Industry Webinar

Reliability Guideline: Parameterization of the DER_A Model

November 8, 2019

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Overview of Webinar

Topic	Presenters
Introduction & Kickoff - *Summary of NERC SPIDERWG Activities*	Ryan Quint, NERC Kun Zhu, MISO
DER Modeling Background - *Review of Recommended DER Modeling Practices*	Mohab Elnashar, NERC
Parameterization and Use of DER_A Dynamic Model - *Review of DER_A Dynamic Model* - *Application of DER_A Model for System Studies* - *Parameterization of DER_A Model*	Deepak Ramasubramanian, EPRI
System Studies using the DER_A Dynamic Model - *CAISO Application of DER_A Model* - *ISO-NE Application of DER_A Model*	Irina Green, CAISO Kannan Sreenivasachar, ISO-NE
Wrap Up - *Key Takeaways & Recommendations*	Ryan Quint, NERC
Q&A	All

Existing NERC Reliability Guidelines

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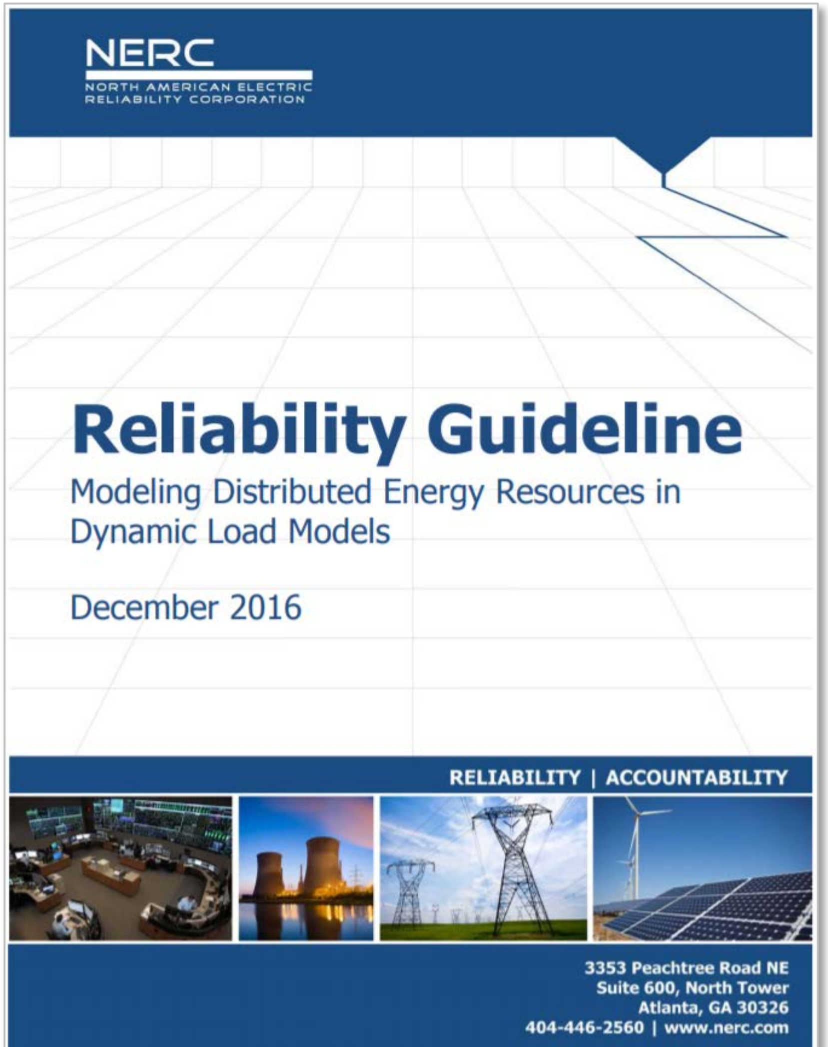
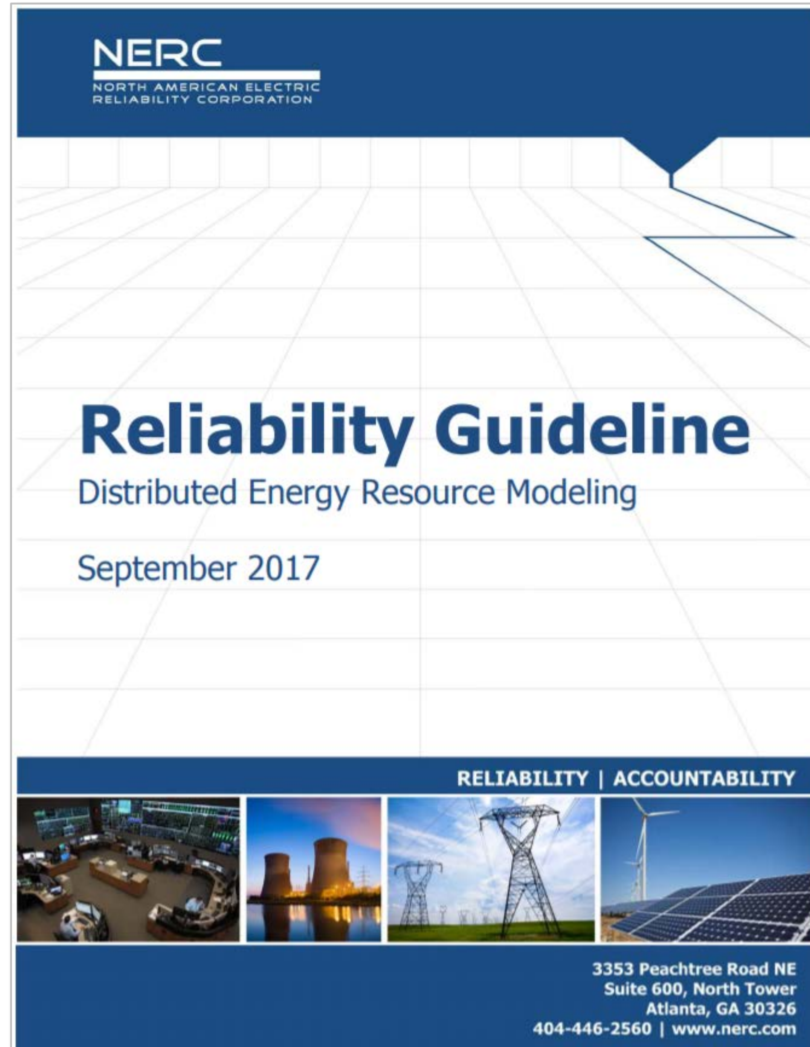
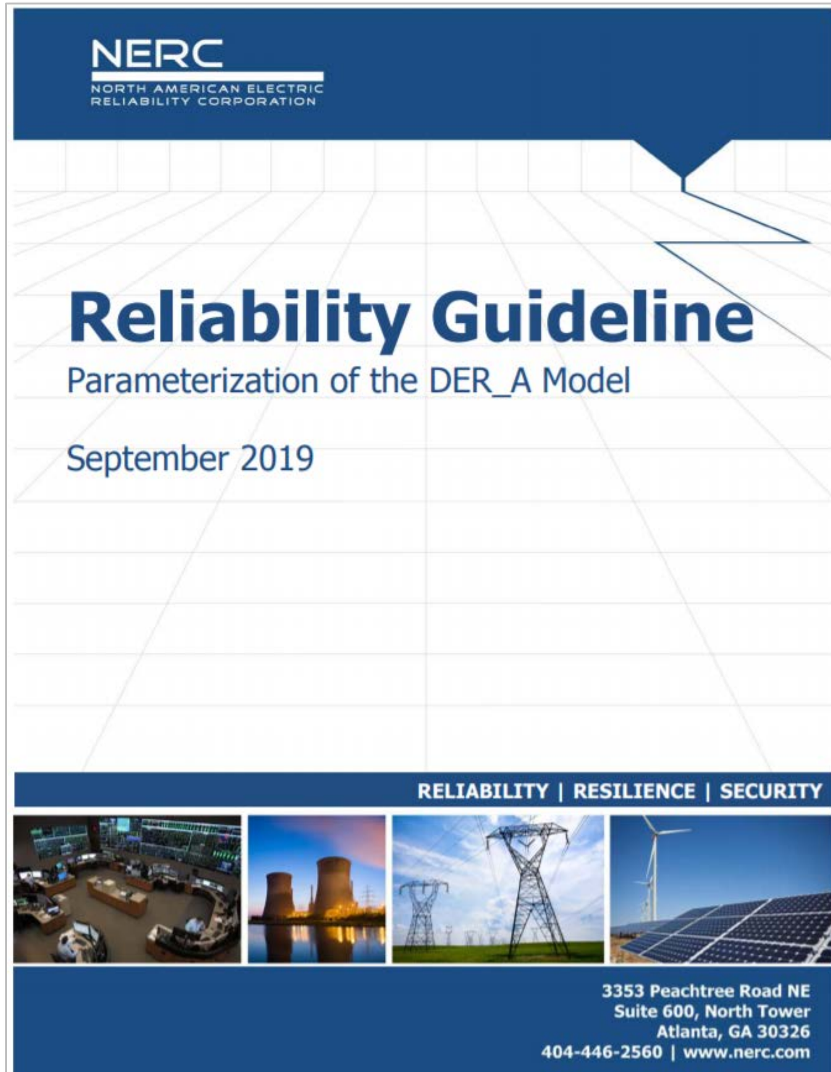




Reliability Guideline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Parameterization of the DER_A Model

