SMA Solar Technology

Solar Integration Technology

ERCOT Solar Workshop, April 25, 2011

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Business Development, Utility Scale

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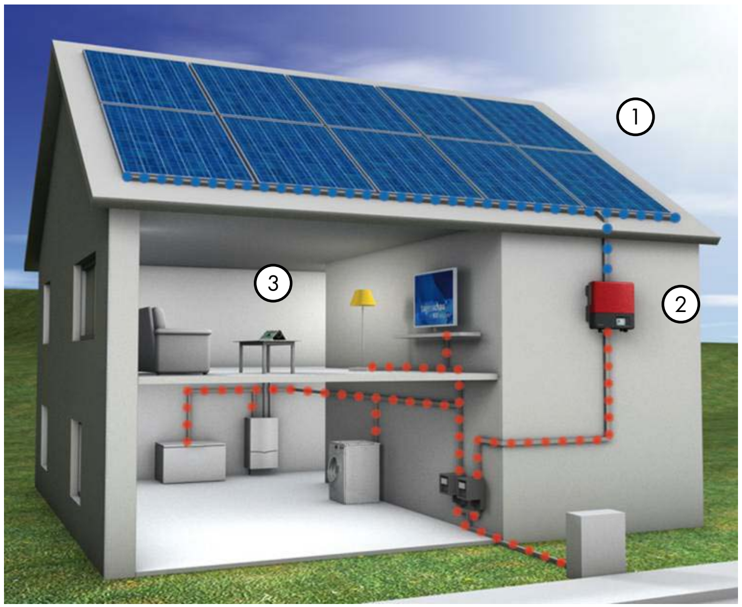
The inverter is the “heart” of every PV system

Visual representation of a PV System



1 Modules create direct current

3 Sunny Beam monitors the entire PV system

2 Sunny Boy converts direct current into alternating current

Direct current (DC)

Solar inverter

Alternating current (AC)

↑↓

Additional inverter tasks

- Solar generator control MPP tracking
- System monitoring
- Grid monitoring + services

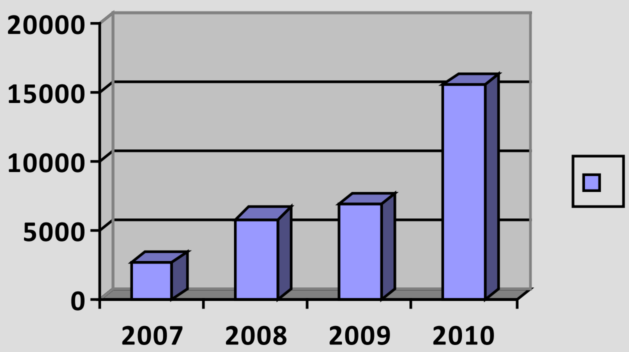
- Inverters are “high-tech products”: The computing power of the seven microprocessors alone is comparable to that of a notebook

SMA Solar Technology

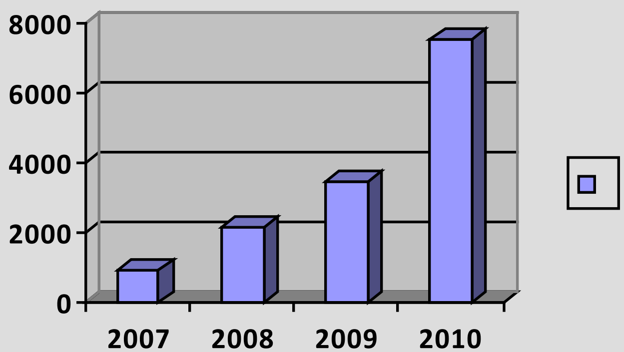
- Founded in 1981
- Headquarters in Niestetal, Germany
- Publicly Traded on the Frankfurt Exchange
- Eighteen Subsidiaries on Four Continents
- More than 5,000 Employees
- Over 600 R&D Engineers
- Strong Balance Sheet
- Over 50% of Revenue Outside of Germany
- Ranked Best Inverter Company by Photon
- Ranked 2nd Best Solar Company in EU
- Top Awards in Product Innovations

World Leader In Installed Capacity

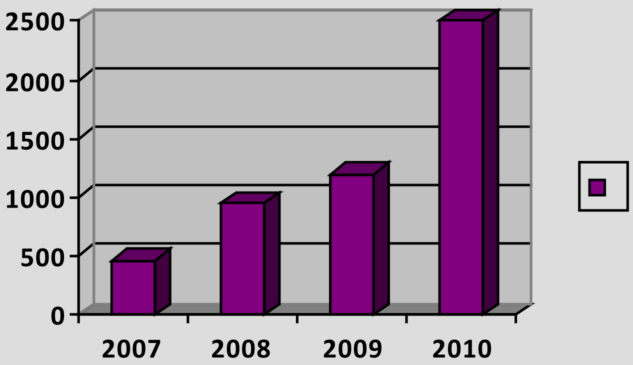
Cumulative PV Installed Capacity (MW)



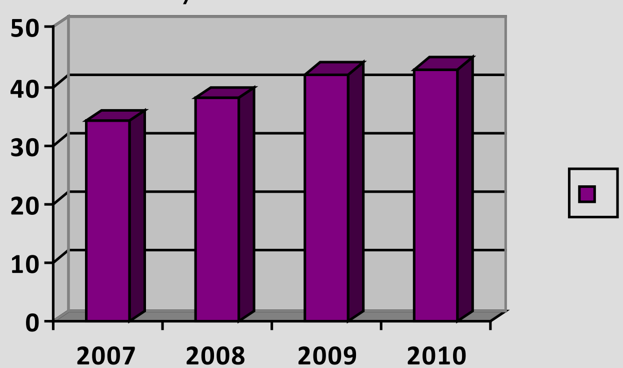
Yearly SMA PV Installed Capacity (MW)



Yearly Sales in Million $



Yearly % Market Share

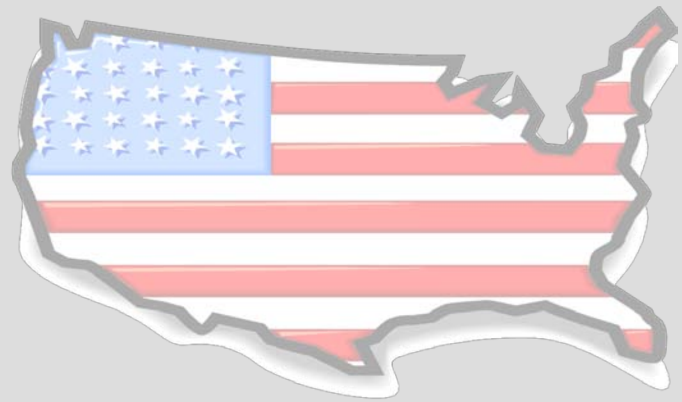


World Leader In Manufacturing Capacity

- 200,000 ft^2 of Manufacturing Space
- Best in Class Quality Control
- 12GW Capacity
- CO_2 Neutral Factory
- Build to Order Process
- ISO 9001 Certification

N.A Leader In Manufacturing Capacity

- US Plant in Denver, CO
- 1GW Production Capacity (World's 2nd Largest)
- Over 700 US Jobs Created
- Fully Compliant with ARRA
- Flex Production Lines



- Ontario Factory with Contract Manufacturing Partner
- Fully Compliant with Ontario Content
- Direct & Indirect Jobs for Ontario

New NA factories will increase flexibility to serve fast growing US & ON markets

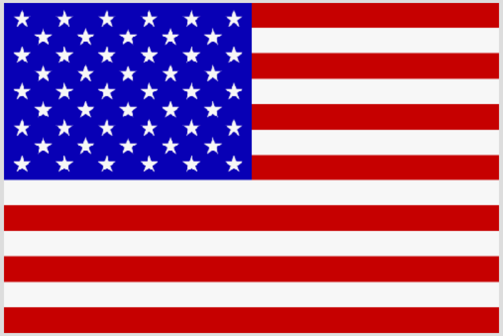
World Leader in Utility Scale Projects

SUNNY CENTRAL

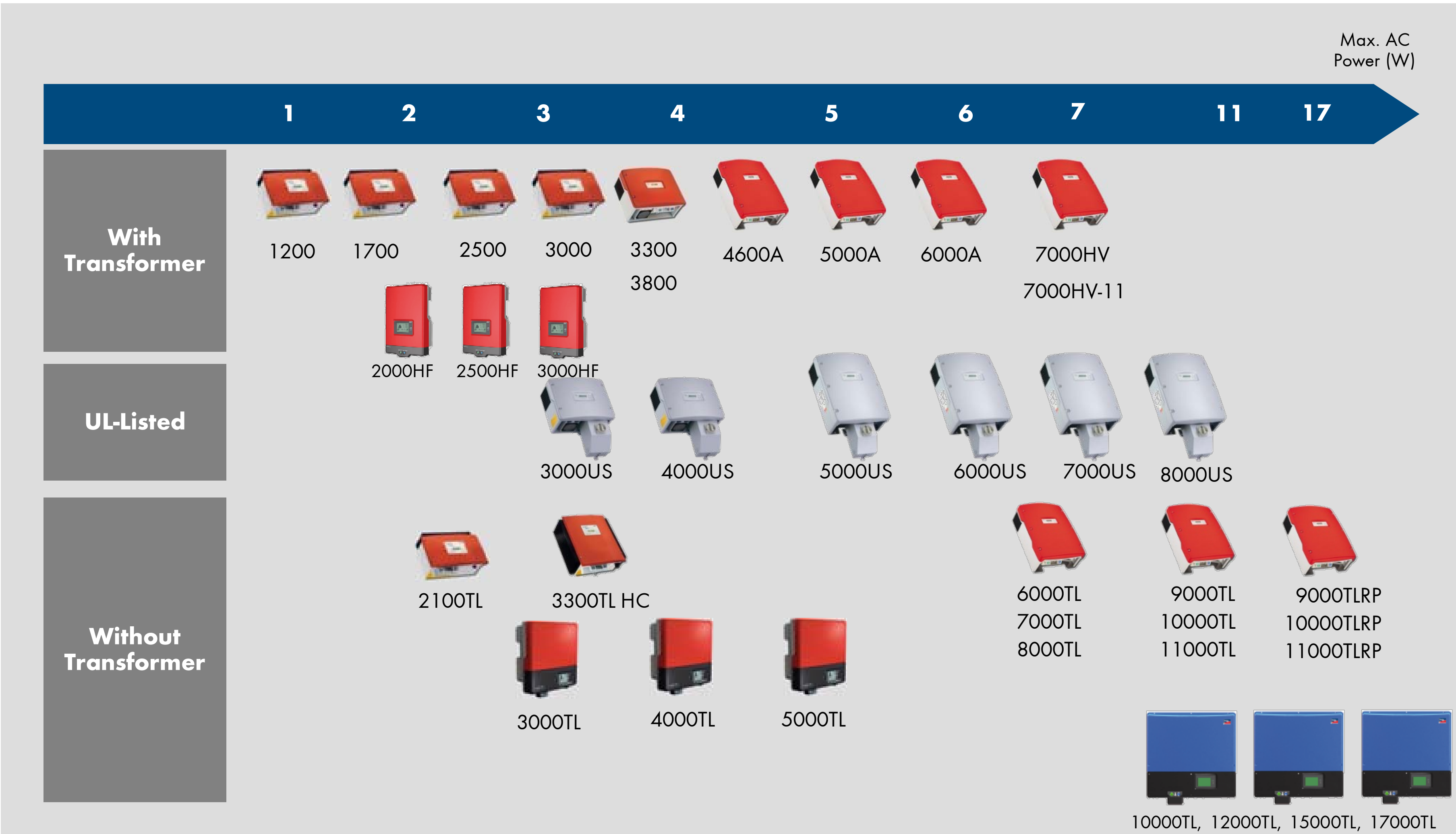
- Energy park Waldpolenz Brandis, Germany
- 40 MWp
- 72 x Sunny Central 500HE

North America Leader in Utility Scale Projects

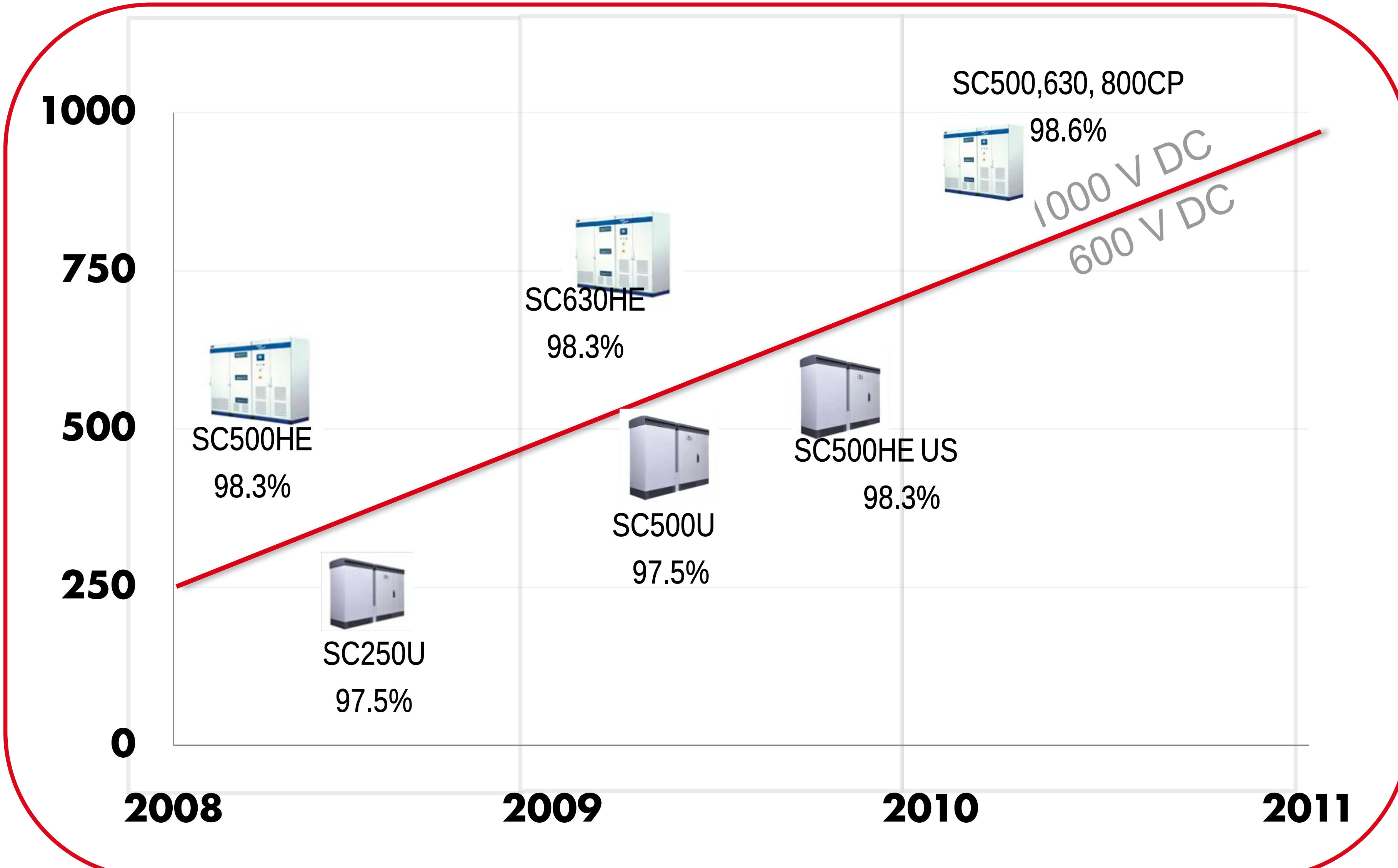
Location	Country	Plant Size	Inverters	Status
Memphis, TN	USA	5 MW	10 SMA 500 kVA	Construction
Tilbury, ON	Canada	5 MW	10 SMA 500 kVA	Completed
Ridgeland, ON	Canada	9 MW	17 SMA 500 kVA	Construction
Wyandot, OH	USA	10 MW	16 SMA 630 kVA	Completed
Jacksonville, FL	USA	13 MW	20 SMA 630 kVA	Completed
San Antonio, TX	USA	14 MW	22 SMA 630 kVA	Completed
Alamosa, CO	USA	19 MW	38 SMA 500 kVA	Completed
Santa Teresa, NM	USA	20 MW	32 SMA 630 kVA	Construction
Cimarron, NM	USA	30 MW	48 SMA 630 kVA	Completed
Brookhaven, NY	USA	32 MW	50 SMA 630 kVA	Construction
Sarnia, ON	Canada	60 MW	120 SMA 500 kVA	Completed



