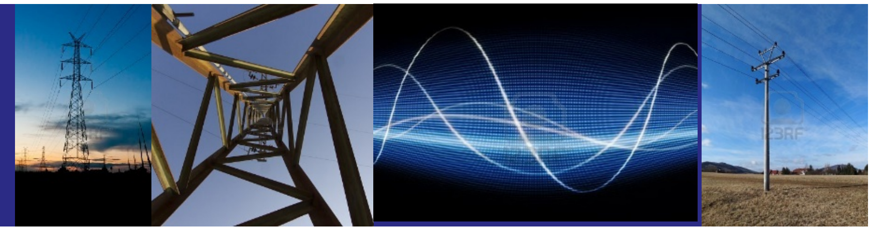


CIS-IEEE 2017 Conference
Renewable Energy Session
Renewable Energy’s Impact of Power Systems

Indiana University
Bloomington, Indiana
November 10, 2017

Ben Huckaba, P.E.
President & Principal Engineer
317-273-9841
benh@alphaeng.us

Alpha Engineering, Inc.
7760 W New York St
Indianapolis, IN
www.alphaeng.us

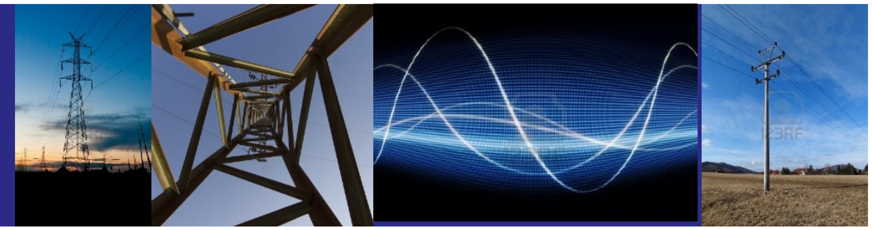
ALPHA ENGINEERING, INC

IEEE

IEEE PES Power & Energy Society®

Agenda

- IEEE Standard 1547 & 2030
- 1547.7-2013, Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection
  - Modeling & System Data
  - Analysis
  - Results & Recommendations
- Case Study – Utility Scale (1 MW PV to 12.47 kV)



IEEE 1547 & IEEE 2030

- IEEE 1547 Series of Interconnection Standards
- http://grouper.ieee.org/groups/scc21/1547_series/1547_series_index.html

- IEEE 2030 Series of Smart Grid Interoperability Stds
- http://grouper.ieee.org/groups/scc21/2030_series/2030_series_index.html

ALPHA ENGINEERING, INC
IEEE
IEEE PES Power & Energy Society®

Renewable Energy's Impact on EPS

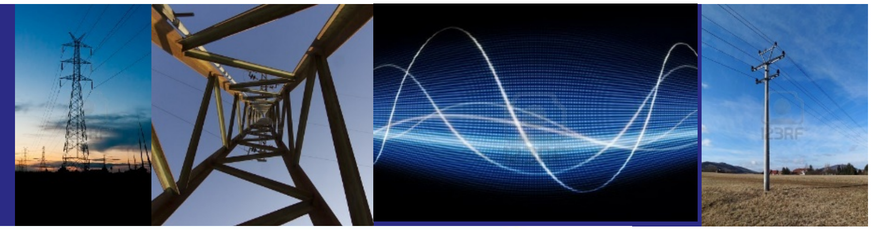
IEEE 1547 Series

Interconnection Impact Study Methodology

- **IEEE Std 1547™(2003 and 2014 Amendment 1) Standard for Interconnecting Distributed Resources with Electric Power Systems**
  - **IEEE Std P1547™(full revision)** Draft Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
  - **IEEE Std 1547.1™(2005 and 2015 Amendment 1)** Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
    - **IEEE Std P1547.1 (full revision)** Draft Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces
- **IEEE Std 1547.2™(2008)** Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems
- **IEEE Std 1547.3™(2007)** Guide for Monitoring Information Exchange, and Control of Distributed Resources with Electric Power Systems
- **IEEE Std 1547.4™(2011)** Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems
- **IEEE Std 1547.6™(2011)** Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks
- **IEEE Std 1547.7™ (2013)** Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection
- **IEEE Std P1547.8™** Draft Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Std 1547-2003

ALPHA ENGINEERING, INC

Renewable Energy's Impact on EPS



IEEE 1547
Interconnection System and Test Requirements

- Voltage Regulation
- Grounding
- Disconnects
- Monitoring
- Islanding
- etc.

IEEE 1547.1
Interconnection System Testing

- O/U Voltage and Frequency
- Synchronization
- EMI
- Surge Withstand
- DC injection
- Harmonics
- Islanding
- Reconnection

UL 1741*
Interconnection Equipment

- 1547.1 Tests
- Construction
- Protection against risks of injury to persons
- Rating, Marking
- Specific DR Tests for various technologies

NEC

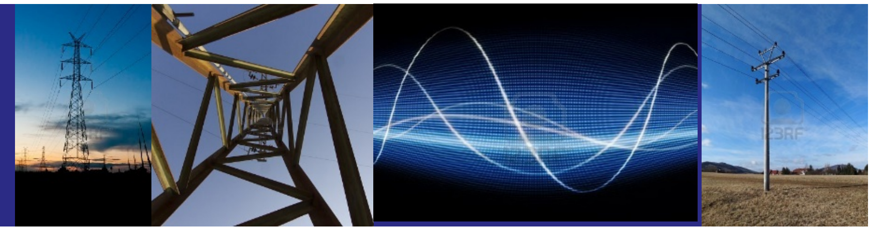
Article 690 PV Systems;

Article 705: interconnection systems (shall be suitable per intended use per UL1741)

PJM Interconnection, Inc.
Small Generator Interconnection Standards
FERC approved
(0-to<10MW and 10-to-20 MW; incorporate 1547 and 1547.1)

* UL 1741 supplements and is to be used in conjunction with 1547 and 1547.1

Source: T. Basso, NREL, "IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid", December 2014.



