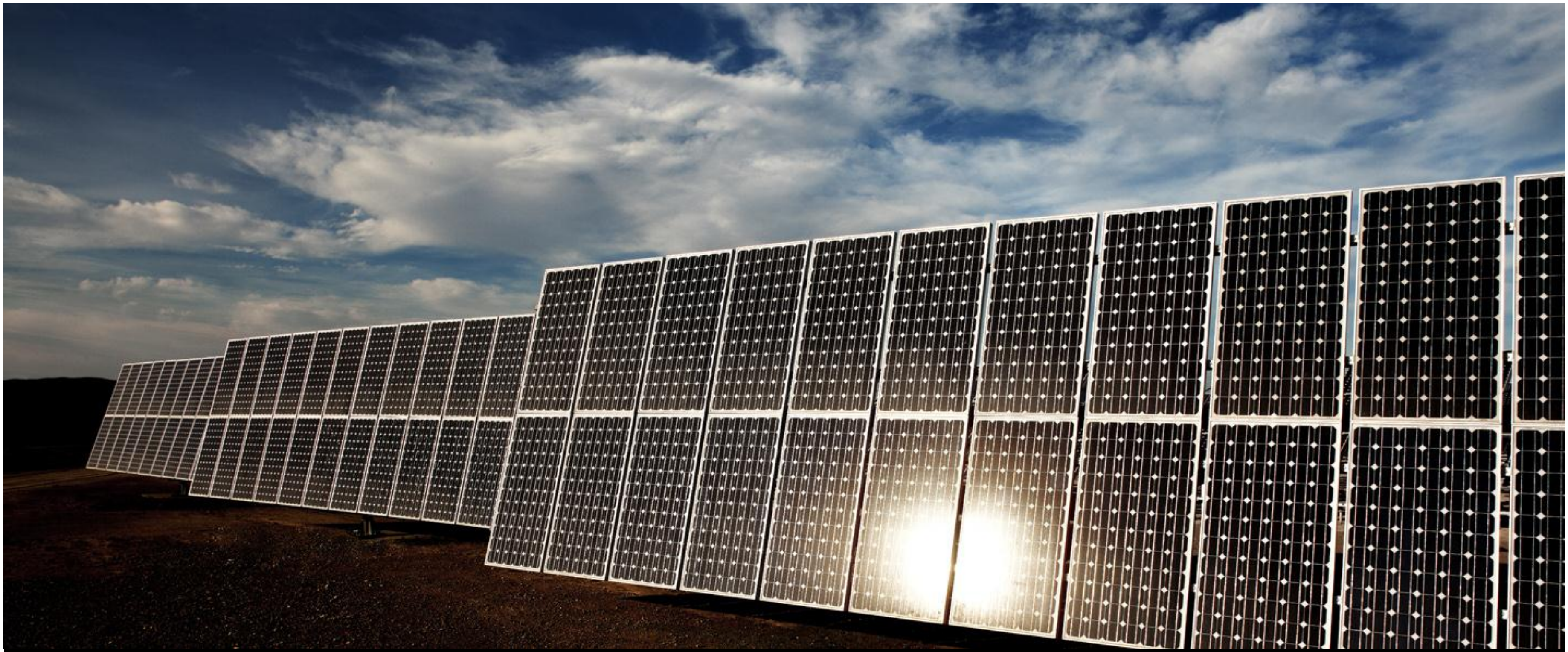


Jaspreet Singh, PG Solar

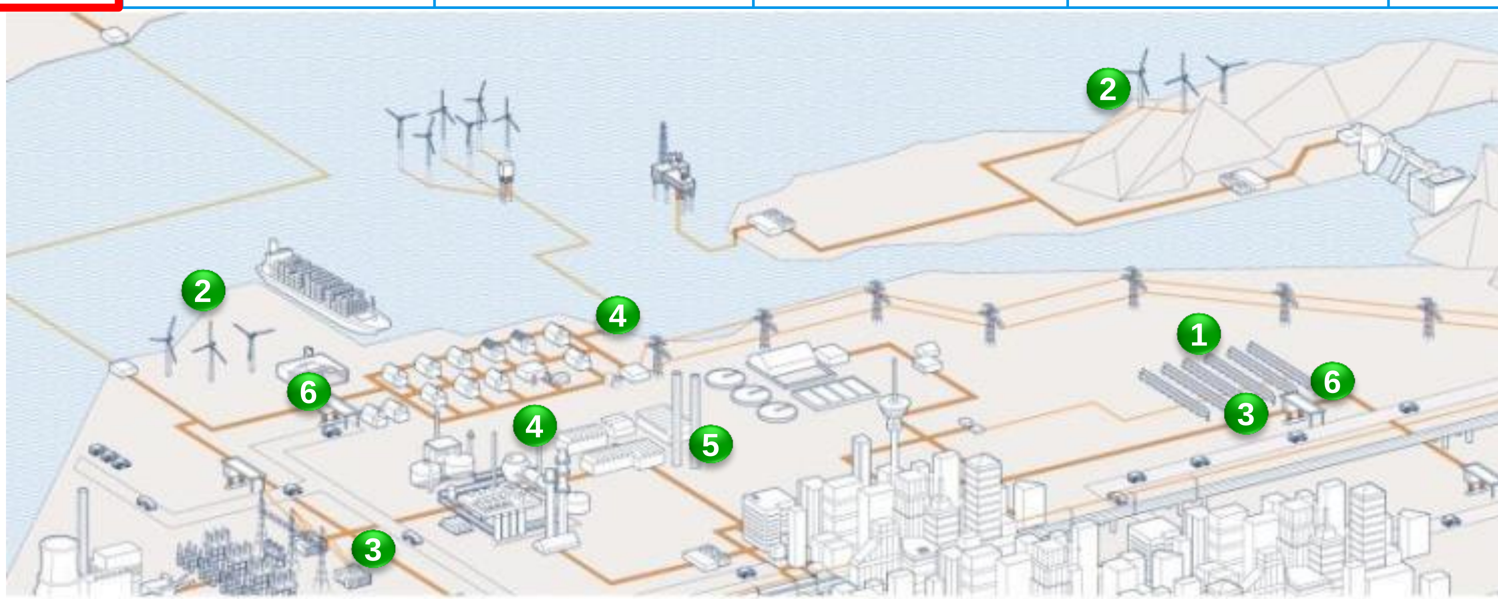
Ancillary support by PV inverters – Case studies from Europe and US

