Reactive Power Compensation for Solar Power Plants

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IEEE PES Chicago Chapter

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Objectives

- Refresh the basics of reactive power from a generator's perspective
- Regulatory history and recent changes
- Differences between wind/solar
- Inverter quantity and plant specifications
- How to get involved

Developer's Perspective

- Preliminary engineering in house – cost estimates and lead times very important
- Detailed engineering and studies carried out by consultants
- Obligated to demonstrate reactive power compliance and pass tests to remain in compliance

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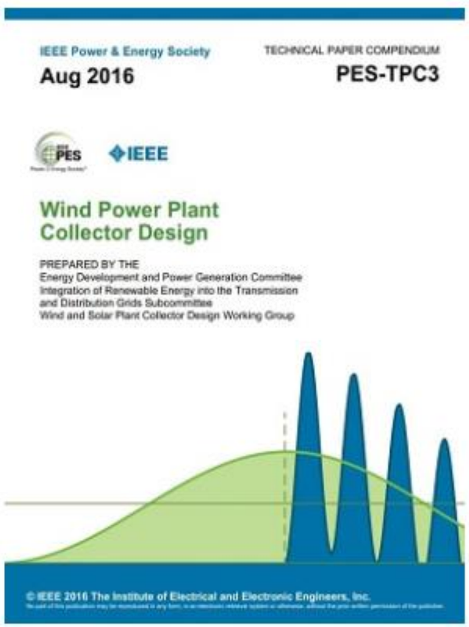
Wind Power Plant Collector Design



Posted: 4 Aug 2016

Primary Committee:
Energy Development and Power Generation Committee

Sponsored by:
Integration of Renewable Energy into the Transmissionand Distribution Grids Subcommit

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Table of

IEEE Wind and Solar Plant Collector Design Working Group

Scope:

- Serve as a focal point within the Power & Energy Society (PES) for addressing issues related to the design of collector systems for wind plants, including tradeoffs associated with overhead vs. underground lines, grounding, distribution equipment applications, cost and reliability tradeoffs for the unique characteristics of this energy resource, protection, reactive compensation, and SCADA application.
- Conduct activities to promote the sharing of knowledge and experience among diverse organizations working on similar issues through the conduct of studies, symposia, workshops, paper session, panel sessions, and tutorials.
- Publish working group papers to document results of working group activities and to share working group positions on issues related to the design of collector systems for wind plants.

Working Group Officers:

Chair:
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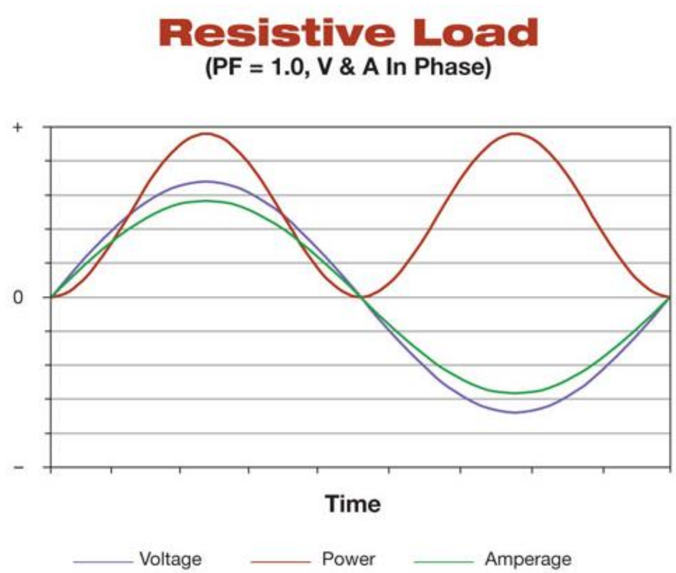
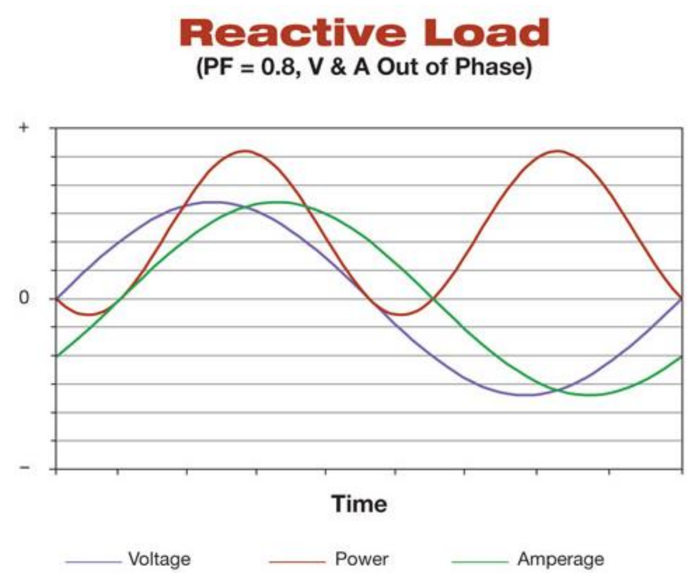
- WG meeting Tuesday January 15th, 8am-12pm at IEEE JTCM in Anaheim
- 2019 IEEE PES GM in Atlanta August 4th-8th
  - WG sponsoring a 2 hour PV Solar Power Plant Design panel session
  - WG and grounding task force scheduled to meet