Sunny Boy/Sunny TriPower



Central Inverters Product Portfolio



Some Facts about Germany

Geographic Size	357,021 km^2 Slightly smaller than Montana (376,55 km^2)
Population	81.8 million Most populous country in EU
Installed Wind Capacity (2010)	~ 27.2 GW (3rd behind China @ 41.8GW & US @ 40.2GW) 37.5 TWh or 6.5% of Generation World's Largest
Installed Solar Capacity (2010)	~ 17GW 12 TWh, 2% of Generation World's largest
Renewable Penetration (2010) (Wind, Solar, Hydro, Biomass)	~ 102 TWh representing 17% of Electricity Consumption World's Largest
Cost to Support Solar	5% increase in average electricity bill
Solar Industry Economic Impact	>200,000 direct jobs related to PV

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Solar PV Capacity (MW)	186	296	439	1,074	1,980	2,812	3,977	5,877	8,877	17,251
PV Generation (GWh)	76	162	313	556	1,282	2,220	3,075	4,420	6,200	12,000
PV % of total electricity consumption								0.7	1.1	2.0

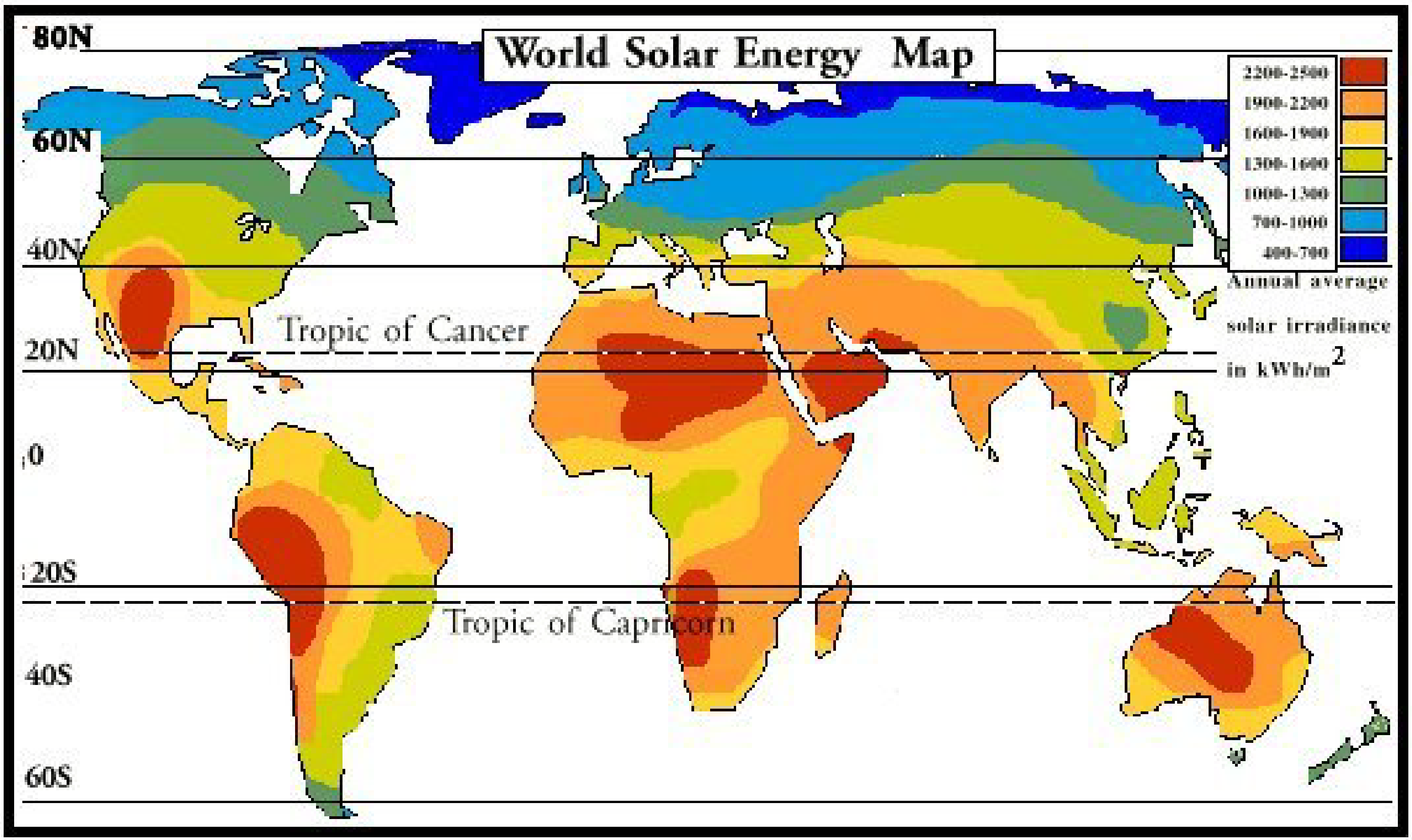
Recent German Energy Policy Announcements

In September 2010 the German Government announced a new aggressive energy policy with the following targets:

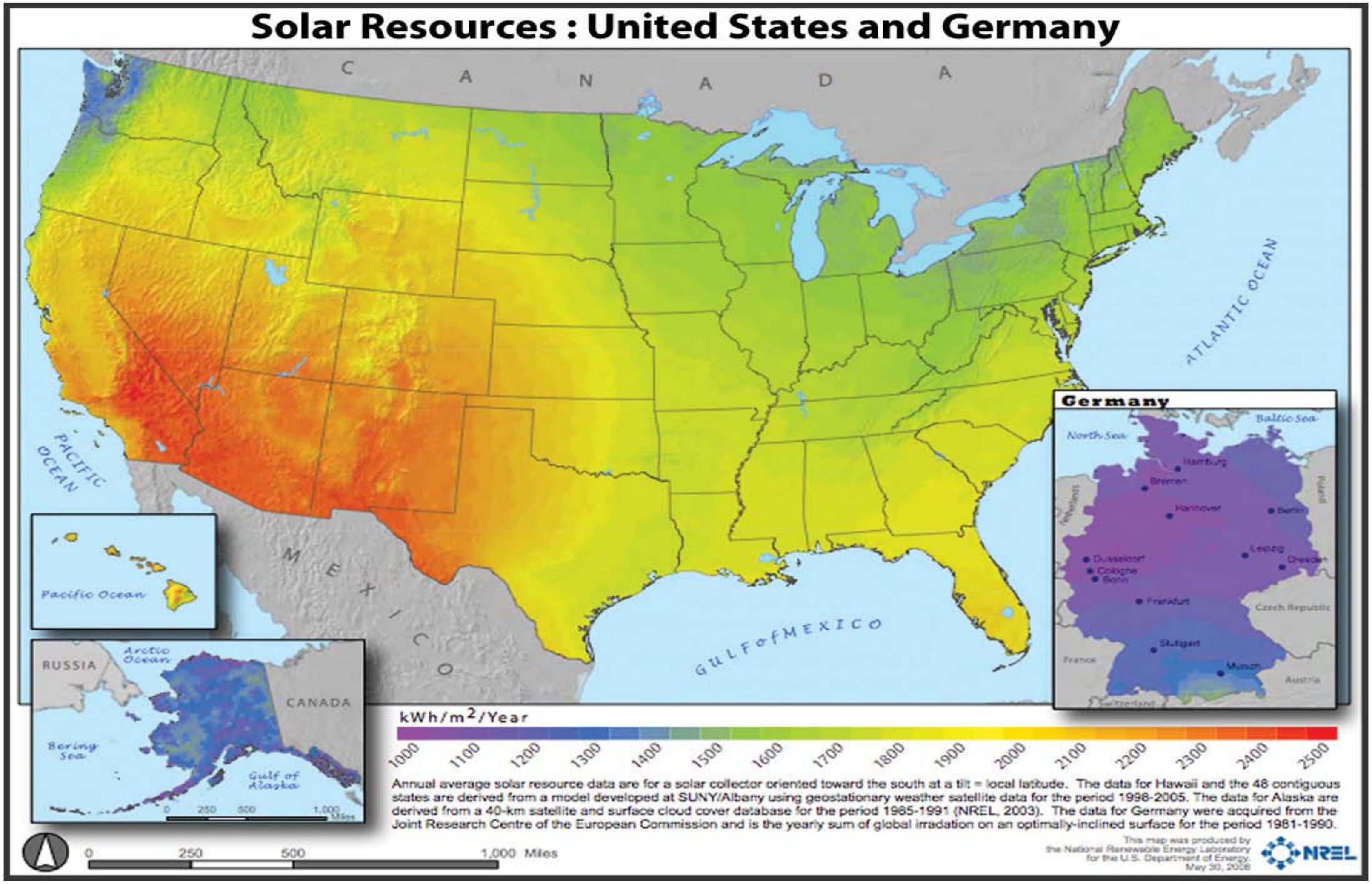
- Reducing CO_2 emissions 40% below 1990 levels by 2020 and 80% below 1990 levels by 2050
- Increasing the relative share of renewable energy in gross energy consumption to 18% by 2020, 30% by 2030 and 60% by 2050
- Increasing the relative share of renewable energy in gross electrical consumption to 35% by 2020 and 80% by 2050
- Increasing the national energy efficiency by cutting electrical consumption 50% below 2008 levels by 2050

World Solar Resource

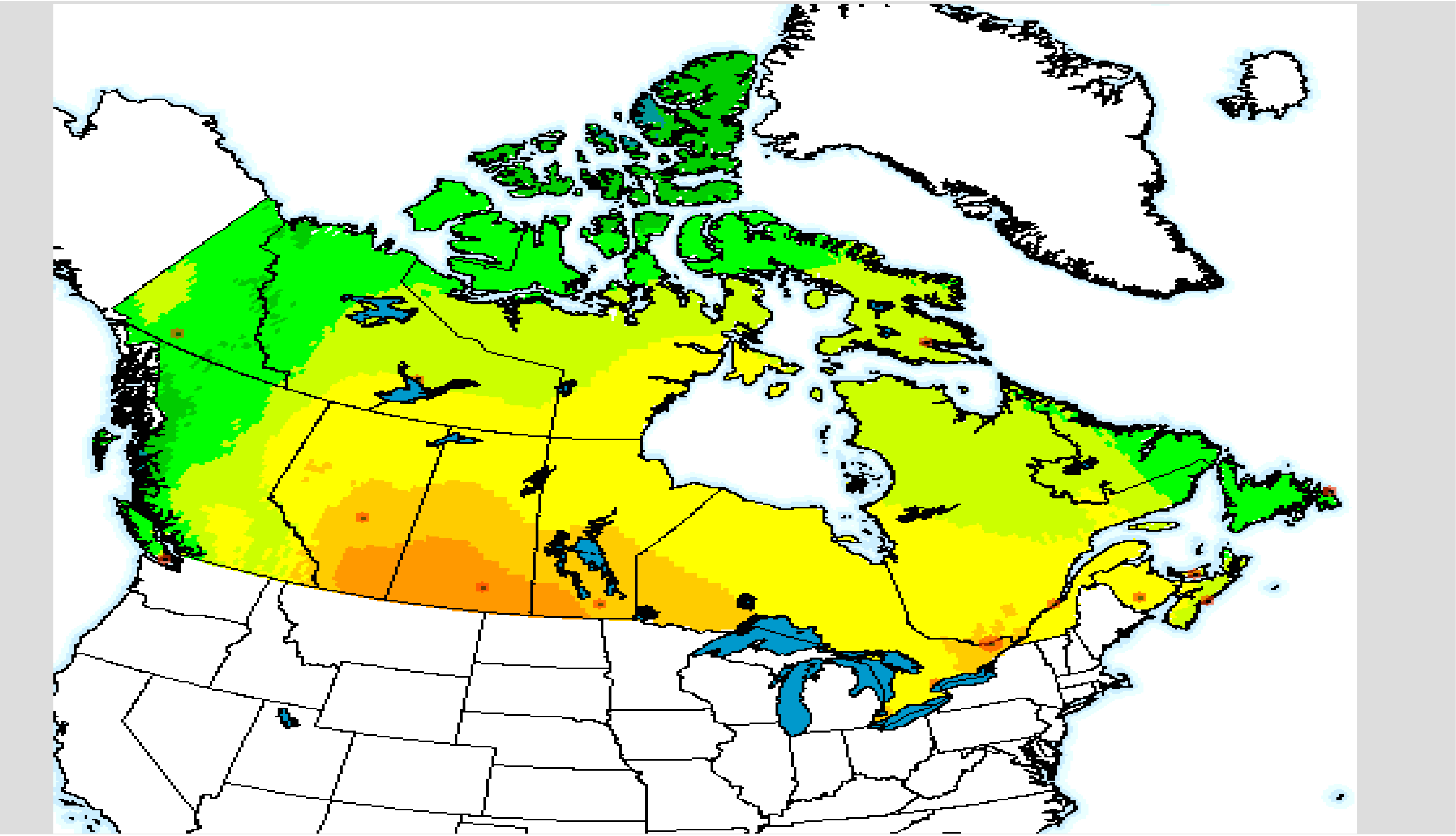
Germany is the highest consumer of solar energy in the world