ABB Overview

- 150,000 employees
- Present in 100+ countries
- $42 billion in revenue (2013)
- Formed in 1988
- Merger of Swiss (BBC 1891) and Swedish (ASEA 1883) engineering companies
- Publicly owned company with head office in Switzerland

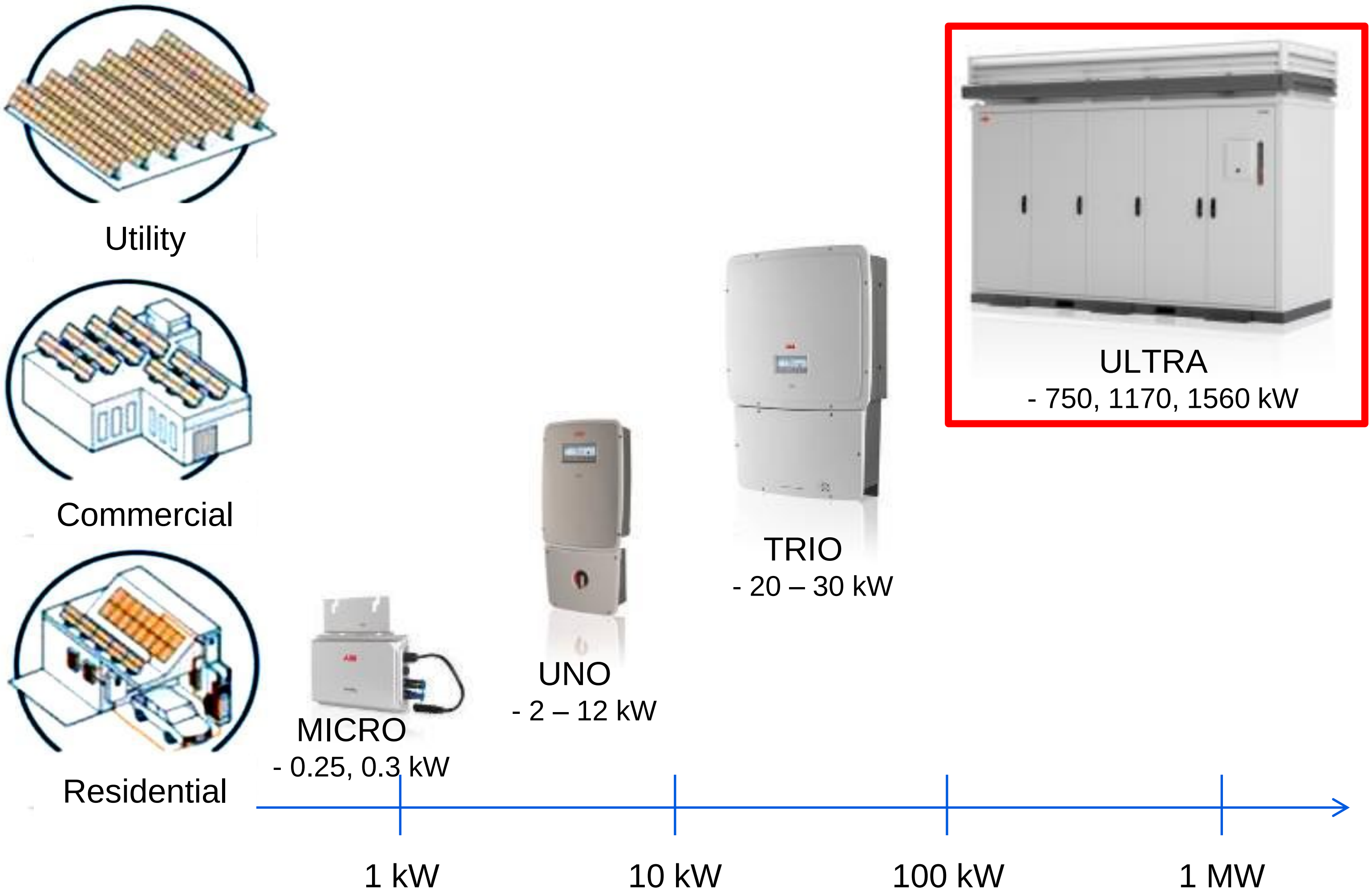
ABB DM Power Control Solutions
Enabling the flow of power from generation to end use

Solar Inverters	Wind Converters	Energy Storage Conversion	Voltage & VAr Management	Power Quality Products	EV Charging Stations
					
