NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Industry Webinar

Technical Report: BPS-Connected Inverter-Based Resource Modeling and Studies

NERC IRPTF
June 8, 2020

RELIABILITY | RESILIENCE | SECURITY




IRPTF Technical Report


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Technical Report

BPS-Connected Inverter-Based Resource Modeling and Studies

May 2020

RELIABILITY | RESILIENCE | SECURITY

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IRPTF Web Page Location

Home > Committees > Planning Committee (PC) > Inverter-Based Resource Performance Task Force

Inverter-Based Resource Performance Task Force

The purpose of the Inverter-Based Resource Performance Task Force (IRPTF) is to explore the performance characteristics of utility-scale inverter-based resources (e.g., solar photovoltaic (PV) and wind power resources) directly connected to the bulk power system (BPS). This task force will build off of the experience and lessons learned from the ad hoc task force created to investigate the loss of solar PV resources during the Blue Cut Fire event and other fault-induced solar PV resource loss events. The joint task force will address many of the recommendations from the Blue Cut Fire Disturbance Report, including additional system analysis, modeling, and review of inverter behavior under abnormal system conditions. Recommended performance characteristics will be developed along with other recommendations related to inverter-based resource performance, analysis, and modeling. The technical materials are intended to support the utility industry, Generator Owners with inverter-based resources, and equipment manufacturers by clearly articulating recommended performance characteristics, ensuring reliability through detailed system studies, and ensuring dynamic modeling capability and practices that support BPS reliability.

Summary of Activities: BPS-Connected Inverter-Based Resources and Distributed Energy Resources

Inverter-Based Resource Performance Task Force

Type	Title	Date
	IRPTF White Papers, Technical Reports, and Assessments (5)	
	BPS-Connected Inverter-Based Resource Modeling and Studies	5/28/2020
	Review of NERC Reliability Standards White Paper	3/16/2020
	Fast Frequency Response Concepts and BPS Reliability Needs White Paper	3/5/2020
	Inverter Based Resource Performance Task Force PRC-024-2 Gaps Whitepaper	2/7/2019
	Western Interconnection Resource Loss Protection Criteria Assessment	3/2/2018

https://www.nerc.com/comm/PC/Pages/Inverter-Based-Resource-Performance-Task-Force.aspx

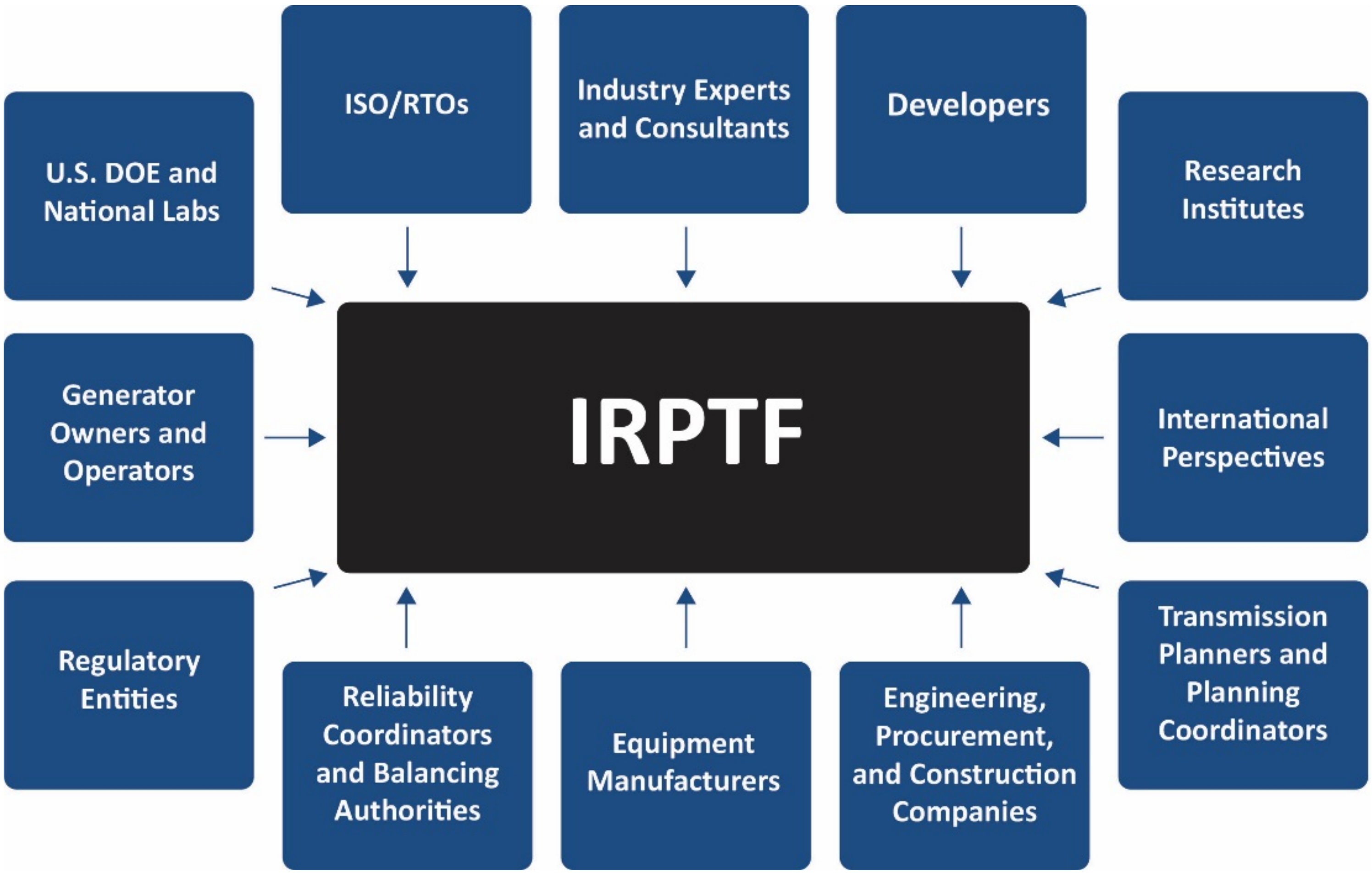
Overview of Webinar

Topic	Presenters
Kickoff and Background of IRPTF Activities	Al Schriver, NextEra
Inverter-Based Resource Modeling Activities	Ryan Quint, NERC
IRPTF Modeling and Simulations	Songzhe Zhu, CAISO David Piper, SCE
Future Efforts Regarding BPS-Connected Inverter-Based Resource Modeling and Studies	Deepak Ramasubramanian, EPRI Andrew Isaacs, Electranix
ERCOT EMT Modeling Requirements and Simulations	Fred Huang, ERCOT
Wrap Up and Q&A	All

Kickoff and Background of IRPTF Activities

Allen Schriver, NextEra

NERC IRPTF Framework



NERC IRPTF Accomplishments

NERC IRPTF Future Activities

* Electromagnetic Transient Modeling and Studies

* Energy Transition to High Penetrations of Inverter-Based Resources

* Generator Interconnection Process Improvements

* Impacts to BPS Protection Systems

* Hybrid Power Plants

* Battery Energy Storage Systems

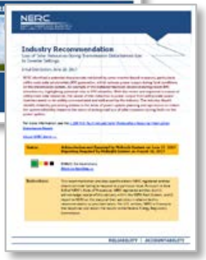
* Advanced Modeling, Simulation, and Study Techniques

Chapter 1: Inverter-Based Resource Modeling Activities

Ryan Quint, NERC

NERC Disturbance Reports of Solar PV Events


NERC
1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report
Southern California 8/16/2016 Event
June 2017


NERC
Industry Recommendation


NERC
April and May 2018 Fault Induced Solar Photovoltaic Resource Interruption Disturbances Report
Southern California Events: April 20, 2018 and May 11, 2018
Joint NERC and WECC Staff Report
January 2019
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900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report
Southern California Event: October 9, 2017
Joint NERC and WECC Staff Report
February 2018
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Industry Recommendation
Loss of Solar Resources during Transmission Disturbances due to Inverter Settings - II

Initial Distribution: May 1, 2018

NERC has identified adverse characteristics of inverter-based resource performance during grid faults that could present potential risks to reliability of the BPS. As the penetration of inverter-based resources (particularly solar PV resources) continues to increase in North America, these adverse characteristics need to be widely communicated. This Level 2 Industry Recommendation alerts industry to these adverse characteristics observed with BPS-connected solar PV resources, and provides recommended actions to address fault ride-through and timely restoration of current injection by all inverter-based resources connected to the BPS.
(See Background section for more information.)

Although this NERC Alert pertains specifically to BES solar PV resources, the same characteristics may exist for non-BES[1] solar PV resources connected to the BPS regardless of installed generating capacity or interconnection voltage. Owners and operators of those facilities are encouraged to consult their inverter manufacturers, review inverter settings, and implement the recommendations described herein. While this NERC alert focuses on solar PV, we encourage similar activities for other inverter-based resources such as, but not limited to, battery energy storage and wind resources.

For more information, see the October 9, 2017 Canyon 2 Fire Disturbance Report.

About NERC Alerts >>

Status:	Acknowledgement Required[2] by Midnight Eastern on May 8, 2018 Reporting Required by Midnight Eastern on July 31, 2018

PUBLIC: No Restrictions
More on handling >>

[1] These resources do not meet the Bulk Electric System definition, and are generally less than 75 MVA yet connected to transmission-level voltage.
[2] To the extent that Canadian jurisdictions have implemented laws or requirements that vary from Section 810 of the ROP, NERC requests entities in such jurisdictions voluntarily participate in response to this Alert.

RELIABILITY | ACCOUNTABILITY

Canyon 2 Fire Alert Findings

- Modeling updates for existing resources
  - Many TPs and PCs stated that minimal or no models provided by GO
  - Models that were provided were incorrectly parameterized, were unusable, or were wrong models entirely
- TP and PC outreach to GOs
  - Rare number of entities doing extensive model follow-up
    - Utilized MOD-032-1 or processes outside NERC Alert or NERC Standards
  - Minimal follow-up actions by TPs and PCs to correct issues
  - Some follow-up met with unwillingness of GO to cooperate
- TPs and PCs stated updated models were correct; cursory review of updated models by WECC showed modeling errors
  - Systemic lack of model “verification” by TPs and PCs

Canyon 2 Fire Alert Findings (cont.)