September 2019

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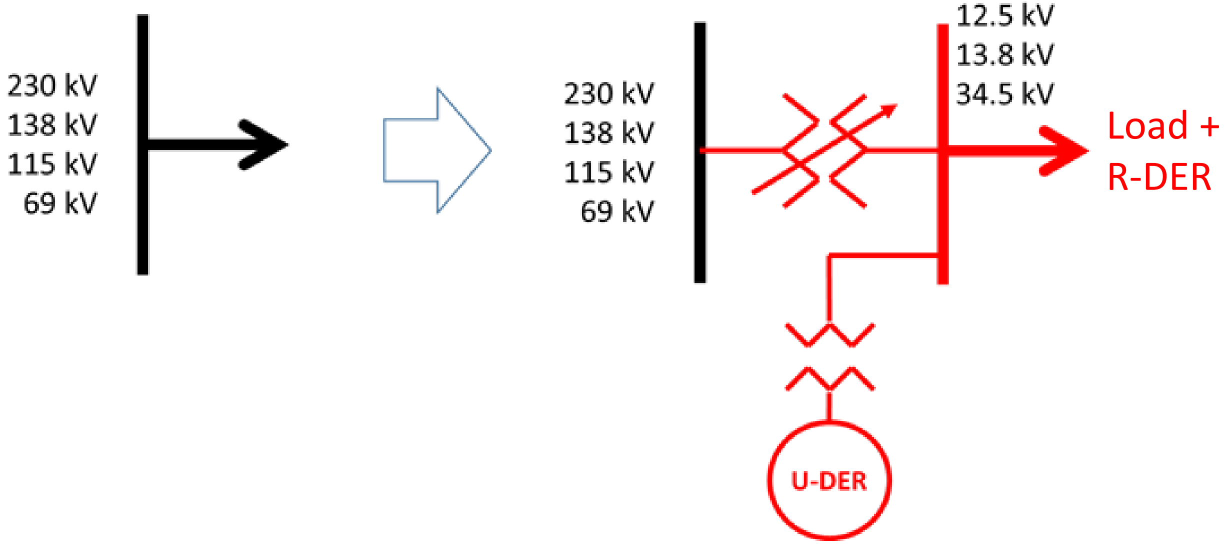
DER Modeling Background:

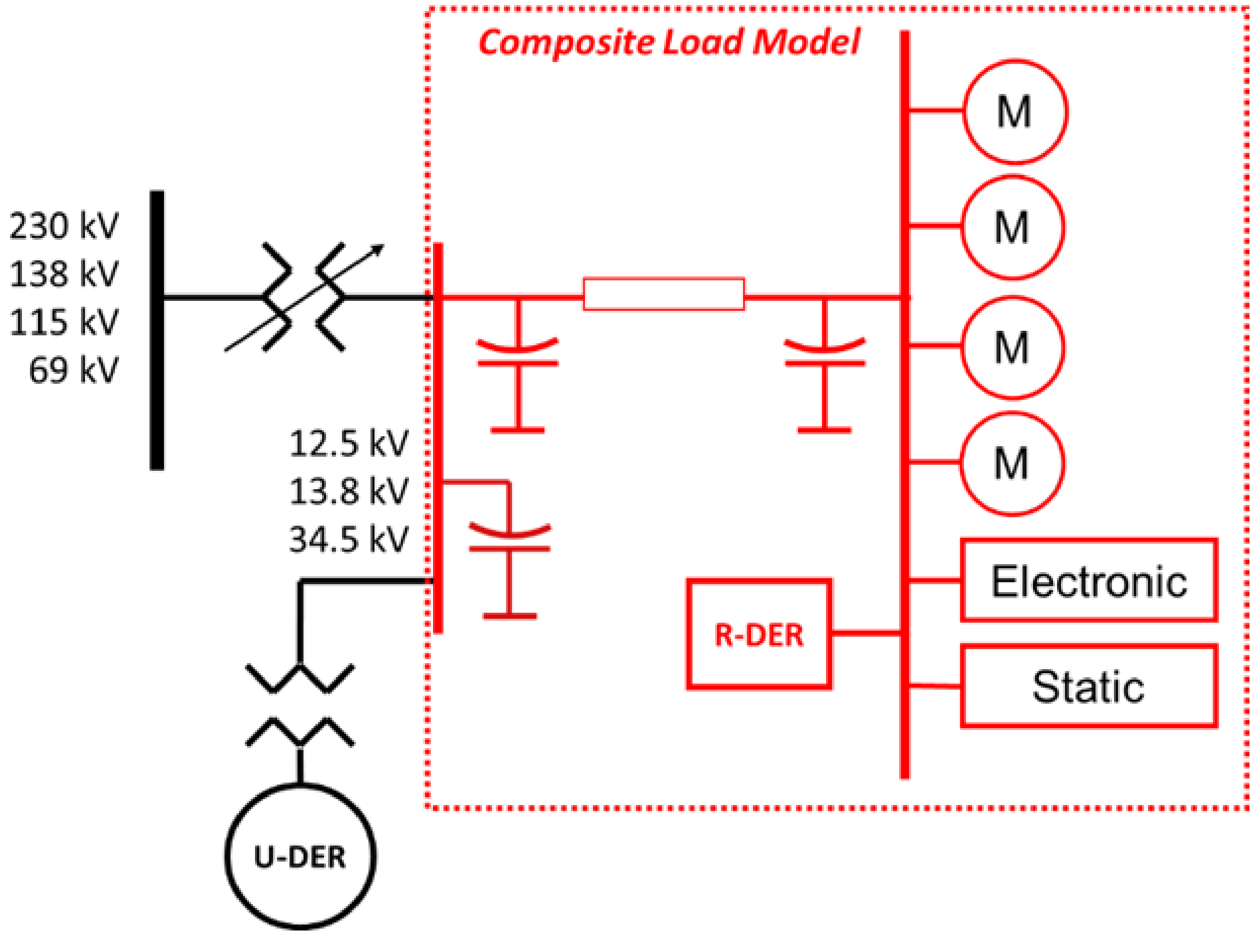
Existing Recommendations for DER Modeling