Solar Resources: US vs. Germany



Solar Resources: Canada



Solar PV for Utilities: Pros and Cons

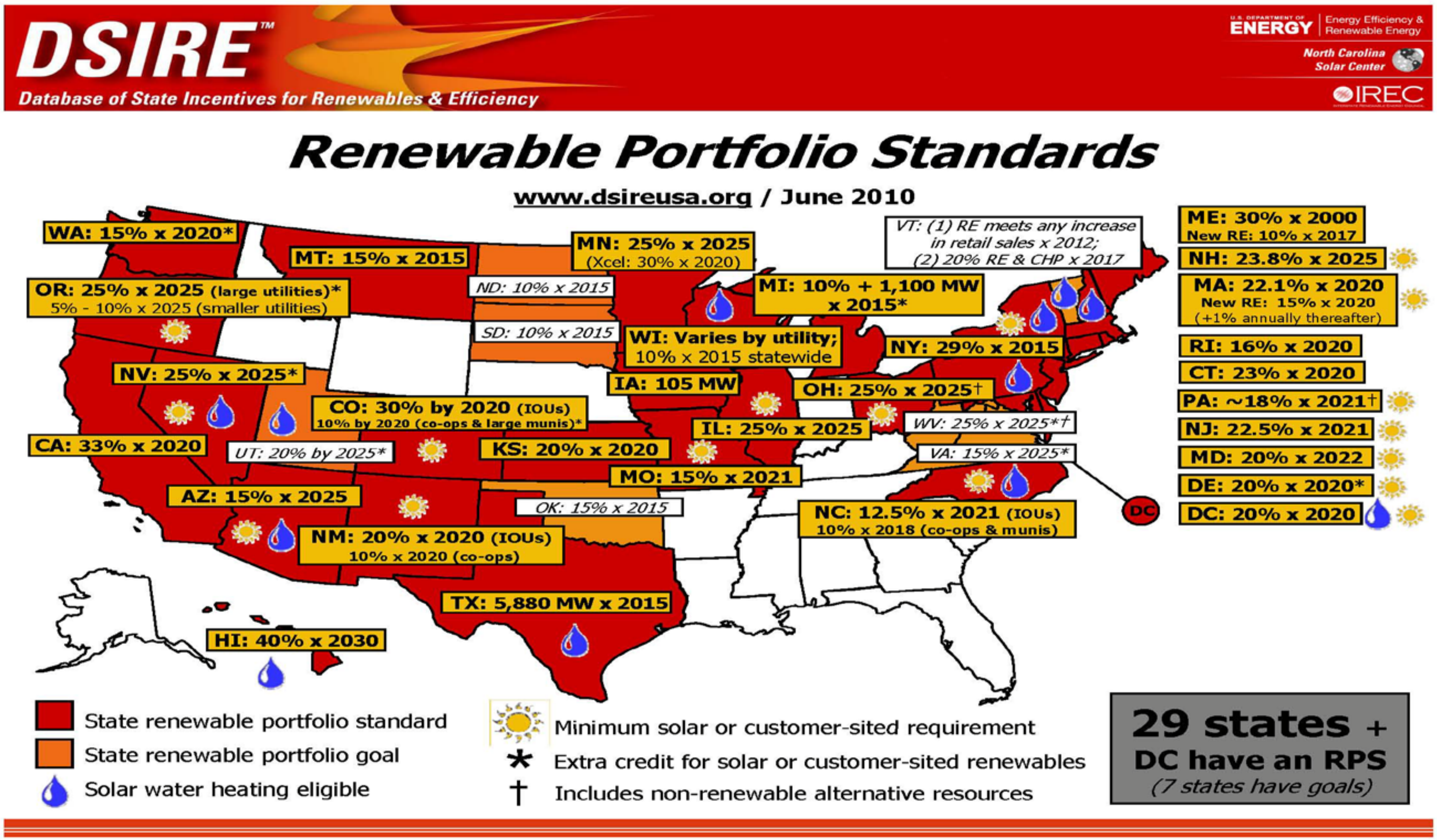
Market Forces/Drivers

- Growing Support for Renewable Energy
- State RPS Policies – 1/3 for CA
- ITC Extended to Utilities – Uncapped
- Smart Grid Infrastructure: Sporadic DG Improves Grid Reliability
- Smart Grid Infrastructure: DG One Solution to Transmission Congestion
- Smart Grid Infrastructure: DG Load Serving Cuts Power Losses
- Unlike Wind, Solar Correlates better with Load Demand
- Loss of Customers to Emerging Solar Utilities
- Sun Shot initiative driving cost down to grid parity ($1/watt installed)

Market Threats/Risks

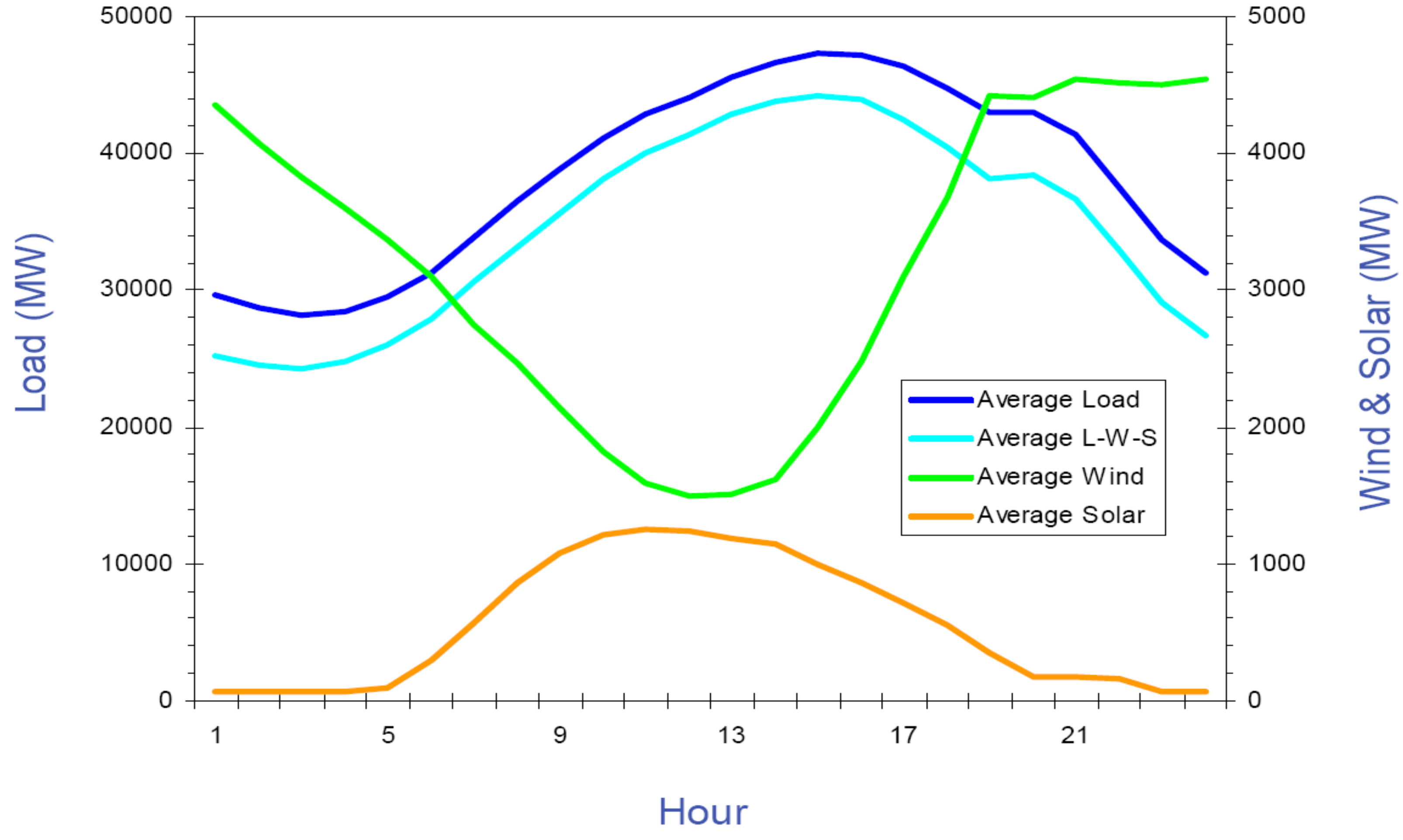
- Resources still scarce
- Low Natural Gas prices
- PV highest cost in terms of $/MWh for utilities
- Risk Management is Demanding Higher IRR from Investors
- Insufficient Historical Data for Actual Plant(s) Performance(s) Over Extended Period of Time (15 – 20+ years)
- Intermittency Major Issue
- Regulation Against Owning Generation Assets
- Smart Grid Infrastructure: Too Much DG Penetration Effect on Grid Still Unknown

Individual States' RPS

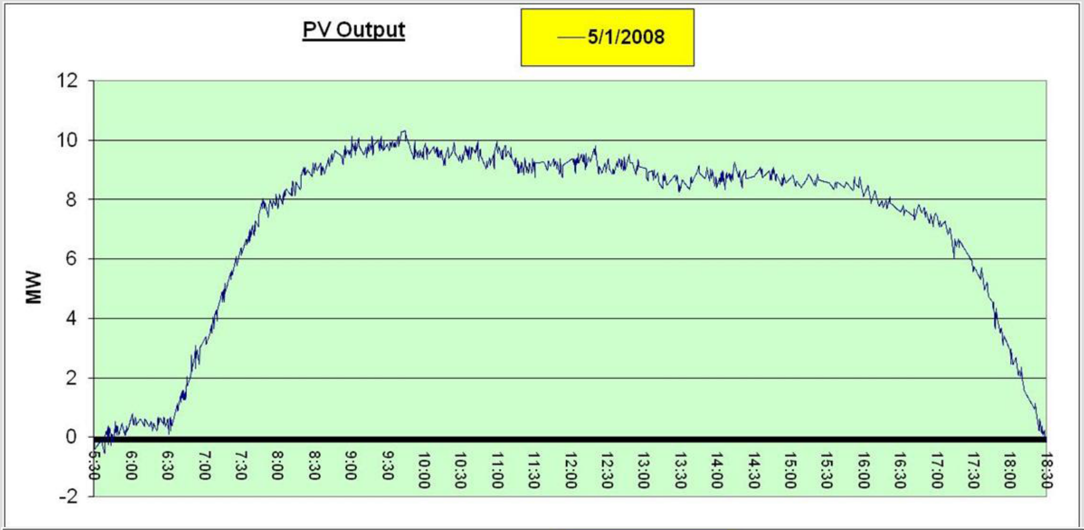


Source: NERC IVGTF

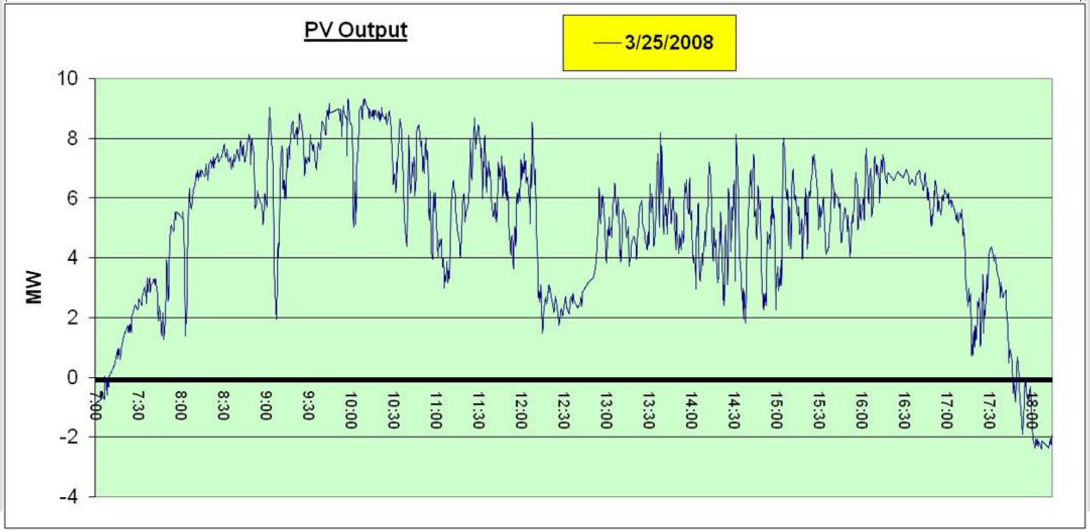
California average wind and solar output, along with net demand, July 2003



PV Intermittency



PV plant output on a sunny day (Sampling time 10 seconds)



PV plant output on a partly cloudy day (Sampling time 10 seconds)

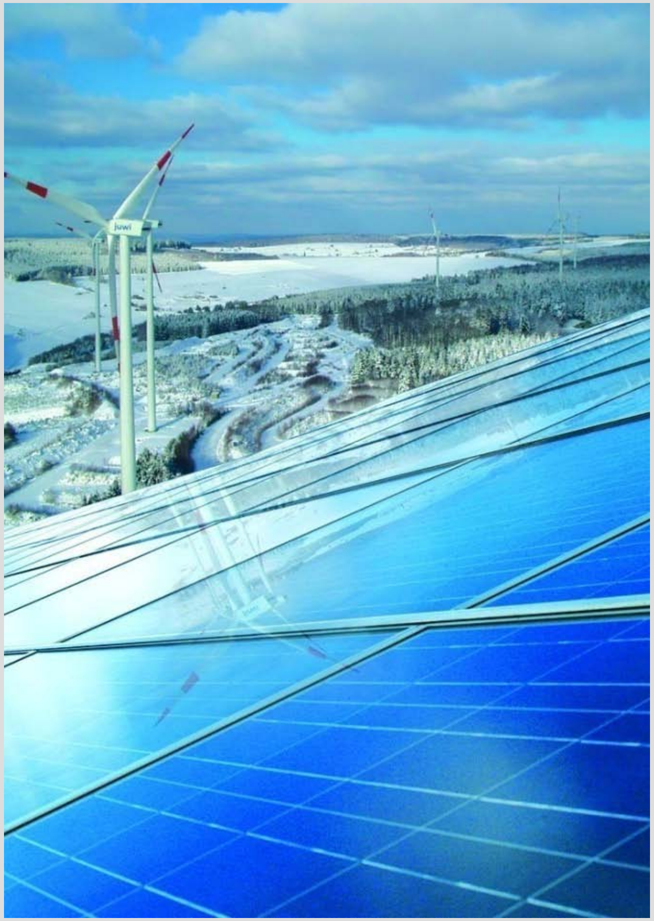
Source: NERC IVGTF Report

Utility Reliability Concerns with PV Plants

Inadequate Characteristics	Required Characteristics
➢ Not Dispatched	➢ Ability to Dispatch
➢ Non-Voltage Regulating	➢ Voltage Regulation
➢ Non-Frequency Responsive	➢ Frequency Response
➢ Unity Power Factor	➢ Power Factor Control
➢ Non-Controlled ramp-rate	➢ Ramp-Rate Control
➢ Trips-off during voltage fluctuations	➢ Ride-Through (LVRT)
➢ No Stability Models	➢ Stability Models

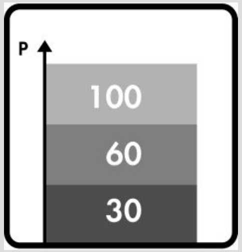
- Currently PV Market "Regulated" by IEEE1547, UL1741
- Market Transformation from PV Business to Energy Business
- PV Power Plants are becoming generation assets to conventional IPPs and Utilities
- Utilities, ISO's and Reliability Coordinators are applying conventional LGIA standards to PV Plants which present conflicts to IEEE1547 standards.