IEEE 2030 Series

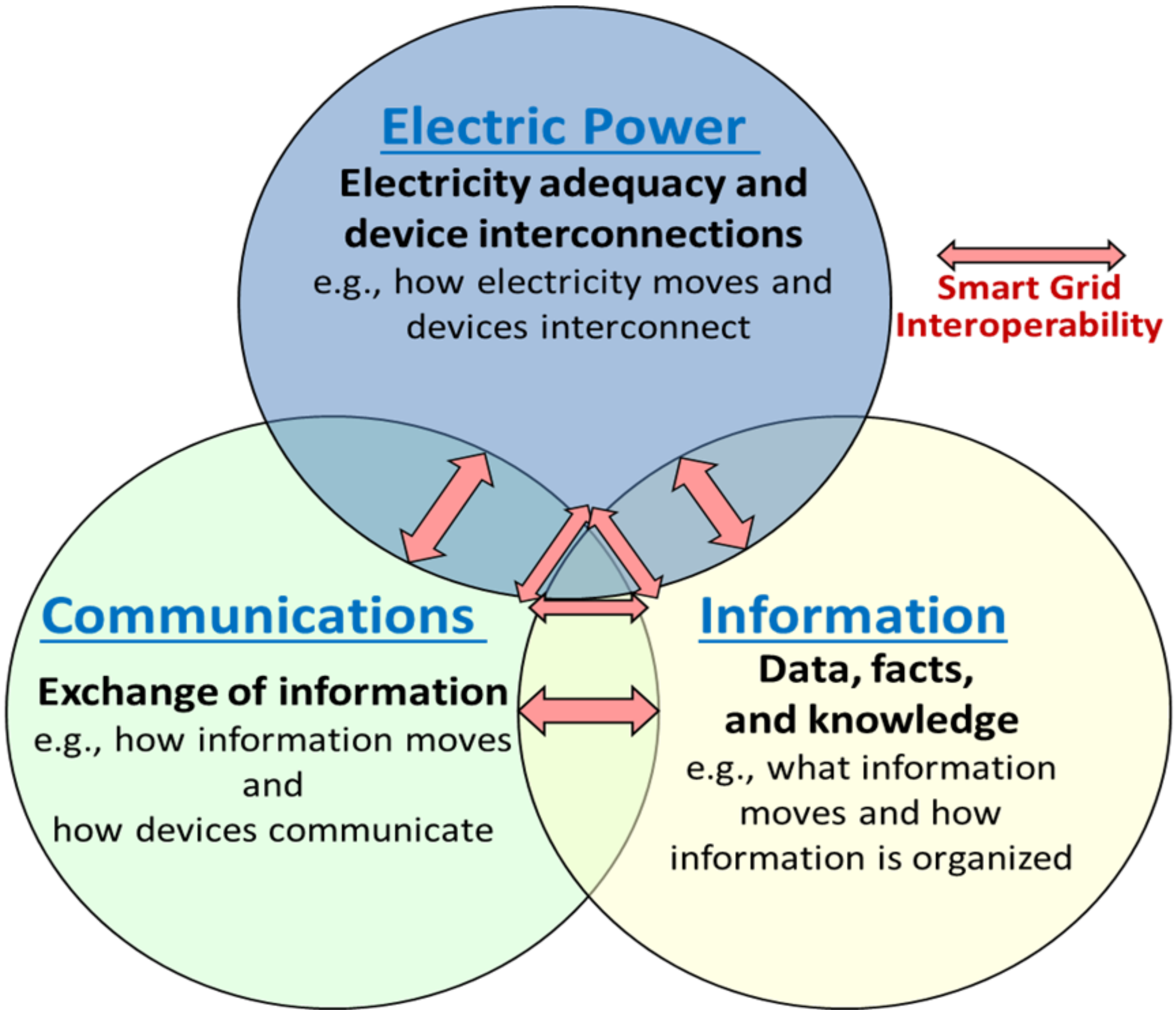
IEEE Std 2030 (2011) Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads

- **IEEE Std P2030.1** Draft Guide for Electric-Sourced Transportation Infrastructure
- **IEEE Std P2030.2** Draft Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure
- **IEEE Std P2030.3** Draft Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications
- Future Smart Grid Interoperability Standards (TBD)

ALPHA ENGINEERING, INC

Renewable Energy's Impact on EPS

IEEE 2030 Series

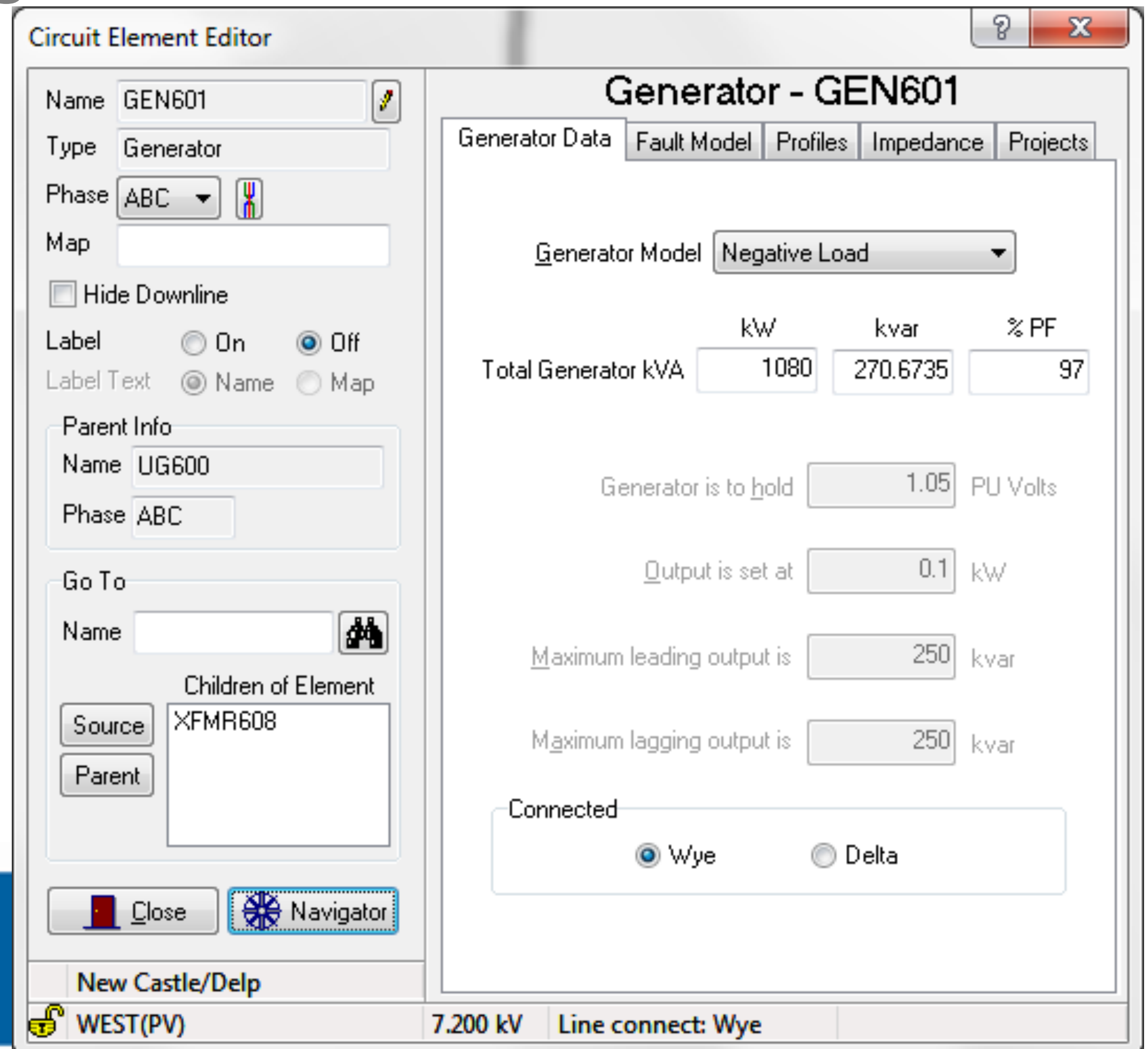


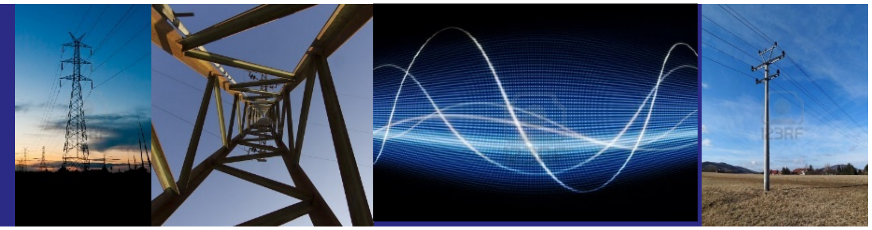
Model Data – Defining the Generator

- Synchronous Generator
  - Adjust KVAR by field winding
- Induction Generator
  - Needs external source of excitation
- Wind Turbines
  - Machine based by typically coupled by converters
- Inverter-based PV