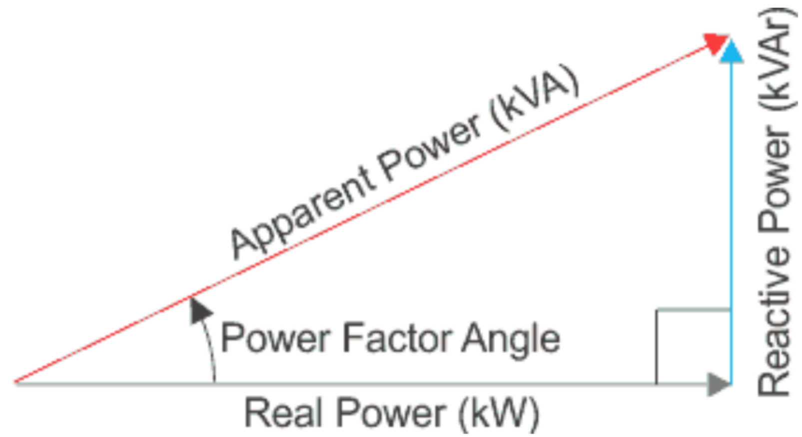
Reactive Power

- Inductive/capacitive loads on the grid shift the phase angle between voltage and current
- Generators can control their power factor





Reactive Power



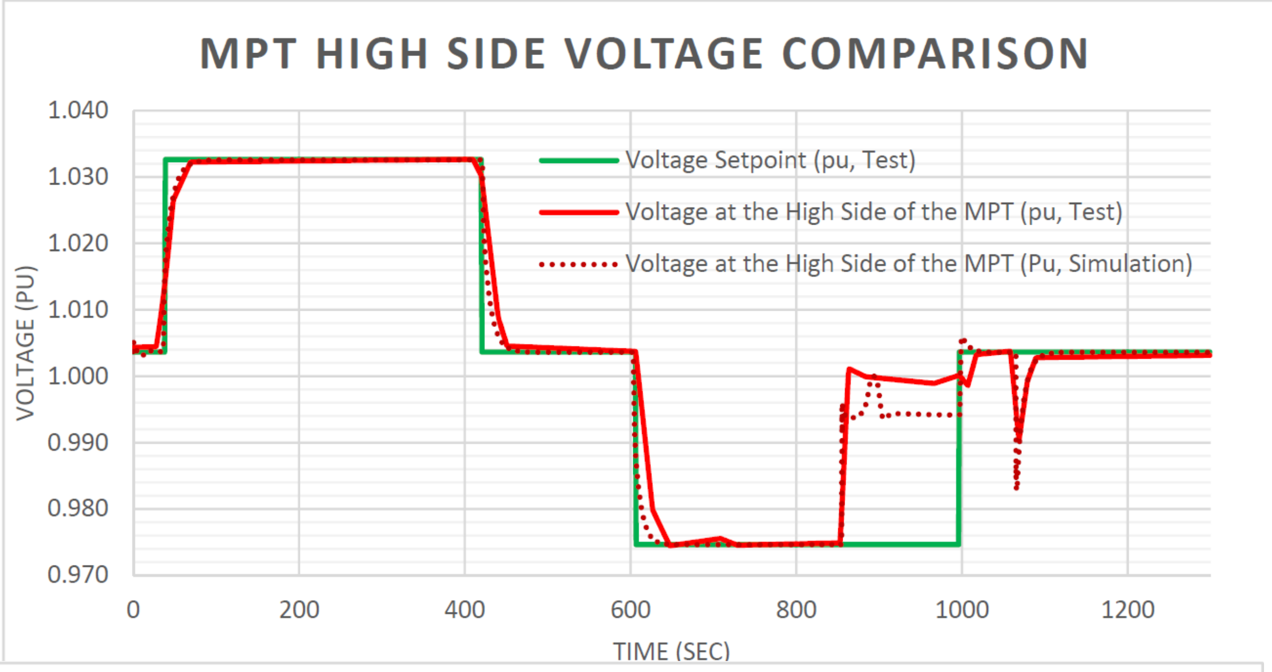
- 100MW
- Unity power factor: 100MVA, 100MW, 0MVAR
- 0.95 power factor: 105MVA, 100MW, 33MVAR
- 0.90 power factor: 111MVA, 100MW, 48MVAR
- Higher MVA = higher current, higher losses