Integrating Renewable Energy

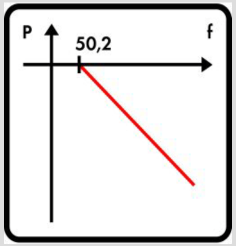


- Target: Maximum possible percentage of electricity from renewable energy sources;
- Phase out fossil and nuclear. EEG law of 2000 grandfathered by Hermann Scheer.
- Generous Feed-In-Tariffs (FIT) for Solar PV
- Force acceptance of PV inverters and guarantee interconnection access.
- PV penetration explodes, mimicking wind
- Situation: Renewable PV generation systems do not contribute to grid stability
- Expert's opinion: increasing share of renewable sources will require new standards for interconnections
- German MV Directive (6/2008), effective July 2010.
- **SMA first inverter company to be awarded BDEW full compliance with MV Directive**

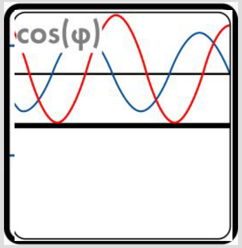
BDEW* Guidelines Summarized



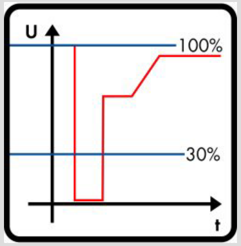
➢ Ability to control PV generation to a specified % of nominal power rating (Remote Dispatch)



➢ Ability to automatically reduce active power with frequency deviations (Over Frequency Response)



➢ Ability to supply/absorb reactive power during PV operation
➢ Ability to Control Power Factor (PF Control Mode)

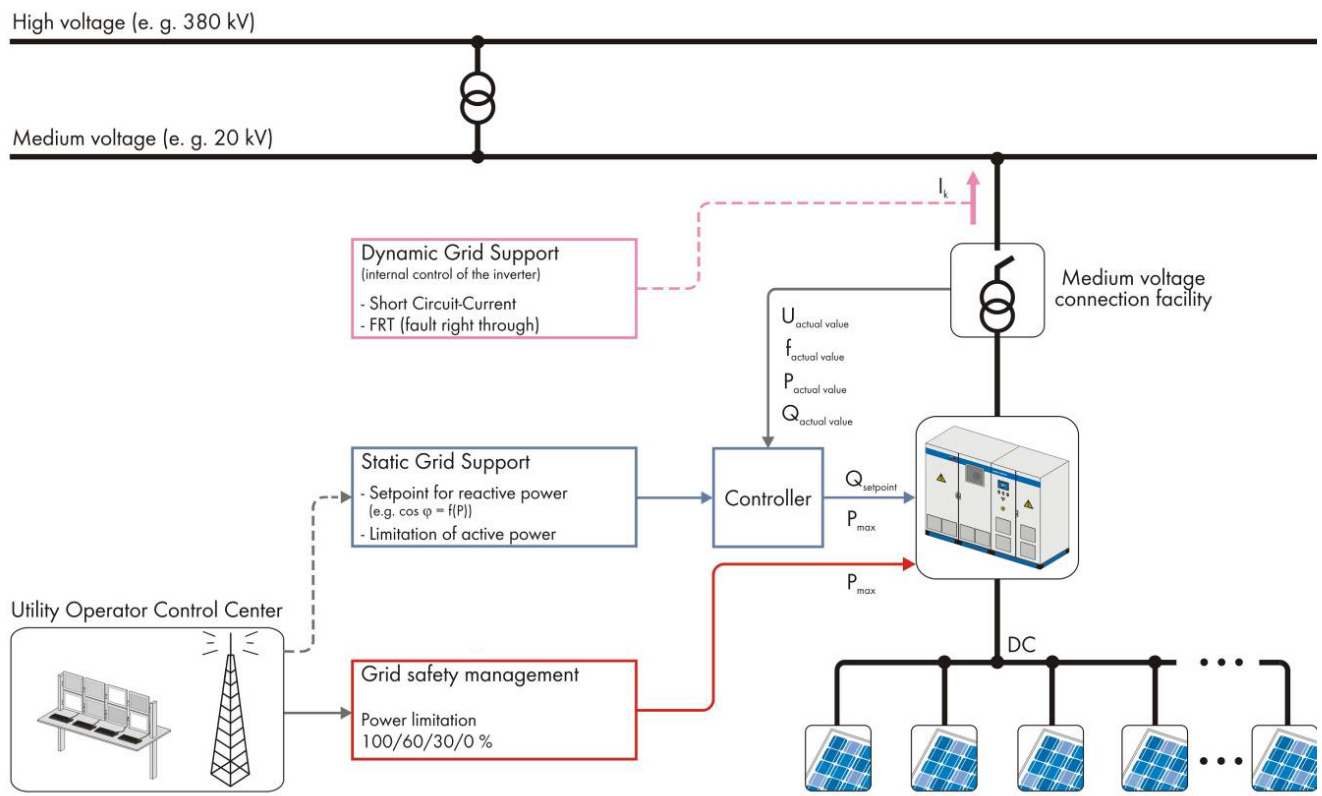


➢ Fault Ride-Through (LVRT)
➢ Ability to supply reactive current during fault ride-through period

* German Association of Energy and Water Industries (BDEW)

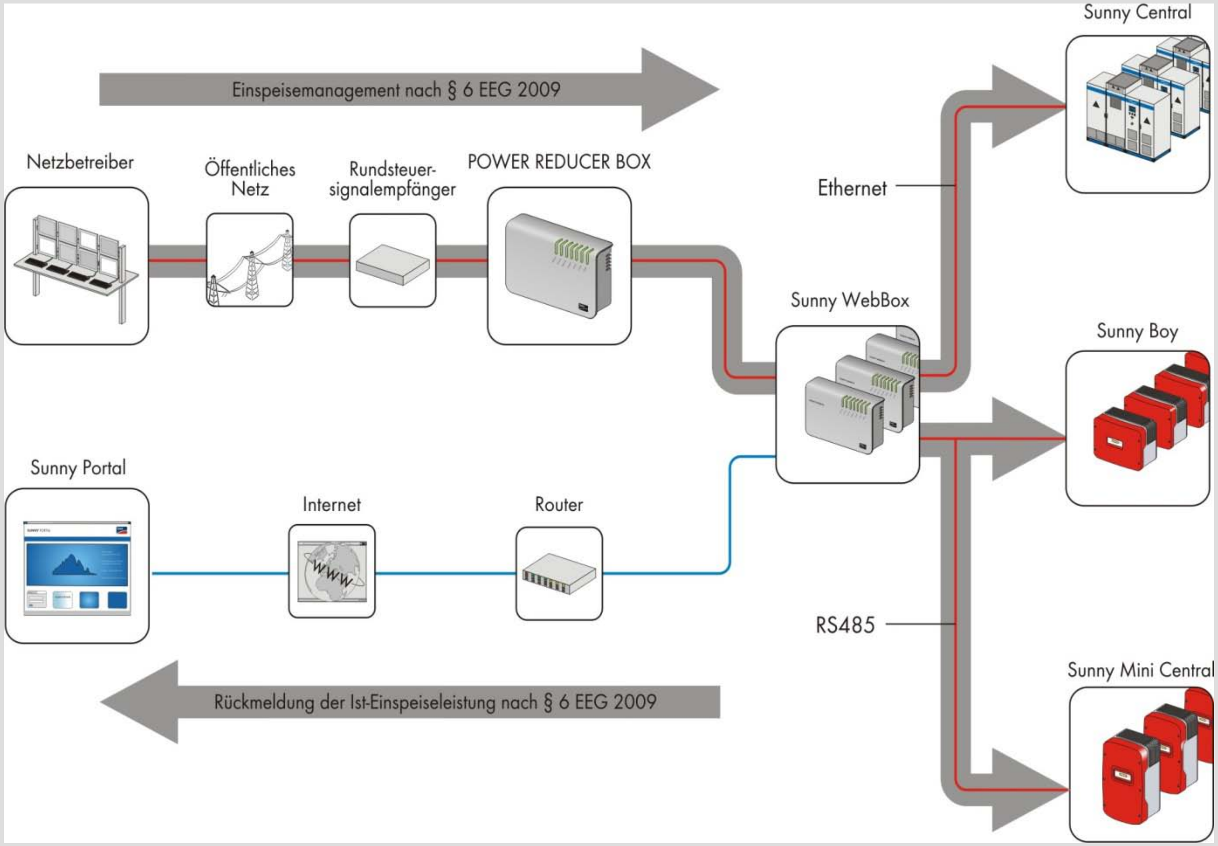
MV Directive – All Under Utility Control

Simplified illustration of grid control using PV plants (medium-voltage grid)



Source: Erzeugungsanlagen am Mittelspannungsnetz. BDEW, Release June 2008

Grid Support: Active Power Limitation



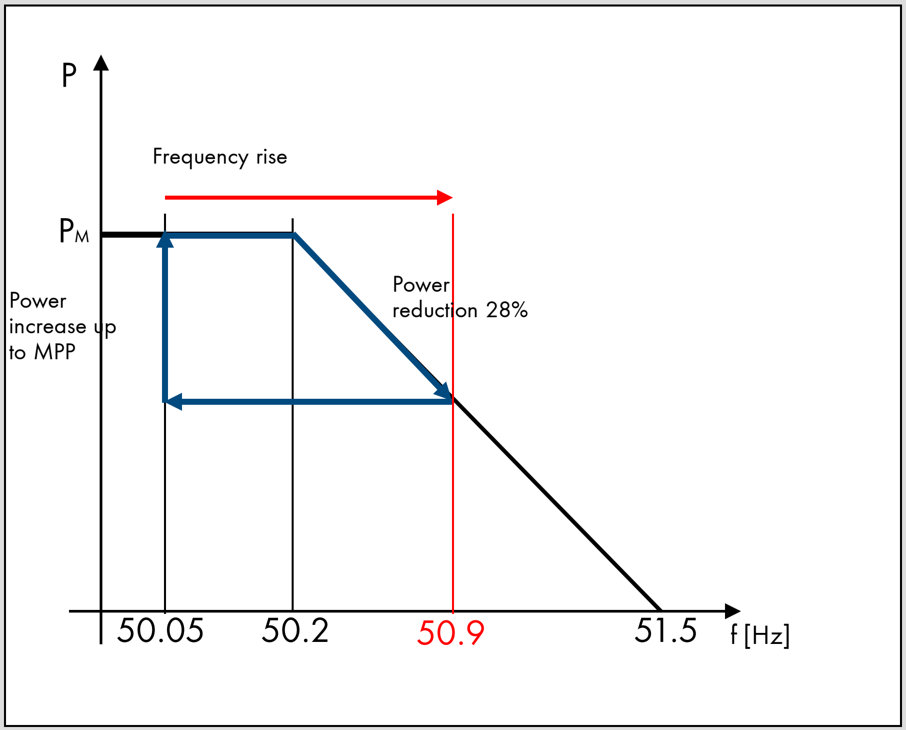
- Prevent overload or grid congestion
- 4 default settings but configurable up to 16 steps. e.g.:

100 % power
60 % power
30 % power
0 % power

- Ramp Configurable % rate increase vs. % rate decrease from 20sec to 60min

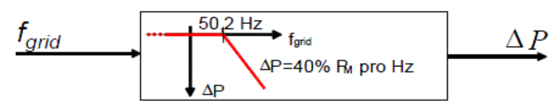
Grid Support: Over Frequency Response

SMA 1000V Inverters Designed for Static and Dynamic Active Power Control



Source: Erzeugungsanlagen am Mittelspannungsnetz. BDEW, Release June 2008

- Reduction of active power dependent on Grid Frequency.
  - in Case of Grid Failures
  - in Case of Power Surplus
  - to avoid Grid Instabilities
- 4% active power reduction / 0.1Hz
- Configurable for 60Hz and various % slopes



$$\Delta P = 20\, P_M \frac{50{,}2\ Hz - f_{grid}}{50\ Hz}$$ when $50{,}2\ Hz \leq f_{grid} \leq 51{,}5\ Hz$

P_M power currently available

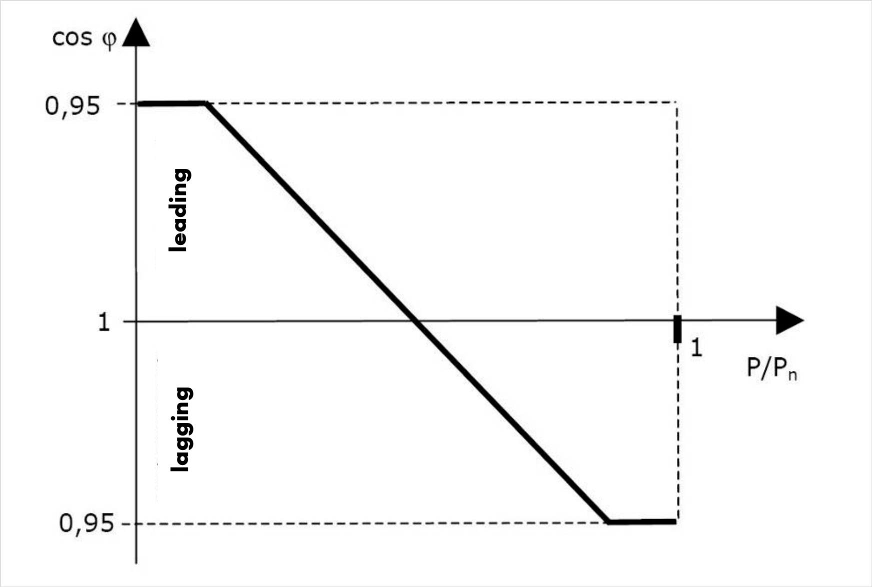
ΔP power reduction

f_{Netz} grid frequency

In the range $47{,}5\ Hz \leq f_{grid} \leq 50{,}2\ Hz$ no restriction

When $f_{grid} \leq 47{,}5$ and $f_{Netz} \geq 51{,}5$ Hz disconnection from grid

Grid Support: Reactive Power Requirements



- BDEW PF Requirement: 0.95 lagging to 0.95 leading at point of interconnection

- Objective: Maintain stable grid voltage
- Static (or fixed) power factor specified by utility
- Dynamic reactive power on demand remotely controlled by utility
- Dynamic reactive power depending on grid voltage
- Dynamic power factor according to a pre-defined schedule

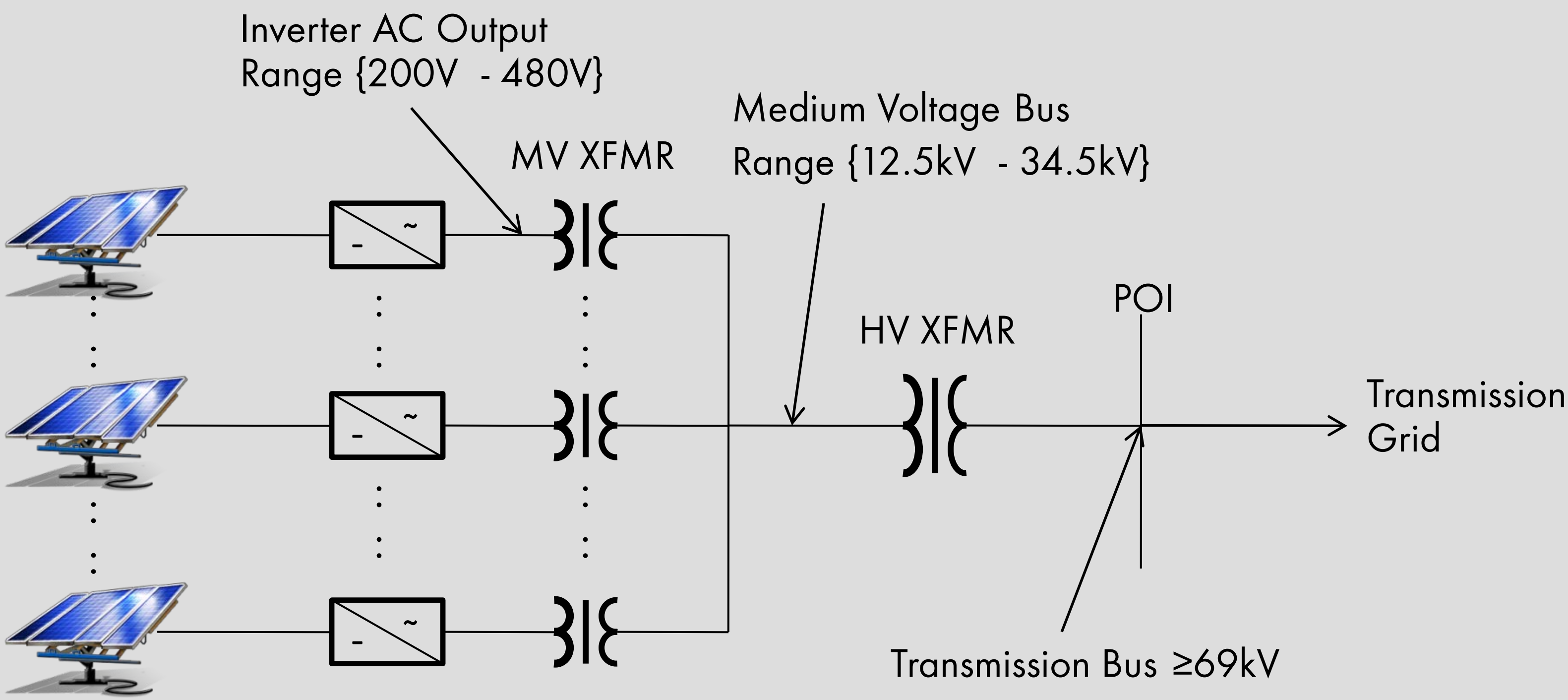
- SMA Power Factor Range at Full Rated Power 0.9 Lag/Lead

