Impacts of Distributed Generation

LESSONS LEARNED

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Introduction and Agenda

- Basic Data and Assumptions
- Short Circuit Analysis
- Voltage and Capacity Review
- Voltage Flicker Review
- Harmonics Review
- Stability Analysis
- Protection Recommendations
- Grounding Requirements
- Conclusions

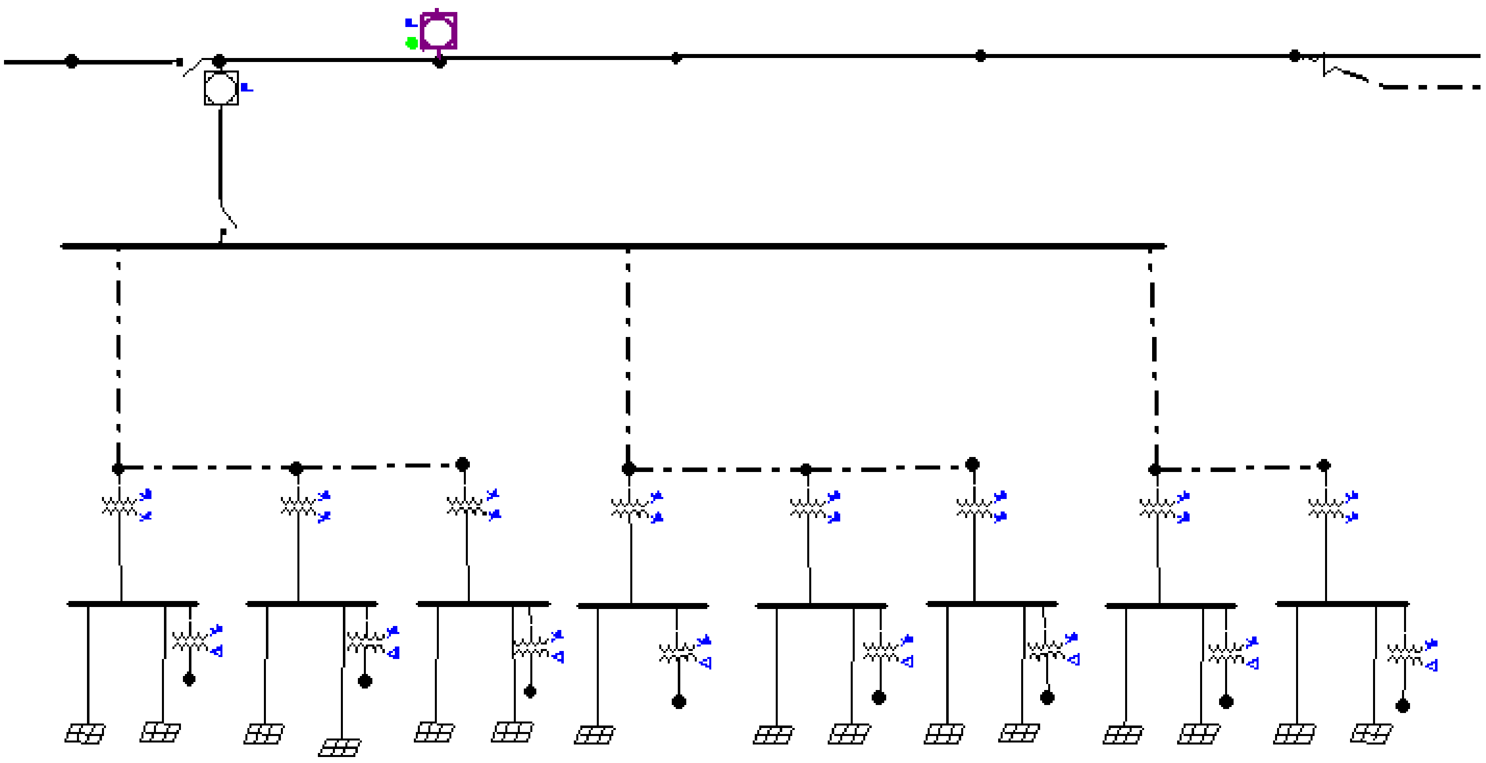
Basic Data and Assumptions

- Load data – from utility; substation and feeder level; 15-minute or smaller increments best
- Power factor – from utility and inverter specs; substation and feeder level historical, requirements for inverters from utility
- Modeling components –vary by software
- Fault current contribution – from inverter manufacturer
- Step-up transformer specifications – from DG site developer
- Substation source impedance – from utility
- Substation transformer specifications – from utility; includes load tap changer or regulator settings
- Line regulator and capacitor specifications – from utility
- Protective device locations and settings – from utility
- DG specifications