Model Data – Defining the Generator

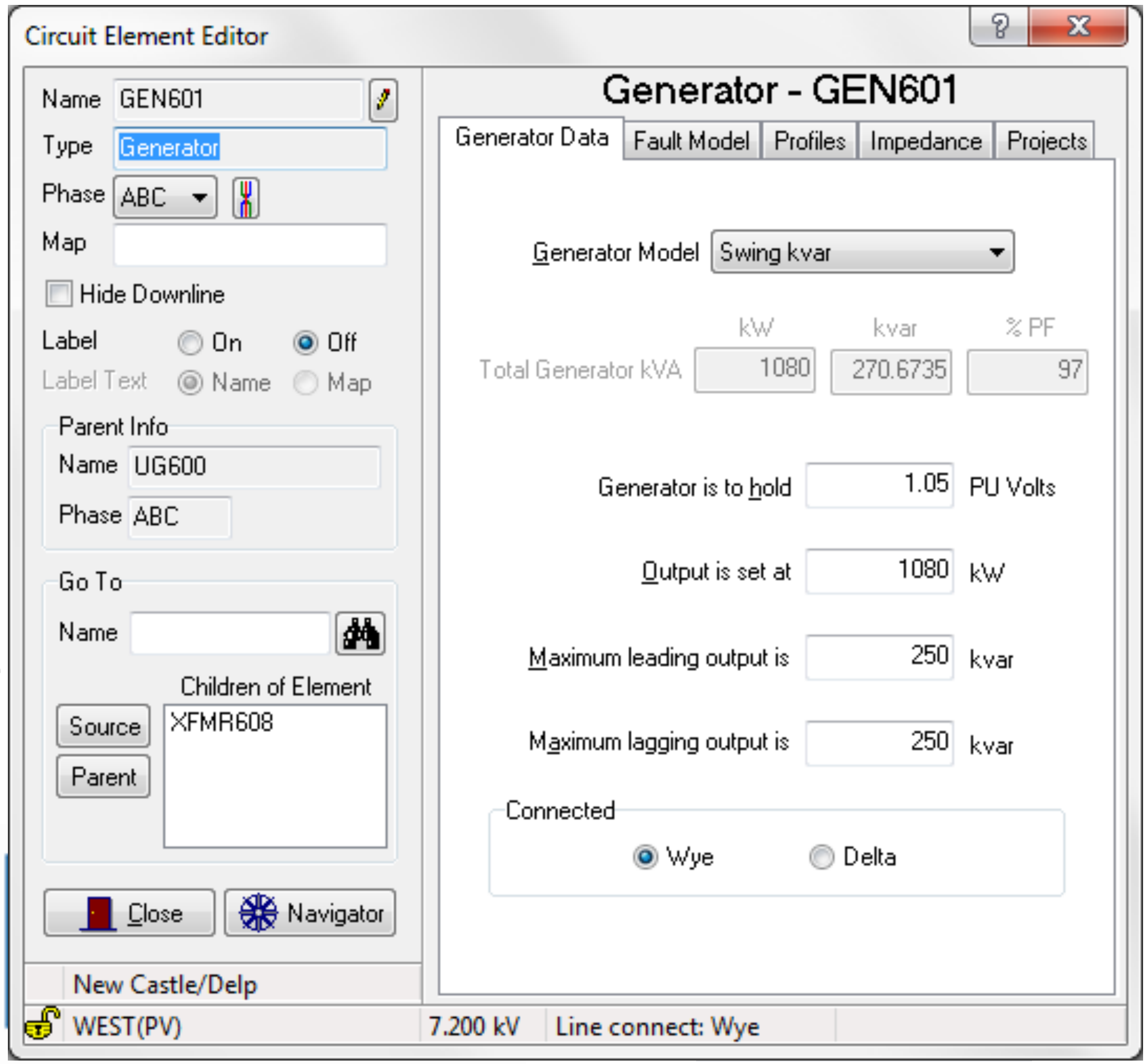
- Negative Load
  - Current Source
  - Real Current Injections
  - Reactive Current Injections

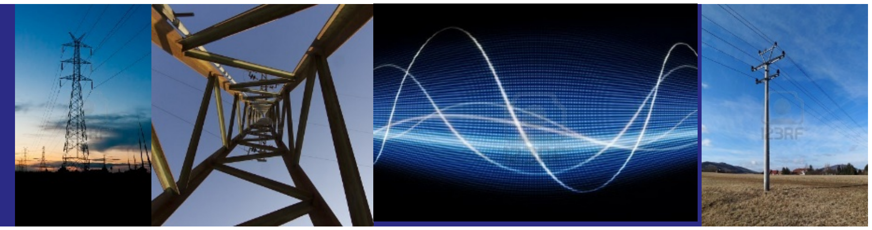




Model Data – Defining the Generator

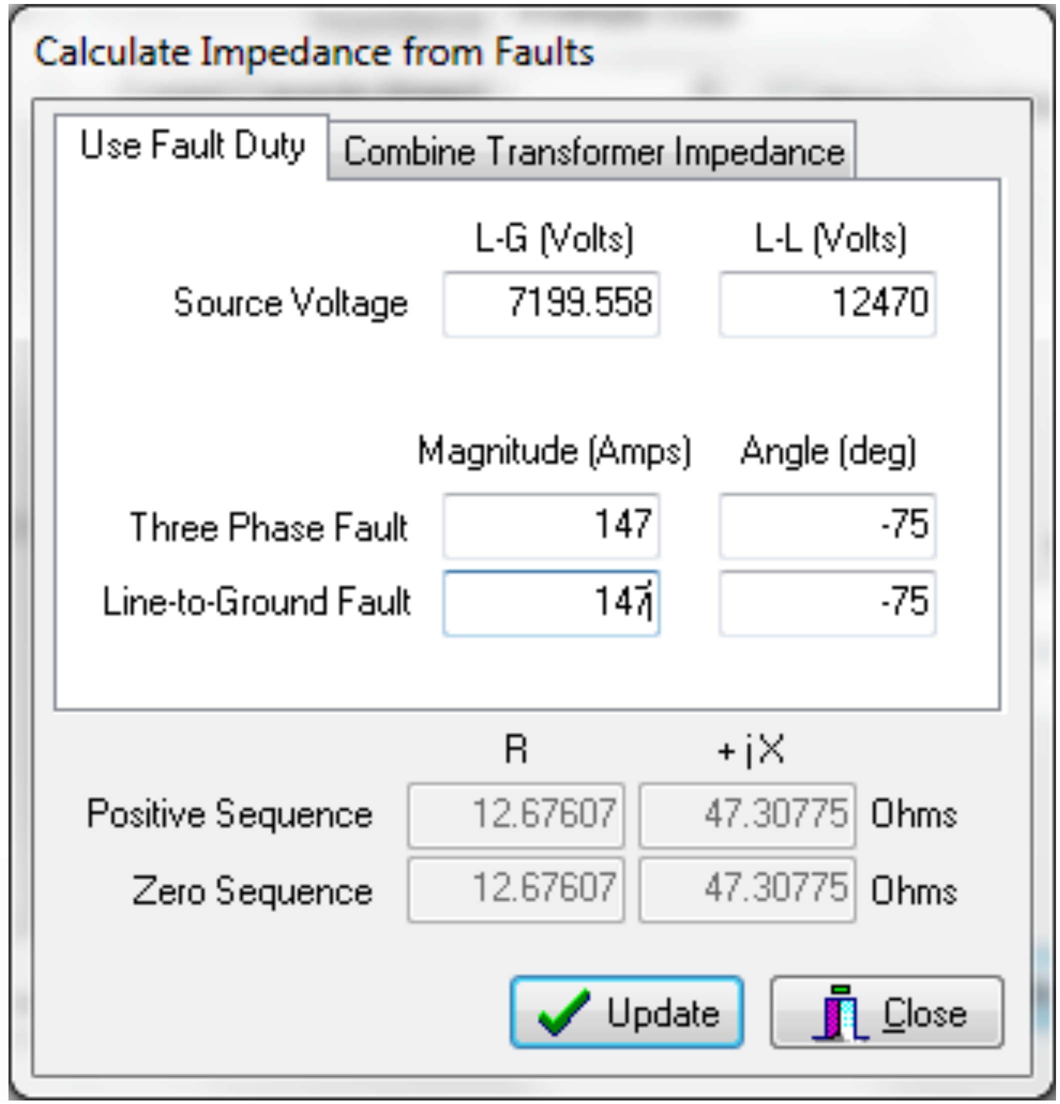
- Swing kVAR
  - Source of fixed KW
  - Variable source of KVAR to hold a specified voltage magnitude at the generator



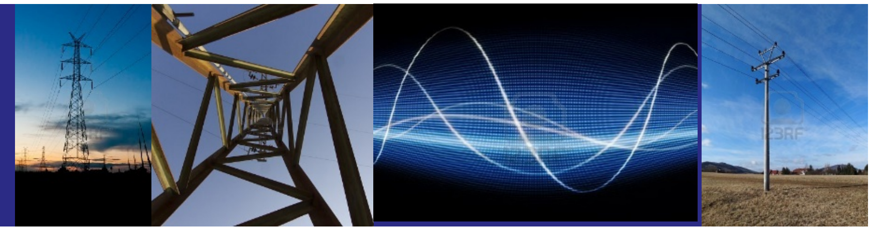


Model Data – Defining the Generator

- Fault Definition
  - Utility grade inverters will have fault contribution specified or manufacturer can provide.
  - Residential inverters fall under general guidelines or rules of thumb.