> **Impact on PV inverter and plant design!**

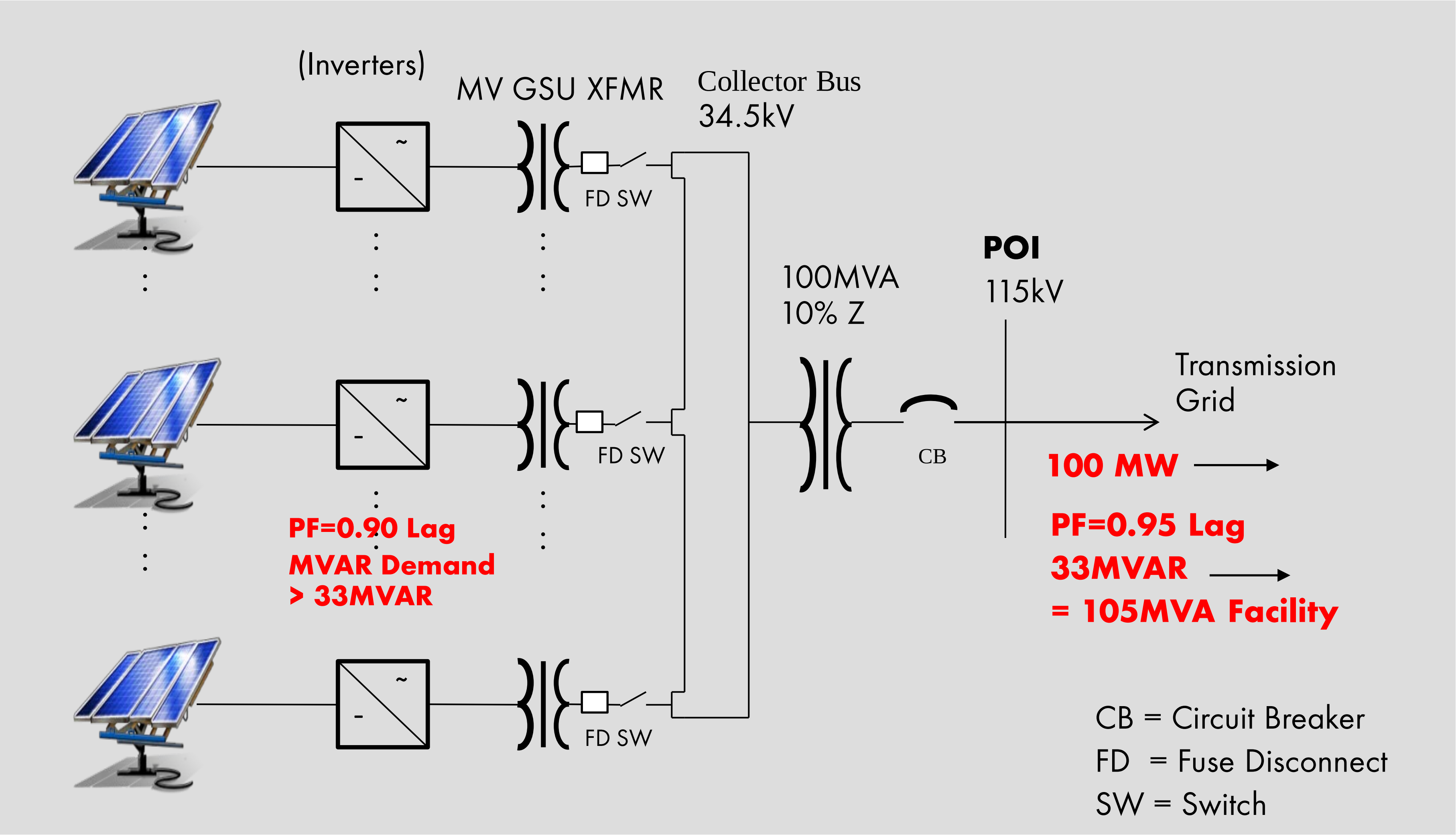
SMA Inverters Comply with PF Control

Source: Erzeugungsanlagen am Mittelspannungsnetz. BDEW, Release June 2008

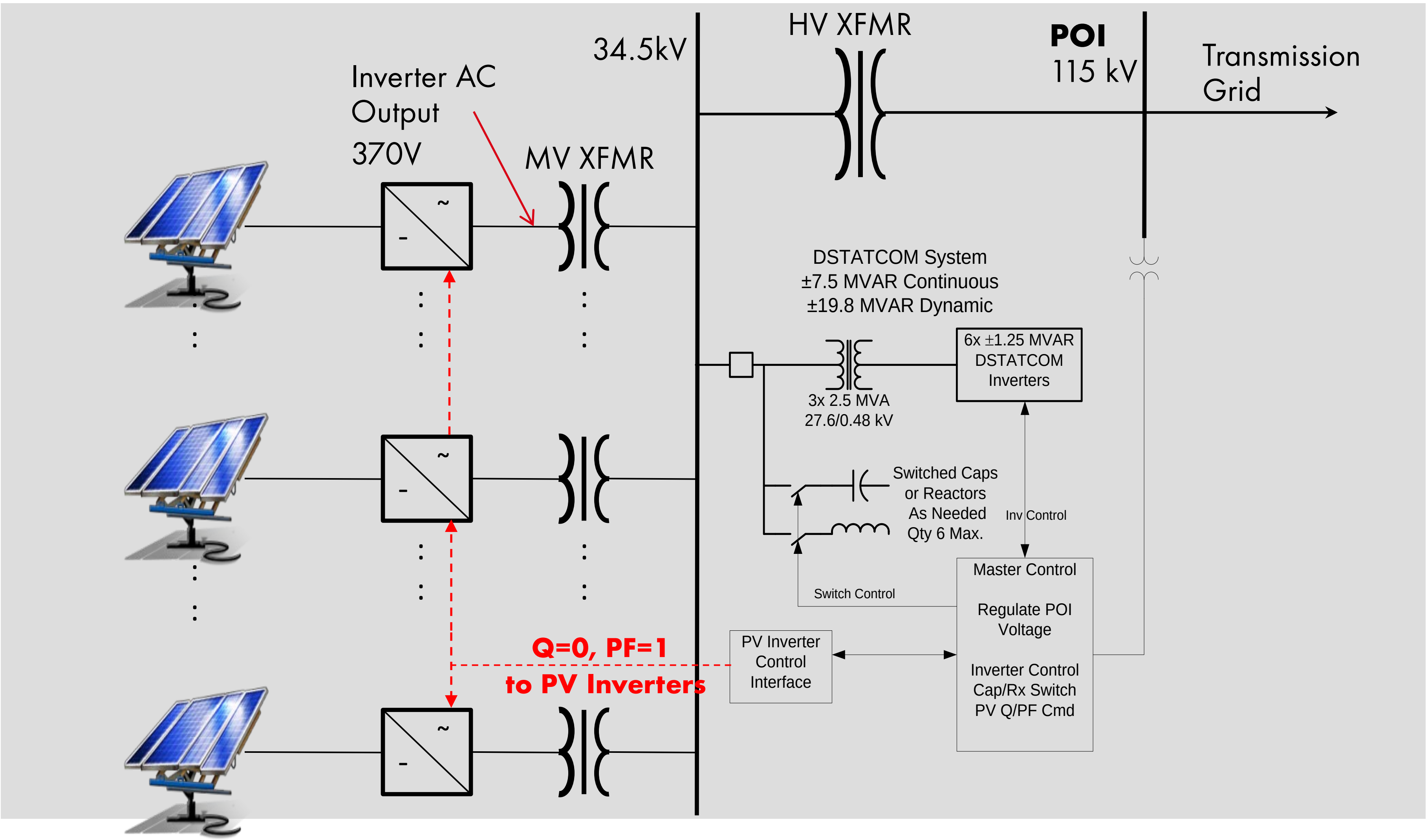
Sample PV Plant Single Line Diagram



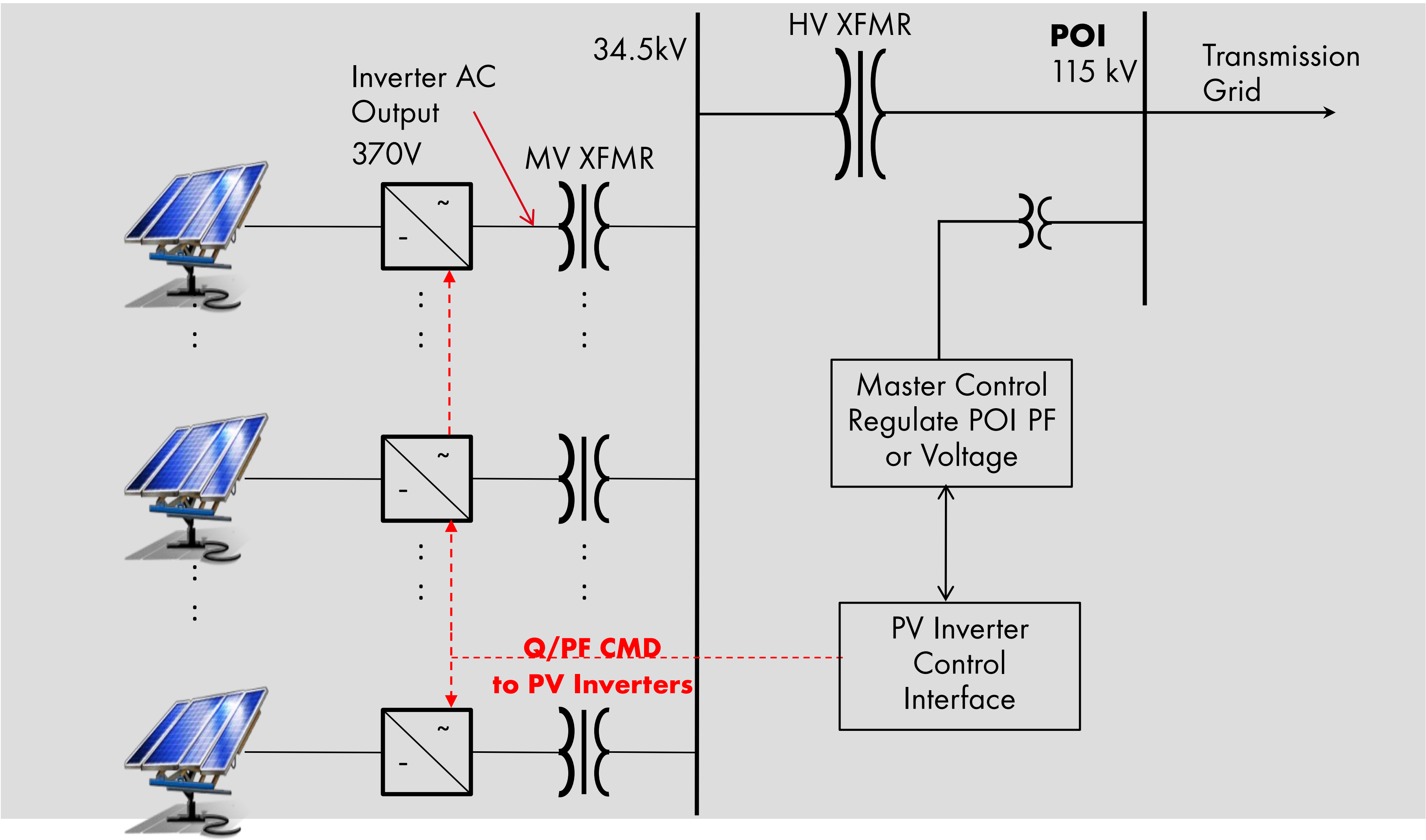
Reactive Compensation, Capacitive Example