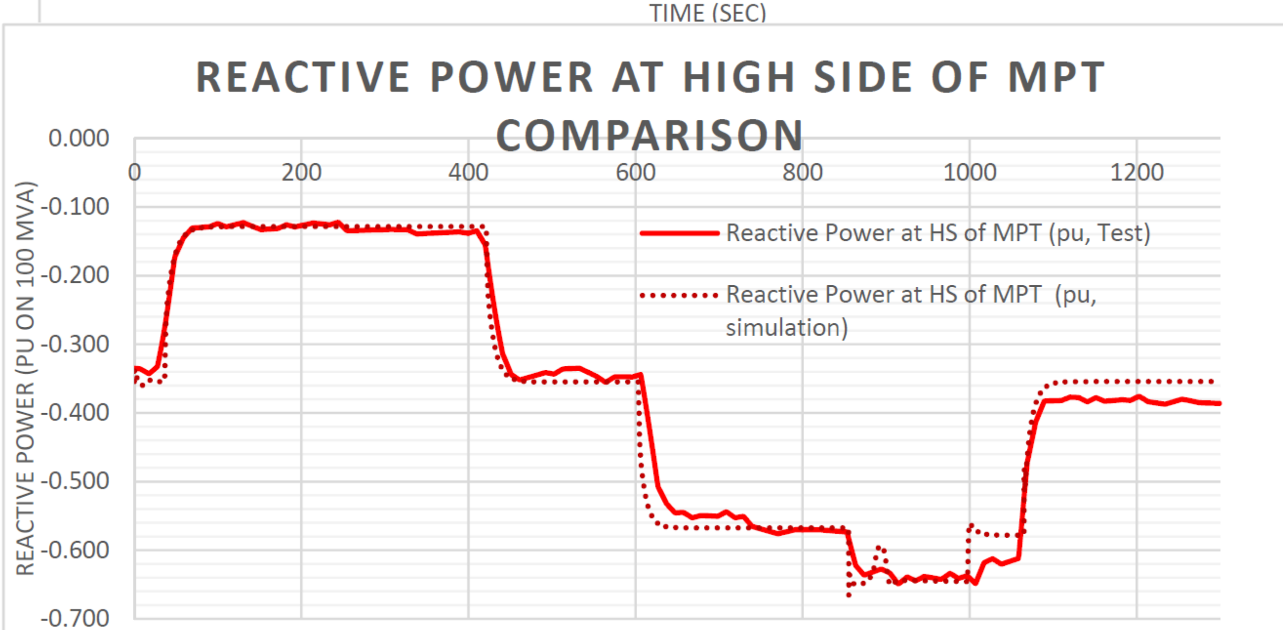
Regulatory Timeline

- 2003: FERC issues standard interconnection agreement and procedure for large generators
- 2005: FERC 661 requires a wind power factor range of +/- 0.95 *if required by studies.*
- 2016: FERC 827 requires all large non-synchronous generators to maintain a *dynamic* +/- 0.95 at the high side of the project substation, at all generation levels.

