Gross Load, MW	858	867	868

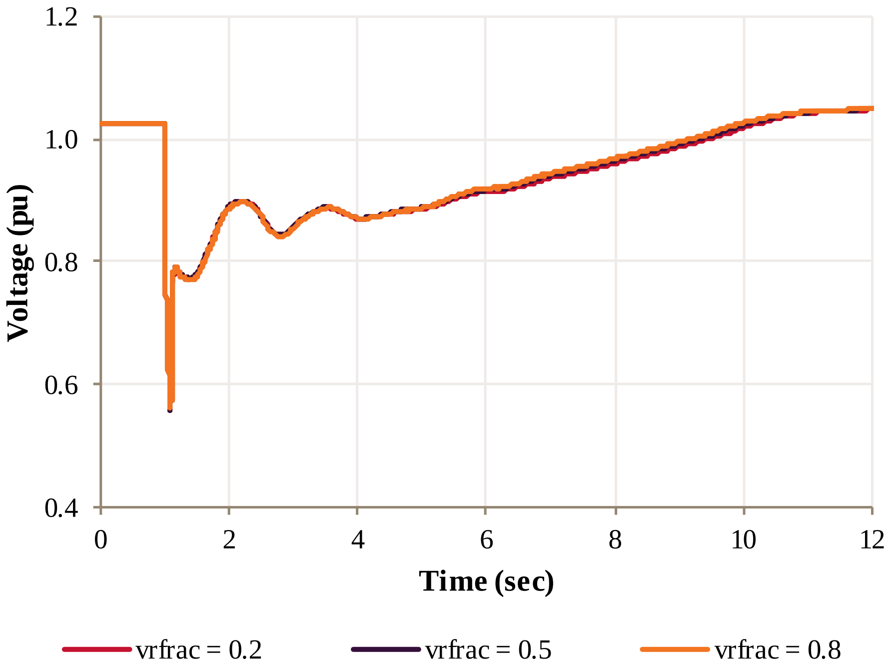
- Same trend as without voltage support: less DER loss with higher recovery percentage
- Less net load loss compared with no voltage support
- Gross load loss inconsistent, but approximately the same