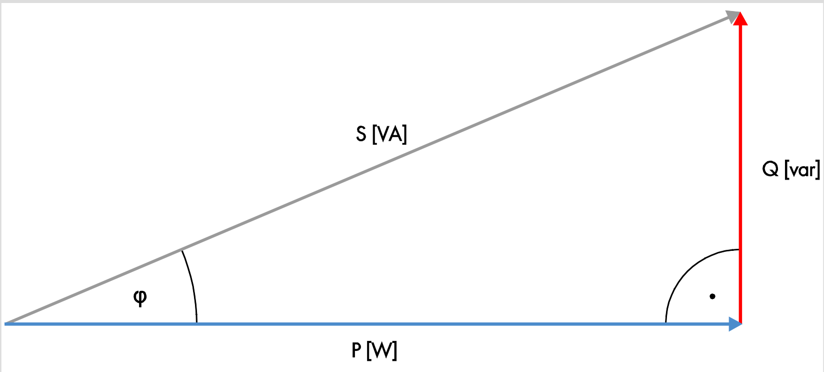
VAR Compensation with FACTS Devices



VAR Compensation with Inverters



SMA Inverters kVA Rating vs. kW Rating



S	Apparent Power
P	Active Power
Q	Reactive Power
Cos φ	Power Factor

tan (phi) = Q/P

$$S = \sqrt{P^2 + Q^2}$$

$$S = \frac{P}{(\cos\varphi)}$$

$$P = S \cdot \cos\varphi$$

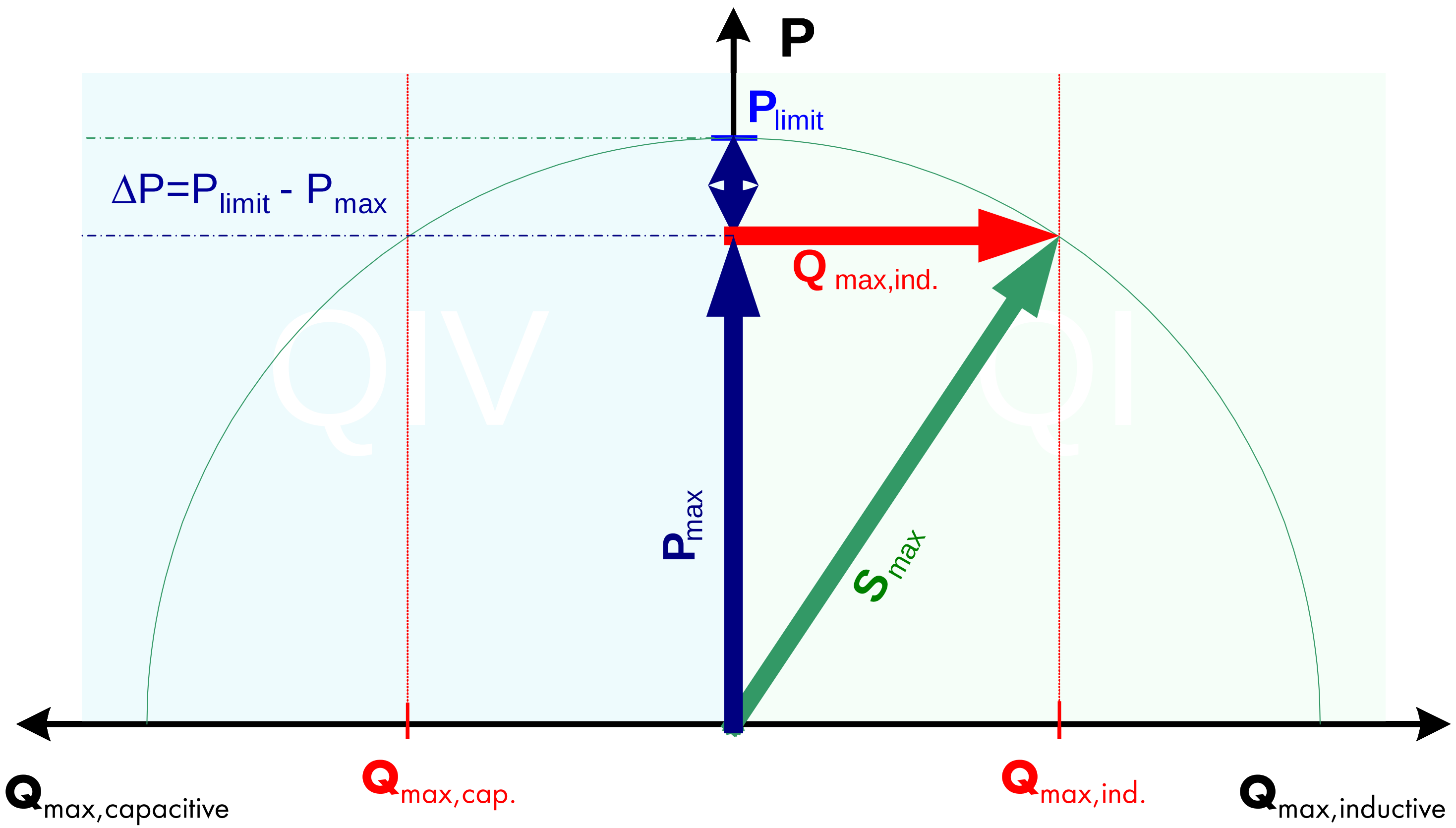
$$Q = \sqrt{S^2 - P^2}$$

The SMA SC800CP is currently the industry's largest single inverter.

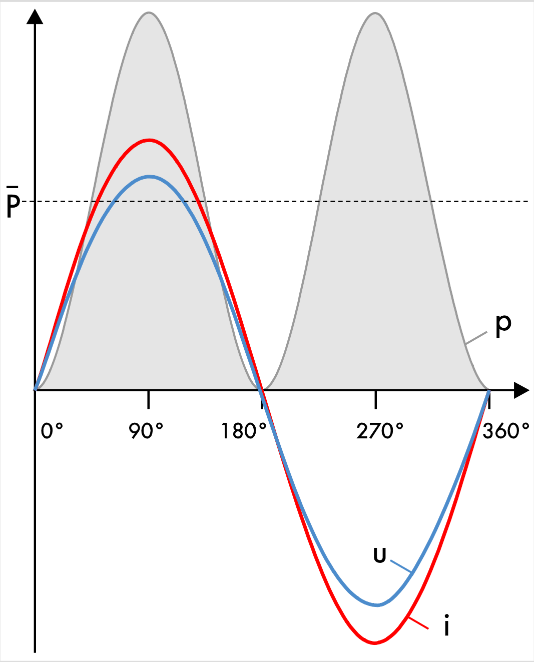
Rated @ 880kVA for T ≤ 25°C means:

800kW and ±360kVAR Range

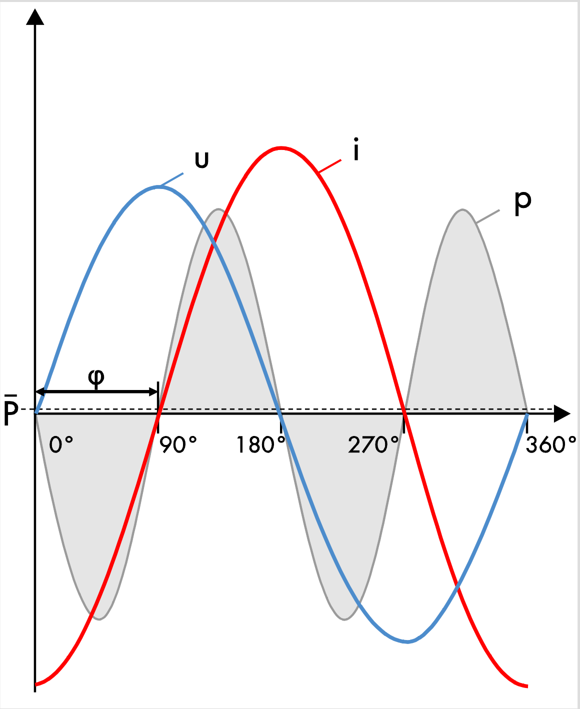
System Design with Reactive Power Supply



Power Factor Value at 0 and 1

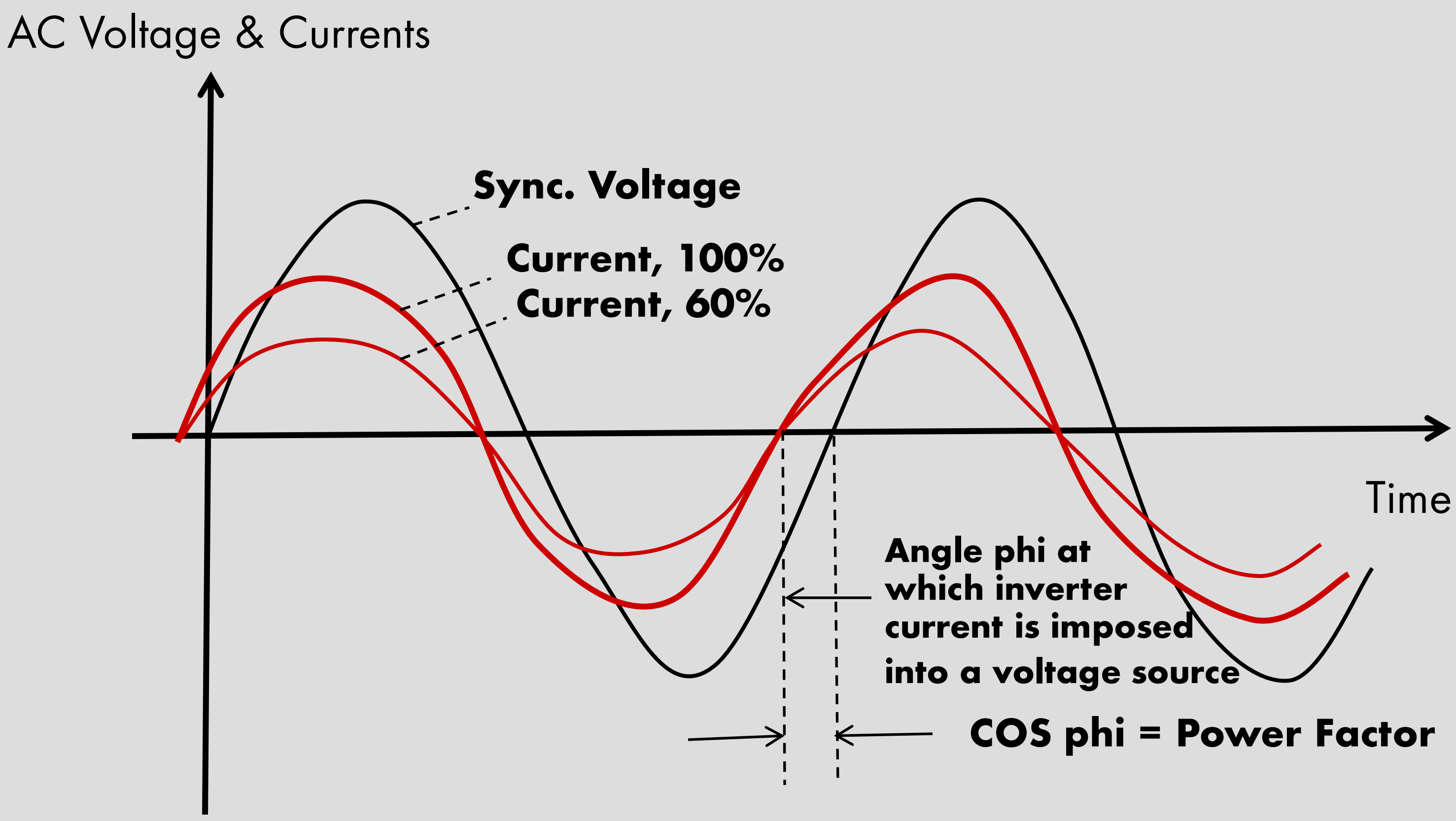


If current i and voltage v are in phase, a fluctuating but always positive power results - pure active power.



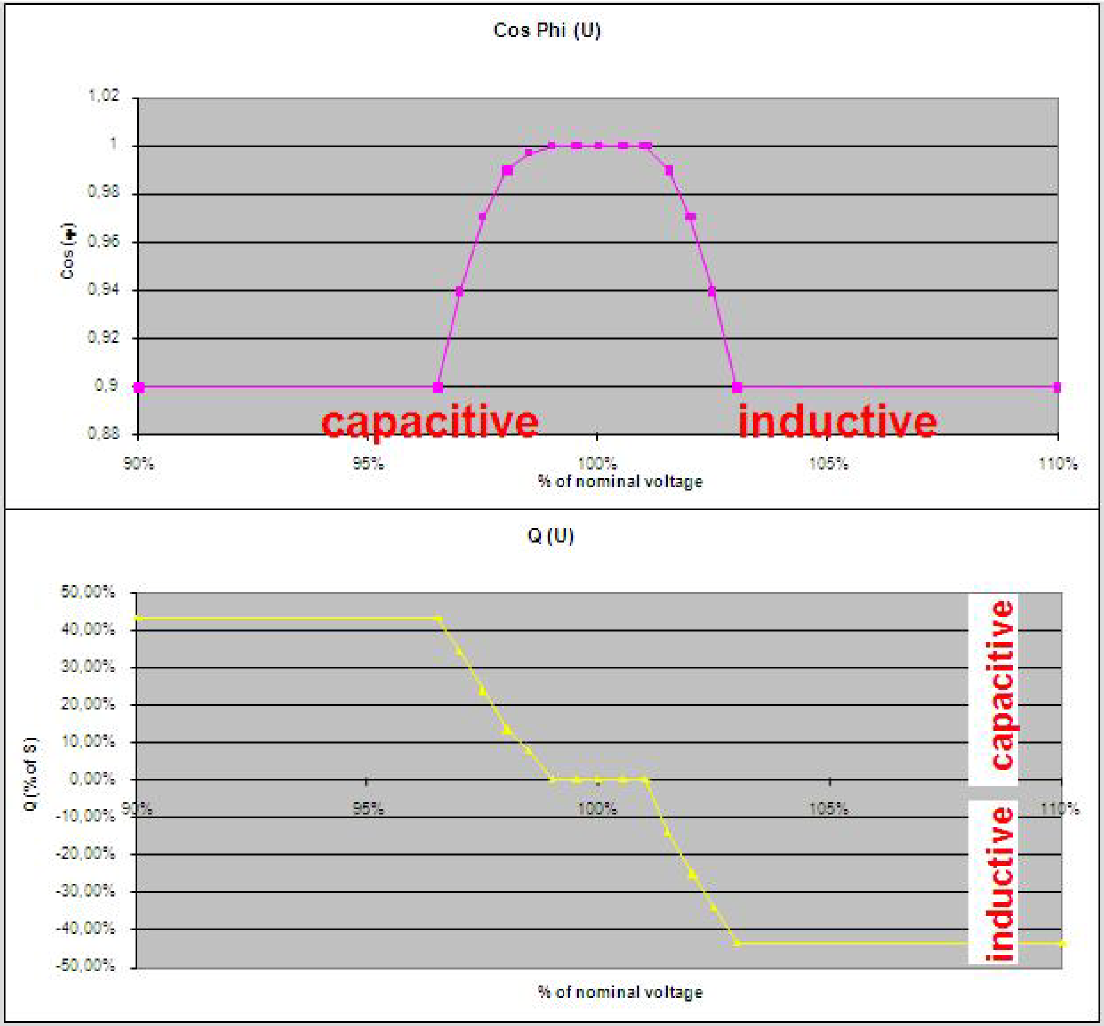
In the case of a phase shift of 90 degrees between i and v, the average value of the power is zero - pure reactive power.