- Most solar PV resource owners stated that they could eliminate momentary cessation or change settings to improve performance
  - Little to no dynamic models provided; unclear as to what has or has not been changed – follow-up activities needed
- BES versus non-BES resources
  - Only about one-half of installed capacity of BPS-connected solar PV resources in the West were part of NERC Alert process due to BES definition (i.e., 75 MVA)
  - Other one-half of capacity has settings and capabilities that are unknown to NERC (and likely to much of industry)

Industry Efforts to Update Dynamic Models

CAISO Model Updates

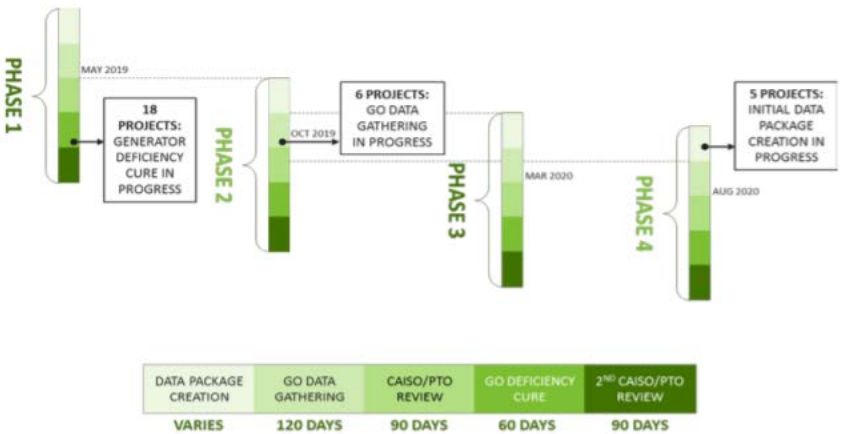
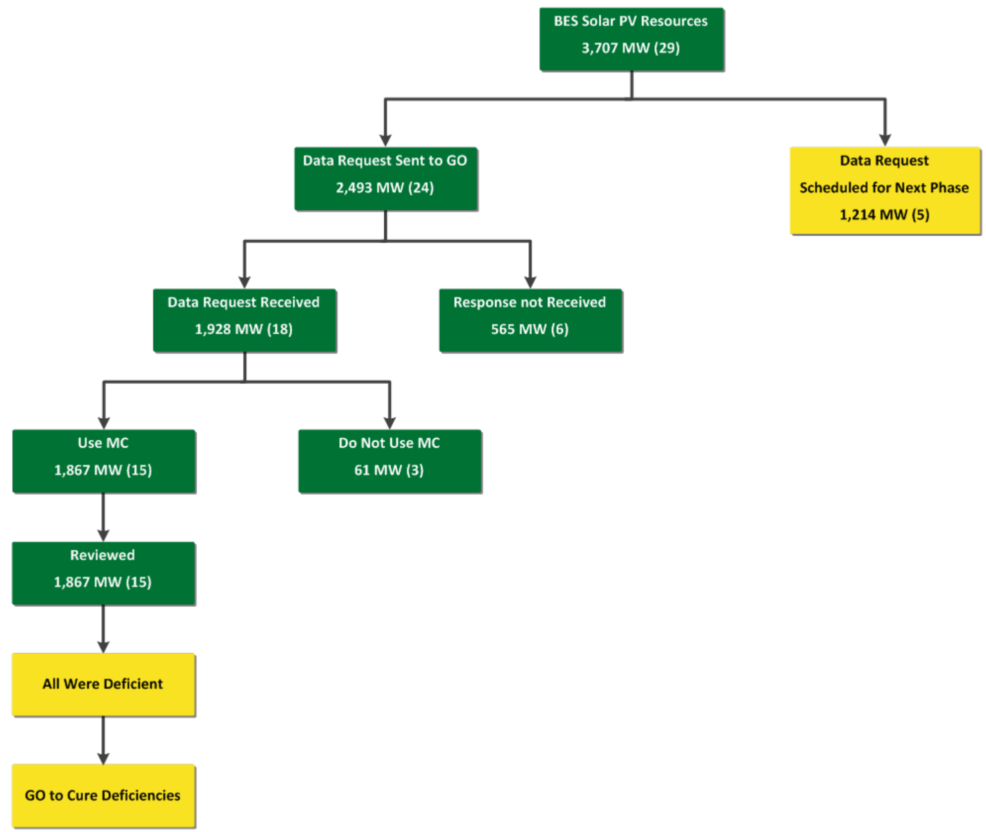


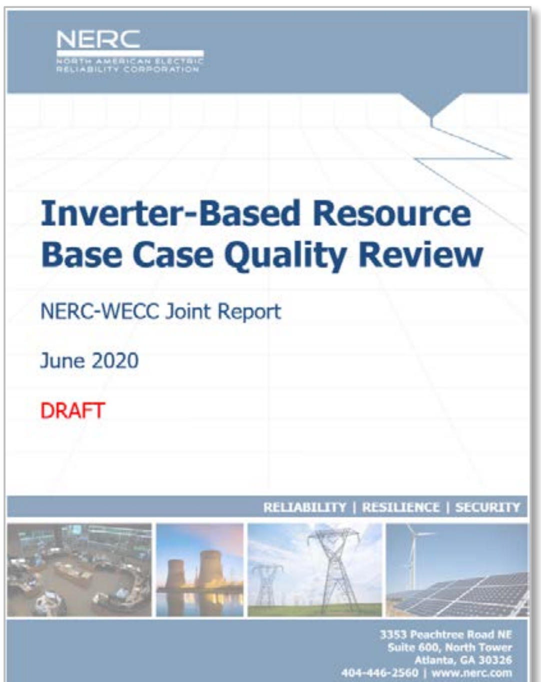
Table 1.1: CAISO Model Updates Schedule

Group	Phase	Submission Deadline	Solar		Wind		Other		Total	
			# Sites	MW	# Sites	MW	# Sites	MW	# Sites	MW
1	1	5/31/2019	28	3337	20	2532	32	6248	**80**	**12117**
	2	10/30/2019	19	1925	3	408	61	8046	**83**	**10380**
	3	3/30/2019	5	220	9	711	58	13006	**72**	**13937**
	4	8/30/2020	22	2171	18	1204	72	11397	**112**	**14771**
2	5	1/31/2021	40	763	6	311	60	1895	**106**	**2970**
	6	6/30/2021	34	626	9	165	55	1886	**98**	**2677**
3	7	9/30/2021	26	79	3	12	52	183	**81**	**274**
	8	12/31/2021	29	97	9	46	36	171	**74**	**314**
	9	3/31/2022	20	67	1	9	49	187	**70**	**263**
4	10	6/30/2022	40	192	14	132	35	801	**89**	**1125**
5	11	9/30/2022	26	166	4	19	28	114	**58**	**299**
		Total	**289**	**9645**	**96**	**5549**	**538**	**43933**	**923**	**59128**

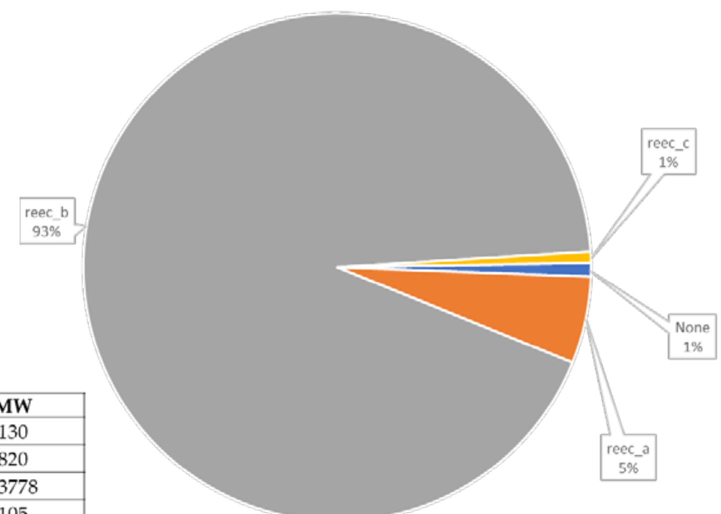
SCE Model Updates



WECC Solar Modeling Advisory Group



- Charter:
  - Address systemic modeling issues in WECC interconnection-wide base cases
  - Coordinate with generator owners to educate and support model development
  - Accountability to inverter-based resource modeling in West



DYD EC Type	Number of Units	MW
None	2	130
reec_a	11	820
reec_b	260	13778
reec_c	1	105
Total	**274**	**14833**

Predominant Issues for Modeling Inverter-Based Resources

- Dynamic models often do not meet basic model quality checks
  - Initialization, no-disturbance flat run, positive damping, etc.
  - Typically caused by incorrect parameterization
- Dynamic models often in the incorrect format, not meeting TP and PC requirements
  - Wrong simulation platform, tabular format, etc.
- Incorrect parameterization of dynamic models
  - Model parameters do not match data provided by GO – NERC Alert data
  - Use of reec_b rather than reec_a with momentary cessation
  - Generic model parameters, no site-specific tuning
  - Generic inverter-level model, not overall plant model – useless to TP/PC
  - Uncoordinated dynamic models (e.g., Vdip and VDL tables, active and reactive current controls)

Predominant Issues for Modeling Inverter-Based Resources (cont.)

- GOs making changes to installed equipment without updating dynamic models
  - Expressed anecdotally in IRPTF meetings multiple times
  - GOs and GOPs stated changes not considered “material modifications” in their opinion;
- Unclear industry understanding of “material modification” in NERC FAC Standard and FERC GIA process; not the same intent
- Lack of info available for TPs and PCs to “verify” whether models reasonably match installed equipment
  - Overreliance on MOD-026-1 and MOD-027-1 activities; not capturing large disturbance behavior of models
- TPs and PCs stated difficulties and shortcuts to meet interconnection process timelines; inability to fully execute studies; potential reliability gaps

Predominant Issues for Modeling Inverter-Based Resources (cont.)

- EMT models not provided during interconnection study process.
  - Extremely difficult to acquire after-the-fact once resource is in-service
  - Poses challenges and risks for TPs and PCs to execute studies in future.
- Interaction of BPS-connected inverter-based resource and distributed energy resource modeling/studies
- Stability issues during high-penetration inverter-based resource conditions not easily detectible using positive sequence stability simulations.
  - Controls interactions, controls instability, subsynchronous control interactions (SSCI), low short-circuit strength issues, etc.
- Positive sequence simulation tools need improvements
- Lack of coordination among entities – GO→TP→→PC→MOD-032 Designee; neighboring entities

Challenges Relying on MOD-026-1 and MOD-027-1

Types of Verification	Examples of Verification	Dynamic Model Parameters Verified	Required by MOD Standards
Small Disturbance	• Capacitor switching test • Plant-level voltage or frequency reference step or play-in test	• Plant-level controller • Possibly some inverter-level settings	Yes
Large Disturbance	• On-site staged fault test	• Inverter-level and plant-level controls, coordinated	No
Other “Verification” Activities	• Review of factory test reports • Review of plant-level and inverter-level settings • Review of one line diagrams	• Majority of model parameters • Useful in combination with engineering judgment	Yes / No

Recommended Questions to Ask When Receiving Dynamic Models

- Type of inverter-based resource facility being represented?
  - (i.e., a solar PV, wind, battery energy storage, or hybrid facility)
- Models provided meet TP/PC list of acceptable models?
- One-line diagram provided? Power flow model meet TP and PC recommended modeling practices?
- Make, type, and models of inverters and relevant controls? Inverter spec sheets and settings used to develop models?
- Installed control modes match modeled control flags and settings?
  - Any limitations in the ability of the models to match actual performance? Verified with inverter and plant-level OEMs?
- Appropriate protection and controls modeled?
- Understanding of return to service behavior following a trip?

Modeling Issues and the Interconnection Study Process

LARGE GENERATING FACILITY DATA

UNIT RATINGS

kVA ____________ °F _________ Voltage _____________
Power Factor ________
Speed (RPM) ________ Connection (e.g. Wye) _____
Short Circuit Ratio ________ Frequency, Hertz _________
Stator Amperes at Rated kVA ________ Field Volts ______________
Max Turbine MW ____________ °F ______

Primary frequency response operating range for electric storage resources:
Minimum State of Charge:____________

Maximum State of Charge:____________

COMBINED TURBINE-GENERATOR-EXCITER INERTIA DA

Inertia Constant, H = ____________________ kW sec/kVA
Moment-of-Inertia, WR^2 = ____________________ lb. $ft.^2$

REACTANCE DATA (PER UNIT-RATED KVA)

	DIRECT AXIS		QUADRATURE AXIS	
Synchronous – saturated	X_{dv}	_______	X_{qv}	_______
Synchronous – unsaturated	X_{di}	_______	X_{qi}	_______
Transient – saturated	X'_{dv}	_______	X'_{qv}	_______
Transient – unsaturated	X'_{di}	_______	X'_{qi}	_______
Subtransient – saturated	X''_{dv}	_______	X''_{qv}	_______
Subtransient – unsaturated	X''_{di}	_______	X''_{qi}	_______
Negative Sequence – saturated	$X2_v$	_______		
Negative Sequence – unsaturated	$X2_i$	_______		
Zero Sequence – saturated	$X0_v$	_______		
Zero Sequence – unsaturated	$X0_i$	_______		

WIND GENERATORS

Number of generators to be interconnected pursuant to this Interconnection Request: ______________

Elevation: ______________ _____ Single Phase _____ Three Phase

Inverter manufacturer, model name, number, and version:

List of adjustable setpoints for the protective equipment or software:

Note: A completed General Electric Company Power Systems Load Flow (PSLF) data sheet or other compatible formats, such as IEEE and PTI power flow models, must be supplied with the Interconnection Request. If other data sheets are more appropriate to the proposed device, then they shall be provided and discussed at Scoping Meeting.