Increasing DER Recovery Sensitivity with Voltage Support

Net Load and DG



Voltage



Net load higher with less DER portion that recovers

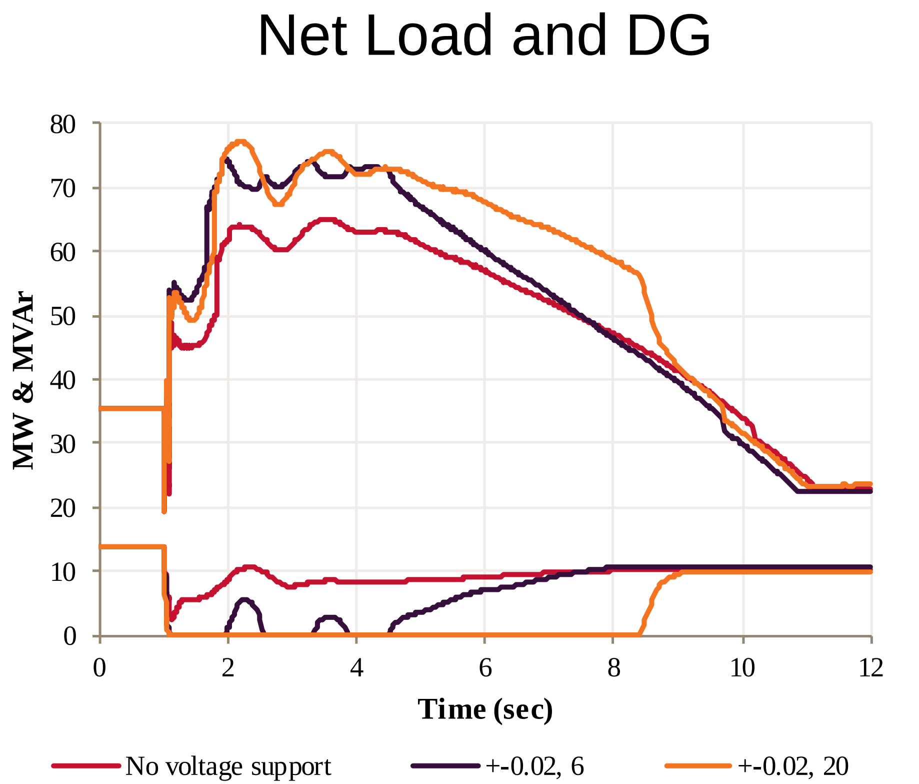
Voltage the same

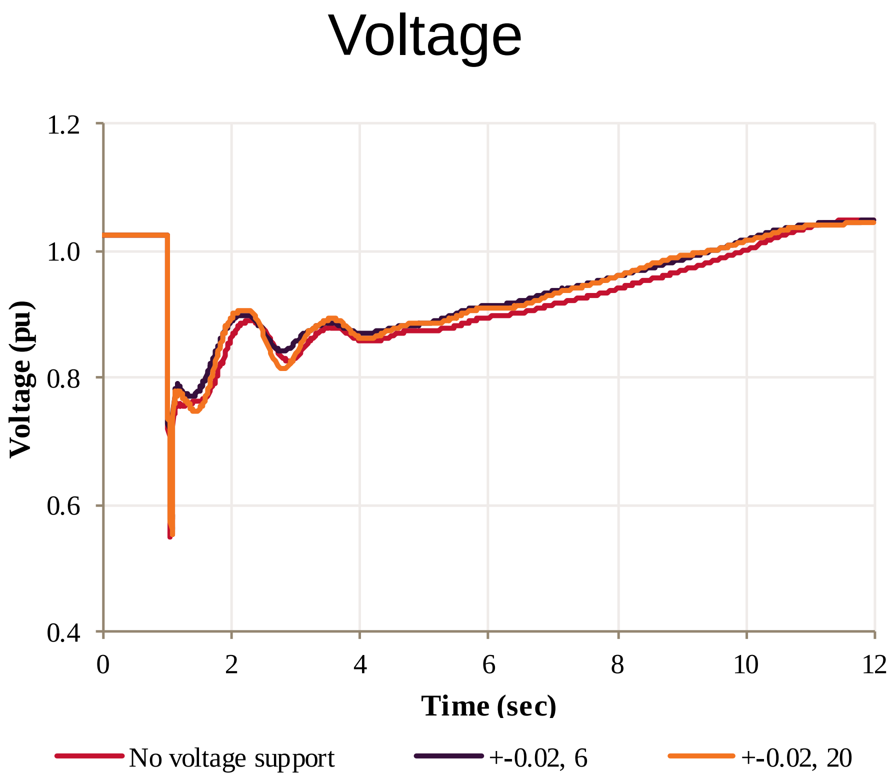
Sensitivity to Increasing Gain on Voltage Regulation

	Gain=0 deadband=+/-99 vfrac = 0.2 Q Priority	Gain = 6 deadband = +/- 0.02 vrfrac = 0.2 Q Priority	Gain = 20 deadband = +/- 0.02 vrfrac = 0.2 Q Priority
Net Load Loss Across Northern California, MW	577	541	514
Loss of Distributed Generation, MW	281	233	258
Loss of Gross Load, MW	858	774	772

- With higher gain, more DER loss
- Gross load loss the same with voltage regulation due to higher voltage
- Without voltage regulation, gross load loss is higher

Sensitivity to Increasing Gain on Voltage Regulation





More decrease in DER with higher gain.
Kqv = 20 may be too high
Due to Q Priority, real power output from DER is lower until voltage recovers