DER Powerflow Modeling

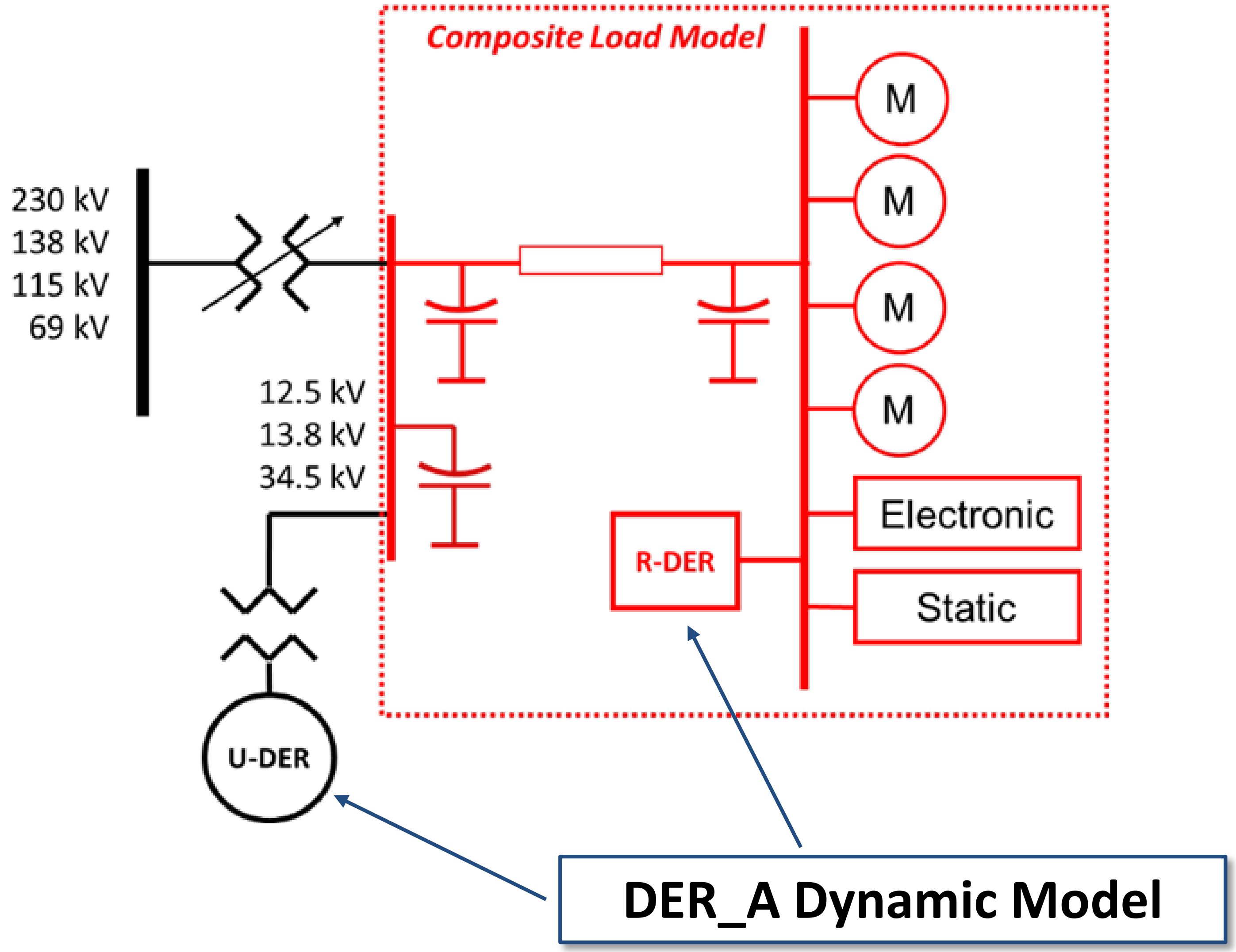


	Number of Bus	Name of Bus	Area Name of Load	Zone Name of Load	ID	Status	MW	Mvar	MVA	S MW	S Mvar	Dist Status	Dist MW Input	Dist Mvar Input	Dist MW	Dist Mvar	Net Mvar	Net MW
1	2	Two	Top	1	1	Closed	80.00	20.00	82.46	80.00	20.00	Closed	40.00	0.00	40.000	0.000	20.000	40.000
2	3	Three	Top	1	1	Closed	220.00	40.00	223.61	220.00	40.00	Open	110.00	0.00	0.000	0.000	40.000	220.000
3	4	Four	Top	1	1	Closed	160.00	30.00	162.79	160.00	30.00	Closed	80.00	0.00	80.000	0.000	30.000	80.000
4	5	Five	Top	1	1	Closed	260.00	40.00	263.06	260.00	40.00	Open	130.00	0.00	0.000	0.000	40.000	260.000
5	6	Six	Left	1	1	Closed	400.00	0.00	400.00	400.00	0.00	Closed	200.00	0.00	200.000	0.000	0.000	200.000
6	7	Seven	Right	1	1	Closed	400.00	0.00	400.00	400.00	0.00	Closed	200.00	0.00	200.000	0.000	0.000	200.000

DER Dynamics Modeling

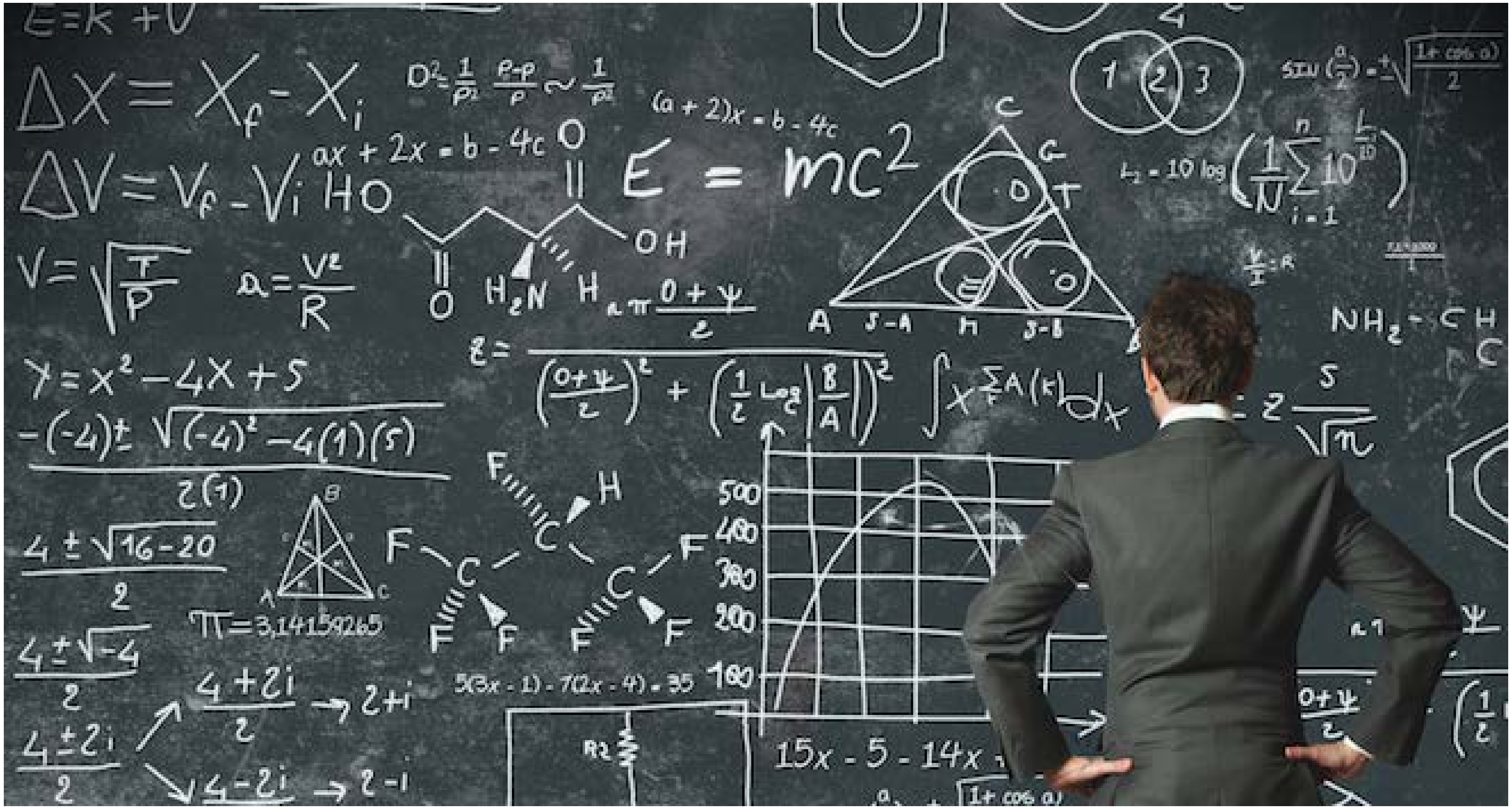


DER_A Model Application



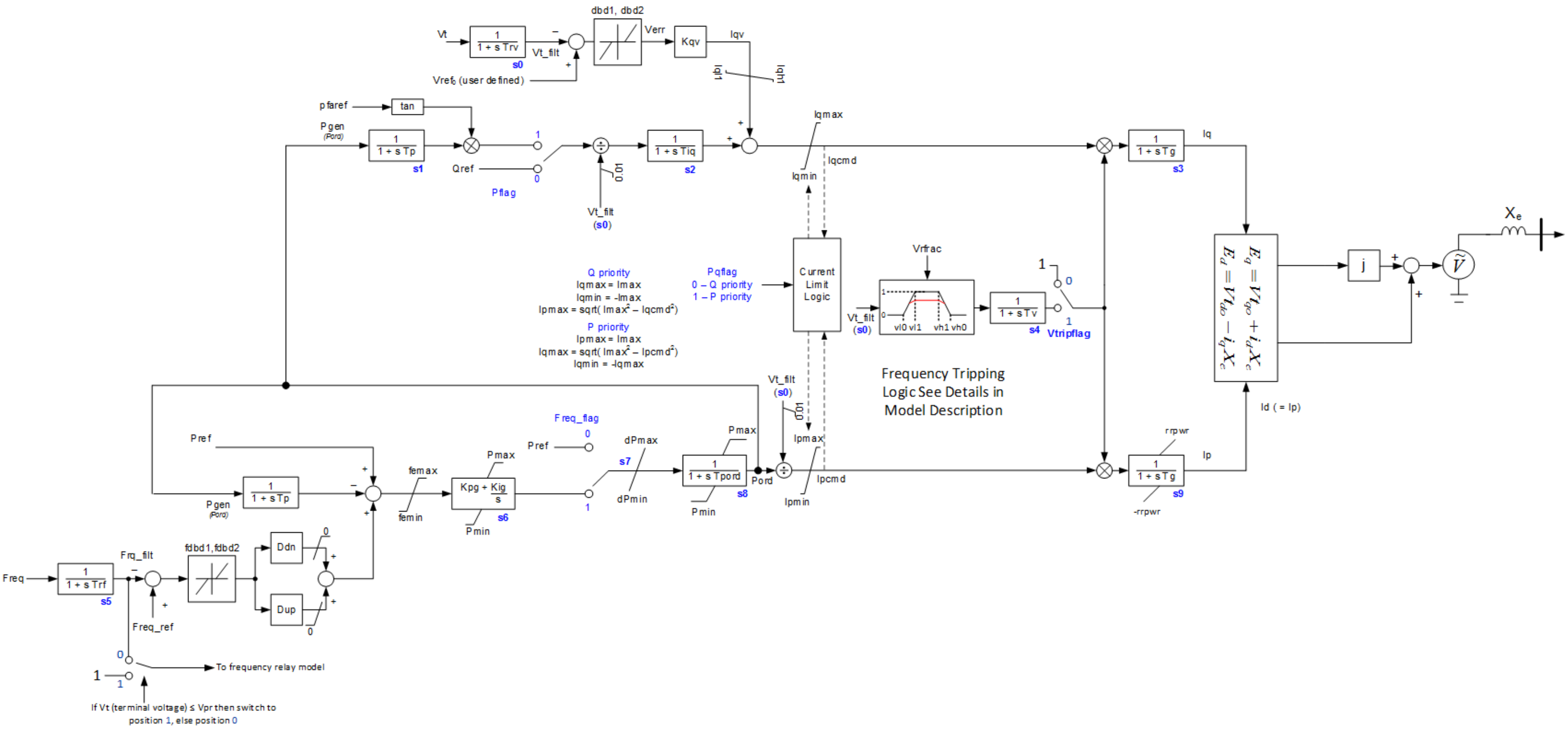
It's That Simple...