DG= distributed generation

Basic Data and Assumptions

Example from CYME model; recloser and switch, step-down transformers, inverters/PV modules, grounding banks. 7.5 MW site



PV = photovoltaic

Short Circuit Analysis

DG Status	Fault Location	LG (Amps)	LG (MVA)	LLL (Amps)	LLL (MVA)
OFF	PCC	3,561	81	4,727	108
ON	PCC	6,038	138	5,043	115
OFF	13 kV Bus Substation	8,937	204	8,856	202
ON	13 kV Bus Substation	9,676	221	9,168	210
OFF	138 kV Bus Substation	28,540	6,822	34,057	8,141
ON	138 kV Bus Substation	28,548	6,824	34,089	8,148

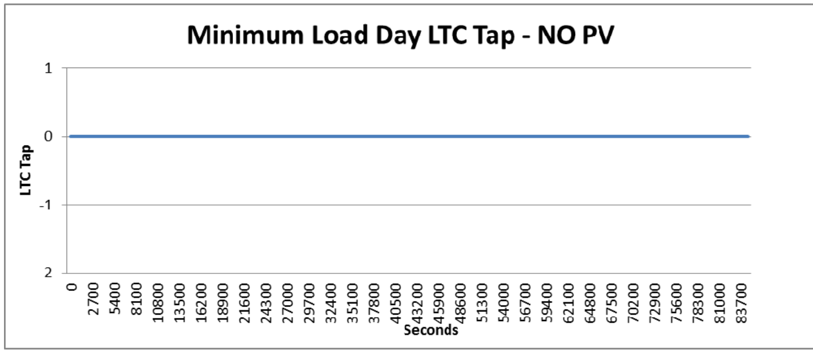
DG = distributed generation; PCC = point of common coupling; LLL = three phase fault type; LG = line to ground ;
kV = kilovolts; MVA = megavolt ampere; Amps = ampere

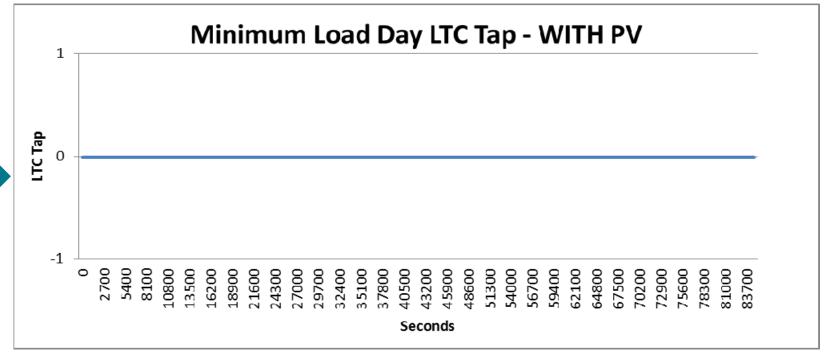
Voltage and Capacity Review

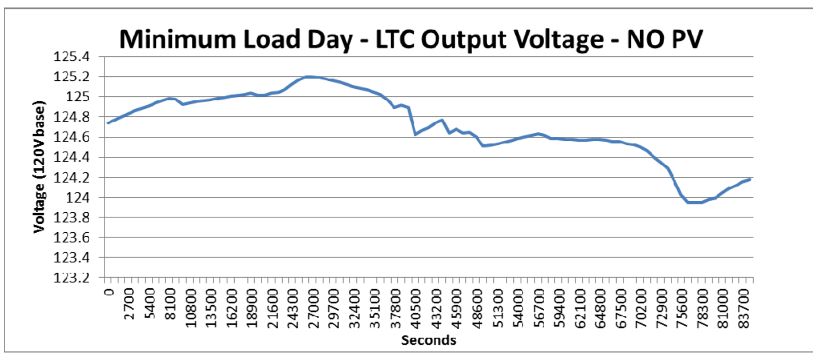
Scenario	DG Status	PCC				Substation				Minimum Voltage		Maximum Voltage	
		V	KVAR	KW	P.F.	V	KVAR	KW	P.F.	V	Location	V	Location
5.472 MVA Peak at -99.6% P.F. – 1.5 MW DG added													
1	OFF	125	-929	2,656	-94.3%	125.5	-378	5,624	-99.8%	124.5	1664756	125.5	Substation
2	ON	125.2	-852	1,198	-80.6%	125.5	-337	4,153	-99.7%	124.7	1664756	125.5	Substation
1.974 MVA Peak at -99.9% P.F. – 1.5 MW DG added													
3	OFF	125.2	-709	961	-80.1%	125.4	22	2,031	100.0%	124.9	1208871	125.4	Substation
4	ON	125.4	-641	-497	-61.2%	125.4	81	570	98.9%	124.9	1208871	125.4	Substation