SOLAR PV GENERATORS

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BATTERY ENERGY STORAGE

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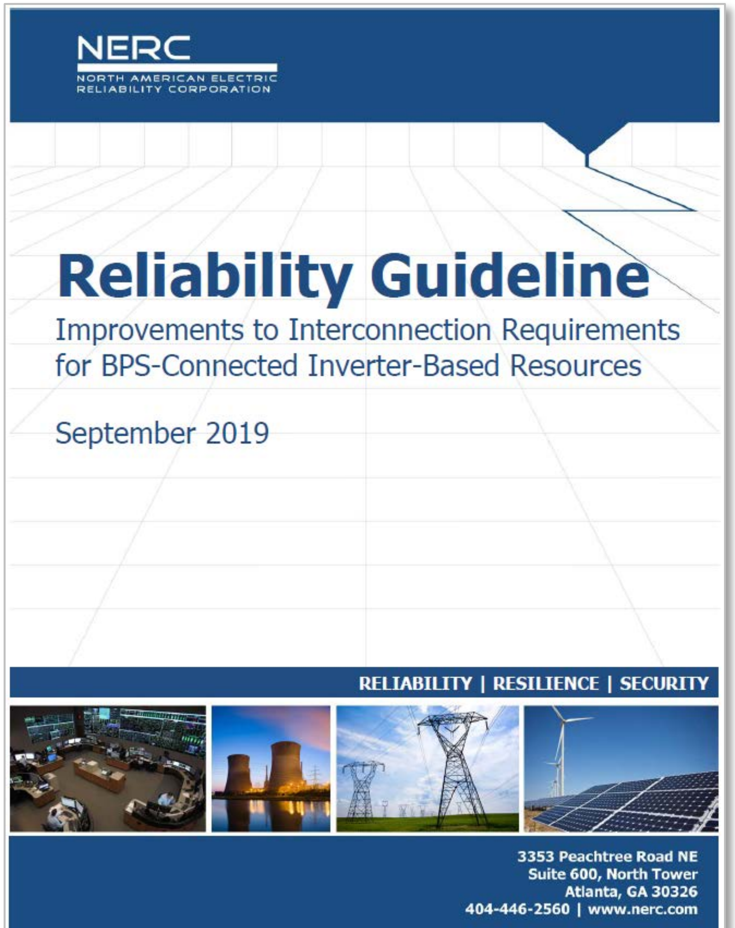
Growing Need for EMT Modeling



- Recommendations for TPs and PCs:
  - Require EMT models for all newly interconnecting BPS-connected inverter-based resources
  - Perform screening studies to identify any potential risks that may require EMT simulations
  - Execute EMT simulations to identify any potential reliability risks
    - Controls interactions, controls instability, SSCI, low short circuit, etc.
  - Growing body of industry expertise
  - Much further to go in developing capabilities as an industry

Chapter 2:
IRPTF Modeling and Simulations

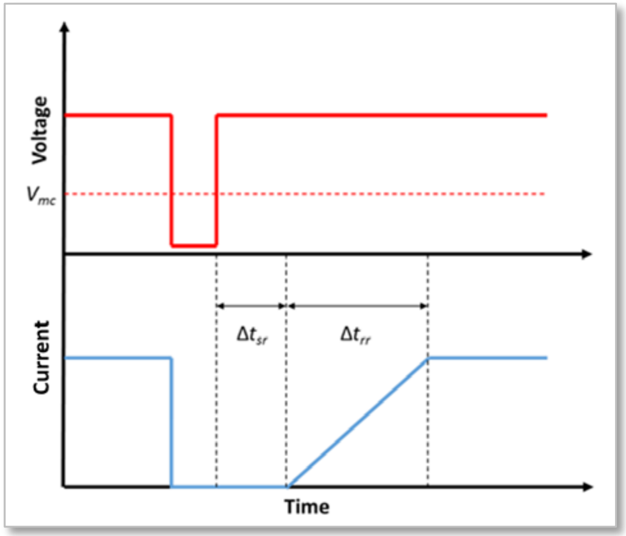
Songzhe Zhu, CAISO

David Piper, SCE

Overview of IRPTF Studies

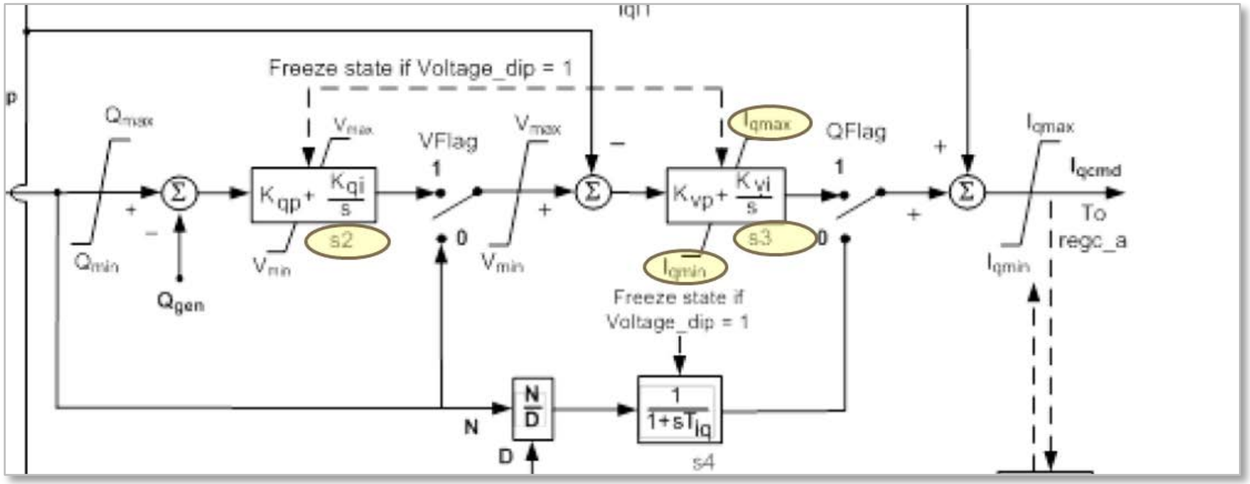
- **Phase 1:** Resource Loss Protection Criteria Studies
  - Minimum inertia, minimum reserves, overly stressed operating condition
  - No reliability risks identified w.r.t. frequency stability and RLPC
- **Phase 2:** Realistic High Solar PV Penetration Conditions
  - Light summer base case, high solar PV, moderate wind, reasonable on-line reserves
  - All resources potential employing momentary cessation (based on data available at the time)
- **Phase 3:** Updated Dynamics Data and High Solar PV Conditions
  - Same base case and operating conditions
  - Updated dynamics data to match NERC Alert data following Canyon 2 disturbance

Development of User-Written Model to Represent Momentary Cessation

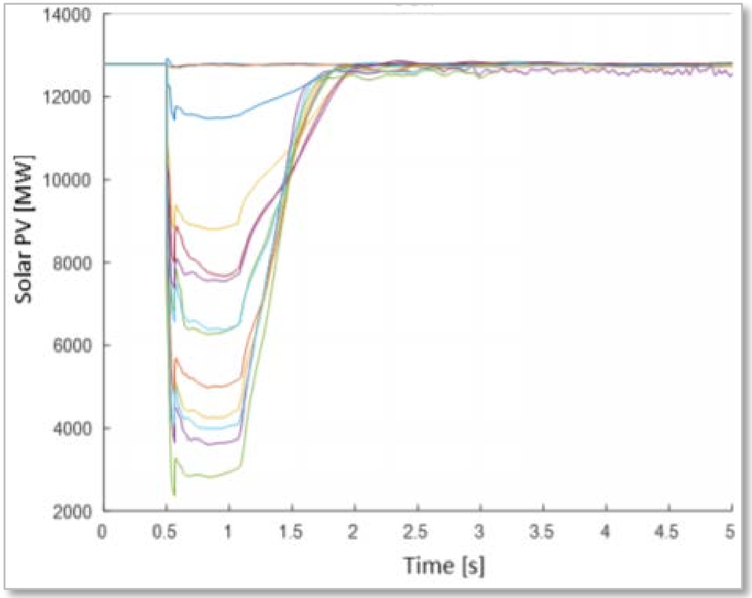


- Momentary cessation blocking threshold
- Recovery delay of inverter current
- Active power ramp rate during recovery
- Number of successive events