DER_A Dynamic Model

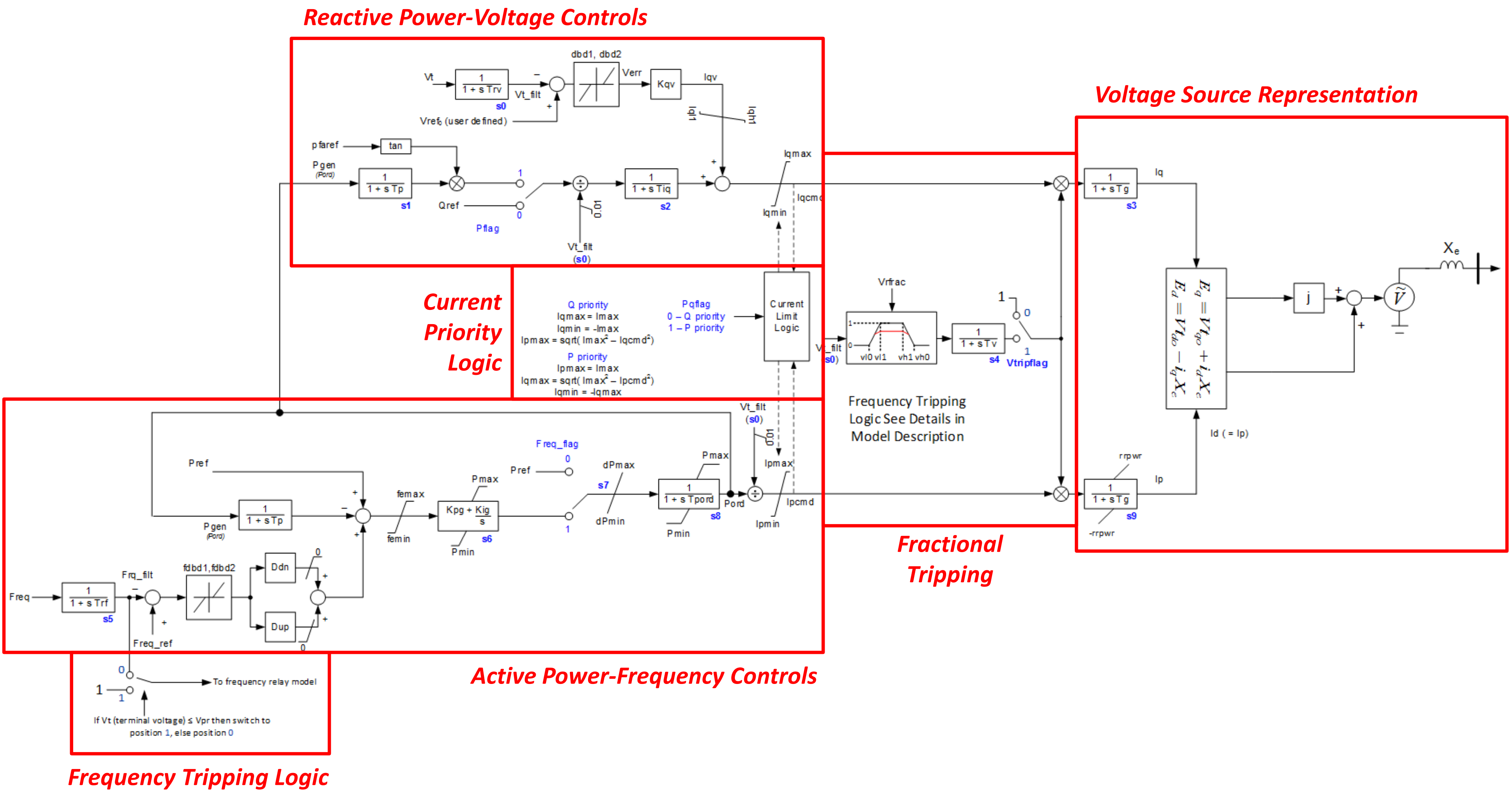


Understanding the DER_A Dynamic Model

The DER_A Dynamic Model

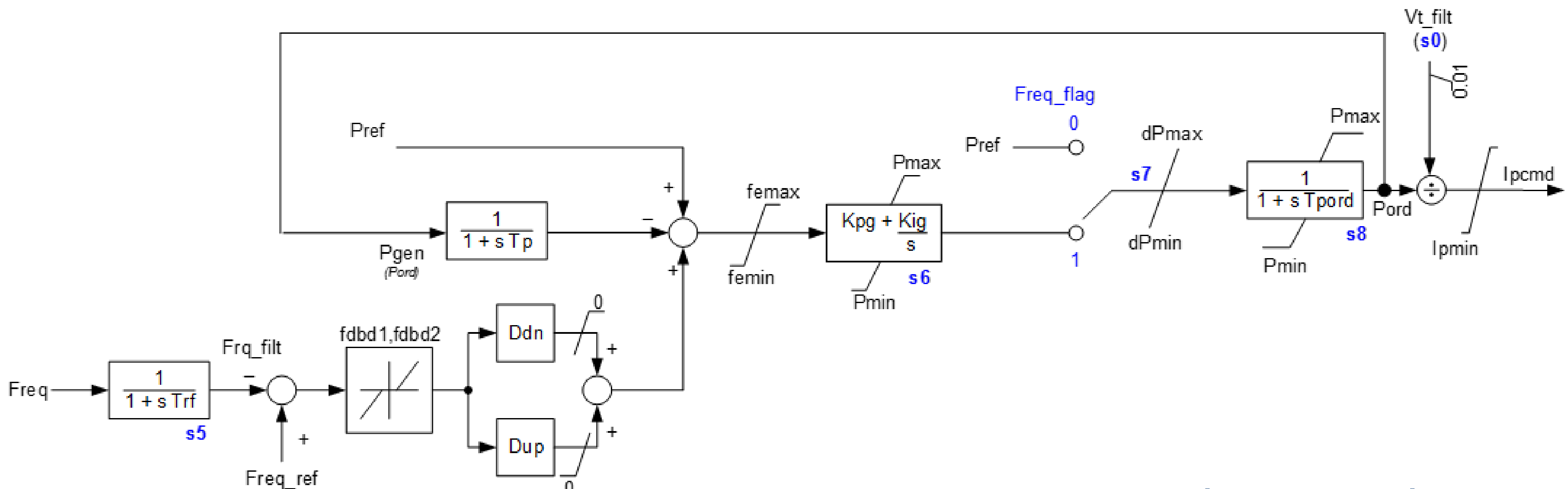


The DER_A Dynamic Model



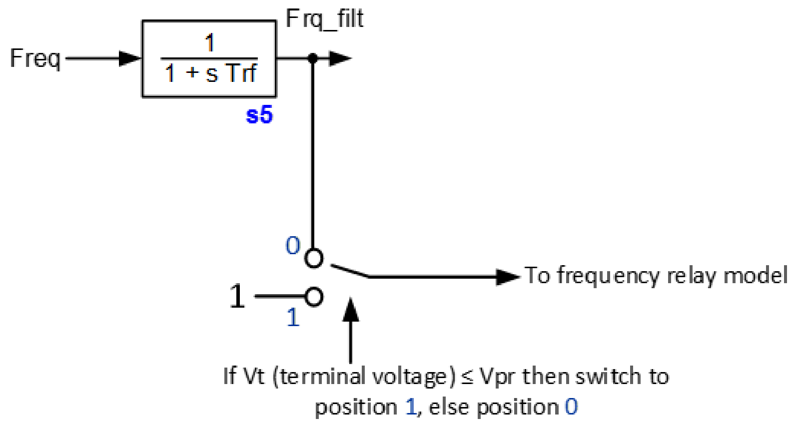
Active Power-Frequency Control

- Typical frequency-droop control with PI controller
  - Tfr = frequency measurement time constant; Tp = active power measurement time constant
  - Fdbd1 and fdbd2 = over- and under-frequency deadbands, respectively
  - Ddn and Dup = over- and under-frequency droop gains, respectively
  - Freq_flag = 1 enables controls
  - Kpg and Kig PI control gains
  - dPmax and dPmin limit active power up and down ramp rates; Pmax and Pmin are max and min power output
  - Tpord is power-order time constant; can be used to represent small time lag for changing power reference (when Freq_flag = 0) or open-loop time constant associated with full controls (when Freq_flag = 1) as specified in IEEE Std. 1547-2018
  - Active current command (ipcmd) calculated using power-order (Pord) divided by filtered terminal voltage (Vt_filt), and it is limited by Ipmax and Ipmin