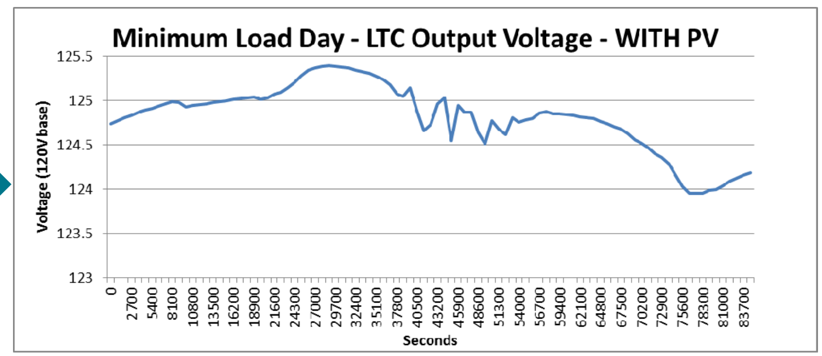
DG = distributed generation; PCC = point of common coupling; V= volt; KW = kilowatt; KVAR = kilovolt-amperes reactive; P.F. = power factor; MVA = megavolt ampere; MW = megawatt

Voltage and Capacity Review



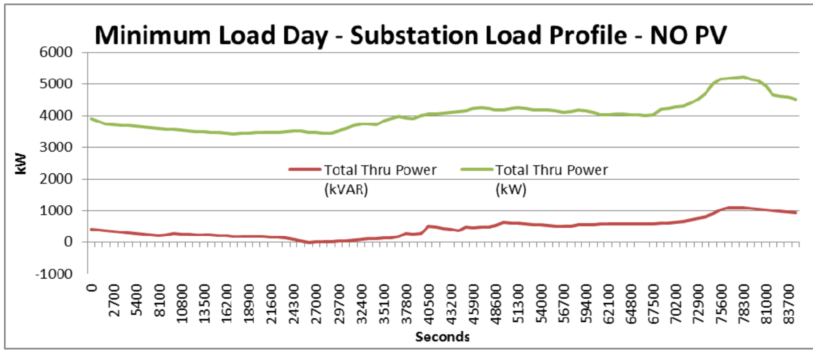


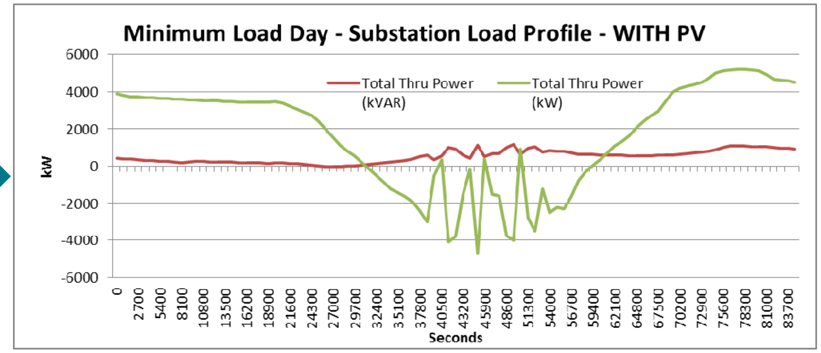


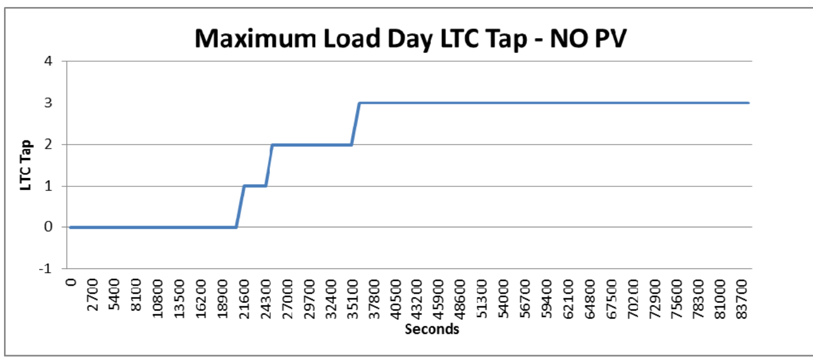