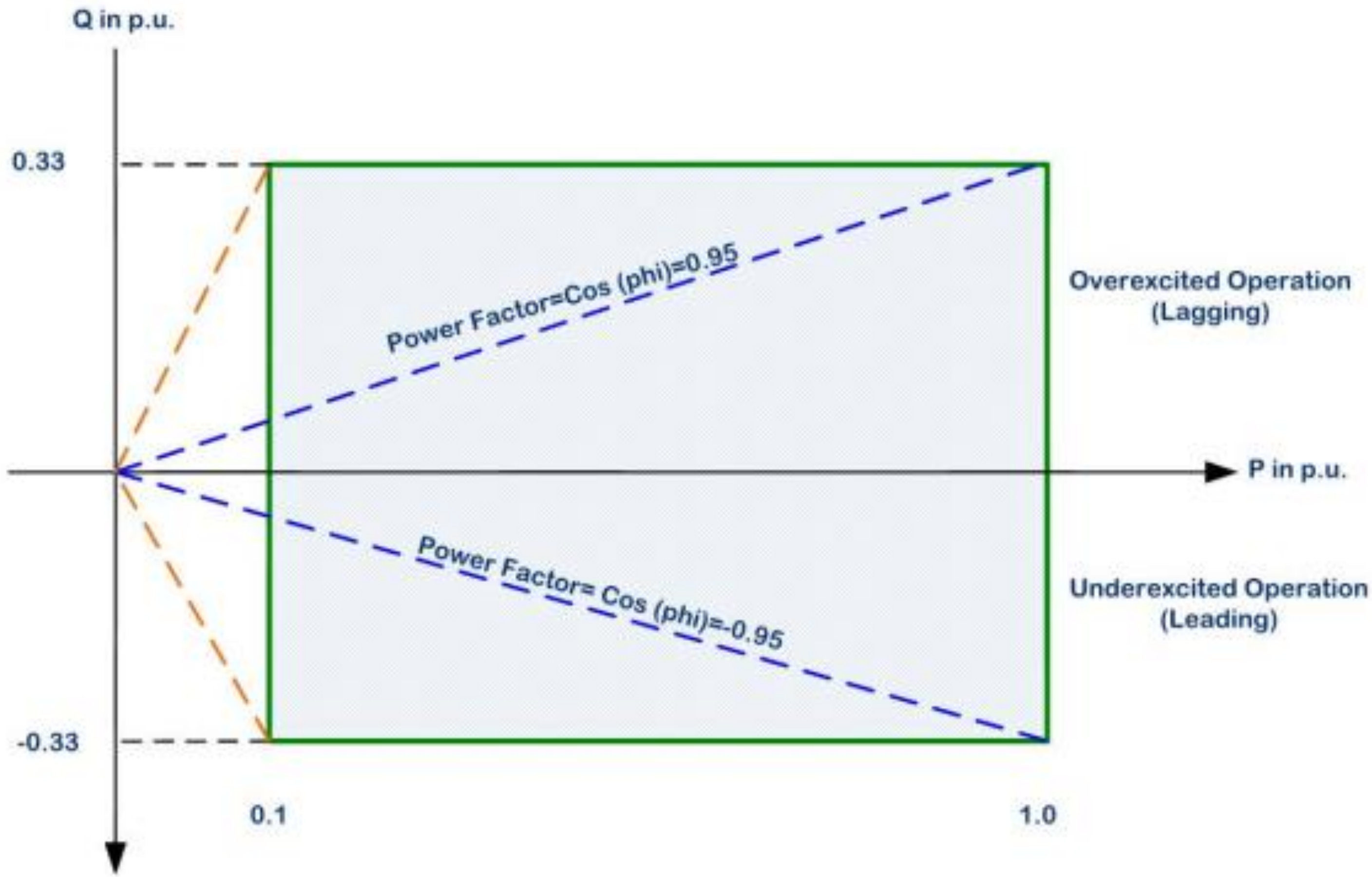
Voltage Controller

- Wind farm management system packaged with turbines, solar farm management systems often third party integrated
- Can operate in voltage mode, var mode, power factor mode
- Voltage mode most common – SFMS monitors grid voltage and dispatches reactive power to maintain voltage setpoint at POI