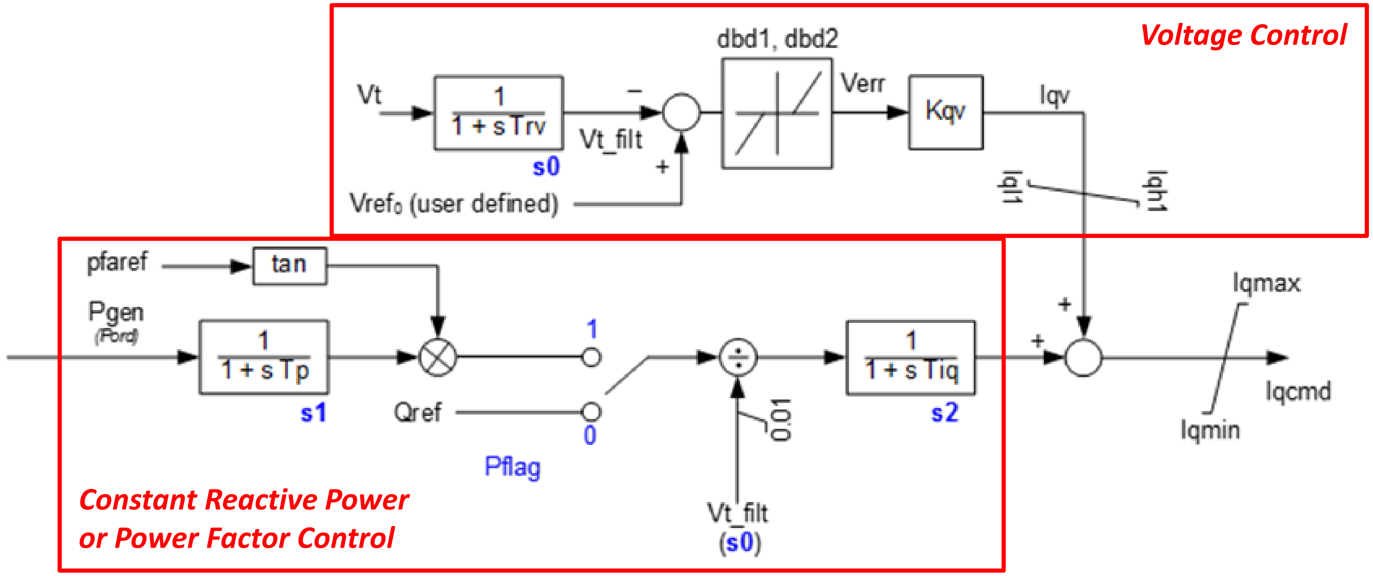
Frequency Tripping Logic Input

- Tfr = frequency measurement time constant
- Low voltage inhibit logic added to model
- When V < Vpr, then the frequency relay model is bypassed
  - This is common in frequency protective functions to avoid spurious tripping during transients
  - In numerical simulations, this low voltage inhibit is also used to avoid tripping on numerical spikes during discontinuities



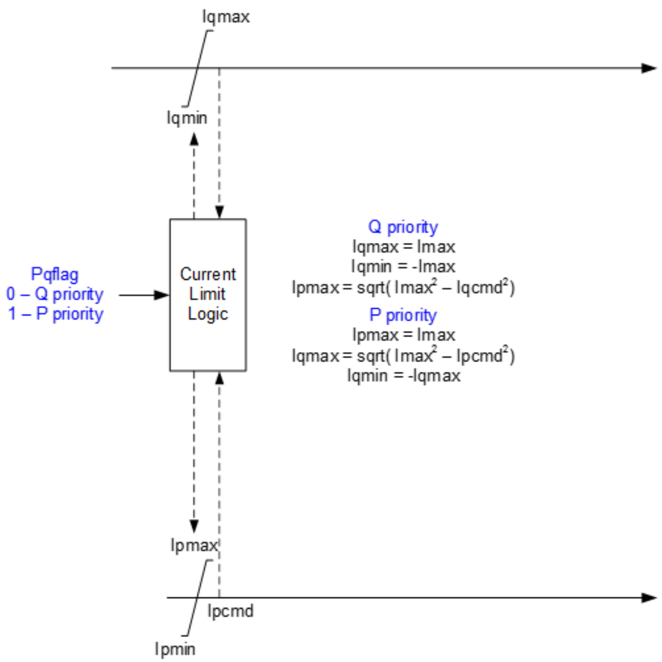
Reactive Power-Voltage Controls

- pflag = 0 is constant reactive power control; pflag = 1 is constant power factor control
  - pfaref is initialized and held constant to achieve necessary reactive power order for the current active power order
  - Reactive power divided by filtered terminal voltage (Vt_filt), passed through reactive current calculation time constant (Tiq)
- Voltage control is included in the model
  - Terminal voltage (Vt), after a measurement time constant (Trv), passes through a lower (dbd1) and upper (dbd2) deadband and proportional control gain (Kqv)
  - Respectively, Iqh1 and Iql1 specify maximum and minimum limits of reactive current injection
  - To disable the reactive power-voltage control function of the model, set Kqv to 0



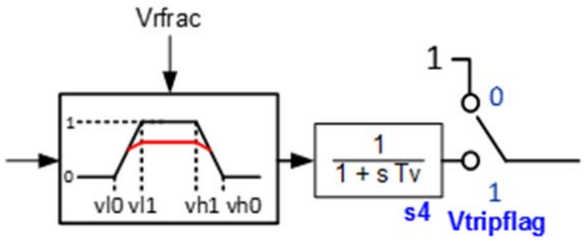
Active-Reactive Current Priority Logic

- With active and reactive current commands established in P-f and V-q control blocks, the command values are passed through maximum (Ipmax/Iqmax) and minimum (Ipmin/Iqmin) current limits.
- When typeflag = 0, this denotes a DER that is a generating unit with Ipmin = 0
- When typeflag = 1, this denotes a DER that is an energy storage device with Ipmin = -Ipmax
- Current limits, particularly in inverter-based resources, dominate how the resource responds to large disturbances (e.g., BPS faults).
- Current limit logic based on whether resource is operated in active or reactive current priority (pqflag parameter)
- Priority logic controls Iqmax and Iqmin based on priority setting and maximum total inverter current inverter (Imax)
- Example:
  - If reactive current priority selected, then Iqmax and Iqmin are limited to Imax and -Imax, respectively
  - Based on reactive current ordered by controls, active current limit is simultaneously calculated to utilize the remaining total apparent current capability (Imax)
  - A circular capability curve is assumed

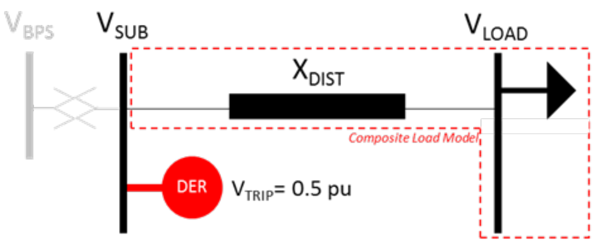


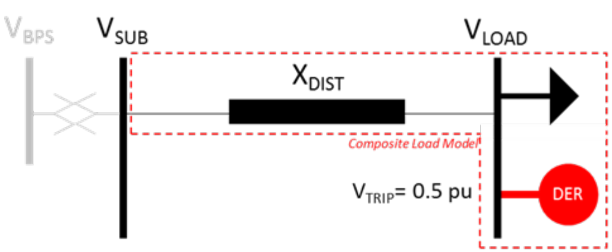
Fractional Tripping

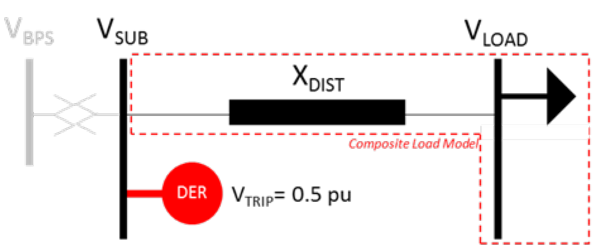
- Represents fraction of DER tripping and recovering for abnormal V and f
- Specific data related to DER tripping often not available; engineering judgment used
  - Based on expected vintage of DERs and distribution circuit characteristics
  - Each interconnection standard may have different ride-through and trip settings, multiple magnitude/time duration pairs
  - Proportion of DERs applicable to each standard may be inferred by DPs by assessing the date of each DER installation
  - Planners should coordinate with Distribution Providers to track proportion of DERs expected to fall within each standard
- Fractional trip settings not *necessarily* intended to match IEEE Std. 1547 exactly; DER_A model may represent aggregate behavior of many DERs.
- DER_A does not include multiple points; consider needs of stability study and select parameters appropriately (likely use shorter trip time points)
- vtripflag controls voltage tripping; ftripflag controls frequency tripping
- tvl related to trip timing; vl related to trip thresholds
- Vrfrac defines fraction of DERs that recover after voltage returns to within acceptable limits after dropping below or above the threshold values
- No partial tripping on frequency (single set of frequency breakpoints, low (fl) and high (fh))
- Tv = time delay for voltage related partial tripping
- Can crudely model momentary cessation, if needed
  - Set vl1, vl0, tvl0, and tvl1 with care; vl0 set to highest undervoltage point where momentary cessation starts occurring
  - Momentary cessation not required for Cat II in IEEE Std. 1547-2018; however, permissive operation range does allow its use