Higher voltage with voltage support

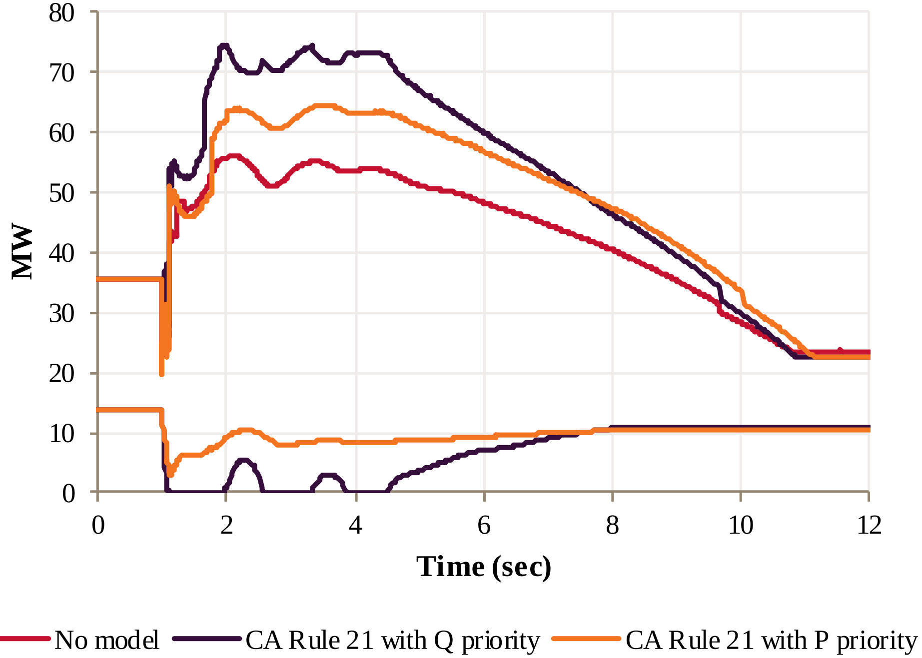
Sensitivity to P Priority & Q Priority

	Absent Model (DER netted)	Gain=0 deadband=+/-99 vfrac = 0.2 Q Priority	Gain = 6 deadband = +/- 0.02 vrfrac = 0.2 Q Priority	Gain = 6 deadband = +/- 0.02 vrfrac = 0.2 P Priority
Net Load Loss Across Northern California, MW	633	577	541	567
Loss of Distributed Generation, MW	0	281	233	270
Loss of Gross Load, MW	633	858	774	837

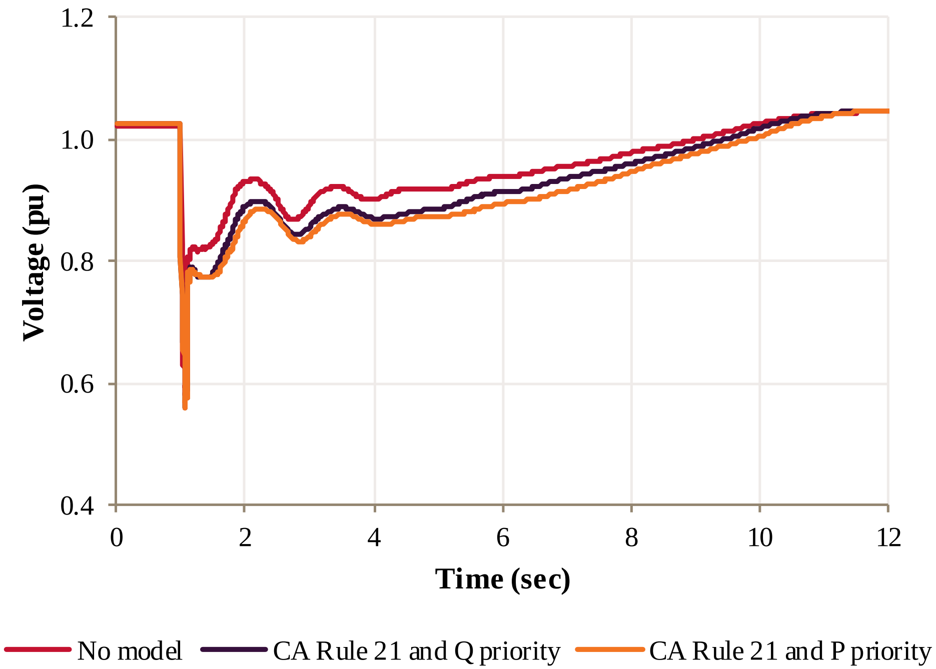
- Higher DER loss with P priority because of lower voltage
- Gross load higher with P priority
- Total net load loss higher with P priority because of lower voltage