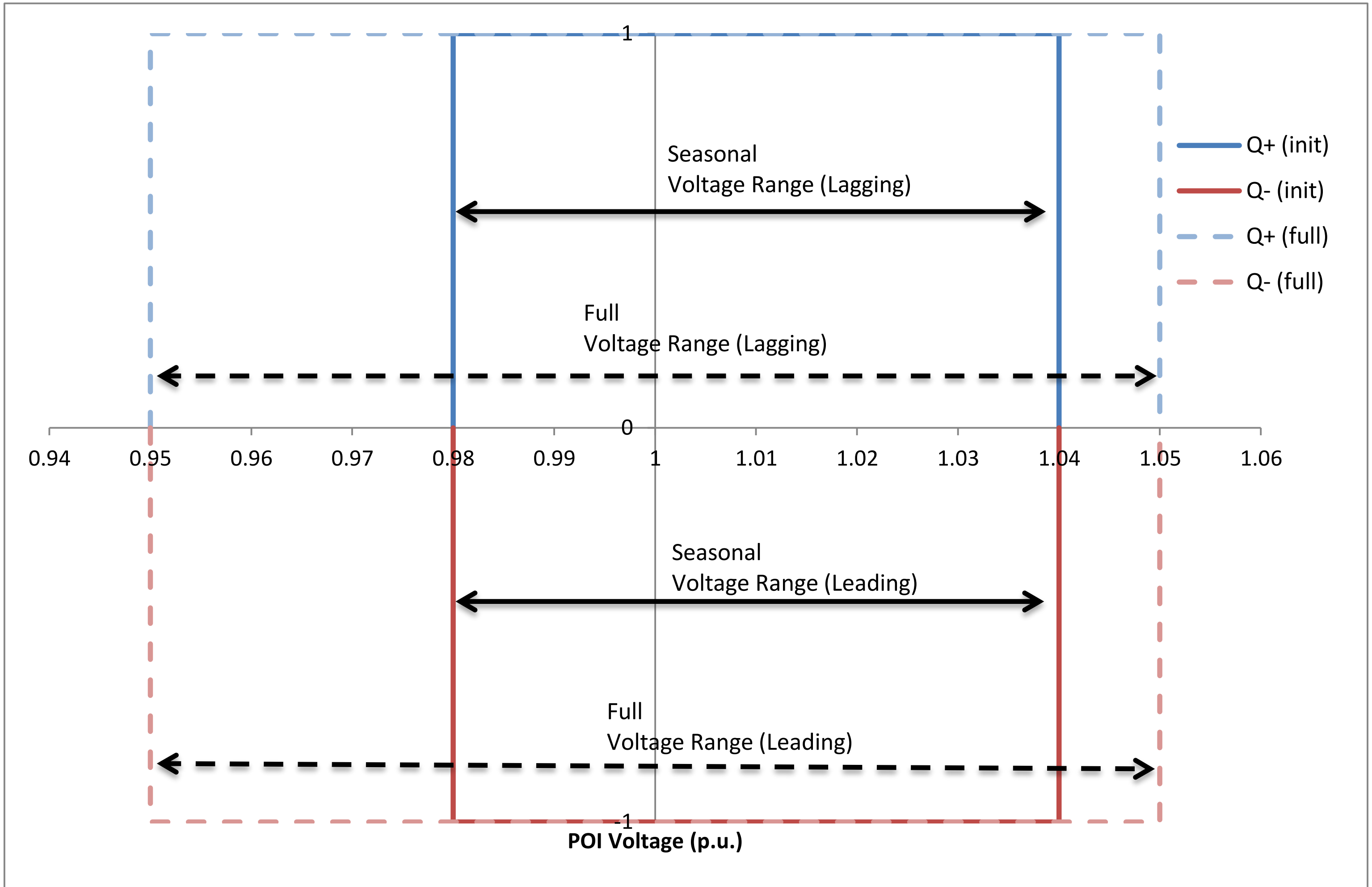

MPT HIGH SIDE VOLTAGE COMPARISON
1.040
1.030
1.020
1.010
1.000
0.990
0.980
0.970
VOLTAGE (PU)
0
200
400
600
800
1000
1200
TIME (SEC)
Voltage Setpoint (pu, Test)
Voltage at the High Side of the MPT (pu, Test)
Voltage at the High Side of the MPT (Pu, Simulation)


REACTIVE POWER AT HIGH SIDE OF MPT COMPARISON
0.000
-0.100
-0.200
-0.300
-0.400
-0.500
-0.600
-0.700
REACTIVE POWER (PU ON 100 MVA)
0
200
400
600
800
1000
1200
Reactive Power at HS of MPT (pu, Test)
Reactive Power at HS of MPT (pu, simulation)