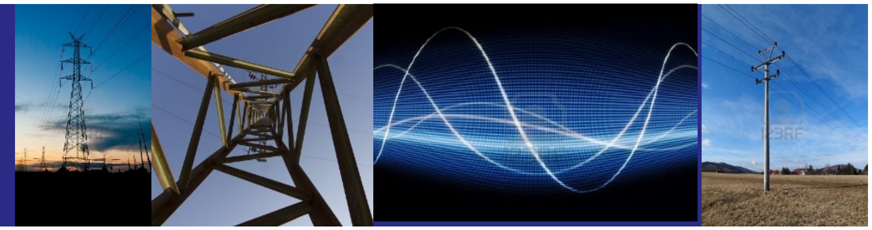
Renewable Energy’s Impact on EPS



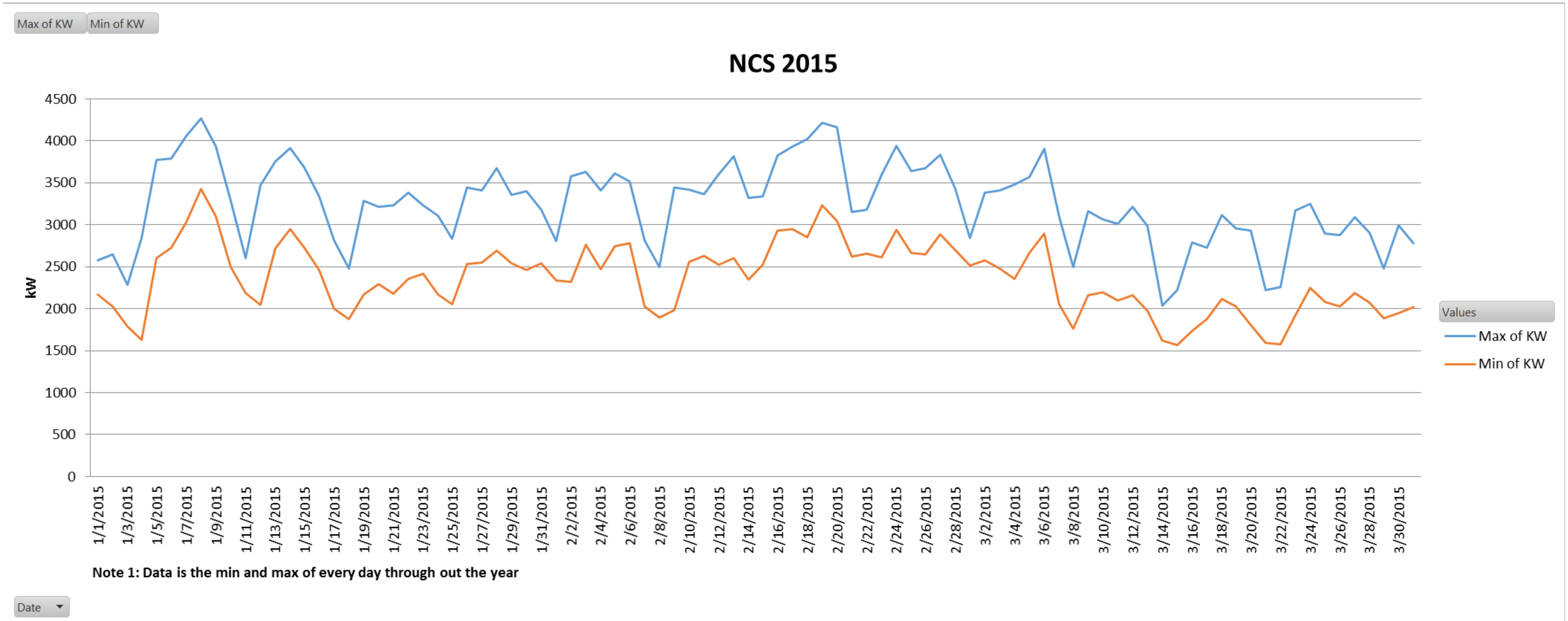
System Data

- Updated available fault current at substation
- Retail usage data, preferable detailed AMI/AMR data
- Detailed (<= 15 minute) wholesale usage data
- In case of solar, can filter out only daylight hours
- System data
  - Regulator and capacitor sizes and settings
  - Very important to accurately model behaviors of each
  - Conductor size and distance (impedance)

Renewable Energy’s Impact on EPS



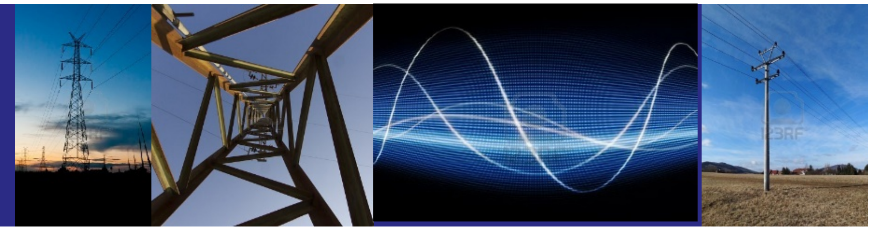
Source Data Example – 15 Minute Wholesale Data



ALPHA ENGINEERING, INC

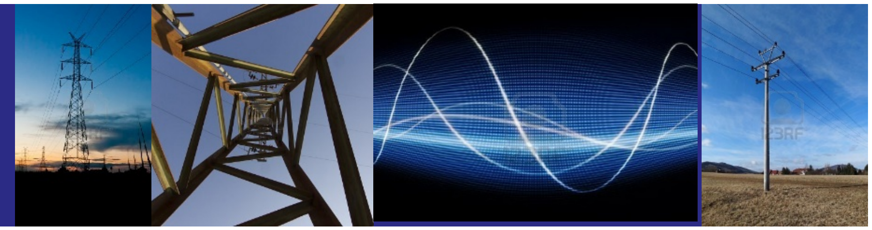
IEEE

IEEE PES Power & Energy Society®



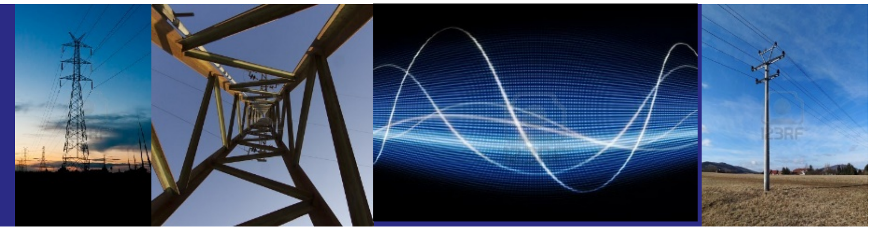
Methodology – Potential for Unintended Islands