- Normal mode
- Block mode
- Delay mode
- Recovery mode



Phase 1: WECC Resource Loss Protection Criteria Assessment



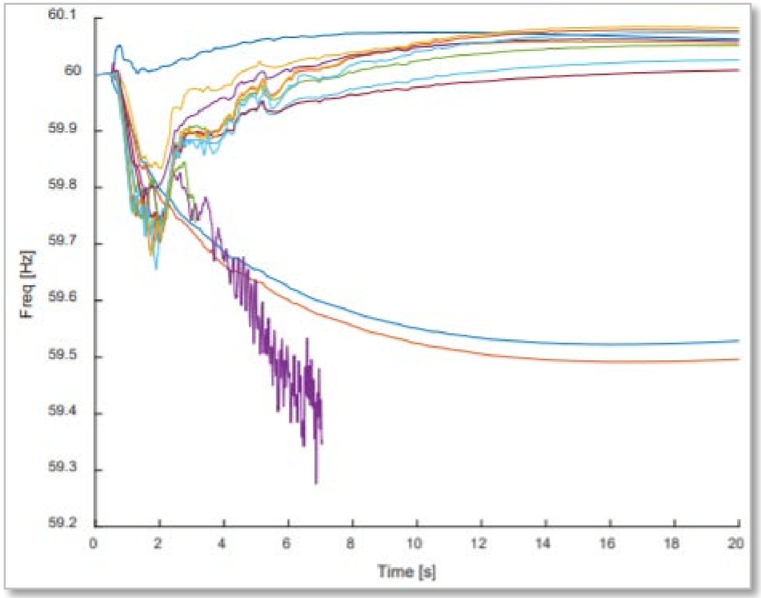
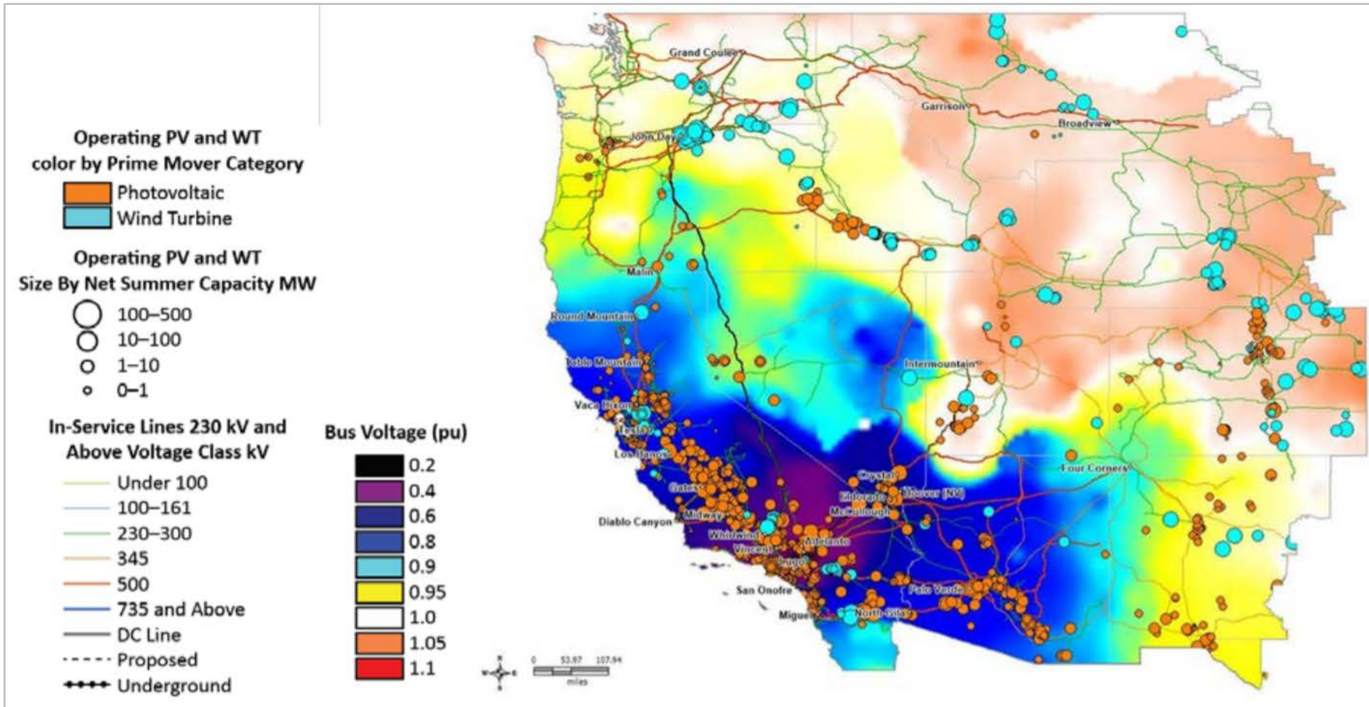
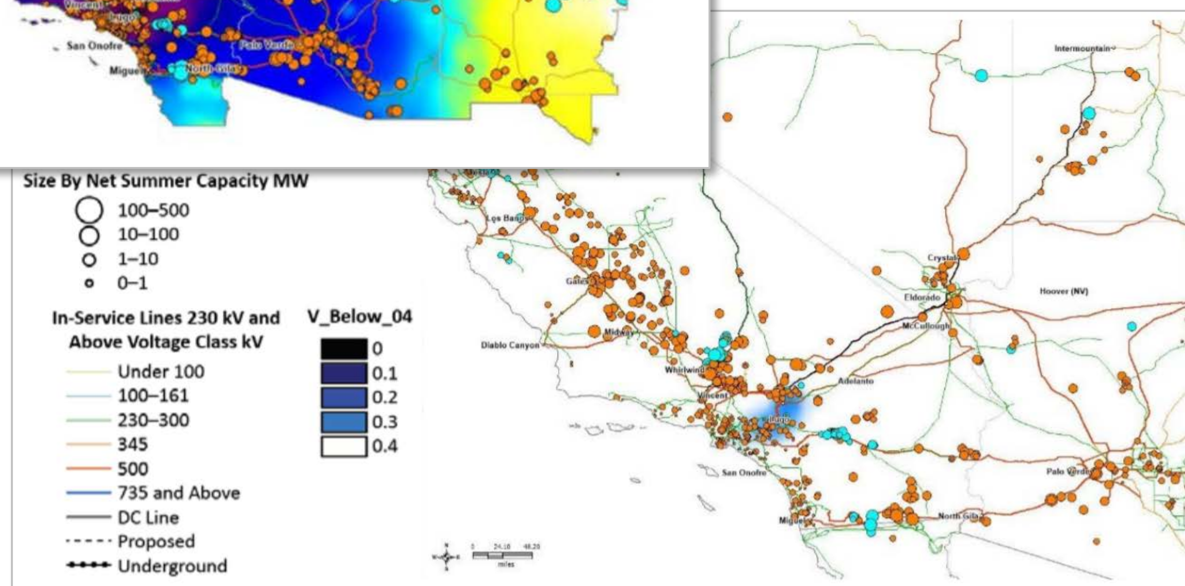


Table 2.1: MC Default Settings	
Characteristic	**Default Setting**
Low Voltage Threshold	0.9 pu
Recovery Delay	0.5 s
Active Current Recovery Ramp Rate	1.0 pu/s

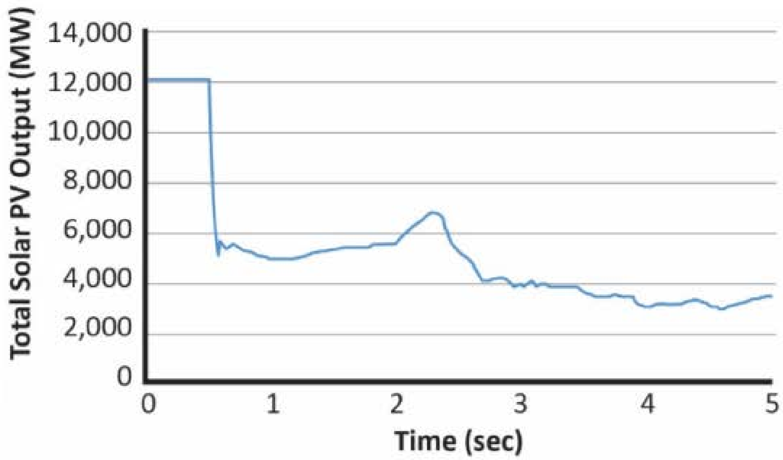
Phase 2: Initial WECC Stability Simulations

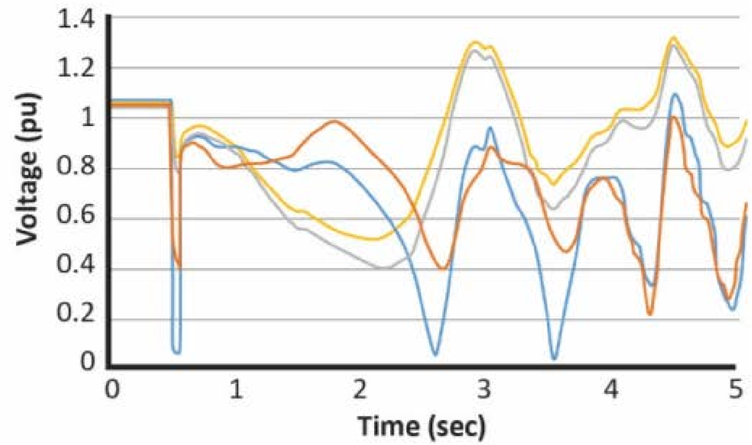




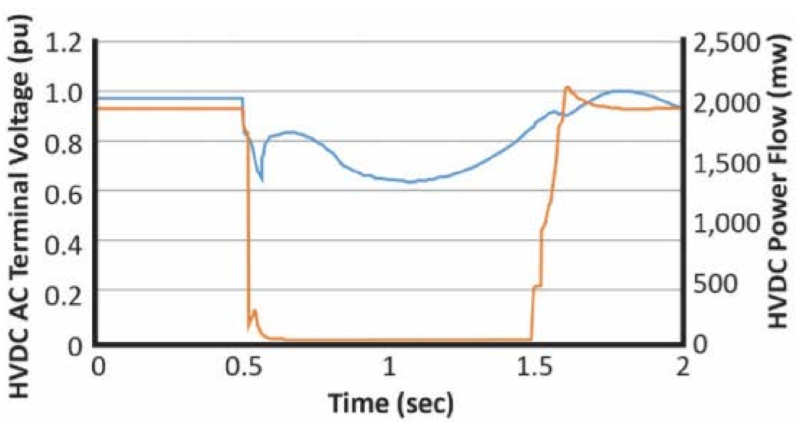
Identified Potential Instability Events: N-1 Fault Simulation

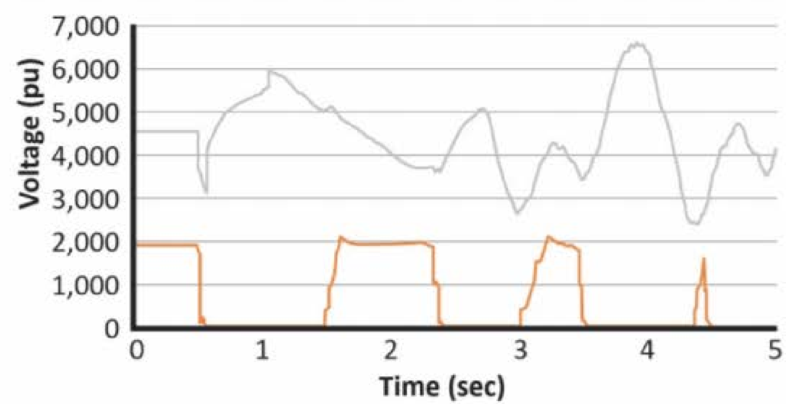
1: Solar PV Enters Momentary Cessation; BPS Bus Voltages Start Collapsing





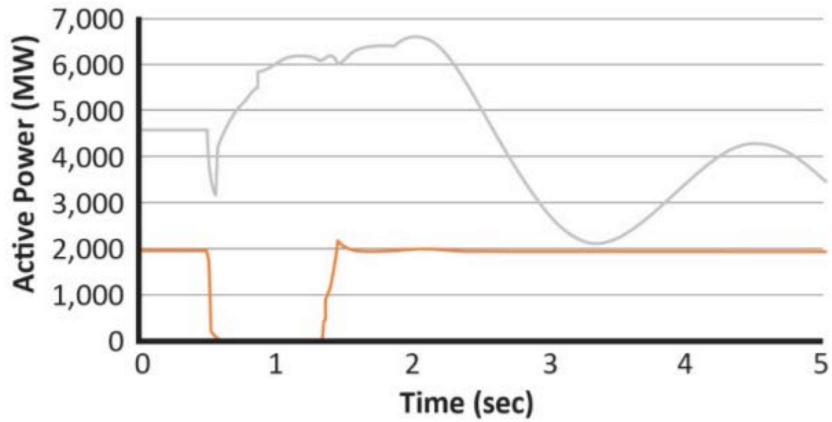
2: HVDC Circuit Blocks Due to Low Voltage; Re-Enters Blocking



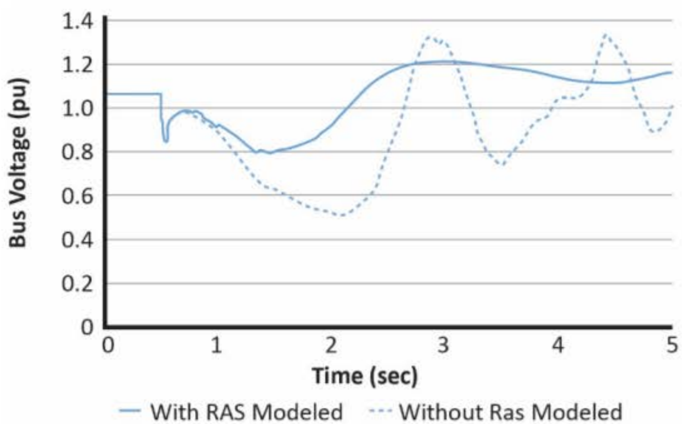


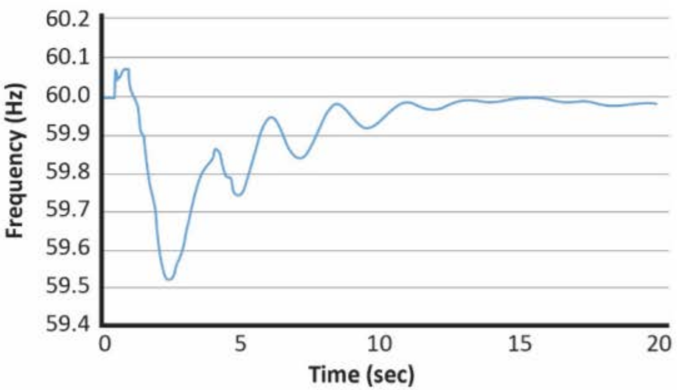
Identified Potential Instability Events: N-1 Fault Simulation