Adjustable Current Angle = Adjustable Power Factor



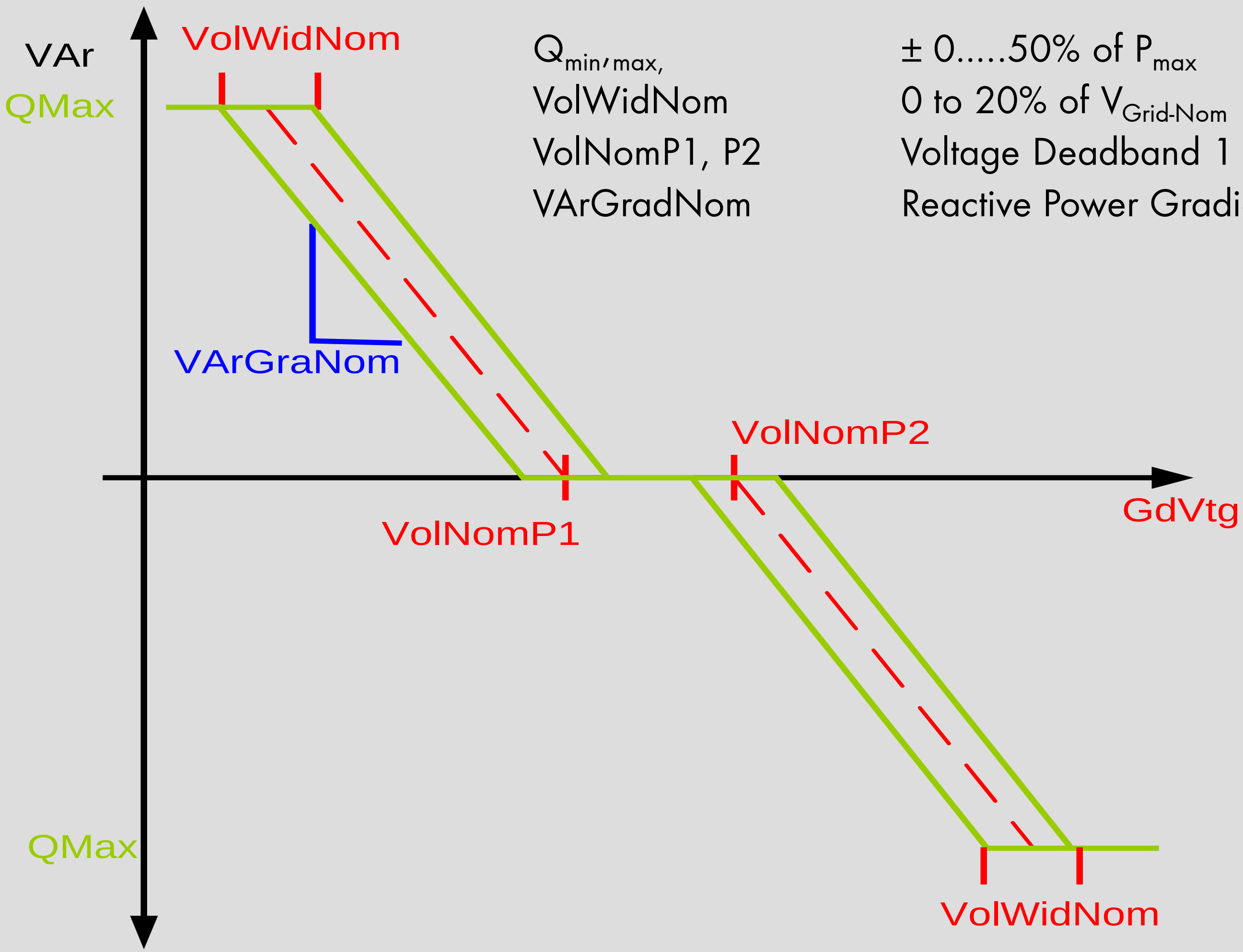
Voltage Dependent Power Factor Adjustment

Voltage	Relais 4bit	Cos φ	equals Q
90%	1	0,9	43,59%
96,5%	1	0,9	43,59%
97,0%	2	0,94	34,12%
97,5%	3	0,97	24,31%
98,0%	4	0,99	14,11%
98,5%	5	0,997	7,74%
99,0%	6	1	0,00%
99,5%	7	1	0,00%
100,0%	8	1	0,00%
100,5%	9	1	0,00%
101,0%	10	1	0,00%
101,5%	11	0,99	-14,11%
102,0%	12	0,97	-24,31%
102,5%	13	0,94	-34,12%
103,0%	14	0,9	-43,59%
110%	14	0,9	-43,59%



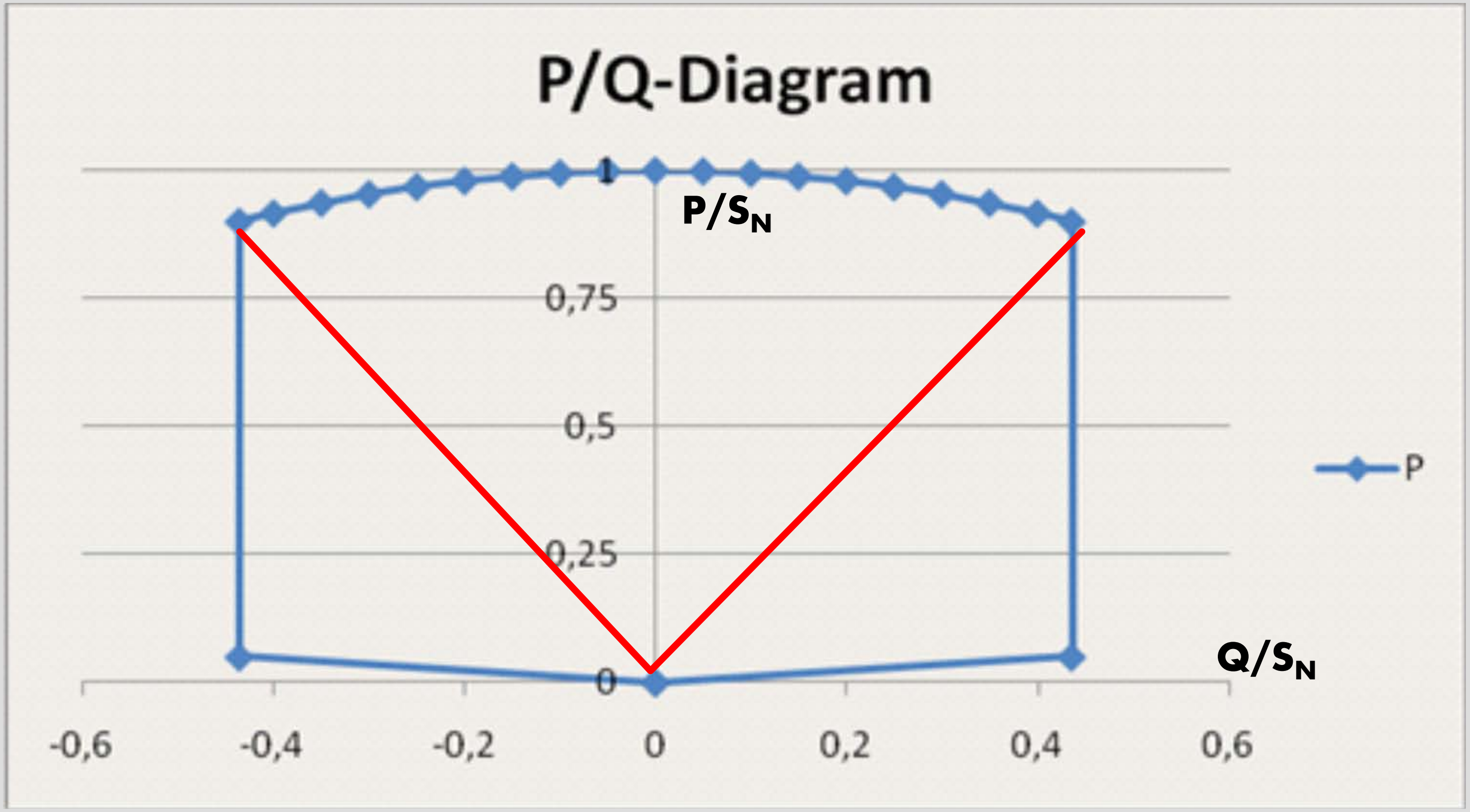
SMA Inverters Q(V) Characteristic

$Q_{min, max,}$	$\pm$ 0.....50% of P_{max}
VolWidNom	0 to 20% of $V_{Grid\text{-}Nom}$
VolNomP1, P2	Voltage Deadband 1 & 2, 0.8pu to 1.20pu
VArGradNom	Reactive Power Gradient(0 to 10%P_{max}/$V_{inv\text{-}nom}$)

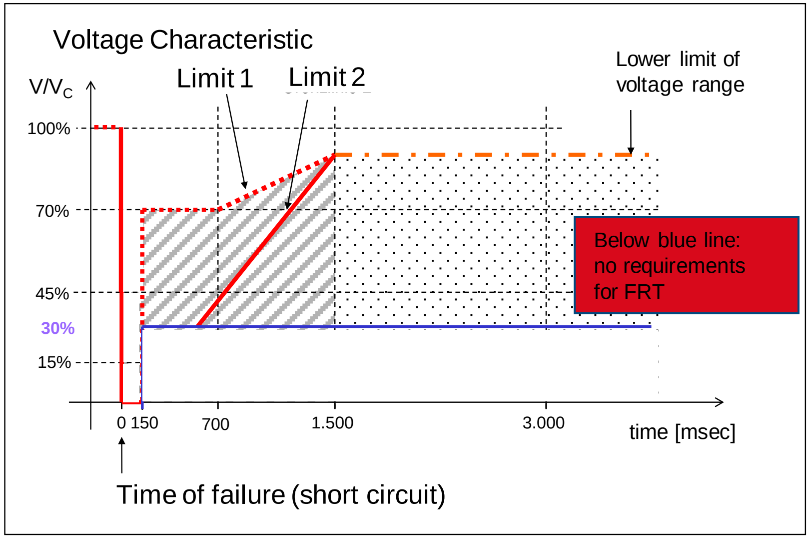


SMA Inverters P/Q Diagram

The inverter can be operated at any point inside the PQ-diagram. The red lines represent PF limits of 0.9 leading to 0.9 lagging. The reactive limits are expanded to 0.44pu when QREG=1



Grid Support: Low Voltage Ride-Through

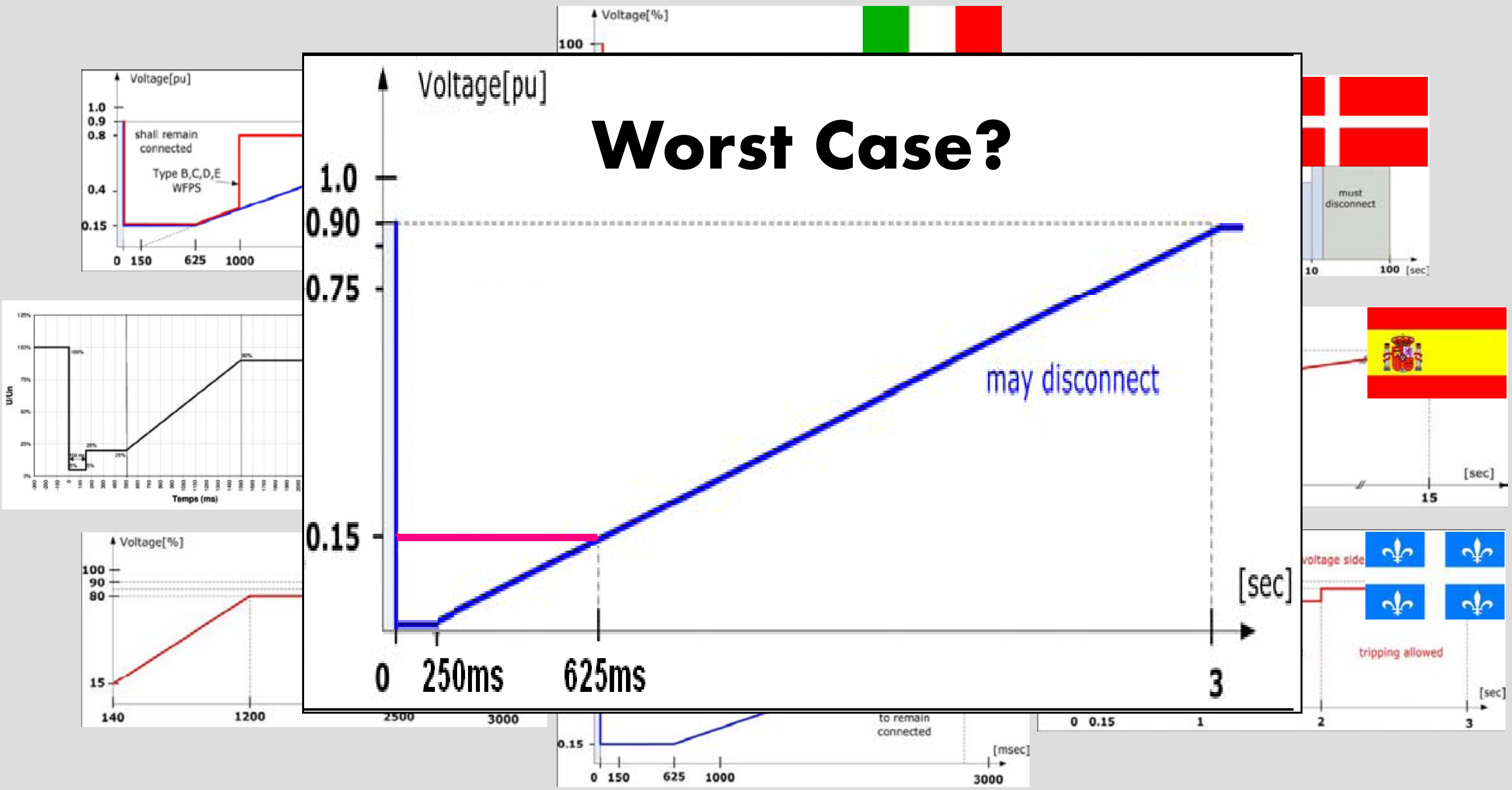


- Objective: Stay connected during HV grid disturbances in a manner similar to FERC Order 661-A. Why? To avoid simultaneous shutdown of generation sources.
- Required performance:
- Voltage dips to "0" at utility interconnection point (HV side of the transformer)
- Inverter must stay connected during a grid failure for 150 ms (7.5 cycles for 50Hz systems)
- If within 150 ms voltage is back above Limit 1: *stable operation*
- If after 150 ms voltage stays below Limit 2 (30% of V_{nom}): *May disconnect from the grid*
- If voltage between Limit 1 and Limit 2, then recovery behaviour to be defined by utility interconnected to.

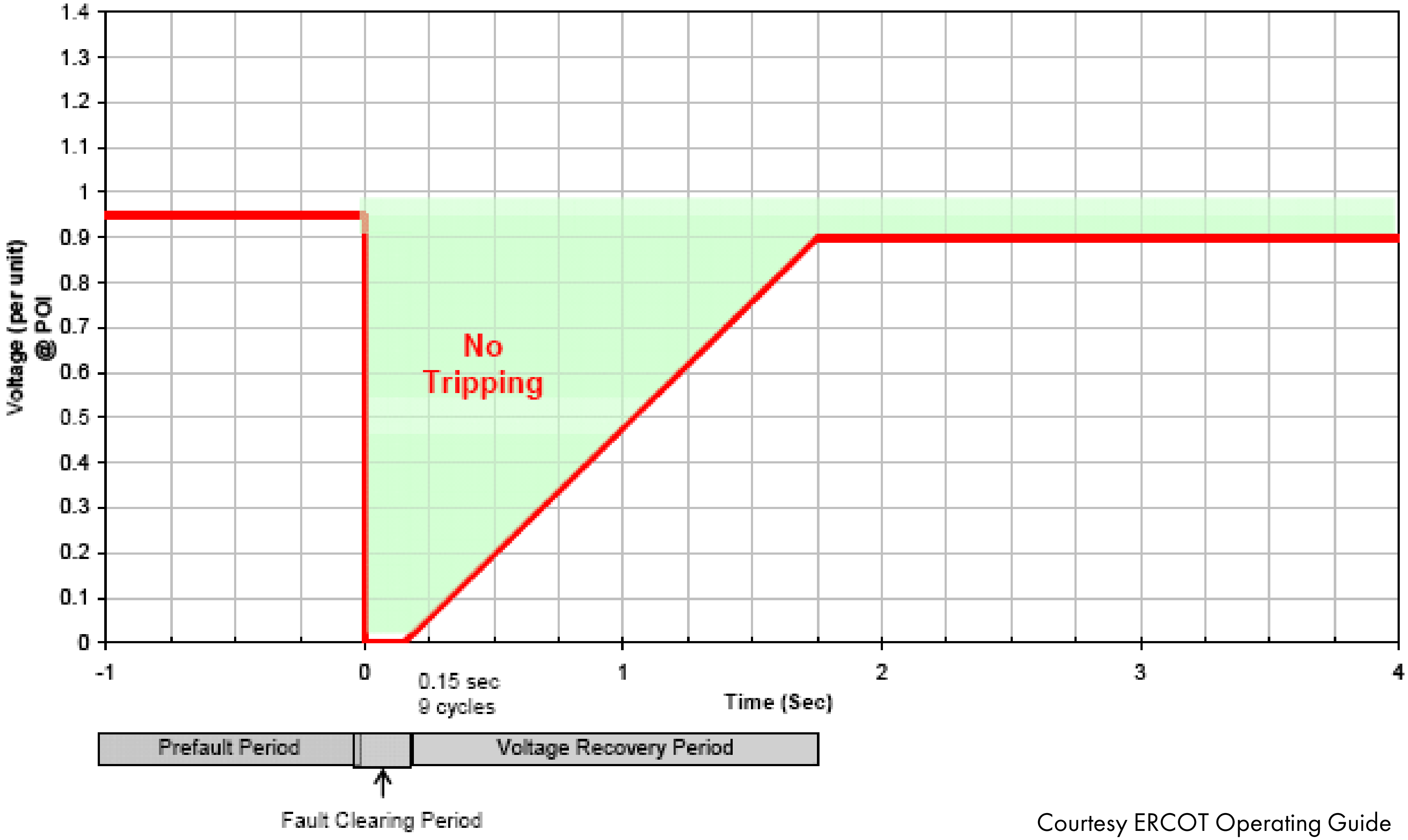
SMA Inverters are Designed to Support LVRT Requirements Worldwide