1 Solar Inverters	2 FC/DF Wind Converters	3 Energy Storage Inverters	4 Statcom Devices	5 AVC & UPS-I	6 AC Regular & DC Fast Charging
Power Rating: 250W – 1.5MW	Power Rating: 30kW – 6MW	Power Rating: 50kW- 30MW	Power Rating: 100kVAr - 30MVAr	Power Rating: 125kVA - 20MVA	Power Rating: 50 kW



ABB

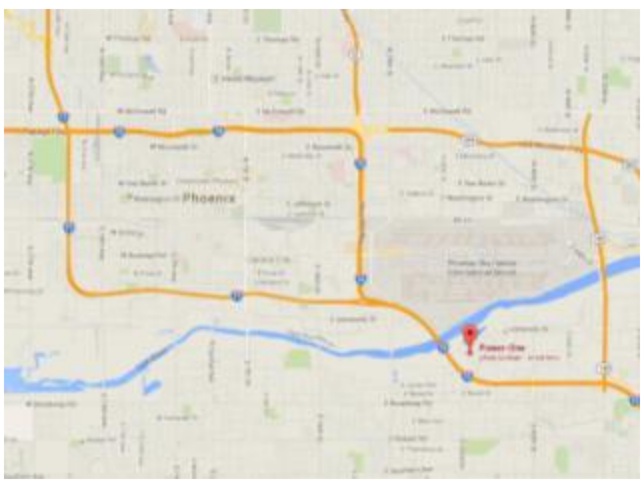
Full Spectrum of Solar Inverters for North America
From 250 W to 1.5 MW



ABB's Solar Inverter Office Location
US HQ located in Phoenix, AZ

US Solar Headquarters

- Utility-scale solar inverters
- EV charging stations
- Traction equipment
- ISO 9001:2008



Core Functions

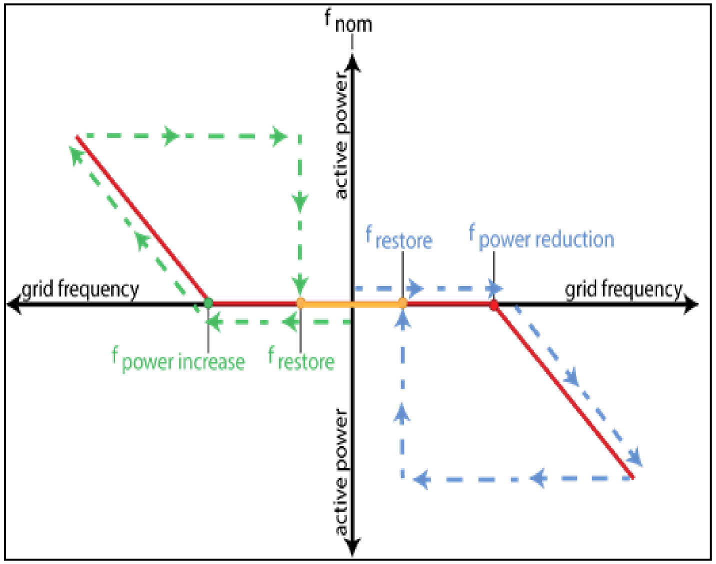
- Sales & Marketing
- Product Management
- Project Management
- Testing / Manufacturing
- After-Sales Support & Service

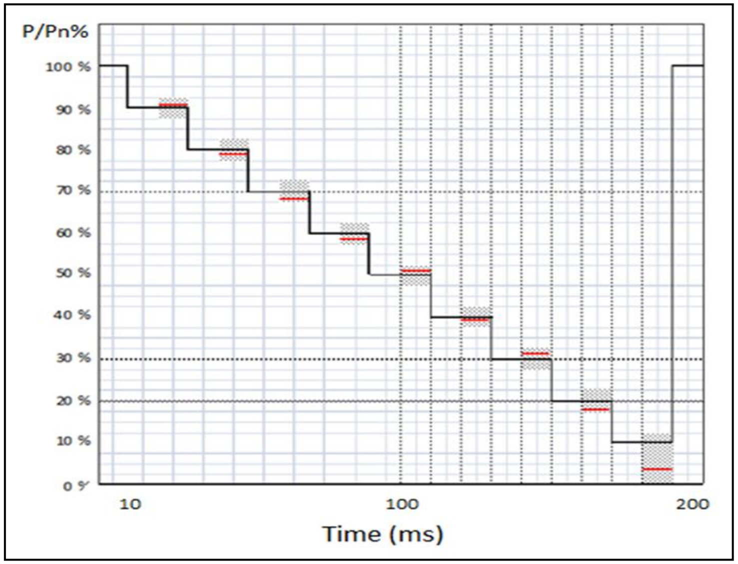
Ancillary Services
PV Inverters

Introduction

- Ancillary services & PV Inverters
  - More and more PV inverters are becoming a part of the Power System infrastructure
  - System reliability is critical for both customers and operators
  - PV Inverters should be able to survive contingencies
  - PV Inverters to act as “good citizens” and support when situation demands