Fractional Tripping Derivation: Modeling Options



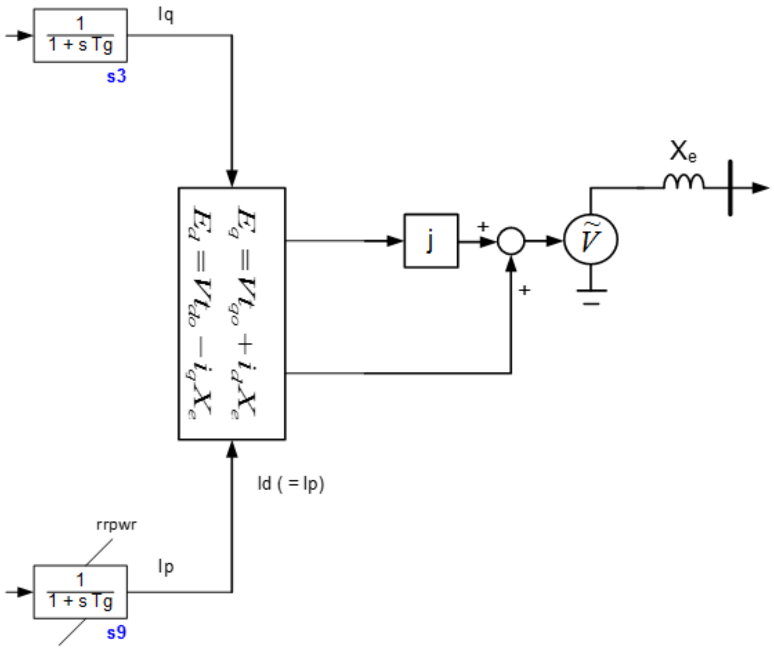




- **Option 1 (Recommended for U-DERs):**
  - U-DER is represented in powerflow as generator; has associated DER_A model in dynamics intended to represent one or multiple U-DERs
  - Load modeling unrelated here since U-DER modeled explicitly
  - Partial tripping not applied; the DER trip settings can mirror those specified in the respective interconnection requirements (vl0, vl1, vh0, and vh1 have a direct relation to interconnection requirements; Vrfrac either 1 or 0 depending on vintage of DER)
- **Option 2 (Recommended for R-DERs):**
  - Aggregate R-DERs represented in powerflow as part of load record; in dynamics, integrated into CLM with DER representation (e.g., cmpldwg).
  - Equivalent distribution impedance represented in CLM; load and DER at load bus
  - Voltage drop (VDROP) across feeder accounted for explicitly (V_DROP=V_SUB-V_LOAD)
  - VDROP of 2–8% typical for most distribution feeders; 5% is reasonable assumption
  - Example: Assuming trip setting of 0.5 pu, then DERs start tripping when the load bus voltage reaches 0.5 pu. All DERs tripped when substation bus voltage reaches 0.5 pu (meaning load bus voltage is 0.45 pu). vl1 equals 0.5 pu; vl0 equals 0.45 pu.
- **Option 3 (Not Recommended):**
  - All DERs (U-DER and/or R-DER) represented in powerflow as stand-alone generator
  - Same concept as in Option 2 applies, with minor modifications. In this case, the DERs are connected to the substation bus.
  - Example: DERs start tripping when implied load-side bus (feeder impedance not represented) reaches 0.5 pu (VSUB=VLOAD+VDROP=0.55 pu) and all are tripped when substation bus voltage reaches 0.5 pu; vl1 = 0.55 pu and vl0 = 0.5 pu.
  - Does not follow recommended DER modeling framework; however, it is an option.

Voltage Source Representation

- Implemented at network interface to support numerical stability of the model in the simulation tools.
- In reality, all modern inverters on grid-side of power electronic interface use a voltage source converter (VSC)
  - Specifically, a dc voltage source behind a full four-quadrant controlled dc to ac power electronic converter
- Current through VSC is strictly controlled by inverter controls (can be represented as a voltage source behind an impedance)
- In order to develop the value of the voltage behind the impedance, values of ipcmd and iqcmd are used to evaluate voltage drop across the impedance and thereby develop the complex voltage
- Xe most typically around 0.25 pu



Parameterization of the DER_A Model

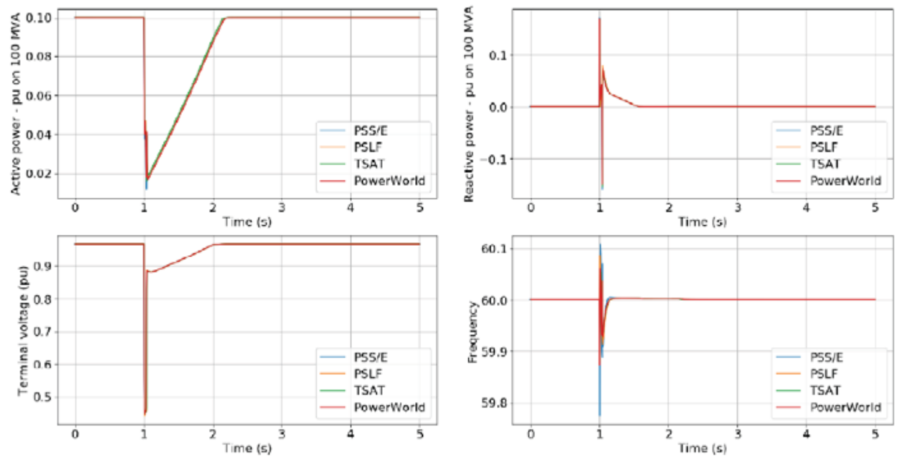
Table 2.1: Default DER_A Model Parameters					
Param[40]	IEEE Std. 1547-2003 Default	IEEE Std. 1547a-2014 Default	CA Rule 21 Default	IEEE Std. 1547-2018 Category II Default	Notes
trv	0.02	0.02	0.02	0.02	† Note 1
dbd1	-99	-99	-99	-99	† Note 1
dbd2	99	99	99	99	† Note 1
kqv	0	0	0	0	† Note 1
vref0	0	0	0	0	† Note 2
tp	0.02	0.02	0.02	0.02	†
tiq	0.02	0.02	0.02	0.02	†
ddn	0	0	20	20	Note 3
dup	0	0	20	20	Note 3

Practical DER_A Model Implementation

Table 3.1: Default Parameter Selection for Mixed Vintages of DER				
Param	Early Vintage DER System IEEE Std. 1547-2003	70% of -2003 30% of -2018	30% of -2003 70% of -2018	Newer Vintage DER System IEEE Std. 1547-2018 (Category II)
trv	0.02	0.02	0.02	0.02
dbd1	-99	-99	-99	-99
dbd2	99	99	99	99
kqv	0	0	0	0
vref0	0	0	0	0
tp	0.02	0.02	0.02	0.02
tiq	0.02	0.02	0.02	0.02
ddn	0	6	14	20
dup	0	0	0	0
fdbd1	-99	-0.0006	-0.0006	-0.0006
fdbd2	99	0.0006	0.0006	0.0006
femax	0	0	99	99
femin	0	0	-99	-99
pmax	1	1	1	1
pmin	0	0	0	0

DER_A Model Benchmarking

Software-specific model benchmarking



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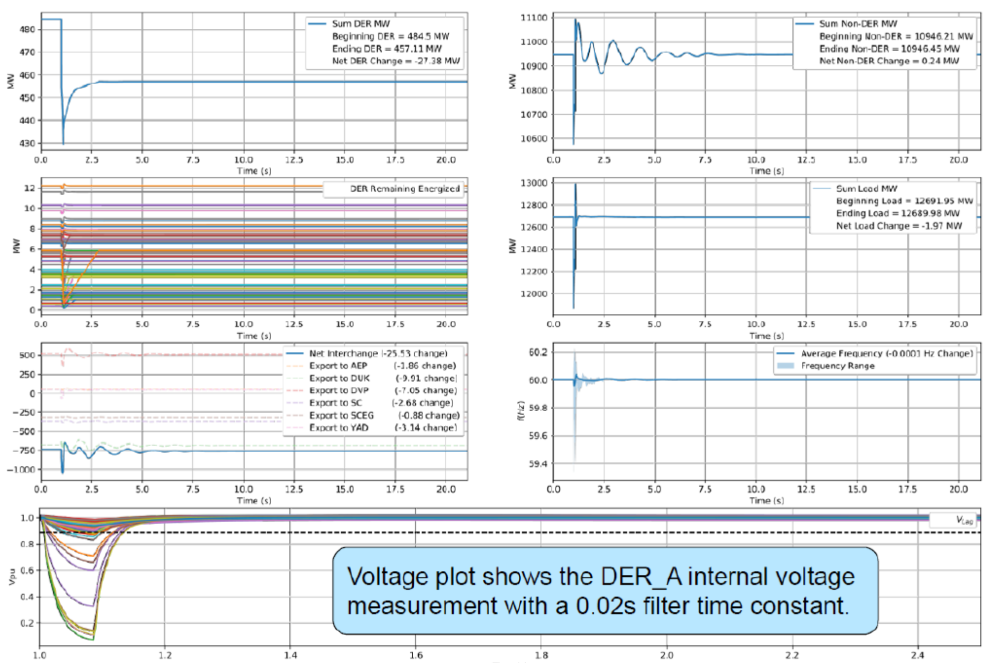
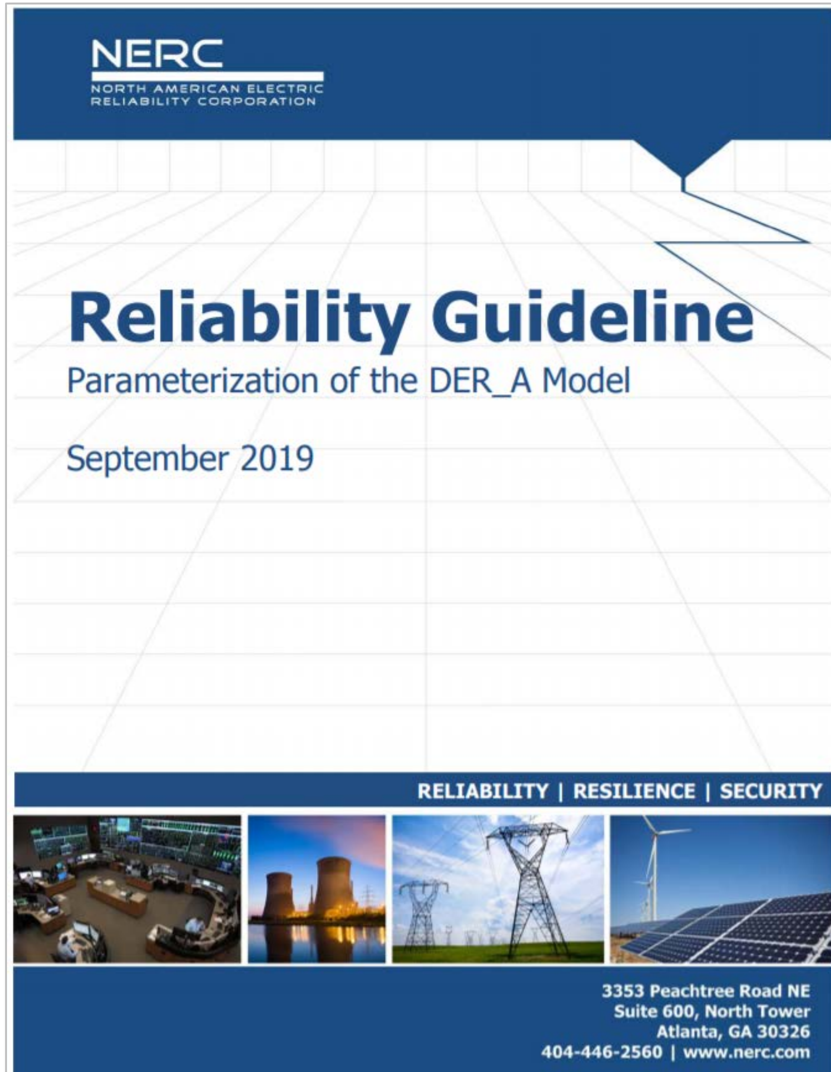