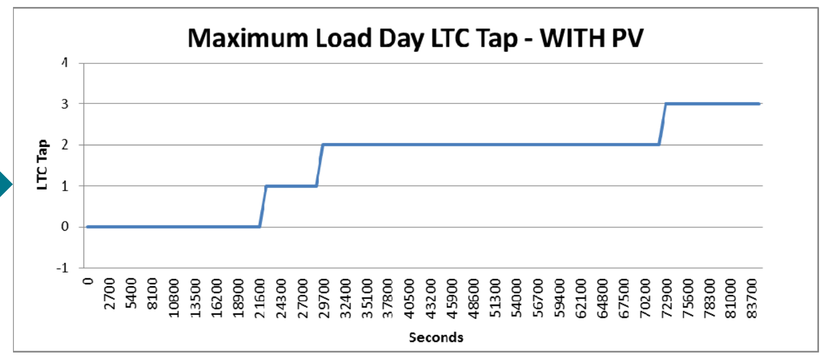
PV = photovoltaic   LTC = load tap changer

Voltage and Capacity Review









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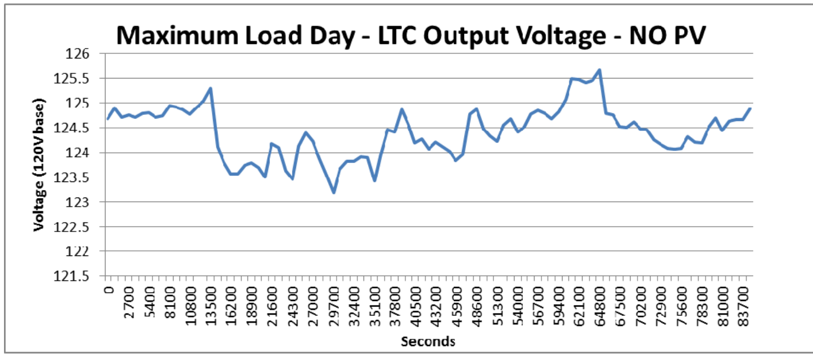
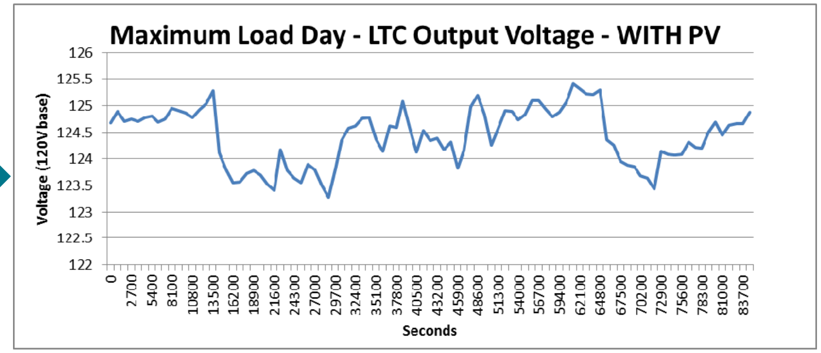
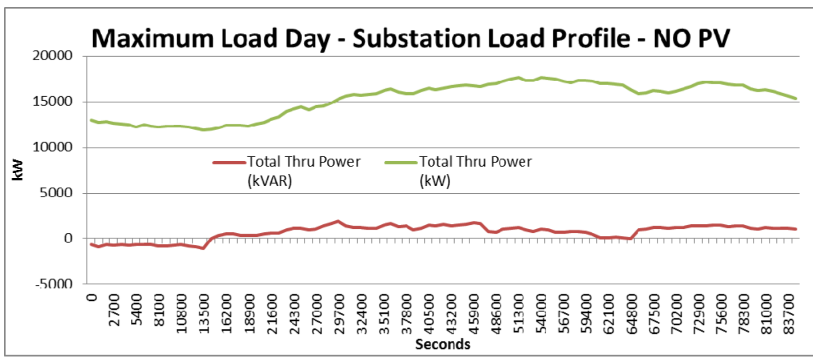
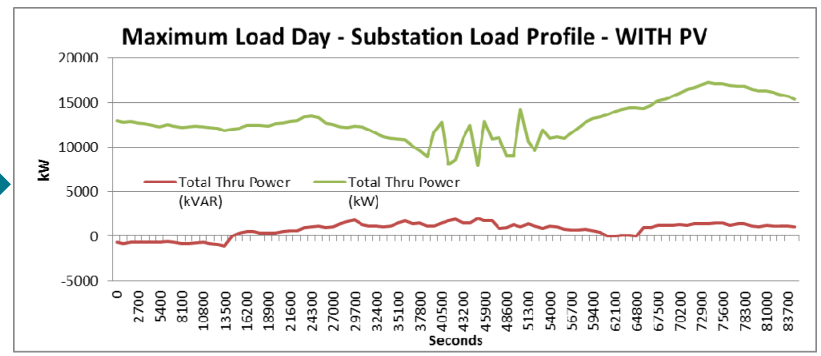
Voltage and Capacity Review