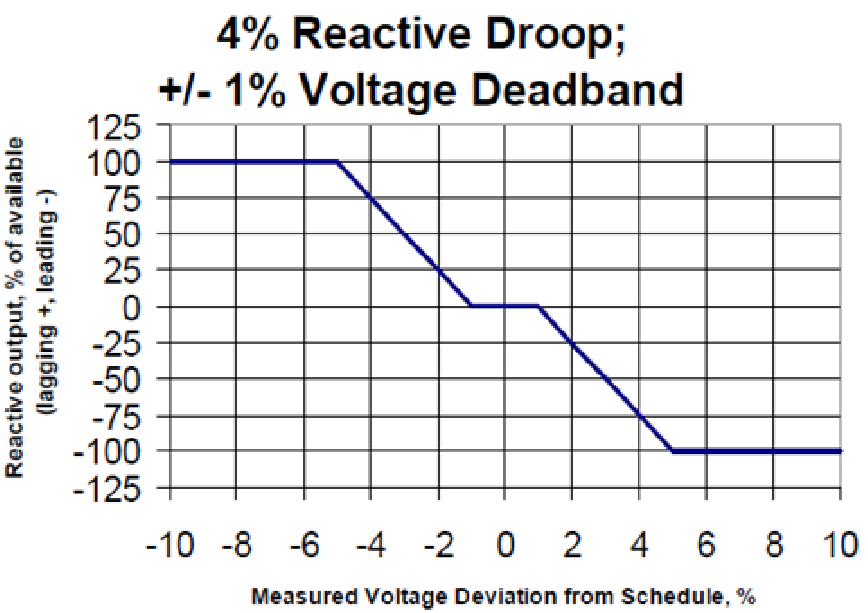
Current Features
Frequency Regulation



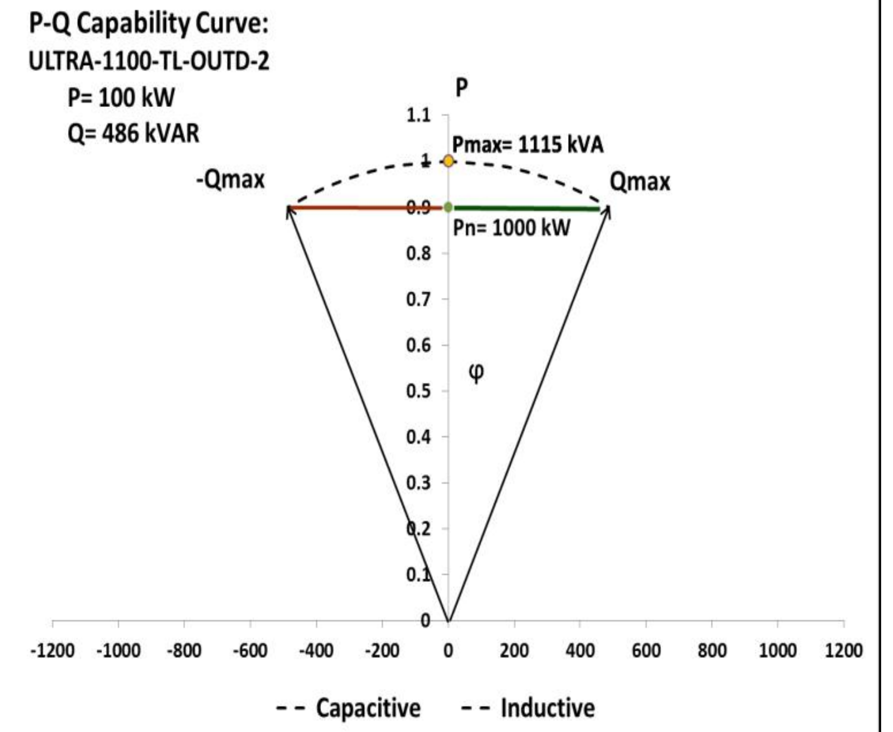


- DROOP characteristics: No response to dead band. Linear response relation thereafter
- Over frequency: Adjustable limits and reduction in active power as a gradient function
- Under frequency: Adjustable limits and increase in active power as a gradient function of a preset overhead
- Static/Dynamic active power curtailment: Command based