Source: Erzeugungsanlagen am Mittelspannungsnetz. BDEW, Release June 2008

LVRT Or Fault Ride Through – Worldwide

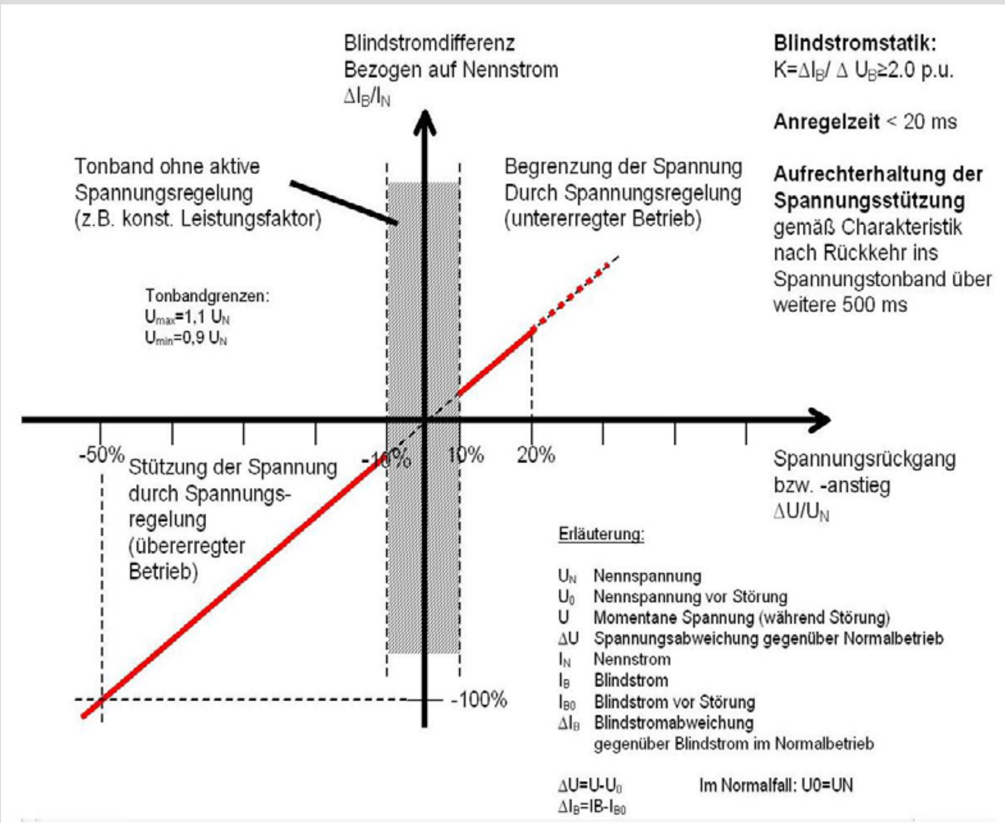


LVRT for North America: Supported



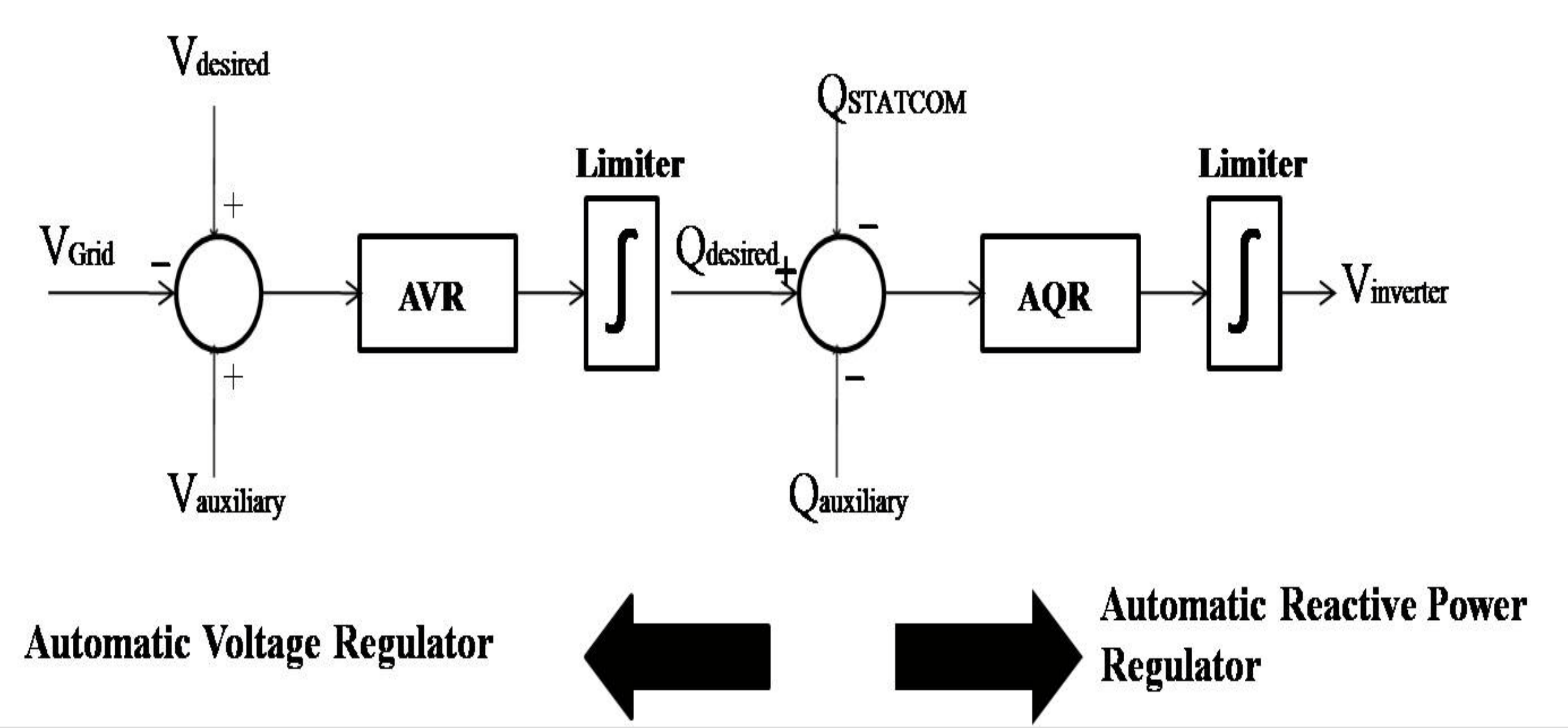
Courtesy ERCOT Operating Guide

Reactive Current Supply During Fault Ride-Through

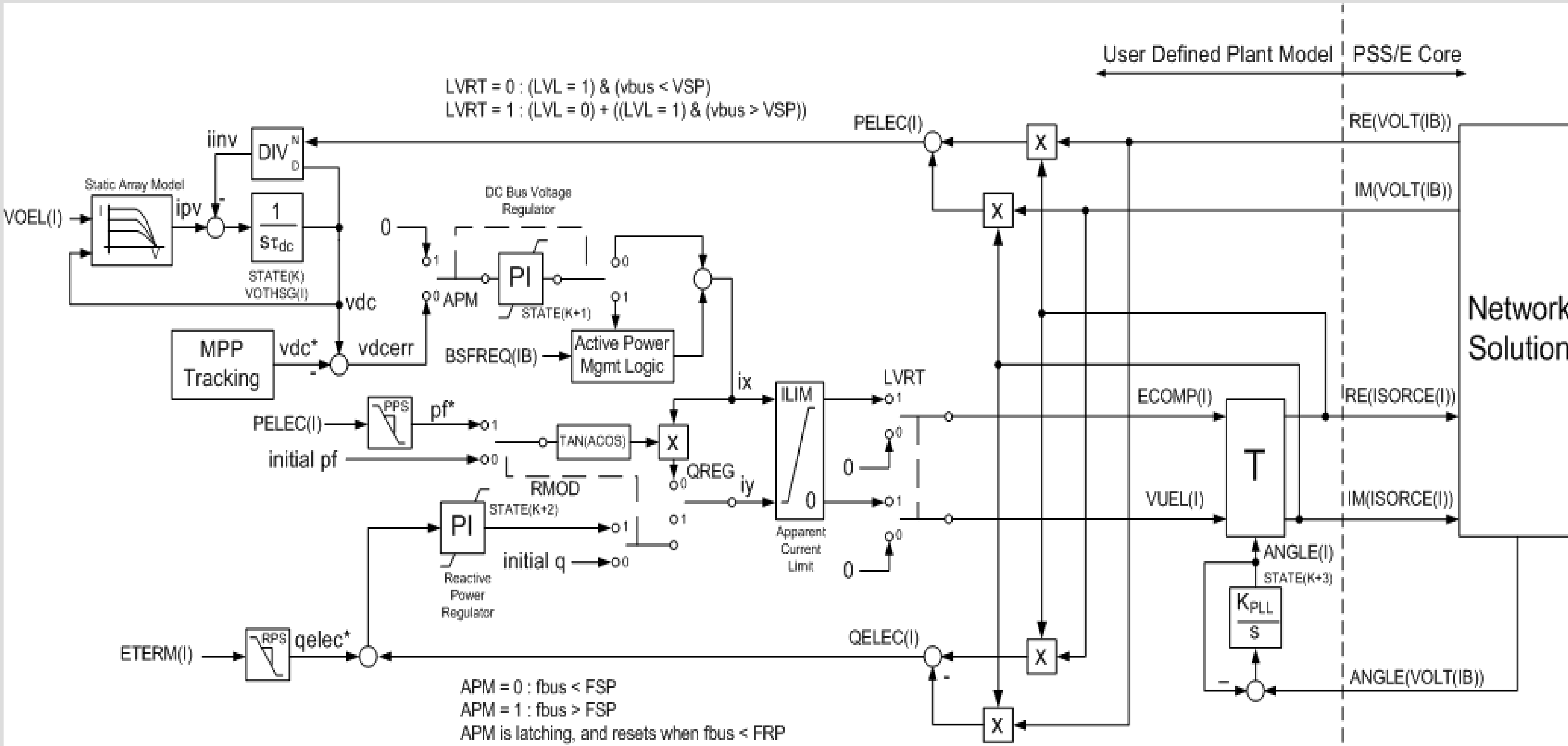


- <u>Targets</u>: Faster recovery of the grid after grid failures
- Reactive current supply in the event of dramatic voltage drops
- Avoid simultaneous shutdown of significant renewable sources
- No significant influence on PV inverter design.

Grid Support: Automatic Volatge Regulation



Grid Stability: Dynamic Models



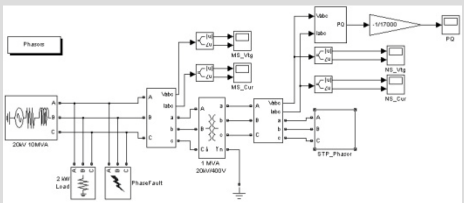
SMA Inverter Dynamic Stability Models for PSSE Versions, 29, 30, 31, 32 & PSLF Versions 16, 17

RMS Modeling of SMA Sunny Central CP

Modeling approach

1st step: Derivation of an RMS model from instantaneous value models in Matlab/Simulink

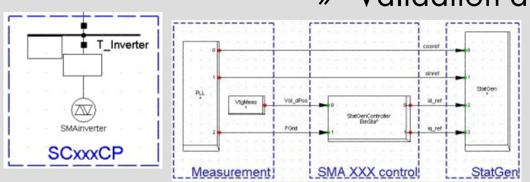
» Verification against accurate models



MATLAB & SIMULINK

2nd step: Manual translation of the Simulink model to DIgSILENT PowerFactory (Version 14.0.519.1)

» Validation against measured data



DIgSILENT Model Validation by 3rd party Germanischer Lloyd

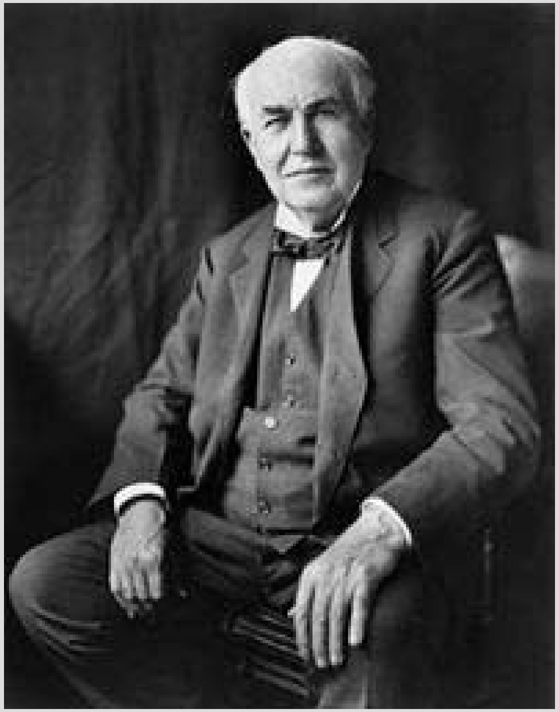
3rd step: Manual translation of the DIgSILENT model to PSS/E FLECS code (Version 32.3)

» Verification against PowerFactory simulations using representative test cases

» Test in representative networks

PSS®E

The Time May Have Come!



Thomas A. Edison, 1931.

"We are like tenant farmers chopping down the fence around our house for fuel when we should be using Nature's inexhaustible sources of energy – sun, wind and tide. I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

Our Most Valuable Reference

Since 2003, the White House in Washington DC has produced solar energy. A PV system as well as a solar-thermal station is installed on the roof of the main administration building. The grid-connected PV system has an output of 10 kilowatt peak (kWp) and provides some parts of the Presidential residence with solar energy.

With three Sunny Boy 2500U devices, SMA delivered the best fitting inverters for this system. Equipped with the OptiTrac MPP control, the PV generator will always be operated at the optimal power point, even under fluctuating weather conditions.

SOLAR TECHNOLOGY

Thank You

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