3: HVDC Circuit Blocks; AC System Experiences Large Power Swings

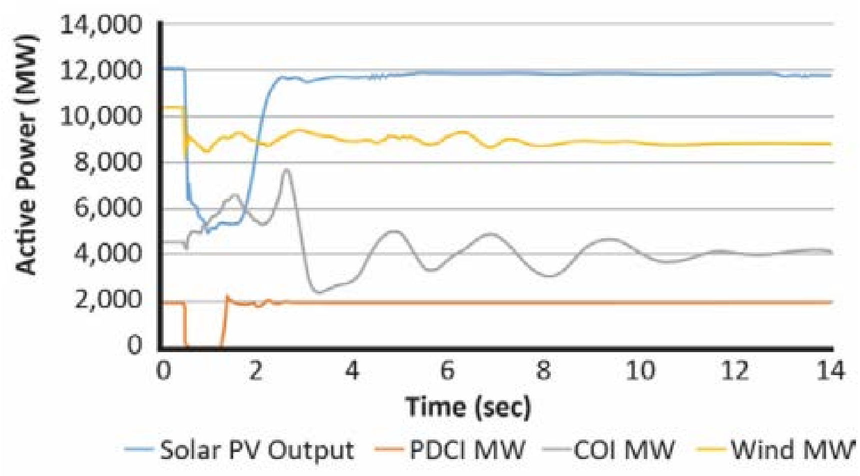


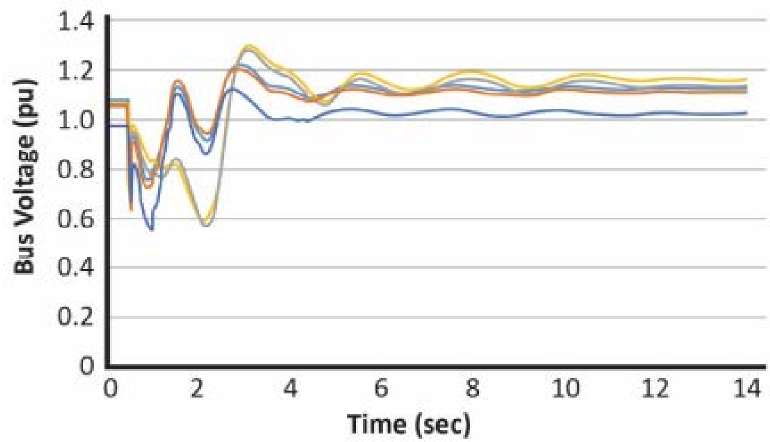
4: Without RAS, System Unstable; With RAS, Severe Frequency and Voltage Swings





Identified Potential Instability Events: N-1-1 Fault Simulation





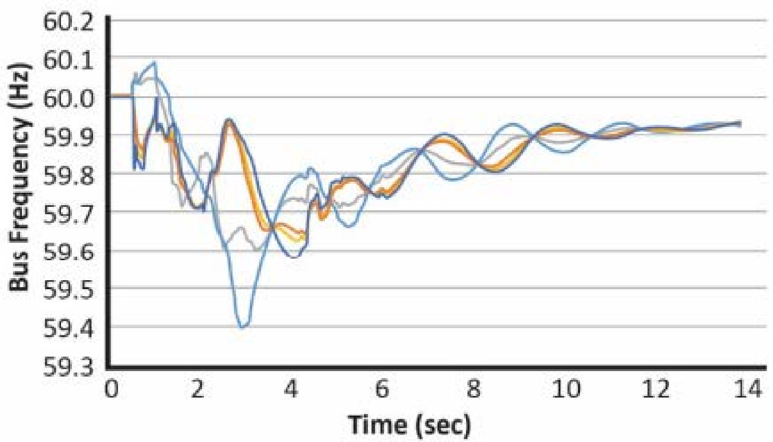


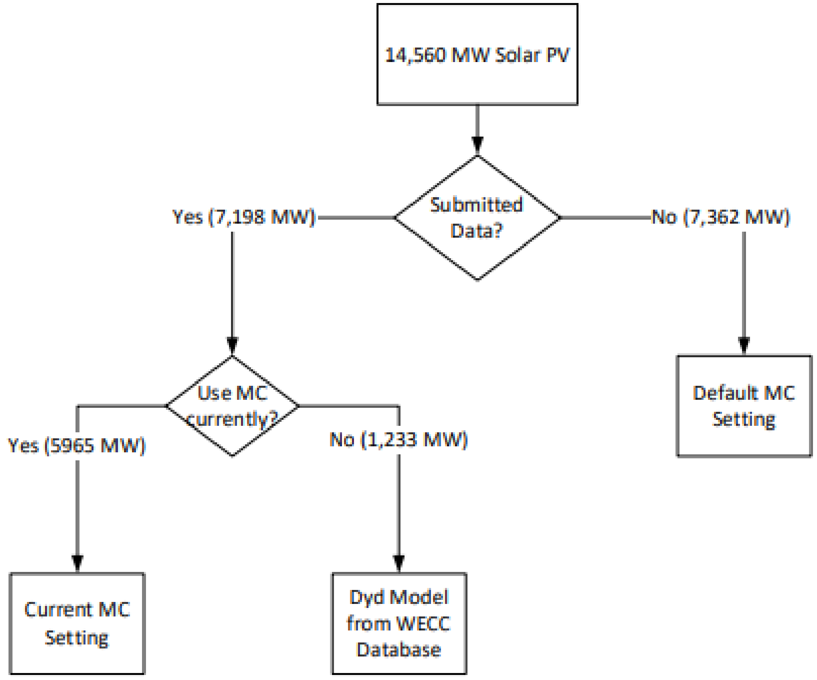
Table 2.2: Overview of Mitigation Options for Instability Conditions

Mitigation Option	Instability Mitigated	Acceptable BPS Performance	Discussion
Eliminate MC	Yes	Yes	Eliminating MC greatly improves BPS performance including angular, voltage, and frequency stability. Interaction with HVDC controls and RAS are eliminated. All alternative options for inverter controls provided adequate BPS performance (P-priority had local performance issues (see Chapter 3)).
Operating Limit Restrictions	Yes	Yes	Stability issues are mitigated if operating limits are restricted; no operation of RAS if ac and dc intertie flows are limited; MC still causes adverse impacts on system performance, although performance requirements are met; costly solution due to economic impacts of curtailment.*
Reactive Power Support	Marginal	Marginal	Multiple STATCOM locations were explored; a significantly large amount of reactive power was needed to mitigate transient voltage collapse along corridor and depressed voltage at inverter-end of HVDC circuit; ineffective solution for this specific problem.
Additional RAS Actions	Unlikely	Unlikely	The only additional RAS action suitable to address this issue would be load tripping in Southern California, which is not an acceptable solution for N-1 contingency events. This solution would have significant economic impacts and load service degradation.
Transmission Reinforcement	Likely	Possibly	Significant EHV network improvements needed to eliminate need for RAS; extremely costly solution option, and likely not possible due to permitting, expense, and regulations; not recommended.

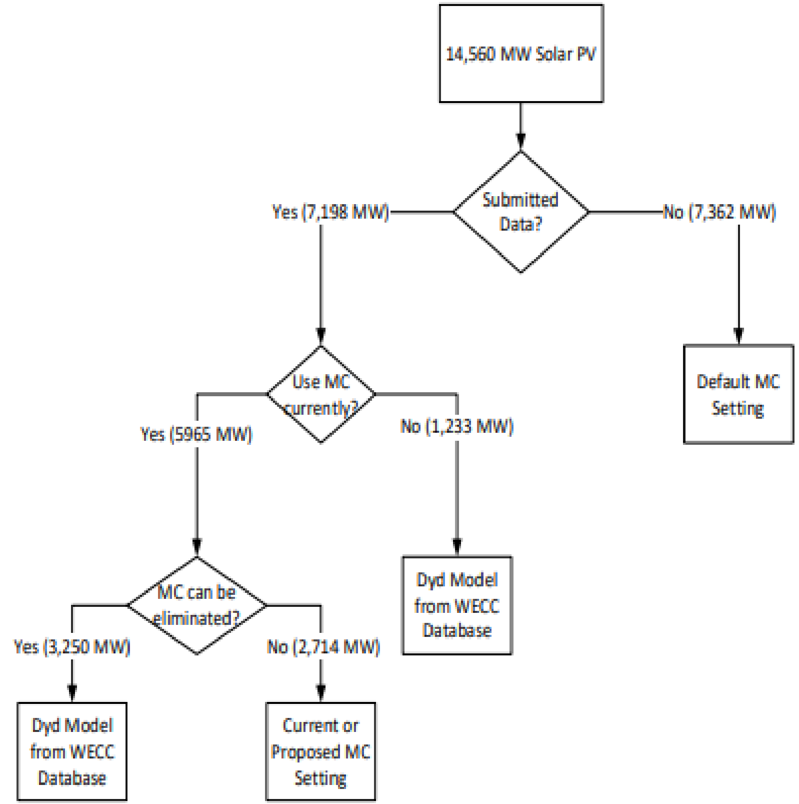
* Instability could be mitigated through generation redispatch in PG&E area near ac intertie, and reducing generation in the Pacific Northwest. System remains stable; transient performance is marginal, with severe voltage dip during first swing. System redispatch as preventive measure should include detailed studies under various system operating conditions to define the stability boundary.