- **IEEE 1547.7 - Section 7.3**
- Generator must detect island condition and trip offline within 2 seconds
- Generation exceeds 33% of circuit loading, particularly during minimal loading
- Direct Transfer Trip is common mitigation strategy when islanding conditions are present
- If substation feeder reclosing is allowed on a DG circuit, incorporate breaker status and DTT in reclosing scheme or increase trip interval to allow DG to de-energize and open
- Monitor utility side voltage of PCC and only allow DG to close when utility source is present and healthy



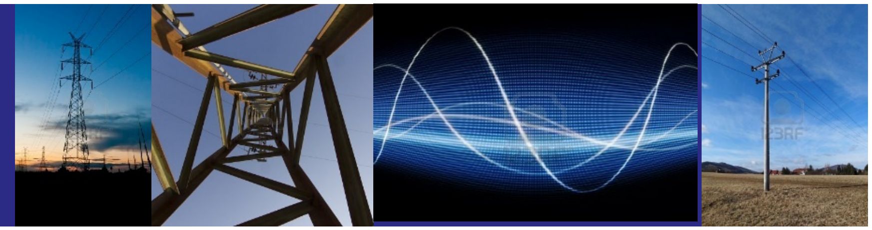
Methodology – Steady State Conditions

- **IEEE 1547.7 - Section 7.4**
- Compare DG rating to the rated capacity of the substation transformer and circuit. DG rating must be less than rating of both substation and feeder
- Transformer serving DG must be larger than rated size of DG itself



Methodology – System Protection

- **IEEE 1547.7 - Section 7.5**
- Device ratings must be sufficient to interrupt the combined fault current of the EPS and PV generation.
- DTT scheme typical
- Protective devices be programmed one trip lockout or have open interval delayed.
- DG should contribute less than 10% of available fault current on primary system nearest the DG source.
- Prefer radial system configuration and not looped or meshed
- Recommend three phase, four wire, effectively grounded system, terminated as a grounded wye on the utility side of the PV generation step up transformer. This avoids overvoltage conditions on EPS during single phase to ground faults.



Methodology – Steady State Voltage Regulation

- IEEE 1547.7 - Section 7.6
- Must maintain ANSI C84.1-2011 Range A voltage values (118-126V)
- Allow the inverters to import or export reactive power as needed to maintain 97% PF, as mentioned in IEEE 1574.7 – 7.6.2.4.
- Concerned that during periods of light loading unacceptably high voltage will result during periods of back-feeding.
  - What is normally a voltage drop in a radial-fed system becomes a voltage rise during when PV is exporting energy back onto the distribution system.

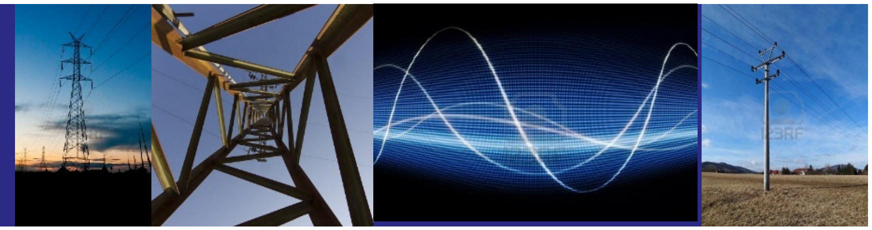
ALPHA ENGINEERING, INC

IEEE

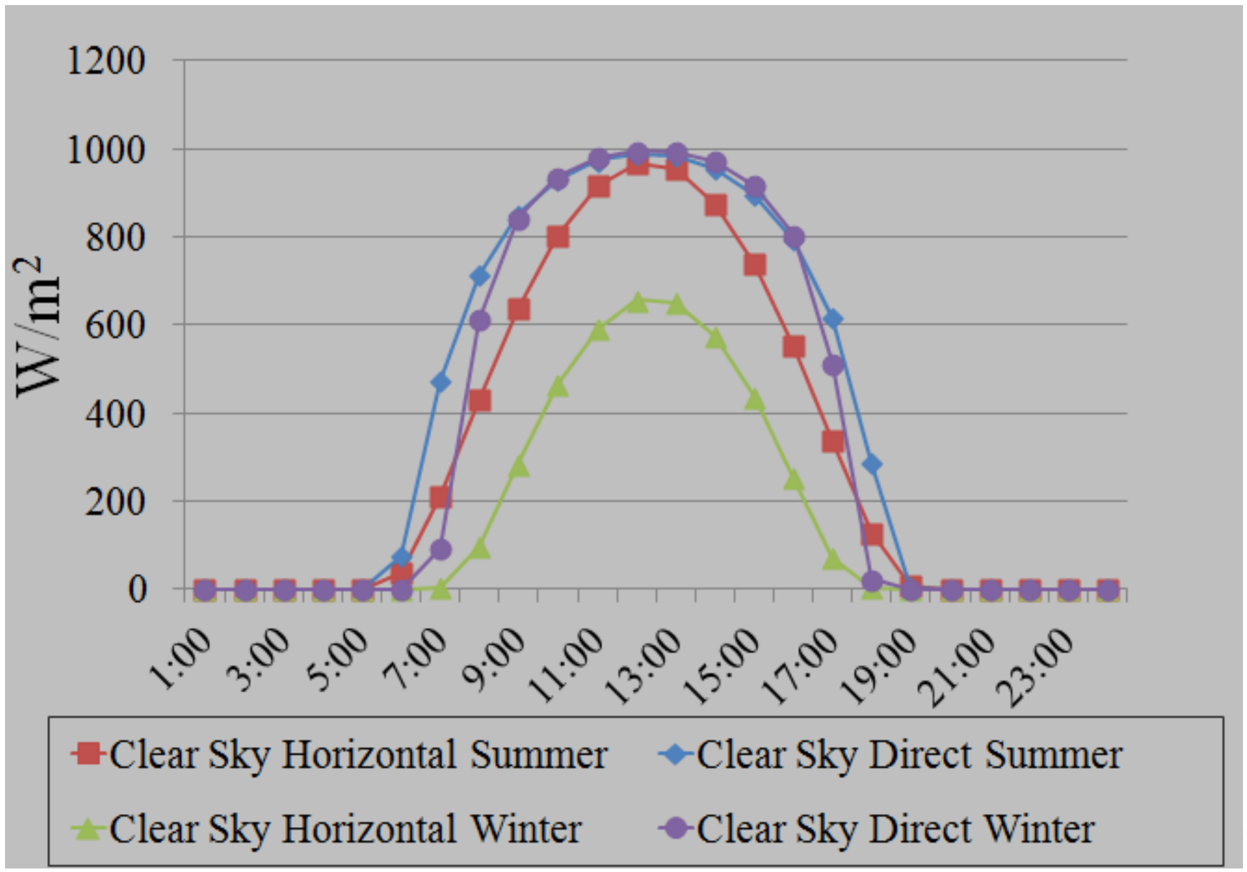
IEEE PES Power & Energy Society®

Methodology – Power Quality

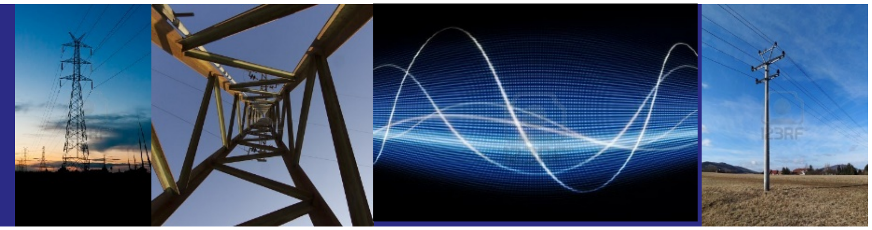
- IEEE 1547.7 - Section 7.7
- Addresses how the "rapid fluctuation or loss of output from the proposed DR may cause voltage sag/swell or flicker. DR may introduce unacceptable harmonic distortion."
- Review historical solar insolation data from the National Renewable Energy Laboratory (NREL) NREL Historical Solar Insolation Data: https://mapsbeta.nrel.gov/nsrdb-viewer/.
- Convert to Watts: NREL's PV Watts calculator NREL PV Watts Calculator: http://pvwatts.nrel.gov/pvwatts.php.
- Alpha Engineering has found that most pronounced impact on the EPS is the complete loss of generation due to breaker trip.
- Rely upon inverter manufacturer to certify acceptable THD.