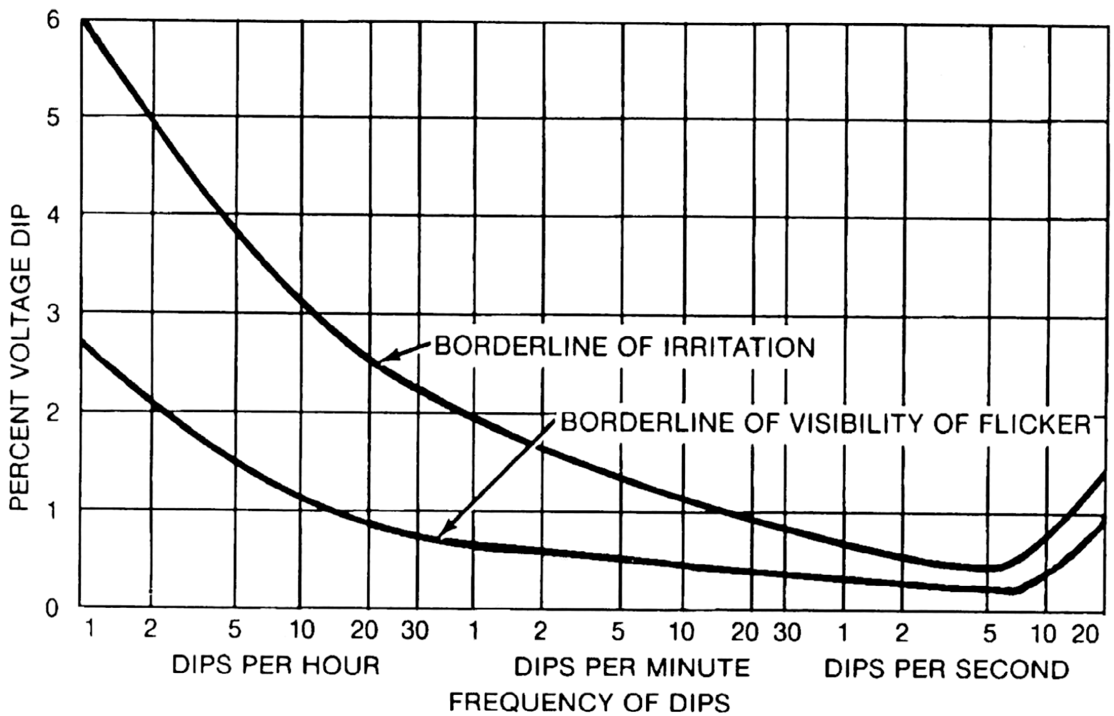




PV = photovoltaic   LTC = load tap changer

Voltage Flicker Review

P_{st} planning level of 0.9 from the IEC® 61000-3-7 standard is essentially equal to the line of irritation on the IEEE® 519 chart.



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Voltage Flicker Review

- Per IEC® 61000-3-7 standard for medium voltage systems
- Stage 1 K Factor – Ratio of DG size to short circuit calculation at PCC

	Allowable (1)	Calculated
P_{st}	0.90	0.475
P_{lt}	0.70	0.446

Note: (1) From IEC 61000-3-7 Table 2 for medium voltage systems.