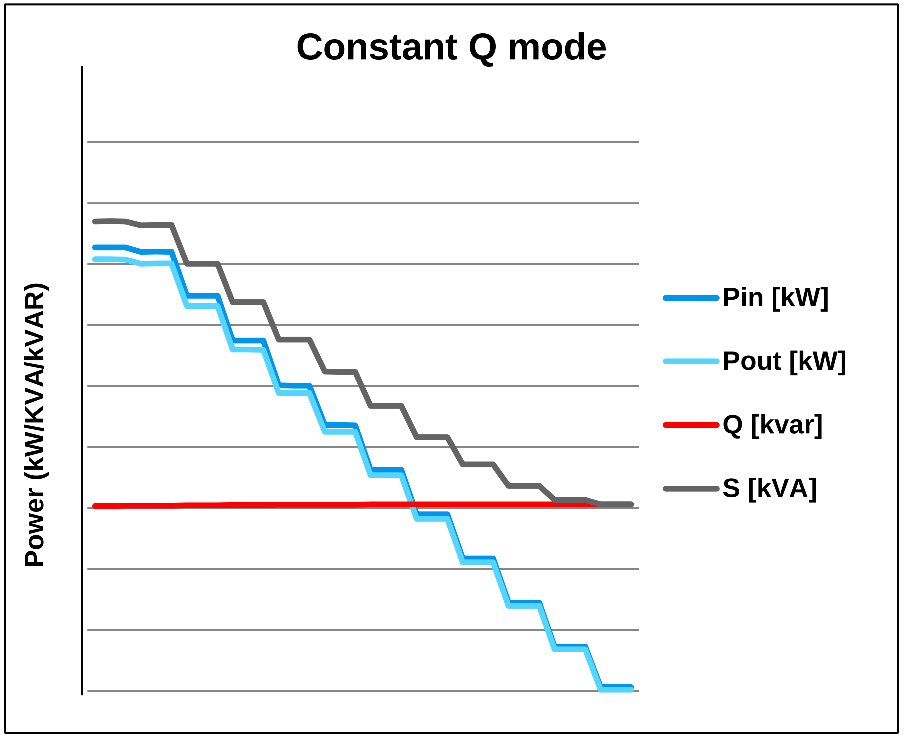
Current Features
Voltage Regulation

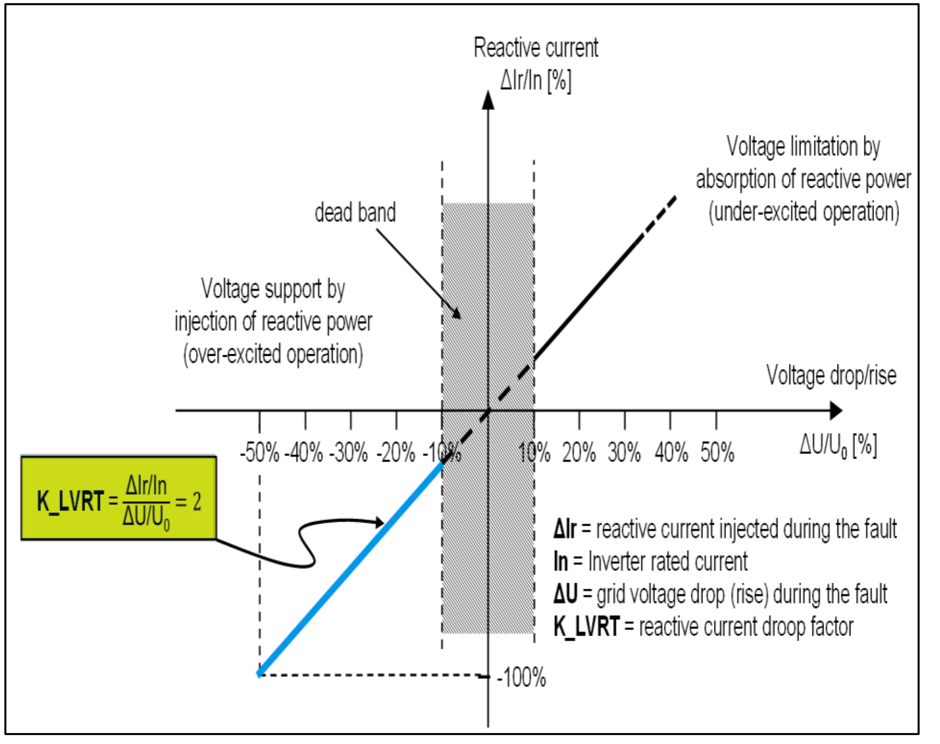


Example of Reactive Droop control with Deadband.



Current Features
Voltage Regulation



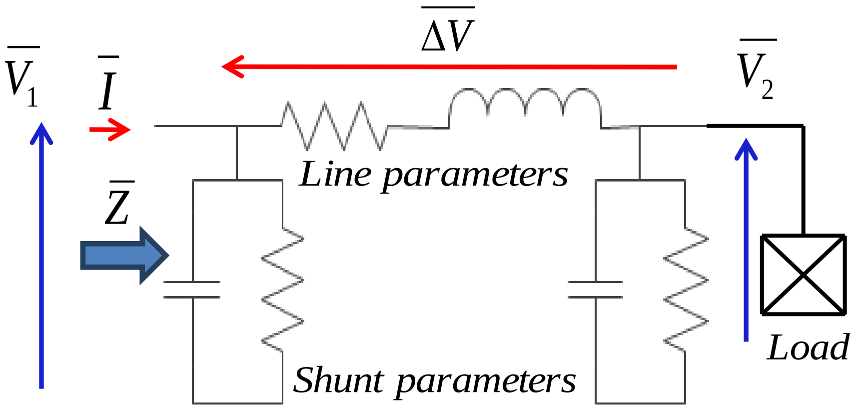


Case Study 1- EU

Background

- Extending DG reactive power support on full-time basis: background and benefits
- Case study: “Cavriglia 1” PV plant – simulation at HV/MV substation level based on hourly measured data
- Extending inverter operation on “full-time” basis – challenges and solutions
- Utility inverter performance with daytime mixed mode and nighttime reactive power mode

Full-time DG reactive power support
Background and benefits



$Q_L = X_L \times I^2$

$Q_C = V^2 / X_C$

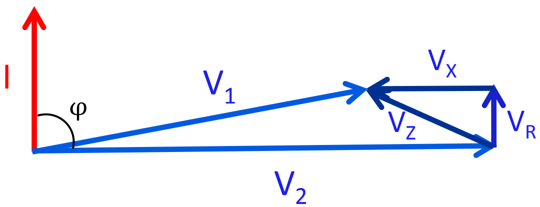
- During daytime **I** is large, so the inductive effect of cable prevails over the capacitive effect:

DAYTIME: $Q_L >> Q_C$

- During nighttime **I** is small, so the capacitive effect of cable is bigger than the inductive effect

NIGHTTIME: $Q_L << Q_C$

FERRANTI EFFECT



$Q_C > Q_L \rightarrow V_2 > V_1$

Conventional approach :

- **DAYTIME:** switched compensating capacitors
- **NIGHTTIME:** under-excited operation of conventional generating plants, reduced number of connection points of the HV network