Phase 3: Detailed Stability Studies using NERC Alert Data

Current MC Settings

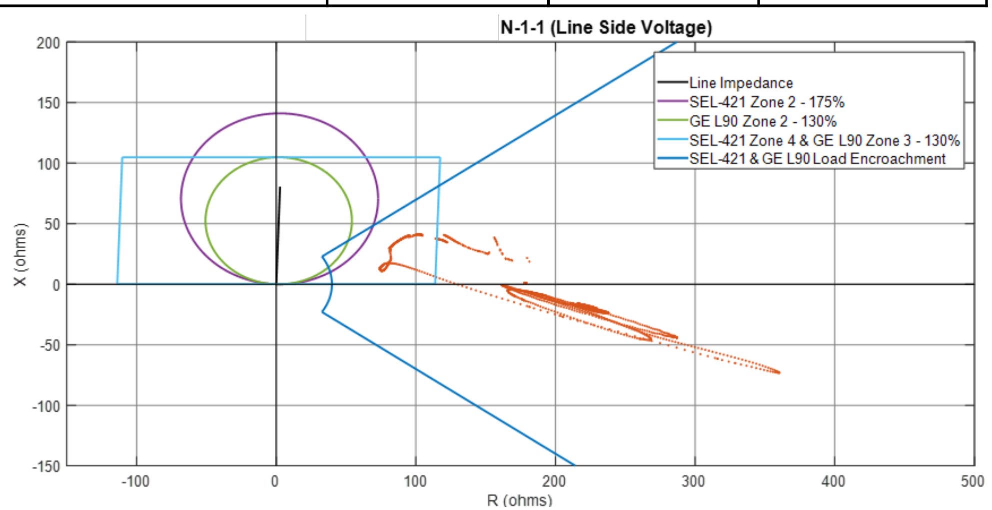


Proposed MC Settings

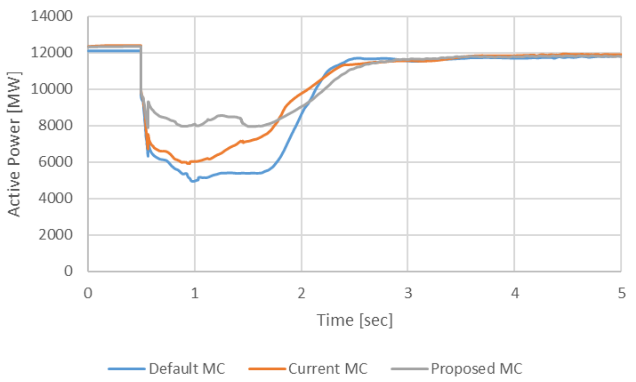


Phase 3 Simulation Results

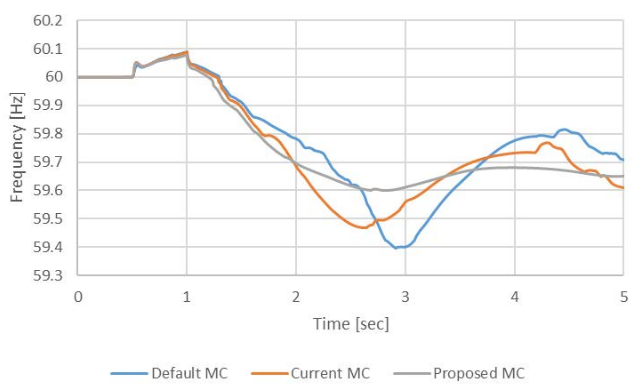
Table 2.3: Performance Comparison for Different MC Settings for N-1 Contingency (without and with RAS Action)			
System Response	**Default MC**	**Current MC**	**Proposed MC**
RAS Actions Not Modeled			
Initial HVDC blocking duration [s]	0.93	0.90	0.84
Successive HVDC Blocking	Yes	No	No
System Stable	No	Yes	Yes
System Frequency Nadir [Hz]	N/A (Unstable)	59.63 Hz	59.78 Hz
RAS Actions Modeled			
Successive HVDC Blocking	No	No	No
System Stable	Yes	Yes	Yes
System Frequency Nadir [Hz]	59.52	59.6	59.71



Solar PV Entering MC



BPS Frequency



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Inverter Current Control Sensitivities

- BPS stability and acceptable performance maintained in all cases
- Active current (Ip) priority caused solar PV plant to trip
  - Sustained low voltage due to lack of local reactive support post-fault
- Reactive current (Iq) priority helped boost voltage post-fault and allow active current to return to pre-disturbance levels quickly

- Iq priority is recommended control strategy for this area
  - Ability to support BPS voltage during and immediately after the fault
  - Enables quick and reliable active current recovery to pre-disturbance levels
- Detailed studies needed by TPs and PCs to determine appropriate control strategy in some areas; simulation results should be used to provide a technical basis for this decision

Future Efforts Regarding BPS-Connected Inverter-Based Resource Modeling and Studies

Deepak Ramasubramanian, EPRI

Andrew Isaacs, Electranix

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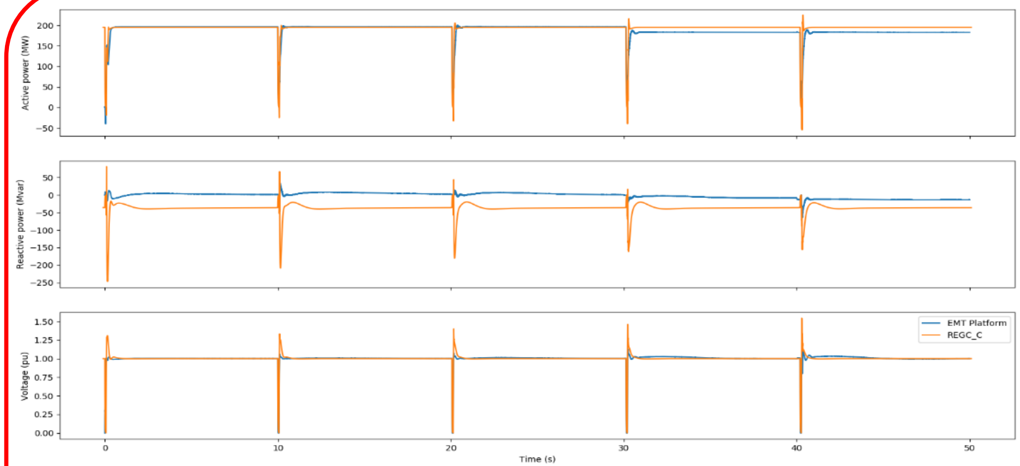
Present status of IBR modeling

- Existing state-of-the-art generic IBR models have limitations
- Placing this in context:
  - Models representing the behavior of synchronous machines (and their governors + excitation systems) are still being updated and modified today
- Simultaneously new, updated, more robust, and more accurate IBR models are also being presently developed.

New Model	Functionality	Status of Implementation by Software Vendors	Agreed Priority for Implementation
REGC_B	Improved converter model (voltage source model)	Beta version in tools	1
REEC_D	Impoved converter electrical controls (to allow for modeling momentary sessation etc.)	Beta version in tools	2
REPC_C	Impoved plant controller model, for better modeling of primary frequency response controls, etc.	One software vendor has beta implemented, others to follow soon.	3
WGO	Weak Grid Option Controls for weak grid applications	Next in line for implementation by software vendors	4
WTGP_B	Improved pitch-controller model for type 3 WTG	Next in line for implementation by software vendors	5
WTGT_B	Slightly improved drive-train model, particularly for type 4 WTG	Next in line for implementation by software vendors	6
WTGQ_B	Alternative torque-controller model for type 3 WTG	Next in line for implementation by software vendors	7
IBFFR	emulated inertia model for WTG	One software vendor has started work, others to follow soon.	8
REGC_C	More advanced converter model, including PLL and inner-current control-loop for select studies	Next in line for implementation by software vendors	9

Reference: WECC REMTF Memo: Proposal for new features for the renewable energy system generic models, DATE: 12/17/19

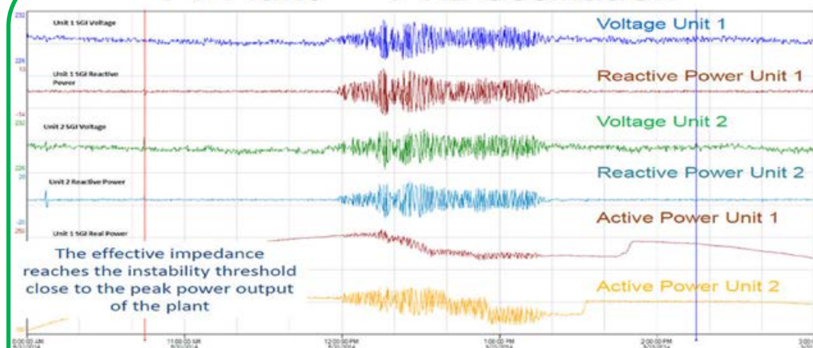
Examples: Validation of behavior of new IBR models for low short circuit conditions



Robust and consistent (when compared with EMT model) fault ride through for SCR as low as 1.0 at plant POI

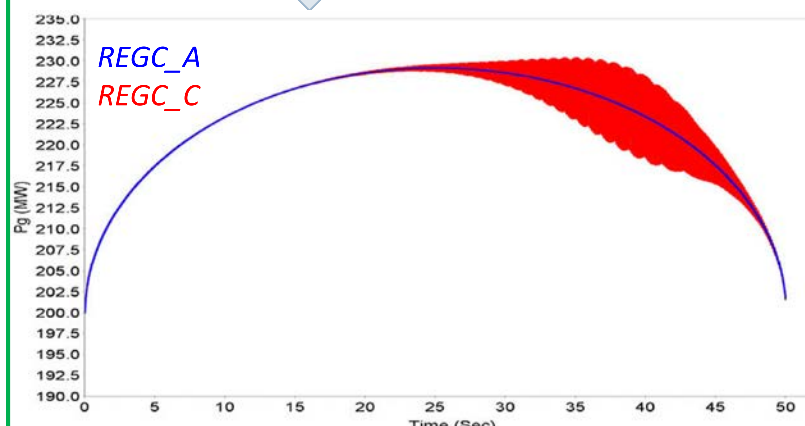
- For any model, accurate parameterization is very important
- New models are not meant to replace any other potential form/method of study
  - Rather intended to supplement and enhance available options
- Industry stakeholder participation and constructive feedback is crucial for improved models

PV Plant – ~7 Hz Oscillation



First Solar Inc.: 'Deploying utility-scale PV power plants in weak grids,' 2017 IEEE Power & Energy Society General Meeting, July 2017

Recreated with new models



Build up of small signal oscillations when plant output is near maximum

EMT Modeling in North America

- Notable current EMT modelling efforts:
  - National Grid >700 MW DER modelled interconnected into ISO-NE bulk grid
  - HECO island-wide models
  - ATC integration of large scale PSCAD group studies into MISO process
  - ERCOT panhandle PSCAD model continues to grow
  - AEP routine group studies for SSCI in PSCAD (very large processing req'ts)
  - Routine EMT analysis of every new IBR interconnection in ISONE, as well as benchmarking against PSS/E models.
  - NYPA wide-area EMTP network simulations
  - Hybrid PSCAD/PSLF analysis of large HVDC projects into WECC system.
  - Hydro-Quebec EMTP studies for low short-circuit strength and SSCI studies
  - EMT model requests for current *and* old becoming standard in large ISOs.
  - Increasing capability and support from major PV OEMs
  - Others!!

EMT Modeling Next Steps

- Where are we going next?
  - Larger system models, with more automated model building and analysis tools. Expecting to double or triple the largest "working study" model size in the next year! (100's of IBR models). This is a software problem, taking advantage of new computing hardware.
  - DLL "Real Code" model standardization and increasing adoption. In the past year, 5-6 OEMs adopted this approach. We want to expand this.
  - Continued refinement of EMT modelling guides and standards.
    - http://www.electranix.com/publication/pscad-requirements-rev-9-may-2020/
    - Draft IEEE 2800 Subgroup 10
    - NERC IRPTF guidelines past and new ones under development
    - ISO/TO standards (ATC/ERCOT/ISONE/CAISO/TVA/HECO/MISO/others)
  - Increased adoption of EMT studies into routine planning studies. Requires all of the above!