Sensitivity to P Priority & Q Priority

Net Load and DG



Voltage



More DER loss during transient period with Q priority, but then recovers to the same value as with P priority

Lower voltage during recovery period with P priority

Summary of the Results. Loss of Load and DER by zone

Local area	Absent Model (DER netted)	CA Rule 21 Voltage Trip settings Q Priority	IEEE 1547-2018 Voltage Trip settings Q Priority	Gain=0 deadband=+/-99 vfrac = 0.2 Q Priority	Gain = 6 deadband = +/-0.02 vfrac = 0.2 Q Priority	Gain = 0 deadband = +/-99 vrfrac = 0.5 Q Priority	Gain = 0 deadband = +/-99 vrfrac = 0.8 Q Priority	Gain = 6 deadband = +/-0.02 vrfrac = 0.5 Q Priority	Gain = 6 deadband = +/-0.02 vrfrac = 0.8 Q Priority	Gain = 20 deadband = +/-0.02 vrfrac = 0.2 Q Priority	Gain = 6 deadband = +/-0.02 vrfrac = 0.2 P Priority
Loss of Net Load, MW											
Humboldt	0	0	0	0	0	0	0	0	0	0	0
North Valley, Coast, Bay San Francisco Bay Area	-11	-21	-22	-21	-19	-24	-26	-19	-20	-18	-15
Central Valley, Coast, Los Padres, Kern	226	237	321	237	155	261	282	168	178	153	218
Fresno	418	362	553	362	405	446	516	477	540	378	365
Loss of Distributed Generation, MW											
Humboldt	0	0	0	0	0	0	0	0	0	0	0
North Valley, Coast, Bay San Francisco Bay Area	0	1	0	1	4	2	1	2	2	2	1
Central Valley, Coast, Los Padres, Kern	0	88	4	88	65	65	45	49	40	66	79
Fresno	0	192	20	192	165	118	51	100	43	191	189
Loss of Gross Load, MW											
Humboldt	0	0	0	0	0	0	0	0	0	0	0
North Valley, Coast, Bay San Francisco Bay Area	-11	-20	-22	-20	-15	-23	-25	-18	-18	-16	-14
Central Valley, Coast, Los Padres, Kern	226	325	325	325	220	326	326	217	217	219	297
Fresno	418	553	573	553	570	564	566	577	584	569	554
Net Load Loss Across Northern California, MW											
	633	577	852	577	541	683	771	626	698	514	567

Conclusions

- The composite load model with the DER representing distributed generation is adequate and shows expected performance in the dynamic stability studies.
- The study results are different when DER are modeled as a part of composite load model or netted with load.
- Need to consider which parameters to use because the results are sensitive to the DER_A parameters.
  - Increased DER recovering resulted in increase of net load lost.
  - Q priority indirectly supports frequency by reducing net load lost.
- Having the DER modeled as a part of the composite load becomes more critical with the higher penetration of the behind-the-meter distributed generation. Other options of modeling these resources give less accurate and less realistic results

Future Work

- Improve the models of load and distributed generation.
- Continue to perform system impact and sensitivity studies of the composite load model with DER, using existing and new models
- Develop DER models for generation other that solar PV
- Compare the simulations with historical events, if data is available
- Continue work on the new modular models, including DER_A model that will become a plug-in into composite load model, as well as be a stand alone model
- Work on the parameters of the DER_A model and on sensitivity studies

QUESTIONS?
COMMENTS?

Please send your comments to Irina Green
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