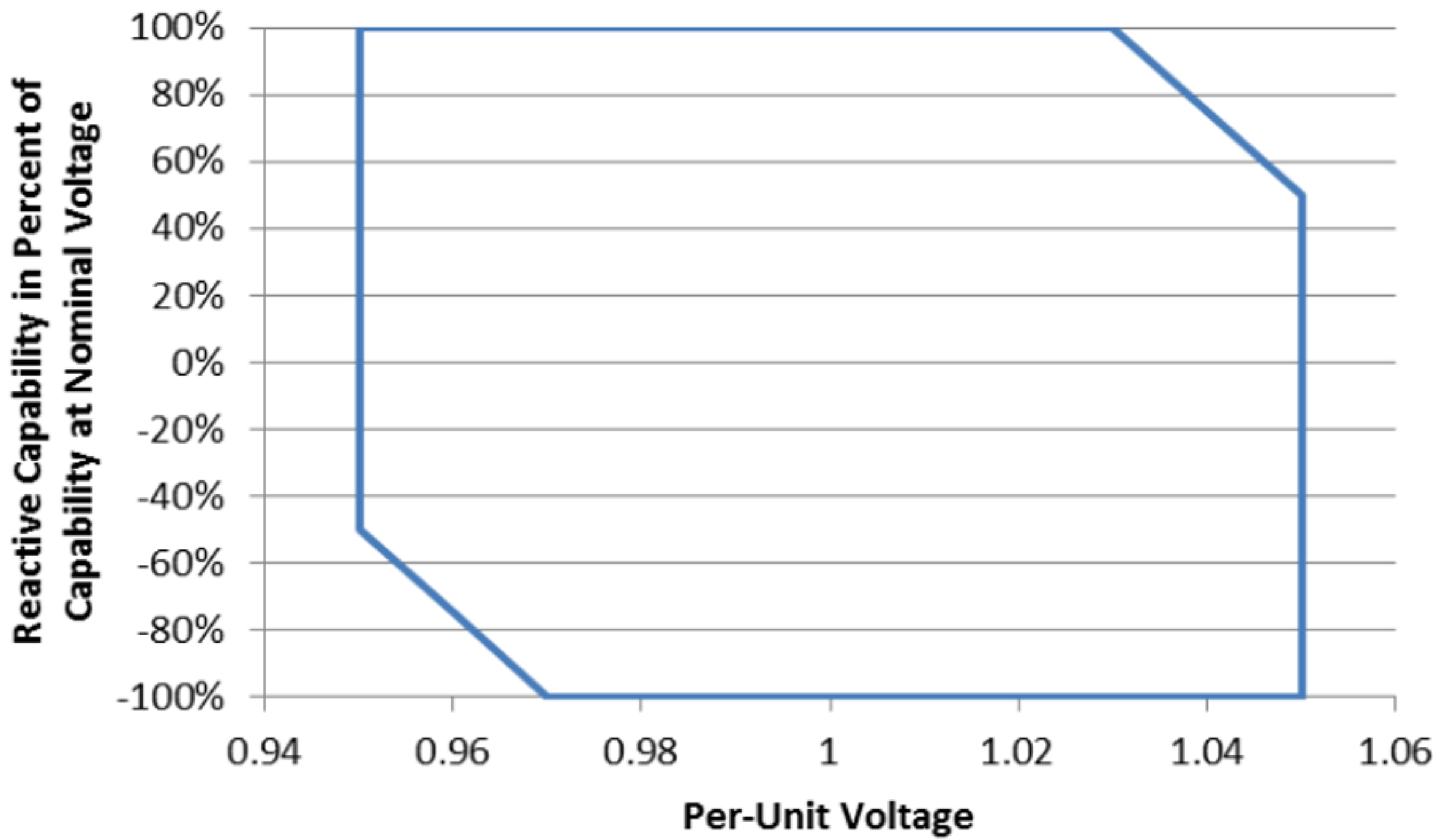
Regional Variance



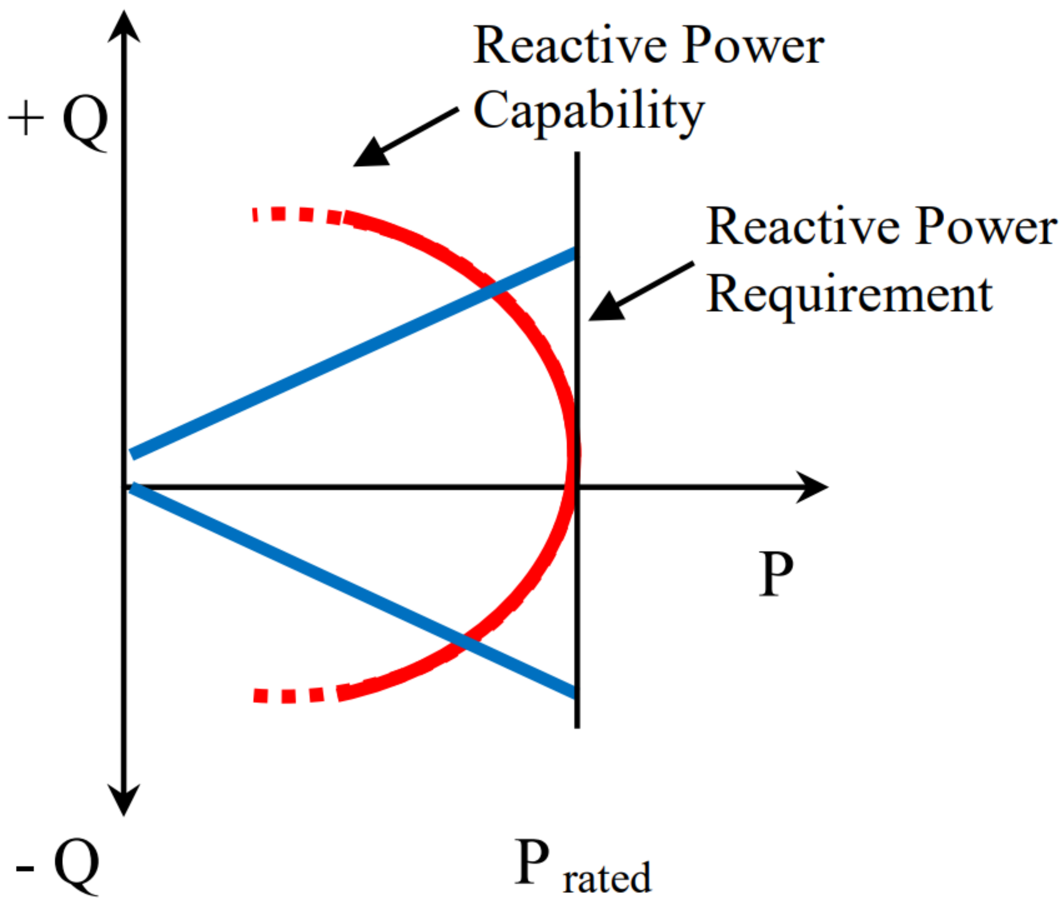
Voltage Schedule



Voltage Schedule



Inverter P/Q Curves



Inverter P/Q Curves

- Request P/Q Curves and documentation from manufacturer to cover:
  - Real/reactive power standard limitations
  - Ambient temperature derating
  - DC voltage limits on apparent power or reactive power
  - AC terminal voltage derating
  - Priority modes – defaults and what is configurable

Quantity of Solar Inverters

- FERC 827 requires 0.95 dynamic power factor
- 100MW solar project example
  - 2.5MVA inverters (inverters rated with MVA)
  - 42 inverters? 100MW/105MVA=0.952 pf
  - 43 inverters? 100MW/107.5MVA=0.93 pf
- Consider derating factors

Inverter Temperature Limits

- Ambient temperature de-rating