AMD Ryzen 3990x CPU (64 cores, 128 threads), 128 GB RAM, liquid cooled…

<$10,000 CAD

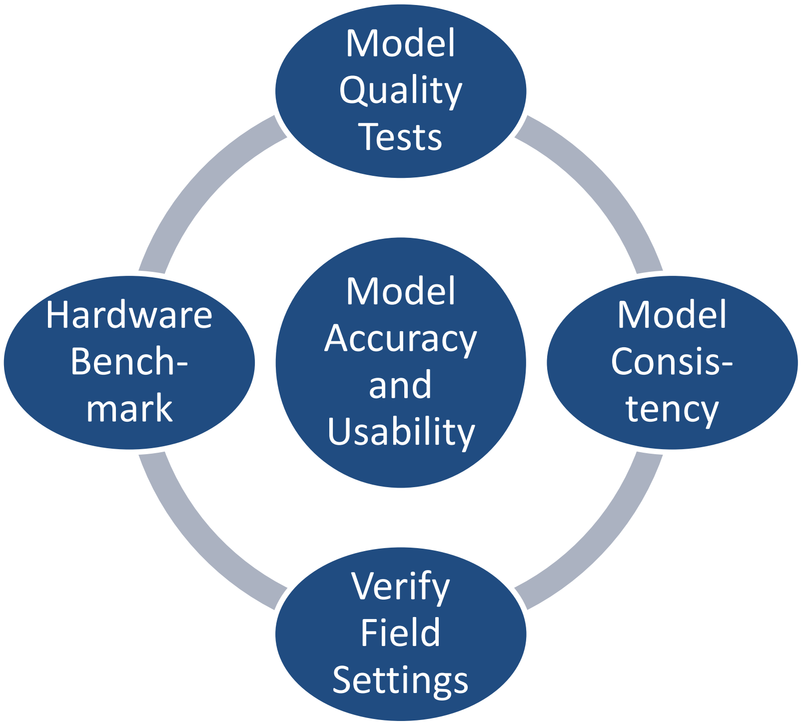
ERCOT Electromagnetic Transient (EMT) Modeling Requirements and Simulations

Fred Huang, ERCOT

EMT Models in ERCOT

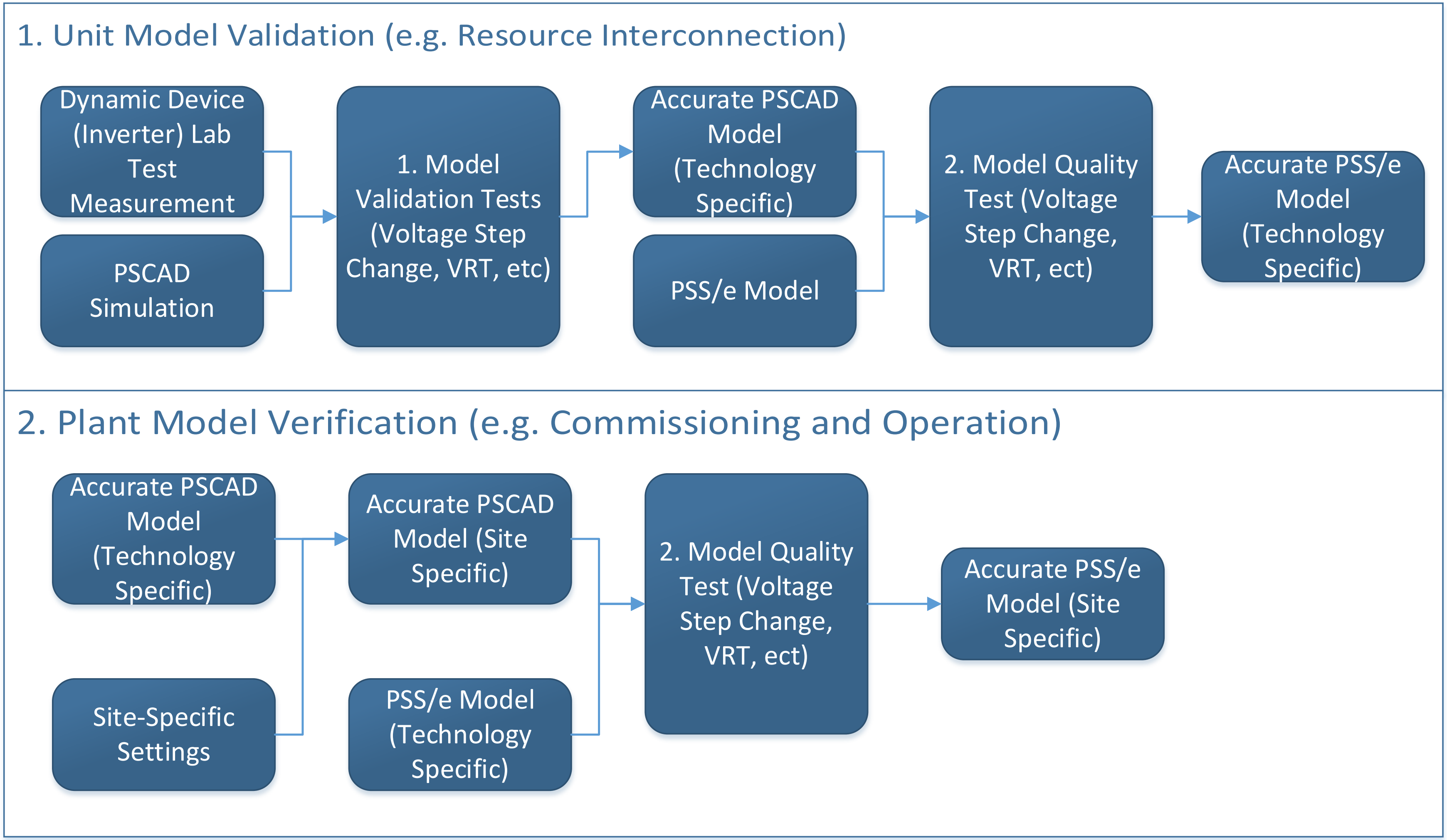
- All IBRs are required to provide EMT (PSCAD) models
  - ERCOT Model Guide: http://www.ercot.com/content/wcm/lists/168284/ERCOT_Model_Quality_Guideline.zip
- EMT models are used for specialized studies such as:
  - Low short-circuit strength conditions
  - Inverter-based resources in the vicinity of series capacitors
- **EMT Model ≠ Good/Accurate**
  - **Validation needed…**

Goal: Improved Model Accuracy & Confidence



Challenge	Proposed Solution
Model performance	Model quality tests
PSCAD model fidelity	Hardware benchmark (unit validation)
Model settings do not match the field settings	Plant verification (periodic setting check)
Consistency between PSSE and PSCAD models	Model quality tests

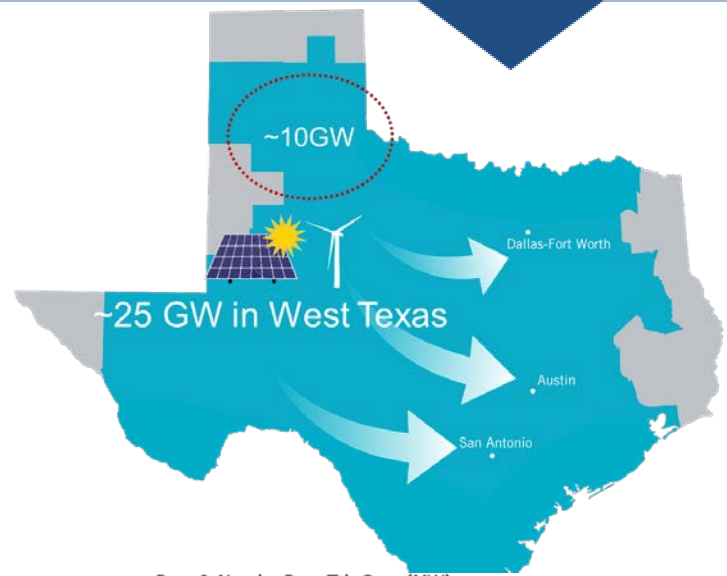
How Proposal Achieves Goals

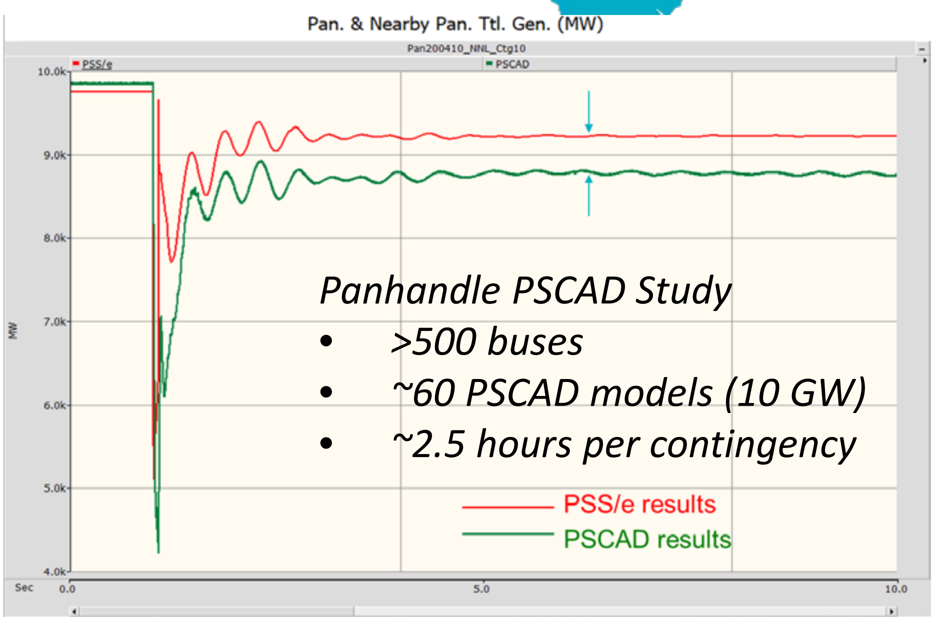


Note: ERCOT is currently working with stakeholders on this proposal

EMT Studies

- With more IBRs…
  - Increasing stability challenges
  - Require EMT (PSCAD) studies
    - Complex and time consuming
- Needs and improvements
  - Model accuracy and usability (EMT and RMS models)
  - Tool and simulation efficiency
  - Is it feasible or practical for system wide study and operation support?
  - Better communication and coordination





Wrap Up – Key Findings and Recommendations

Ryan Quint, NERC

Key Findings and Recommendations

- NERC Alert
  - Modeling issues systemic for solar PV resources; needs quick attention
  - Many resources can improve dynamic behavior; eliminate momentary cessation; uncertain of extent of changes
  - Need more TP and PC engagement in verifying accuracy of models
  - Need better coordination and educations among entities
- IRPTF Studies
  - Widespread momentary cessation poses BPS reliability risks
  - More detailed modeling showed degraded BPS performance with existing momentary cessation
  - Dynamic support, particularly reactive current priority with dynamic voltage control, proved most effective in terms of BPS stability/performance

Key Findings and Recommendations

- IRPTF Technical Discussions
  - MOD-026-1 and MOD-027-1 gaps in verifying large disturbance behavior
  - As-built settings differ from models provided, in all phases of interconnection process and upon commercial operation
  - LGIP (and SGIP) should be revisited to improve understanding of modeling to enable sufficient studies
  - Confusion with “material modification” in FAC-001-3 and FERC GIA process
  - Growing need for EMT models and simulations
  - Significant improvements needed to interconnection requirements to cover modeling of all kinds (e.g., positive sequence, short-circuit, EMT)
  - Case creation becoming increasing challenging; coordination needed
  - “Fringe” (realistic yet highly stressed) operating conditions need to be studied by both planning and operating entities
  - Improved dynamic modeling practices needed moving forward

NERC References

- NERC IRPTF Webpage
  - Technical Reference Document: BPS-Connected Inverter-Based Resource Modeling and Studies
- NERC Reliability and Security Guidelines
  - Reliability Guideline: BPS-Connected Inverter-Based Resource Performance
  - Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources
- Summary of Activities: BPS-Connected Inverter-Based Resources and DERs

Questions and Answers

Want to get involved with IRPTF?
Email: ryan.quint@nerc.net

Key Findings and Recommendations: NERC Alert

Table A.1: Key Findings and Recommendations from IRPTF Modeling and Studies Work	
#	**Key Findings and Recommendations**
A1	**Key Finding:** A significant number of solar PV resource owners submitted positive sequence models for the interconnection-wide case creation process (i.e., MOD-032-1) that do not accurately represent the control settings programmed into the inverters installed in the field. Discrepancies between NERC Alert data and dynamic models in interconnection-wide base cases. **Recommendation:** GOs should submit updated models to the TPs and PCs as quickly as possible to accurately reflect the large disturbance behavior of BPS-connected solar PV resources in the interconnection-wide base cases used for planning assessments. This applies to BES resources as well as non-BES resources connected to the BPS.
A2	**Key Finding:** Many models submitted during NERC Alert intended to represent existing equipment either (1) did not match data provided by GO, or (2) did not meet TP and PC model requirements (incorrect models or parameters, inability to initialize). **Recommendation:** TPs and PCs should proactively work with all BPS-connected solar PV resources in their system to ensure dynamic models correctly represent large disturbance behavior of actual installed equipment. GOs should verify dynamic model parameters with actual equipment and control settings. These activities should occur on a regular basis.
A3	**Key Finding:** A significant number of GOs submitted NERC Alert data indicating they could eliminate MC for existing resources; however, no model of proposed changes provided or provided model had deficiencies. **Recommendation:** TPs and PCs should proactively work with all GOs of BPS-connected solar PV resources in footprint to review NERC Alert data provided, develop updated dynamic models of proposed changes, study the impacts of making these changes, and provide recommendations to the GO to make appropriate changes based on study results.