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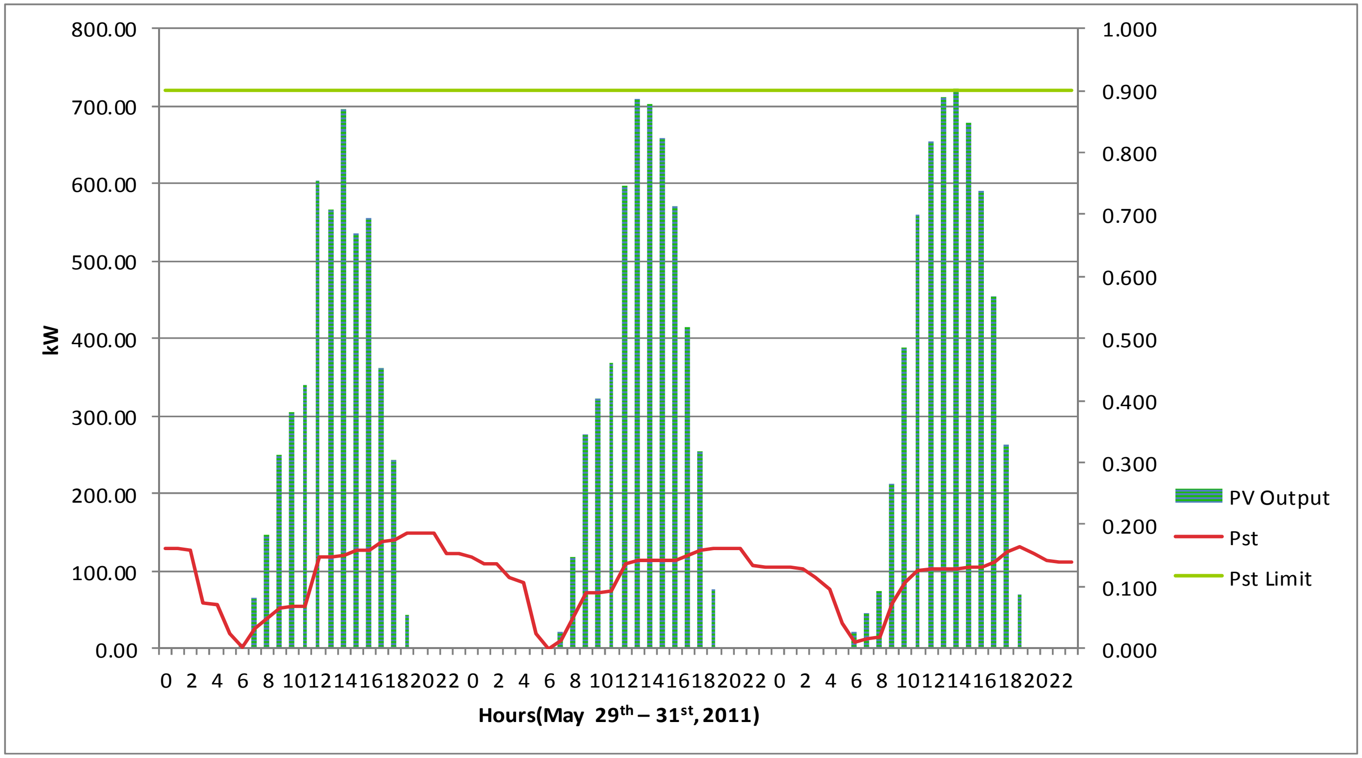
DG = distributed generation; PCC = point of common coupling;

Voltage Flicker Review

1 MW unit adjusted output



MW = megawatt; PV = photovoltaic

Harmonics Review

- Limitation of dc injection (IEEE® Standard 1547-2003 4.3.1).
- "The DR and its interconnection system shall not inject dc current greater than 0.5 percent of the full rated output current at the point of DR connection."
- Inverter manufacturer can provide harmonic contribution information to ensure the requirements, below, from the IEEE® standard are met.

Table 3—Maximum harmonic current distortion in percent of current (I)[a]

Individual harmonic order h (odd harmonics)[b]	$h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h$	Total demand distortion (TDD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

[a] I = the greater of the Local EPS maximum load current integrated demand (15 or 30 minutes) without the DR unit, or the DR unit rated current capacity (transformed to the PCC when a transformer exists between the DR unit and the PCC).
[b] Even harmonics are limited to 25% of the odd harmonic limits above.