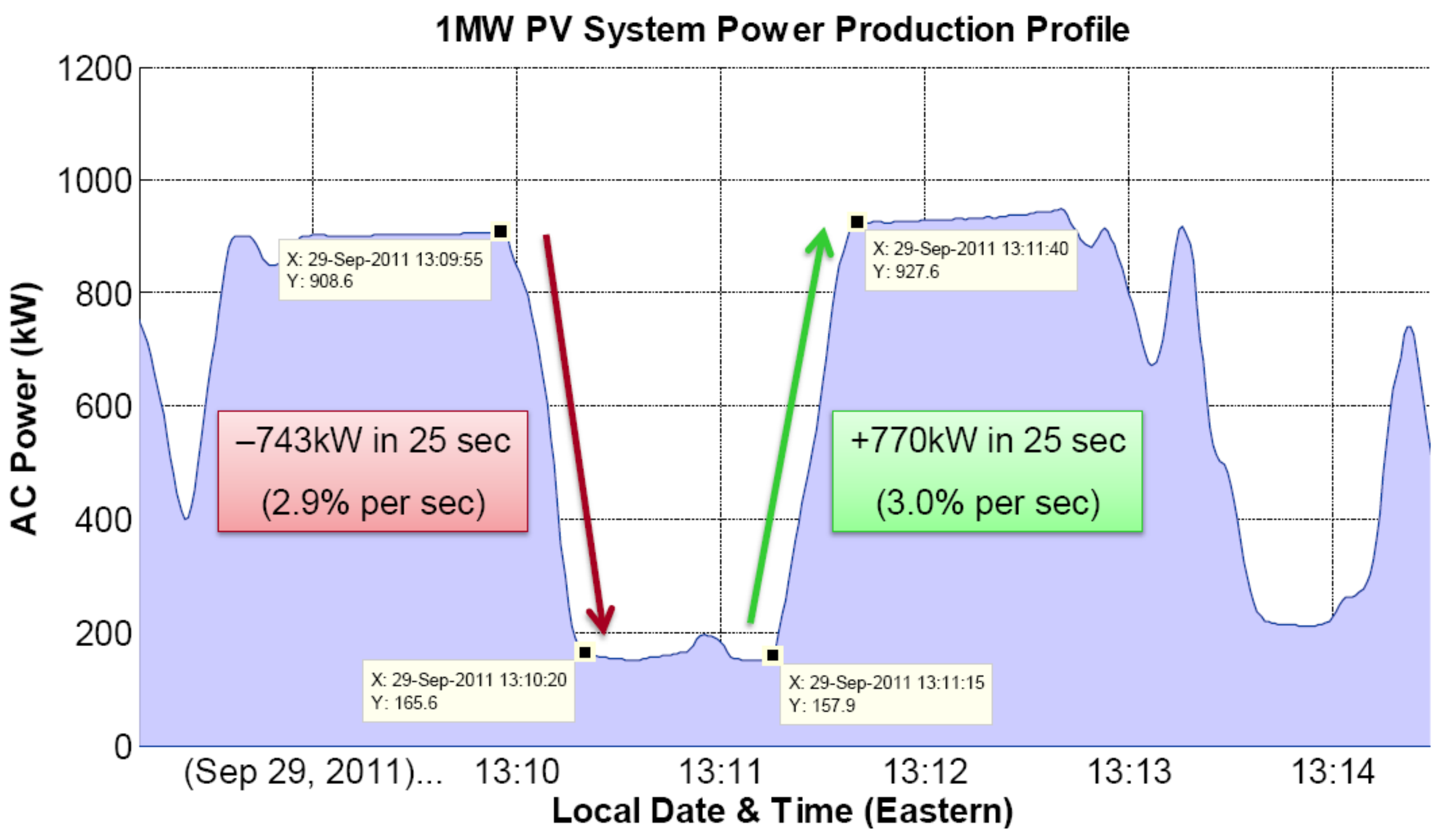
Clear Sky Insolation Profiles



Source: National Renewable Energy Laboratory (NREL) METSTAT (Meteorological/Statistical) solar radiation model.