Key Findings and Recommendations: NERC Alert

Table A.1: Key Findings and Recommendations from IRPTF Modeling and Studies Work

#	Key Findings and Recommendations
A4	**Key Finding:** GOs provided requested data and information about facilities as part of NERC Alert; however, very few GOs provided acceptable models that matched the data provided. Some TPs and PCs were proactive in correcting deficiencies, but these activities are occurring outside the NERC Alert process. The NERC Alert itself did not remedy the issues associated with inaccurate dynamic model representation of BPS-connected inverter-based resources, only highlighted the problem. **Recommendation:** IRPTF should continue to monitor for systemic modeling issues and make appropriate recommendations on future actions. Additional actions needed to address systemic modeling issues identified during NERC Alert process may require another method of engaging or requiring industry to make changes to dynamic models.
A5	**Key Finding:** TPs and PCs still becoming familiar with newer dynamic models for inverter-based resources; documentation for these models is limited; many TPs and PCs not familiar with how to perform reasonability tests during model submittal processes; often requires expert input to parameterize models; in-house expertise on these models is fairly limited for many TPs and PCs; leading to systemic modeling challenges. **Recommendation:** Industry should develop technical guidance and reference materials for parameterizing positive sequence dynamic models for BPS-connected inverter-based resources; training should be provided on this topic.
A6	**Key Finding:** NERC MOD-032-1 does not prescribe details that modeling requirements must cover (leaves the level of detail and data formats up to each TP/PC). Detailed TP/PC data requirements exist; however, little validation of data provided by GOs is performed. In many cases, “usability testing” is performed but assessments on accuracy or reasonableness of parameters are not typically performed. Many entities not utilizing MOD-032-1 Requirement R3 to express “technical concerns” with data submittals. **Recommendation:** See A2 recommendation.

Key Findings and Recommendations: IRPTF Studies

Table A.1: Key Findings and Recommendations from IRPTF Modeling and Studies Work	
#	**Key Findings and Recommendations**
S1	**Key Finding:** Early stability studies using data provided from the first NERC Alert illustrated widespread use of MC could cause system instability issues, if not mitigated. MC caused a lack of reactive power support in voltage-sensitive areas and resulted in large power swings across the BPS in the Western Interconnection. MC actions interacted with HVDC controls and RAS actions. **Recommendation:** Technical justification that MC should be disallowed for newly interconnecting BPS-connected solar PV resources and should be eliminated to the greatest possible extent for existing resources. Industry should be taking actions to eliminate MC for existing resources to the greatest possible extent, and TOs should update interconnection requirements to disallow its use for newly interconnecting resources.
S2	**Key Finding:** Detailed studies using modified models to reflect actual MC settings of BPS-connected solar PV resources (following Canyon 2 Fire disturbance NERC Alert) showed BPS remains stable for aforementioned contingencies. However, BPS performance is degraded by use of MC. Elimination of MC or improvements to the MC voltage threshold or recovery characteristic had greatest positive impact. Interactions with HVDC controls still present, and combined reduction of solar PV and RAS actions resulted in frequencies falling close to or below UFLS thresholds. **Recommendation:** See S1 recommendation.
S3	**Key Finding:** Solution options to mitigate poor BPS performance for widespread MC were explored, and it was determined that none of the system-level solutions (e.g., transmission reinforcement, widespread use of transmission-connected reactive devices, curtailment) proved to be an effective means of ensuring reliability. The best solution to the widespread use of MC to improve BPS performance was to eliminate its use to the greatest possible extent. **Recommendation:** See S1 recommendation.

Key Findings and Recommendations: IRPTF Studies

Table A.1: Key Findings and Recommendations from IRPTF Modeling and Studies Work	
#	**Key Findings and Recommendations**
S4	**Key Finding:** User-defined models used to modify (overlay) models provided by GOs, to accurately represent large disturbance behavior of solar PV resources; necessary since most BPS-connected solar PV models in base case had deficiencies; not intended as long-term solution for planning assessments; interconnection-wide cases need to be updated as quickly as possible. **Recommendation:** See A1 recommendation.
S5	**Key Finding:** Active and reactive current priority during large disturbances provides better BPS performance than MC; however, reactive current priority with voltage control enabled provided most optimal form of ride-through performance. Timely recovery and control of inverter voltage allows active current to resume to pre-disturbance output immediately following a severe fault event without causing overvoltage or delays in response. **Recommendation:** GOs should tune dynamic response of BPS-connected inverter-based resources to meet BPS reliability criteria and support BPS during normal operation and contingency events. Dynamic models should be updated to reflect specific settings used in the field. Refer to NERC *Reliability Guideline: BPS-Connected Inverter-Based Resource Performance* for details on recommended performance, and refer to any local interconnection requirements that may be in place.
S6	**Key Finding:** Protection system models not widely available in planning models; challenge to study whether the large power swings caused by MC and other inverter behavior have a potential impact on BPS protection system operation. Efforts taken to model key transmission paths; however, models were not readily available to transmission planning engineers. **Recommendation:** TPs and PCs should require reasonable representation of protection systems and functions be included in interconnection-wide cases. Models used to represent these protection systems and functions can be used in “monitor only” mode to flag potential operation of protection systems or functions. TPs and PCs should perform detailed analyses to identify any potential inadvertent operation of protection systems or functions during contingency events.

Key Findings and Recommendations: IRPTF Technical Discussions

Table A.1: Key Findings and Recommendations from IRPTF Modeling and Studies Work	
#	Key Findings and Recommendations
D1	**Key Finding:** NERC MOD-026-1 and MOD-027-1 activities do not adequately verify accuracy of dynamic models relative to actual installed equipment performance for large disturbance response. Small disturbance testing does not capture large disturbance behavior and therefore does not verify dynamic models. Contributor to systemic modeling challenges faced by industry. **Recommendation:** IRPTF identified MOD-026-1 and MOD-027-1 as needing revisions to serve intent of standard for BPS-connected inverter-based resources. Changes should ensure that large disturbance behavior of inverter-based resources is verified; activities beyond matching simulated and actual response to small disturbance test should be mandatory step in process. TPs and PCs should be required to verify appropriateness of all model parameters.
D2	**Key Finding:** Issues with transferring knowledge about actual installed settings in the field and how they are parameterized in dynamic models provided to TPs/PCs; stems partly from inverter OEMS and consultants who prepare and submit dynamic models to GOs. Lack of guidance to OEMs on recommended modeling approaches w.r.t. generic models (e.g., reec_b versus reec_a). Need for converting reec_b models to reec_a to better capture dynamic response of solar PV. Not until actual responses of solar PV resources analyzed by NERC and IRPTF did industry become aware of shortcomings in dynamic models. **Recommendation:** GOs should provide appropriate training and guidance to personnel who parameterize models that are submitted for interconnection-wide base cases. Also, see A2 recommendation.

Key Findings and Recommendations: IRPTF Technical Discussions

Table A.1: Key Findings and Recommendations from IRPTF Modeling and Studies Work	
#	**Key Findings and Recommendations**
D3	**Key Finding:** Attachment A of Appendix 1 in the FERC LGIP does not mention solar PV resources and only briefly mentions wind power resources. Lack of specificity for modeling and studying these resources during the interconnection process may be leading to lack of detailed studies prior to interconnection. Unclear in the LGIP and the LGIA what constitutes a “material modification” and how technological change procedures should apply. **Recommendation:** FERC LGIP and LGIA should be reviewed to identify changes necessary to ensure clarity and consistency for inverter-based resources. “Material modification” and technological change procedures should be updated to ensure changes to any equipment that change electrical response of a resources warrant additional interconnection studies to ensure that response is stable under all expected operating conditions.
D4	**Key Finding:** As the system continues to evolve towards increasing penetrations of inverter-based resources, it is incumbent upon TPs, PCs, and TOs to ensure that interconnection requirements, specifically pertaining to modeling and system studies, are updated to ensure that adequate models (steady-state, dynamic, short circuit, and EMT) are provided and benchmarked. Refer to NERC Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources. **Recommendation:** TOs, TPs, and PCs should ensure that the interconnection requirements are updated to ensure that GOs provide adequate models for reliability studies during the interconnection studies process. Requirements should be clear and consistent as to what is required to be provided for BPS-connected inverter-based resources.

Key Findings and Recommendations: IRPTF Technical Discussions

Table A.1: Key Findings and Recommendations from IRPTF Modeling and Studies Work	
#	**Key Findings and Recommendations**
D5	**Key Finding:** As instantaneous penetration of BPS-connected inverter-based resources (in combination with DERs) increases, increasingly difficult to develop interconnection-wide base cases to meet renewable portfolio standards while maintaining acceptable BPS performance (e.g., coordinating renewables outputs, DERs, and path flows); leading to operating conditions never experience before; impacts to neighboring footprints need to be coordinated. **Recommendation:** TPs and PCs responsible for interconnection-wide case creation should consider how to manage very high penetration inverter-based resource operating assumptions and determine necessary steps or practices to handle previously unexpected operating assumptions. Case assumptions should be established collaboratively with all parties. Entities should develop credible operating assumptions, particularly in planning horizon with significant amounts of additional variable energy resources dispatched in the case. Additionally, TPs and PCs should establish communication practices to share relevant modeling and simulation issues and knowledge across footprints within an interconnection.
D6	**Key Finding:** Planning model-related challenges are equally a challenge for operations planning time horizons. Assumptions made in these studies and the modeling improvement efforts in the planning realm by TPs and PCs may not be widely shared with TOPs and RCs. Accurate models are particularly important for studying the “fringe” operating conditions (e.g., high path flows with high renewables conditions) that are relatively unlikely to occur (and may be overlooked in the long-term planning horizon) but may appear in the operations horizon due to outage conditions or other factors. These low-likelihood, high impact operating conditions may pose risks to BPS reliability during certain operating hours. **Recommendation:** Transmission planning and operating entities should be coordinating to ensure that any modeling improvements identified in either timeframe are shared and communicated to other entities. Modeling improvements for inverter-based resources should be accounted for in both the planning and operations studies, to the extent possible. Centralized modeling repositories for planning and operations may help ensure accurate models are being applied to both types of studies.

Key Findings and Recommendations: IRPTF Technical Discussions

Table A.1: Key Findings and Recommendations from IRPTF Modeling and Studies Work	
#	Key Findings and Recommendations
D7	**Key Finding:** The generic RMS positive sequence dynamic models for inverter-based resources connected to the BPS can generally model momentary cessation behavior but with known limitations on modeling the recovery delay. Inaccurate modeling of recovery delay causes inaccuracies in the dynamic simulation results, particularly regarding false voltage overshoot when active current recovery is delayed but reactive current is not. Further, the reec_b model has limitations on capturing voltage-dependent current logic and its use is discouraged moving forward. **Recommendation:** The generic RMS positive sequence dynamic models should be enhanced by model development groups as soon as possible. Once the model enhancements are benchmarked and approved for use in planning assessments, TPs and PCs should notify GOs in their planning footprint that these updated models are available and should be used for any necessary modeling improvements (regarding MC and other improvements to modeling disturbance ride-through performance).