  - Maximum site design temperature?
  - Maximum possible site temperature?
  - Reactive compliance at high temperatures? Q vs P priority?

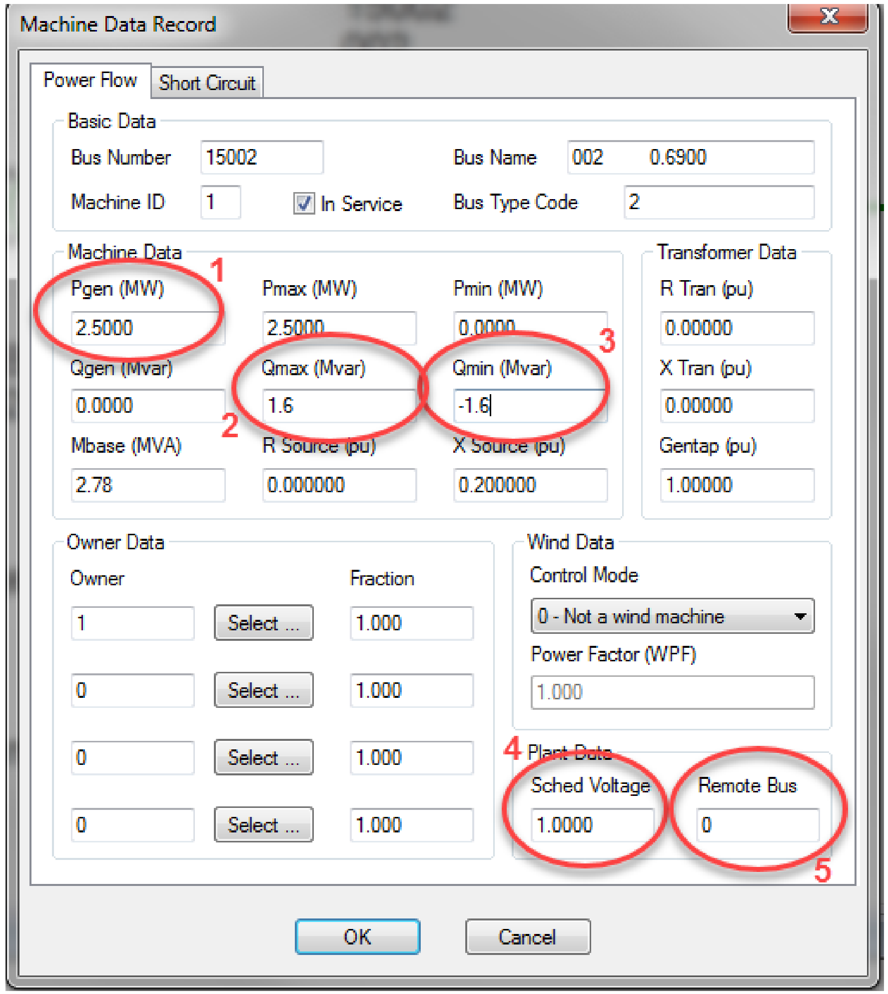
Inverter AC Voltage Limits

- 0.9pu – 1.1pu voltage common continuous operating limit.
- Thermal MVA rating at low AC terminal voltages. Q priority?
- Reactive power limitations based on grid voltage. Can be countered with on load tap changer or deenergized tap optimization.

Inverter DC Voltage Limits

- Injection of AC current onto grid requires DC voltage to exceed AC RMS peak voltage
- Inverter Maximum Power Point Tracking typically selects a DC voltage that optimizes real power output.
- Injection of capacitive lagging reactive power onto grid can be problematic, especially with lower DC rated inverters. Q prioritized.