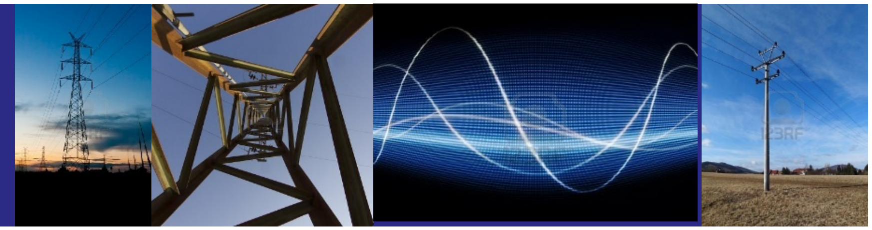


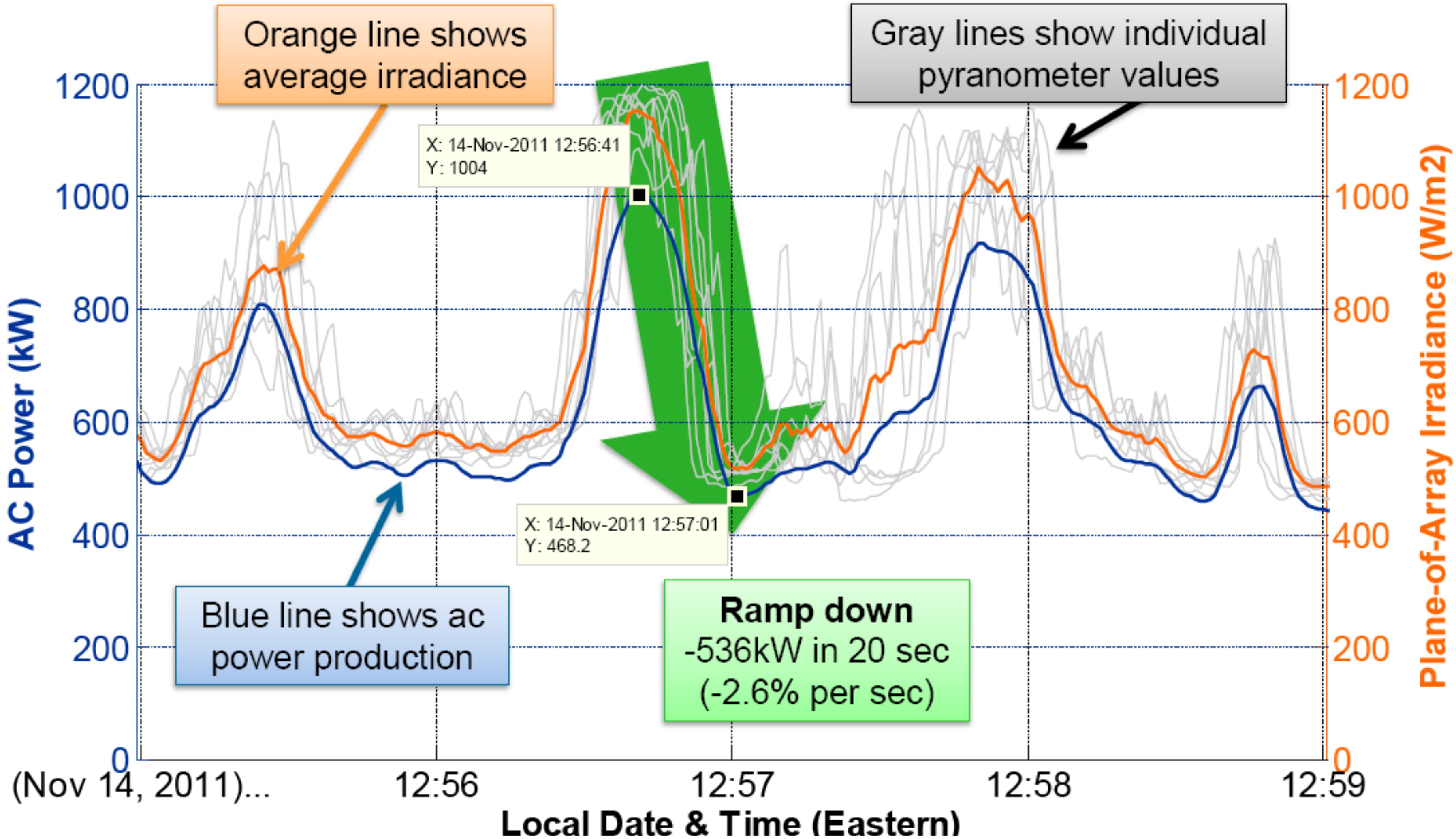
Example Ramping Rates of PV



Source: EPRI Distributed PV Monitoring Project. High Penetration PV Workshop, April 19, 2012.

Renewable Energy’s Impact on EPS





Source: EPRI Distributed PV Monitoring Project. High Penetration PV Workshop, April 19, 2012.

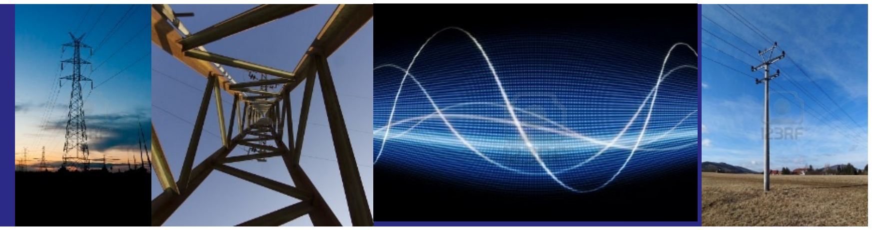
Trip Limits and Tripping Times – Per IEEE 1547.2

Utility Interconnection Voltage and Frequency Trip Limits and Trip Times			
Interconnection System Response to Abnormal Voltages			
Condition	Voltage (V) Range	Frequency (Hz)	Maximum Time at 60 Hz Before Cessation of Current
A	$V < 50\%\ V_{NOM}$	Rated (60 Hz)	<0.16 sec default per IEEE 1547 (Adjustable 0 to 65.535 sec)
B	$50 \leq V < 88\%\ V_{NOM}$	Rated (60 Hz)	<2 sec default per IEEE 1547 (Adjustable 0 to 65.535 sec)
C	$120 < V < 120\%\ V_{NOM}$	Rated (60 Hz)	<1 sec default per IEEE 1547 (Adjustable 0 to 65.535 sec)
D	$V \geq 120\%\ V_{NOM}$	Rated (60 Hz)	<0.16 sec default per IEEE 1547 (Adjustable 0 to 65.535 sec)

ALPHA ENGINEERING, INC

IEEE

IEEE PES Power & Energy Society®



Trip Limits and Tripping Times – Per IEEE 1547.2

Interconnection System Response to Abnormal Frequencies			
Condition	Voltage (V) Range	Frequency (Hz)	Maximum Time at 60 Hz Before Cessation of Current
E	Rated V_{NOM}	70.0 Hz (default set point) (Adjustable 50.0 - 80.0 Hz)	3 sec set point (default set point) (Adjustable 0 to 65.535 sec)
F	Rated V_{NOM}	>60.5 Hz (default per IEEE 1547) (Adjustable 50.0 - 70.0 Hz)	<0.16 sec default per IEEE 1547 (Adjustable 0 to 65.535 sec)
G	Rated V_{NOM}	59.8 Hz (default per IEEE 1547) (Adjustable 40.0 - 60.0 Hz)	Adjustable 0 to 655.35 sec 299.95 sec (defaut in inverter setting)
H	Rated V_{NOM}	<57.0 Hz (default per IEEE 1547) 57.0 Hz (default set point) (Adjustable 40.0 - 60.0 Hz)	<0.16 sec default per IEEE 1547 (Adjustable 0 to 65.535 sec)

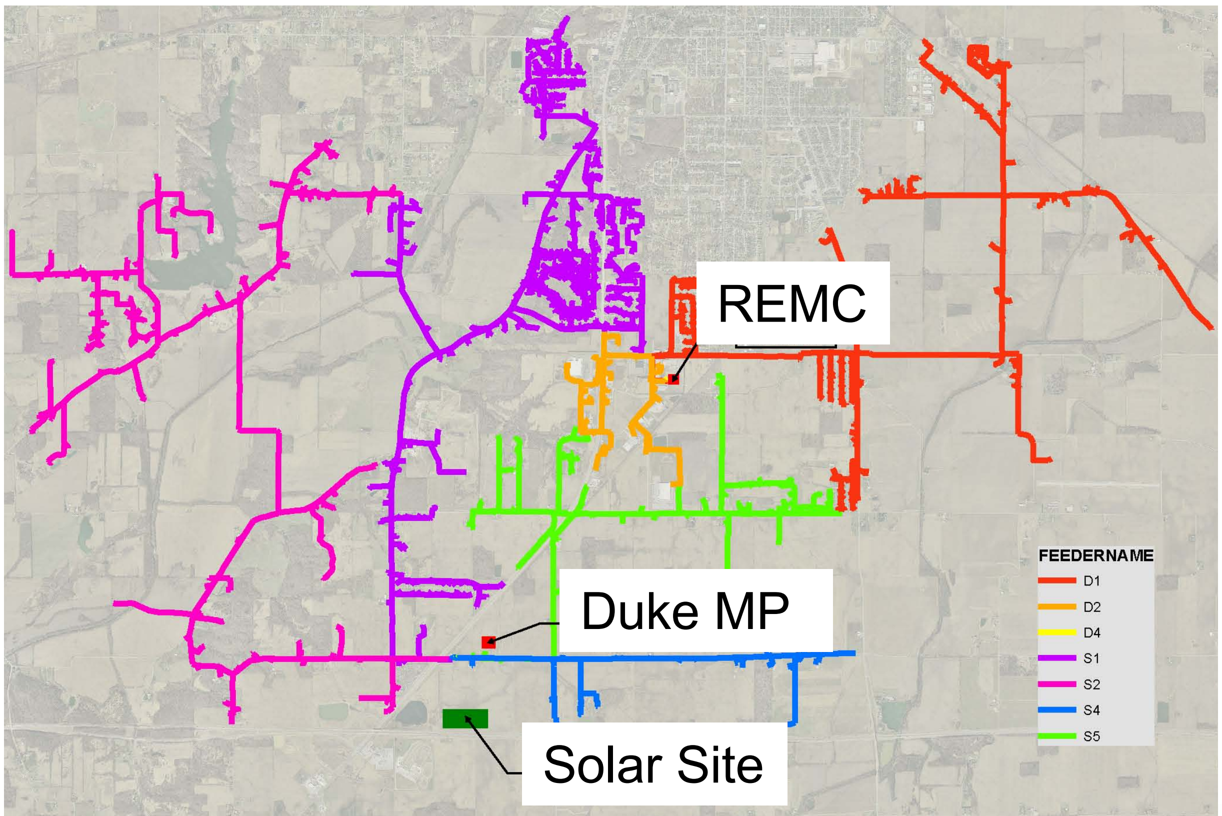
Trip Limits and Tripping Times – Per IEEE 1547.2

Notes:
1. Base voltages are the nominal system voltages stated in ANSI C84.1-1995.
2. DR ≤ 30 kW, maximum clearing times.
3. DR > 30 kW, default clearing times.