System-level implementation benchmarking

Reliability Guideline



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Industry Experience using the DER_A Dynamic Model

CAISO Simulations: Voltage Studies

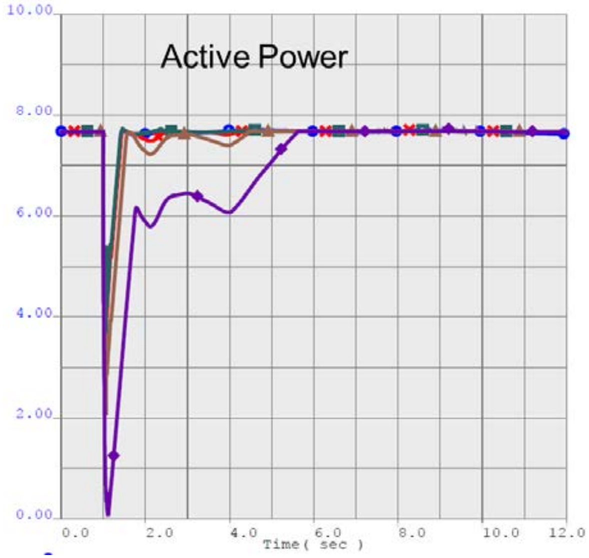
Load and DER in Northern California	No voltage control, P priority, DER MVAR =0		No voltage control, Q priority, DER MVAR =0		Voltage control, P priority, DER MVAR =0		Voltage control, Q priority, DER MVAR =0		Voltage control, Q priority, DER MVAR at 0.95 lagging	
	MW	%	MW	%	MW	%	MW	%	MW	%
Reduction in net load	1701	5.7%	1713	5.7%	1729	5.8%	1530	5.1%	1573	5.3%
Reduction in gross load	1712	5.4%	1713	5.4%	1729	5.5%	1531	4.8%	1574	5.0%
Reduction in DER output	11	0.6%	0	0.0%	0	0.0%	1	0.1%	1	0.1%

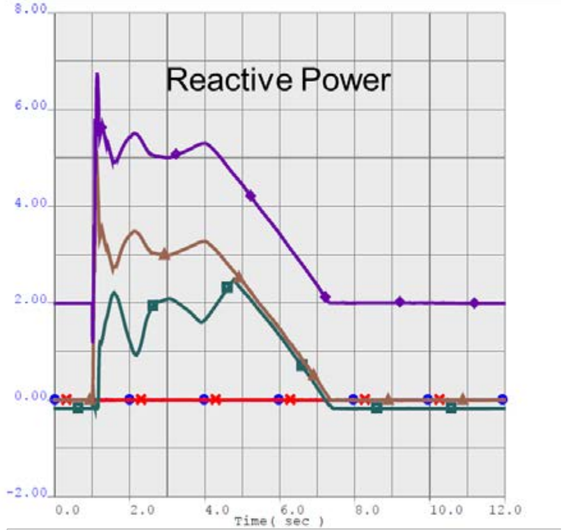
Setup and Settings:

- Proportional voltage control, Kqv=5, dbd1= -0.12, dbd2=0.1
- 70% inverters IEEE1547-2018 and 30% IEEE1547-2003
- Active-reactive current priority options with and without voltage control
- 2029 summer peak base case; 500 kV line fault

CAISO Simulations: Voltage Studies

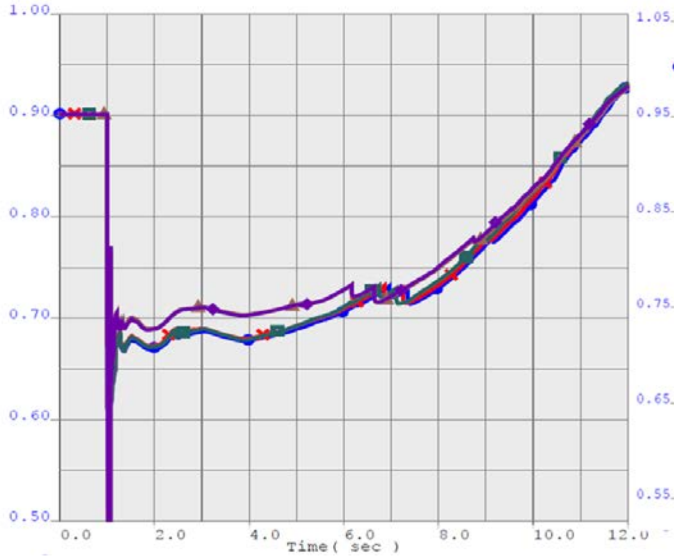
DER Active and Reactive Power

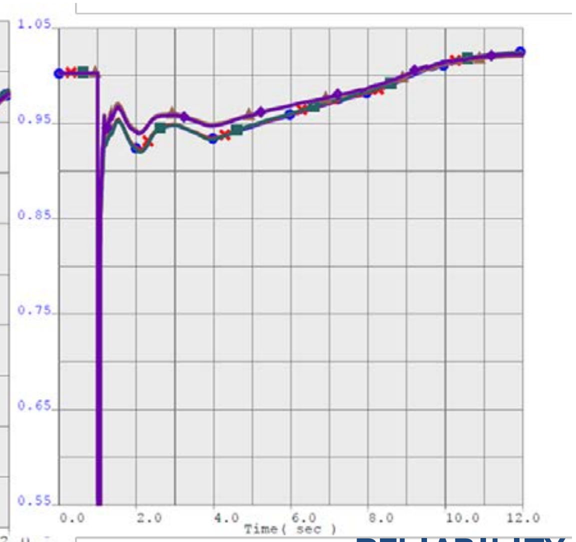




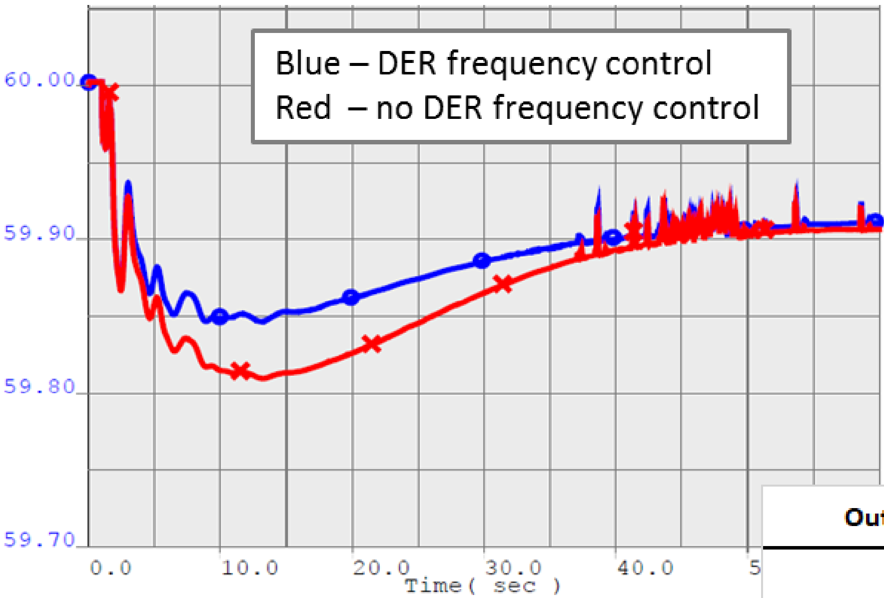
No voltage control, P priority, DER MVAR =0	blue
No voltage control, Q priority, DER MVAR =0	red
Voltage control, P priority, DER MVAR =0	green
Voltage control, Q priority, DER MVAR =0	brown
Voltage control, Q priority, DER MVAR at 0.95 lagging	purple

Bus Voltages Near Fault





CAISO Simulations: Frequency Studies



Setup and Settings:

- Frequency droop gain = 14
- Frequency deadband +/-0.0006
- 70% inverters IEEE1547-2018 and 30% IEEE1547-2003
- 2029 light spring base case; ~2700 MW gen loss