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DR = distributed resources; EPS = entry-level power supply specification; PCC = point of common coupling; dc = direct current

Harmonics Review

Solutions

> Control of component tolerances and timing asymmetry to limit the dc component of output current by design.

> Measurement and feedback control to reduce the dc component of output current.

> Insertion of an isolation transformer between the inverter ac output circuit and the PCC. In this case, the saturation characteristic of the transformer should be chosen to tolerate the expected level of dc produced by the inverter.

PCC = point of common coupling; dc = direct current; ac = alternating current

Stability Analysis

- Generally for larger sites, greater than 5 MW
- Should be considered for a queue of larger DG sites to review the cumulative impact
- Typically use PSLF or PSS/E
- Tests include fault ride-through characteristics, voltage transients, regulating device behavior, islanding, critical clearing time, and evaluation of power swings for out-of-step protection

MW = megawatt; DG = distributed generation; PSLF = positive sequence load flow; PSS/E = power system simulation for engineering

Protection

- Fusing or mid-stream recloser in line with proposed DG site
- Recloser/gang operated air break (GOAB) switch/main breaker requirements at PCC
- Utility protection versus DG site protection and ownership and control at PCC
- Feeder breaker/relay settings reviewed with DG online
  - Is DG offline before feeder reclose?
  - Do the inverters respond fast enough to not cause unintentional islanding?
    - Solutions: DTT (fiber, radio, etc.); recloser/relay protection at PCC looking out to the electric system

DG = distributed generation; PCC = point of common coupling; DTT = direct transfer trip

Islanding

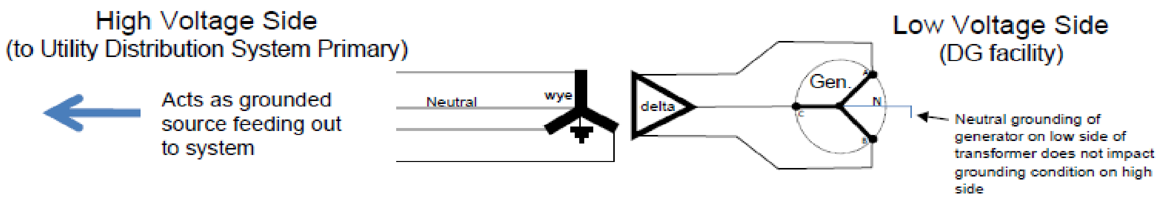
When is islanding a concern:

1. The DG aggregate capacity is less than one-third of the minimum load of the Local EPS.
2. The DG is certified to pass an applicable non-islanding test.
3. The DG installation contains reverse or minimum power flow protection, sensed between the Point of DG Connection and the PCC, which will disconnect or isolate the DG if power flow from the Area EPS to the Local EPS reverses or falls below a set threshold.
4. The DG contains other non-islanding means, such as a) forced frequency or voltage shifting, b) transfer trip, or c) governor and excitation controls that maintain constant power and constant power factor.

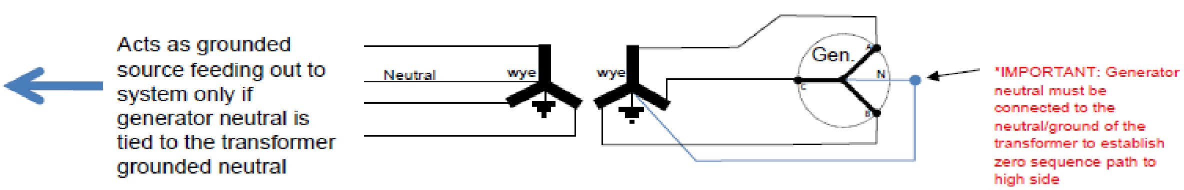
DG = distributed generation; PCC = point of common coupling; EPS = electric power system

Grounding Requirements

Preferred/typical effectively grounded transformer configurations for a four-wire system:

1. 

2. Grounded wye (primary) – Grounded wye (secondary), with generator neutral connected to neutral/ground of transformer



3. Other configurations with grounding transformer banks at DG site
4. Ungrounded neutral at generation source if feeder load = 3 X source

DG = distributed generation

Conclusions

- IEEE® Standard 1547, "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems" and utility interconnection requirements are important documents to study, understand, and follow for analysis.
- Utilities are unique in requirements, facility specifications, protection philosophy, planning criteria, etc.
- Not all DG sites need detailed analysis. Initial screening will detect that.

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Thank You

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