Case Study #1 – 1MW PV to 12.47 kV EPS

- Had to avoid Duke Metering Point within 0.5 Miles of PV site
- Instead connect to the nearby REMC station 4.1 Miles from PV site
- Two (2) Schneider Electric SC 540 Inverters
- 4,320 SolarWorld XL 315 Mono PV Modules
- ATI Single Axis Tracker 33% GCR
- One (1) 1200 KVA, Z = 5.5%, 12.47 kV Wye-Grounded, 300 V Wye Set Up Transformer

Case Study #1 – 1MW PV to 12.47 kV EPS

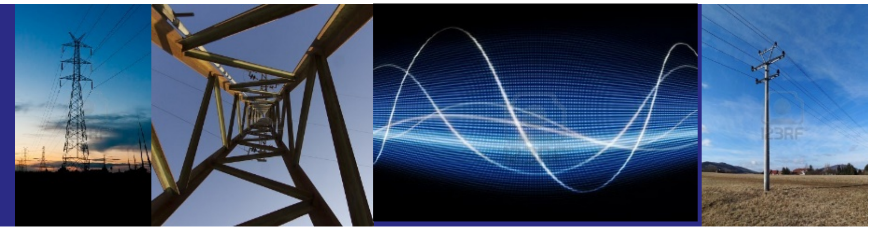


Case Study #1 – System Data

- 2012 – 2015 Retail and Wholesale Data
- Did not have demand or TOU data for residential consumers
- Removed nightly data
- Updated source data
- Updated system model
- Updated device data (capacitor/regulators)

Analysis – Steady State Conditions & Power Quality

- Proposed normal configuration at *maximum* demand loading with no PV generation.
- 1.08 MVA at 97% PF of PV generation at *maximum* demand loading in proposed normal configuration.
- Suddenly trip offline PV generation at rated PV generation at *maximum* demand loading in proposed normal configuration
- Proposed normal configuration at *minimum* demand loading with no PV generation.
- 1.08 MVA at 97% PF of PV generation at *minimum* demand loading in proposed normal configuration.
- Suddenly trip offline PV generation at rated PV generation at *minimum* demand loading in proposed normal configuration.



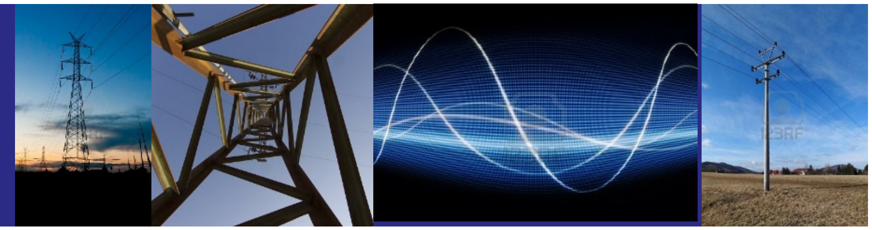
Analysis – Steady State Conditions & Power Quality

Scenario	PV Status	PCC Recloser				Substation Regulated Bus				Minimum Voltage		Maximum Voltage	
		Voltage	KW	KVAR	PF %	Voltage	KW	KVAR	PF %	Voltage	Location	Voltage	Location
PEAK LOAD: Reconfigured NCS Peak (6.63 MW @ 99.2% PF, Reconfigured Circuit 102 Peak: 3.7 MW @ 99.5% PF													
1	OFF	121.97	0*	0*	-	123.4	6,565.4	856.0	99.2%	120.9	06 8550	123.4	Regulated Station Bus
2	ON	123.47	-1,068.3	-122.4	99.3%	123.5	5,492.9	717.2	99.1%	121.3	06 8550	123.5	Regulated Station Bus
		Voltage Flicker (%)				Voltage Flicker (%)				Voltage Flicker (%)		Voltage Flicker (%)	
3	TRIP	1.23%	-	-	-	0.08%	-	-	-	0.33%	06 8550	0.08%	Regulated Station Bus
MINIMUM LOAD: Reconfigured NCS Load : 2.3 MW @ -92.2% PF, Reconfigured Circuit 102 Load 1.3 MW @ -86.4 PF													
4	OFF	122.87	0*	0*	NA	123.5	2,289.4	-971.3	-92.0%	122.8	06 8550	123.5	Regulated Station Bus
5	ON	123.97	-1,068.5	-32.9	99.9%	123.6	1,225.3	-974.8	-78.0%	123.1	06 8550	123.6	Regulated Station Bus
		Voltage Flicker (%)				Voltage Flicker (%)				Voltage Flicker (%)		Voltage Flicker (%)	
6	TRIP	0.90%	-	-	-	0.08%	-	-	-	0.24%	06 8550	0.24%	Regulated Station Bus
Note:	*When PV is offline, there will be minimal load for site equipment and to energize 10 kVA and 1200 kVA transformers.												

ALPHA ENGINEERING, INC

IEEE

IEEE PES Power & Energy Society®



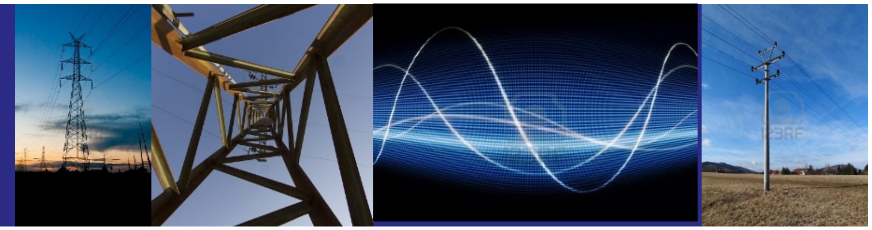
Mitigation – Steady State Conditions & Power Quality

- Rebuilt 1.25 miles of 4/0 ACSR primary 12.47 kV line to 336 ACSR in order to manage voltage drop/rise between PV site and regulated substation bus.
- Installed DTT as PV generation exceeded 33% of minimal system loading.
- Reconfigured distribution circuit in effort to avoid or minimize PV generation from back-feeding onto 12.47 kV bus of substation
- Reduced substation regulators bandwidth setting to avoid voltage rise being too great near PV generation.
- Increased recloser opening interval in order to allow PV inverters to separate from EPS.

ALPHA ENGINEERING, INC

IEEE

IEEE PES Power & Energy Society®

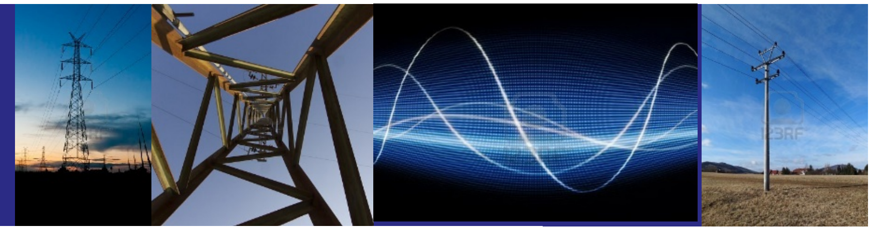


Sources

- IEEE 1547 & IEEE 2030 sites previously listed
- 2012 – 2016 Milsoft User Conference Papers
  - Original source data cited above.

Summary

- IEEE Standard 1547 & 2030
- 1547.7-2013, Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection
  - Modeling & System Data
  - Analysis
  - Results & Recommendations
- Case Study – Utility Scale (1 MW PV to 12.47 kV)



ALPHA ENGINEERING, INC

IEEE

IEEE PES Power & Energy Society®