Results:

- DER_Mbase = -0.8.
  - 4.2% response at nadir and 2.0% at settling frequency
- DER_Mbase = -0.9.
  - 3.2% response at nadir and 1.5% at settling frequency

Outage of two Palo Verde units, 2029 off-peak case with reduced headroom

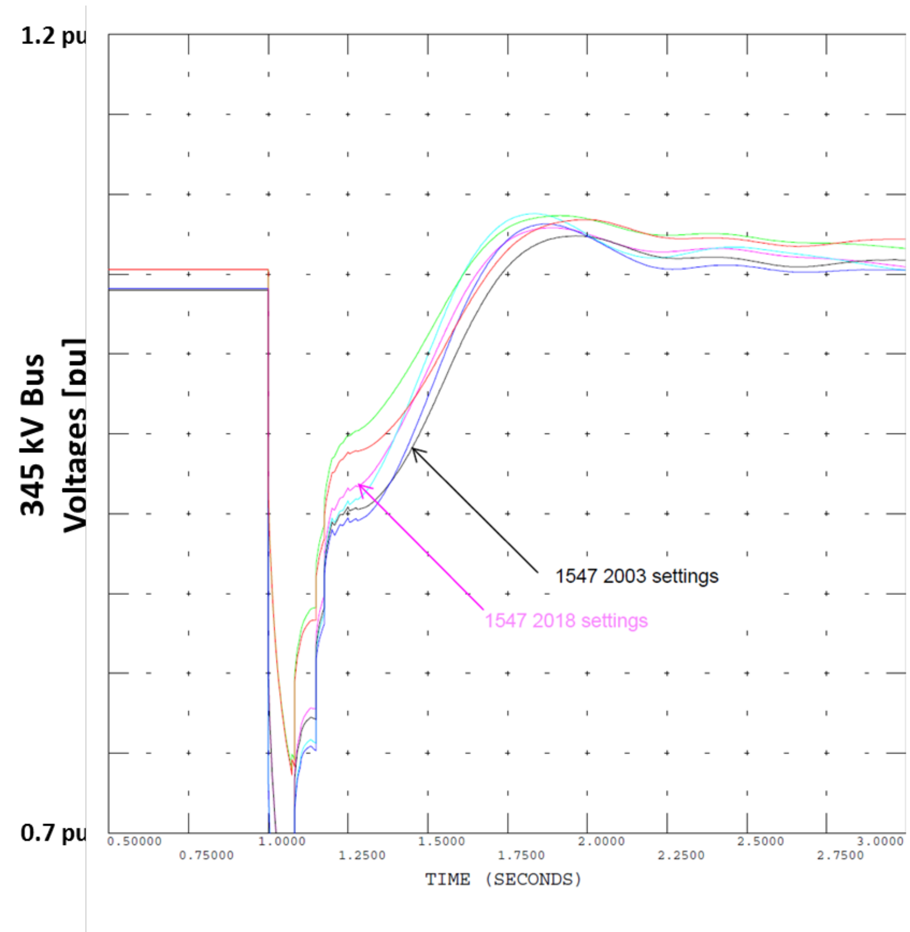
Parameter	No frequency control, DER Load Factor 90%	control, 7.1% droop, DER Load Factor 90%	control, 7.1% droop, DER Load Factor 100%	control, 7.1% droop, DER Load Factor 80%
Settling Frequency, Hz	59.906	59.912	59.909	59.912
Frequency Nadir, Hz	59.810	59.830	59.816	59.830
Governor Response, MW	2004	1838	2004	1811
DER Response, MW	0	234	0	267
Total Response, MW	2004	2072	2004	2078
Gross Load Reduction, MW	841	773	838	767

CAISO Simulations: Conclusions

- Voltage studies:
  - DER voltage control supports fault ride-through and may mitigate induction motor load stalling
  - Slight differences in load and DER response for different DER control settings; however, mainly during transient recovery period (< 6 seconds)
  - Less load reduction when DER controlling voltage
- Frequency studies:
  - DER frequency response provides support to BPS reliability – mainly improves frequency nadir, not settling frequency
  - DER with frequency response enabled is dependent on droop, deadband, time constants, and headroom (modeled through MVA base)
    - With 10%-20% headroom, DER response makes insignificant difference, if there is sufficient response from units with responsive governors
    - DER response displaces response from other frequency-responsive units

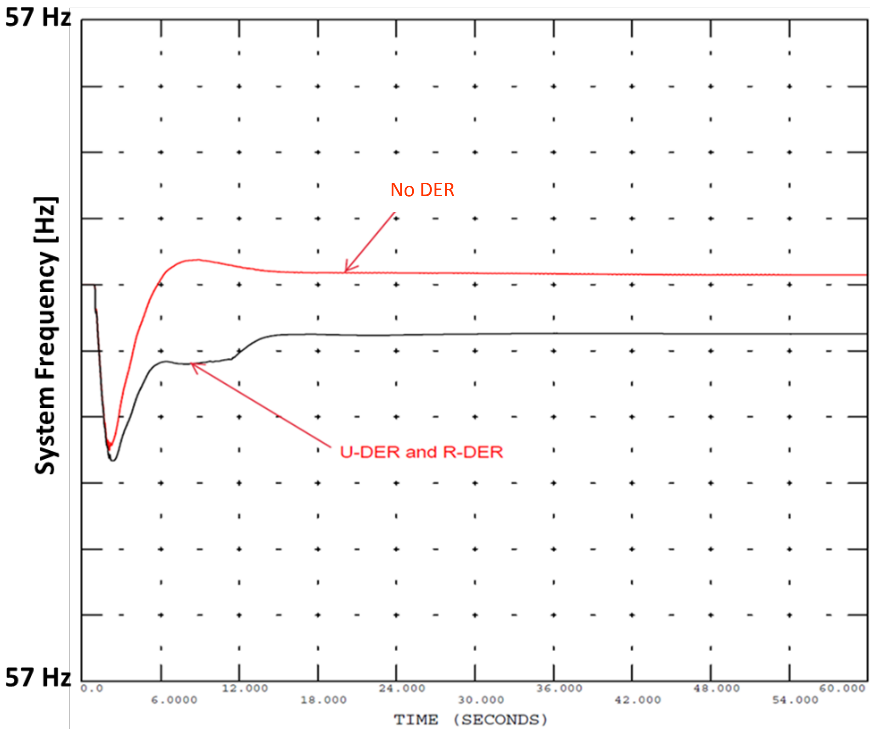
ISO-NE Simulations: 3-Phase Stuck Breaker Fault Study

- 2021 Light Load case
- Nearly 3800 MW of solar PV modeled
  - R-DER: 3000 MW
  - U-DER: 800 MW
- R-DER modeled with DERAU1 with frequency tripping
- Sensitivity
  - -2003 vintage (no voltage control)
  - -2018 vintage (with voltage control)
- U-DER modeled with DERAU1 per IEEE 1547 -2018 settings



ISO-NE Simulations: UFLS with DER_A Model

- 2023 Summer Peak case
- 25% deficiency modeled; 5 stages of load shedding (NPCC requirements)
- Close to 5200 MW of solar PV modeled
  - R-DER: 2200 MW (Cat II 1547-2018)
  - U-DER: 3000 MW (Cat II 1547-2018)
- R-DER modeled with DERAU1 with frequency tripping
  - FRQTPAT model used for tripping R-DER at frequencies set for UFLS
- U-DER modeled with REGCAU1 and REECAU1 with voltage tripping per Cat II (IEEE 1547 -2018)



ISO-NE Simulations: Conclusions

- System response improves with voltage control
- The lowest island frequency and the final island settling frequency are lower for the scenario with DER than without DER
  - Due to additional R-DER tripping along with the load compared to no DER case
  - Due to reduced inertia (DER replacing synchronous generators)
- Increased amount of load shed due R-DER tripping
  - All 5 stages shed for the scenario with DER compared to 4 stages for a scenario without DER
- Works well with other PV models

Wrap Up:

Key Takeaways and Recommendations

Key Takeaways and Recommendations

Key Takeaways:

- Better understanding of DER_A dynamic model
- How DER_A model gets parameterized
- How DER_A model can be parameterized for different systems
- Considerations that should be made for parameterization
- Examples of system-level testing that has been done thus far

Recommendations:

- Ensure aggregate DERs suitably modeled in planning studies (following previous NERC Reliability Guidelines)
- Begin testing DER_A dynamic model in each system footprint
- Participate in SPIDERWG for additional user forum discussions

Technical References

- NERC Reliability and Security Guidelines: https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx
- NERC Reliability Guideline: Parameterization of the DER_A Dynamic Model: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_DER_A_Parameterization.pdf
- NERC SPIDERWG Webpage: https://www.nerc.com/comm/PC/Pages/Inverter-Based-Resource-Performance-Task-Force.aspx
- Summary of Activities: BPS-Connected Inverter-Based Resources and Distributed Energy Resources: https://www.nerc.com/comm/PC/Documents/Summary_of_Activities_BPS-Connected_IBR_and_DER.pdf
- Angeles Forest and Palmdale Roost Disturbances Report: https://www.nerc.com/pa/rrm/ea/Pages/October-9-2017-Canyon-2-Fire-Disturbance-Report.aspx
- NERC List of Acceptable Models: https://www.nerc.com/comm/PC/Pages/System-Analysis-and-Modeling-Subcommittee-(SAMS)-2013.aspx

Questions and Answers