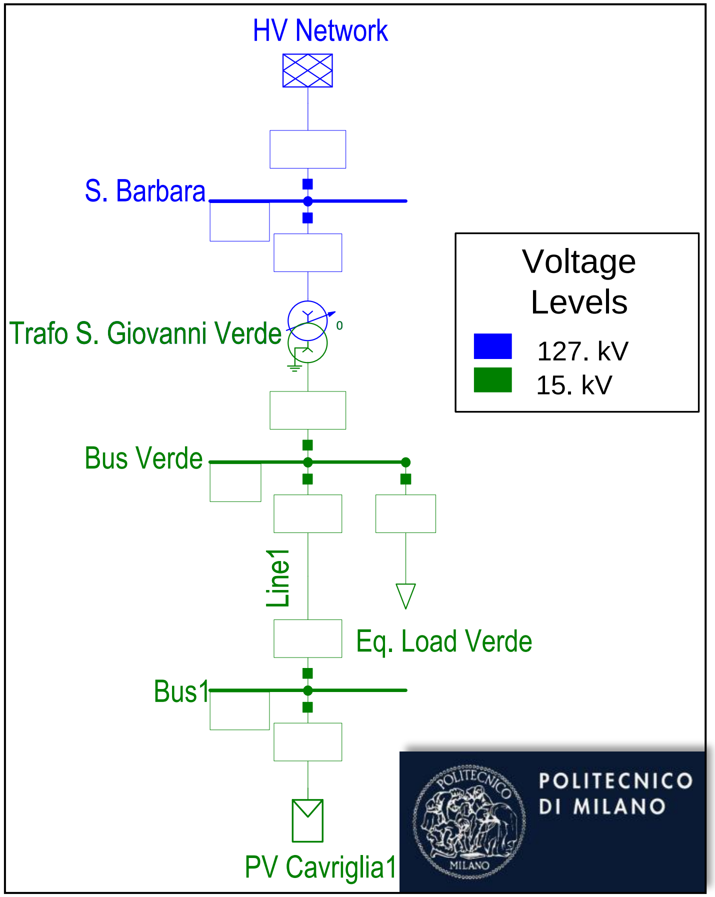
New approach:

PV plants with dedicated feeder used as integral part of the reactive power control scheme

Needs:

- Modified inverter control strategy to allow permanent connection to the grid.
- Full-time reactive power support from inverter (semi-circular capability)

Case study 1
Cavriglia- Italy

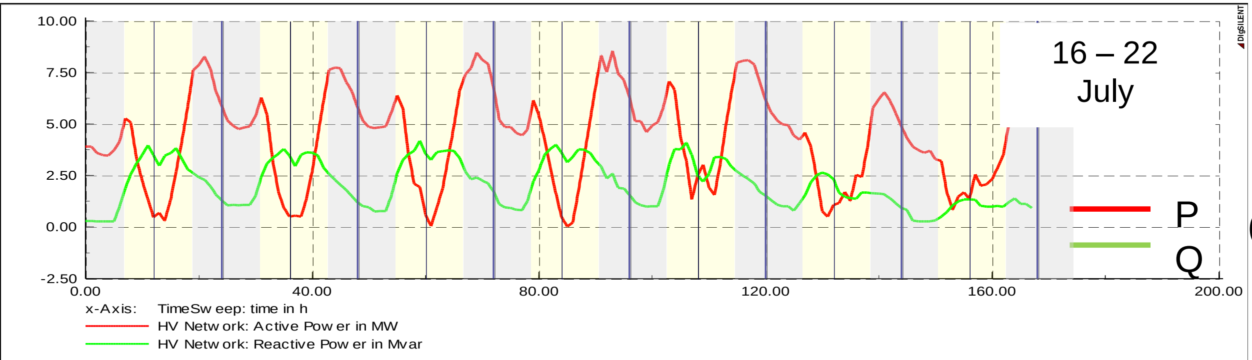


“Cavriglia 1” PV plant:
-10 MW PV Plant connected to dedicated MV feeder
-6km MV cable line 2x3x400mm²

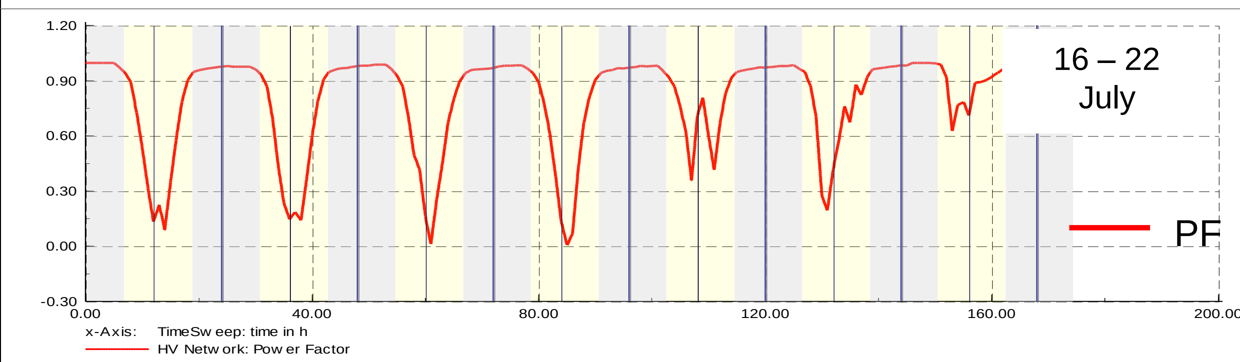
S. Barbara primary substation:
-25MVA HV/MV Transformer 127kV / 15kV; V_{CC}=12.15%
-MT side: 13 lines (186.2 Km total line)
-short circuit impedence of equivalent HV Grid are:

Zd = 0.76 + j4.47 ohm
Zo = 1.45 + j9.32 ohm

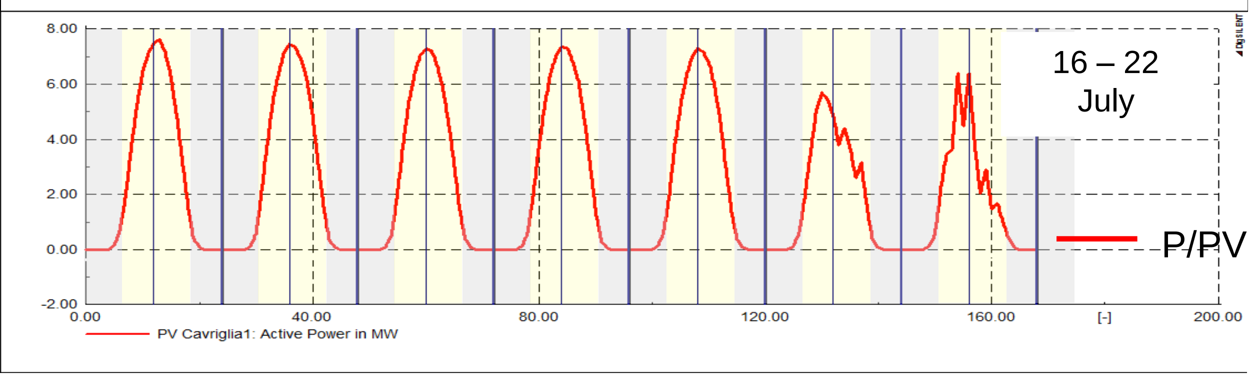
Case study 1
Base scenario



P and Q Power flow
on HV/MV transformer in Santa Barbara primary substation
(observation period: 16-22 July, 2012)

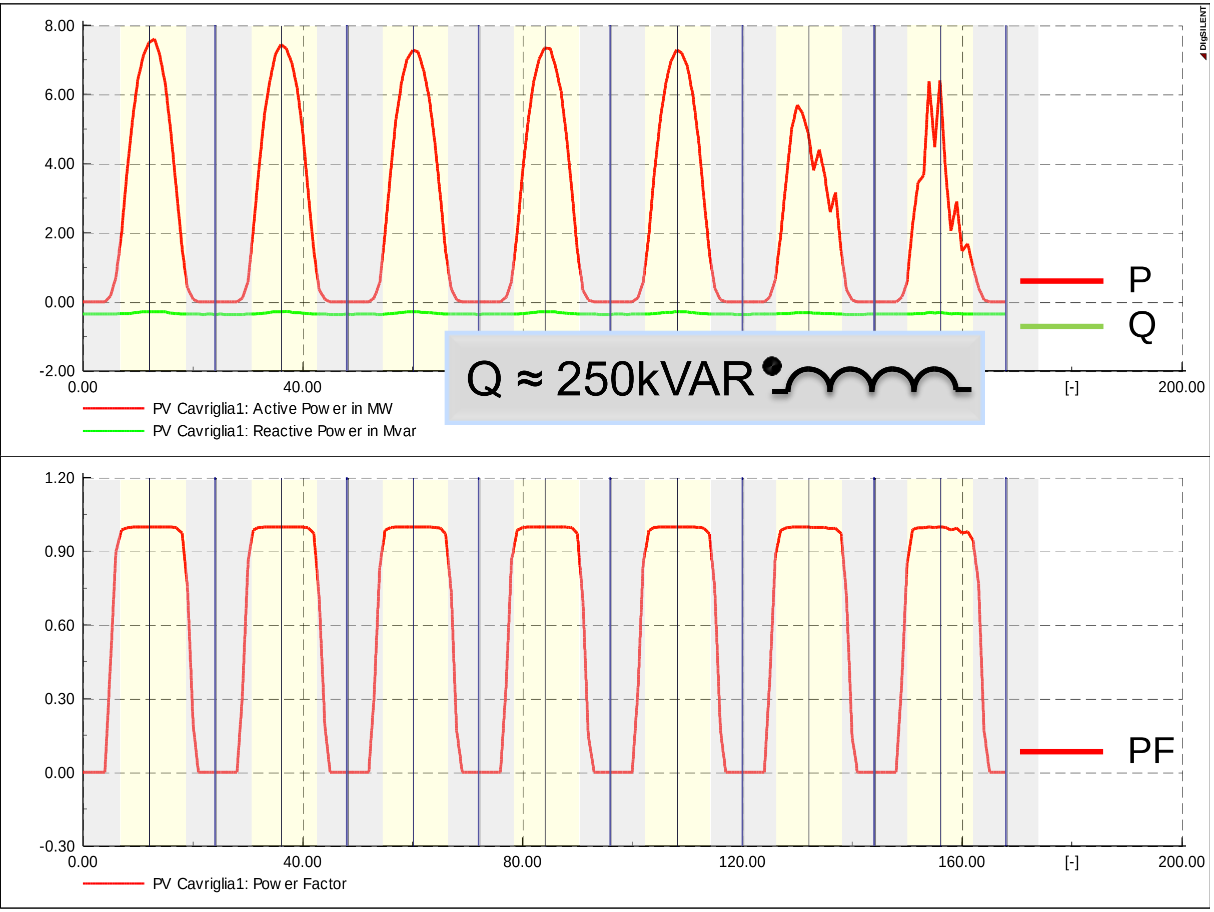


Poor HV Power Factor profile
During daytime TERNA covers only
reactive power load demands