Modeling for Studies



Load Flow Results

Case #	POI Voltage (p.u.)	Description	Reactive test	HS DETC Tap Ratio	Pad mount Tap Ratio	Shunts (T1) MVAR	P (MW)	Q (MVAR)	Q required
1	1.0000	100% Gen	VAR	1.00000	1.025	0.000	24.55	-4.34	N/A
2	1.0000	100% Gen	Lag	1.00000	1.025	0.000	24.52	8.22	8.2170
3	1.0000	100% Gen	Lead	1.00000	1.025	0.000	24.52	-8.22	-8.2170
4	1.0500	100% Gen	Lag	1.00000	1.025	0.000	24.57	4.11	4.1085
5	1.0500	100% Gen	Lead	1.00000	1.025	0.000	24.55	-8.22	-8.2170
6	1.0300	100% Gen	Lag	1.00000	1.025	0.000	24.54	8.22	8.2170
7	1.0300	100% Gen	Lead	1.00000	1.025	0.000	24.54	-8.22	-8.2170
8	0.9700	100% Gen	Lag	1.00000	1.025	0.000	24.50	8.22	8.2170
9	0.9700	100% Gen	Lead	1.00000	1.025	0.000	24.50	-8.22	-8.2170

Load Flow Results

Case #	POI Voltage (p.u.)	Description	Reactive test	Inverter Terminal Voltage (p.u.)			34.5 kV Collector Voltage (p.u.)		
				Max	Avg.	Min	Max	Avg.	Min
1	1.0000	100% Gen	VAR	0.975	0.973	0.972	0.994	0.992	0.991
2	1.0000	100% Gen	Lag	1.057	1.057	1.057	1.049	1.047	1.046
3	1.0000	100% Gen	Lead	0.947	0.947	0.947	0.977	0.975	0.974
4	1.0500	100% Gen	Lag	1.075	1.075	1.075	1.079	1.077	1.076
5	1.0500	100% Gen	Lead	0.996	0.996	0.996	1.027	1.025	1.025
6	1.0300	100% Gen	Lag	1.084	1.084	1.084	1.078	1.075	1.075
7	1.0300	100% Gen	Lead	0.976	0.976	0.976	1.007	1.005	1.004
8	0.9700	100% Gen	Lag	1.031	1.031	1.031	1.021	1.019	1.018
9	0.9700	100% Gen	Lead	0.918	0.918	0.918	0.946	0.944	0.944

Best practices

- Use reasonable or code required assumptions:
  - Power factor criteria and enforcement point
  - Ambient temperature – consider energy model
  - Any relevant DC voltage limitations?
  - Voltage schedule, which cases to run at extremes
  - Specify enough inverters for .95 dynamic capability at typical site maximum temperature
  - To compensate for losses, evaluate cap banks, reactors, or other reactive power compensation.

Simulation vs. reality?

- Q priority, what happens with derating, how is plant controller programmed.
- On load tap changer movement.

On load tap changers

POI Voltage (Voltage Set point) (p.u.)	Dispatch	Reactive Test	Real Power Deliverable to POI (MW)	Reactive Power Deliverable to POI (MVAr)	Station Transformer Tap Position	Total Switched Shunts in Service (+MVAr cap., -MVAr react.)	Lowest Terminal Voltage	Highest Terminal Voltage
1.009	100% Gen	Max Lagging	292.45	96.63	1.01875/1.02500	0.0/0.0	1.074	1.095
		Max Leading	291.80	-96.67	1.01875/1.02500	0.0/0.0	0.949	0.949
	10% Gen	Max Leading	28.96	97.50	1.00625/1.00625	0.0/0.0	1.063	1.063
		Max Leading	28.42	-97.45	1.00625/1.00625	0.0/0.0	0.917	0.917
1.038	100% Gen	Max Lagging	292.48	96.75	1.05000/1.05625	0.0/0.0	1.072	1.092
		Max Leading	291.78	-97.20	1.05000/1.05625	0.0/0.0	0.946	0.946
	10% Gen	Max Leading	28.99	96.69	1.03750/1.03750	0.0/0.0	1.059	1.059
		Max Leading	28.42	-96.64	1.03750/1.03750	0.0/0.0	0.915	0.915

Q at night

- Most grid codes (and 827) do not require VAR support when there is no power generation.
- Possible concerns:
  - Utility disconnects plant if charging currents from cable/t-line are contributing to high voltages
  - Plant voltages exceed equipment ratings
  - Real power consumption if Q at night enabled (auxiliary and no load losses)

Other considerations

- Shunt switching – flicker, voltage step %
- Harmonics
- Tap changer tradeoffs
- Actual test protocols

Wind and Solar Power Coordinating Committee

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Questions?

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