PV plant production
(data acquired using plant monitoring system)

Case study 1
Scenario 1-Dedicated feeder Q compensation



Simulated P-Q load profile of PV plant "Cavriglia 1": reactive power modulated at the level required to mantain cos(φ)=1 on the dedicated feeder

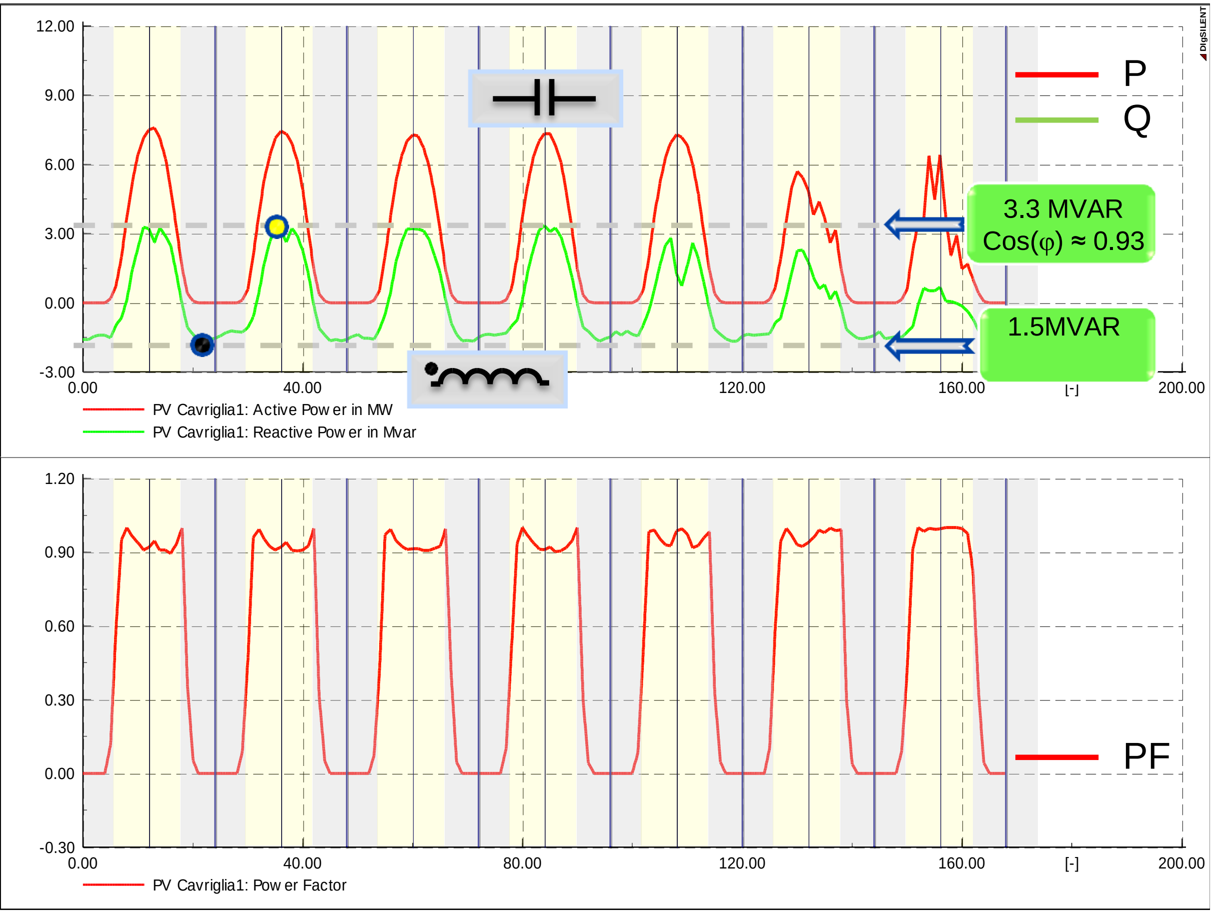
•The PV plant and its dedicated feeder behaves like a ideal generator at cos(φ)=1

•No relevance for local voltage control at the substation.

•Benefit shall be seen at HV system level with neutralization of the effect of a multitude of capacitive lines

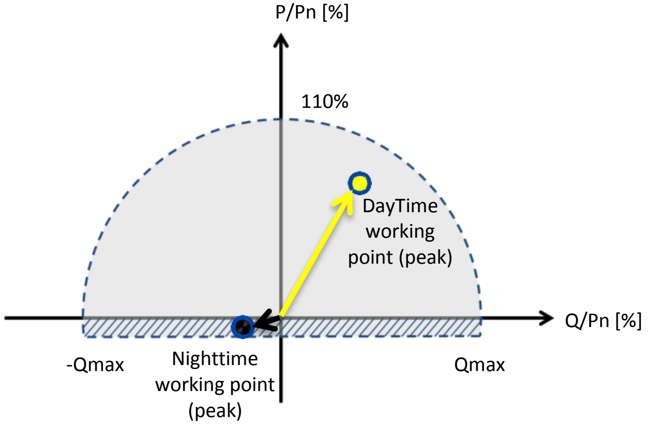
- Inverter only plots

Case study 1
Scenario 2- Constant Cos(φ) at HV/MV Transformer



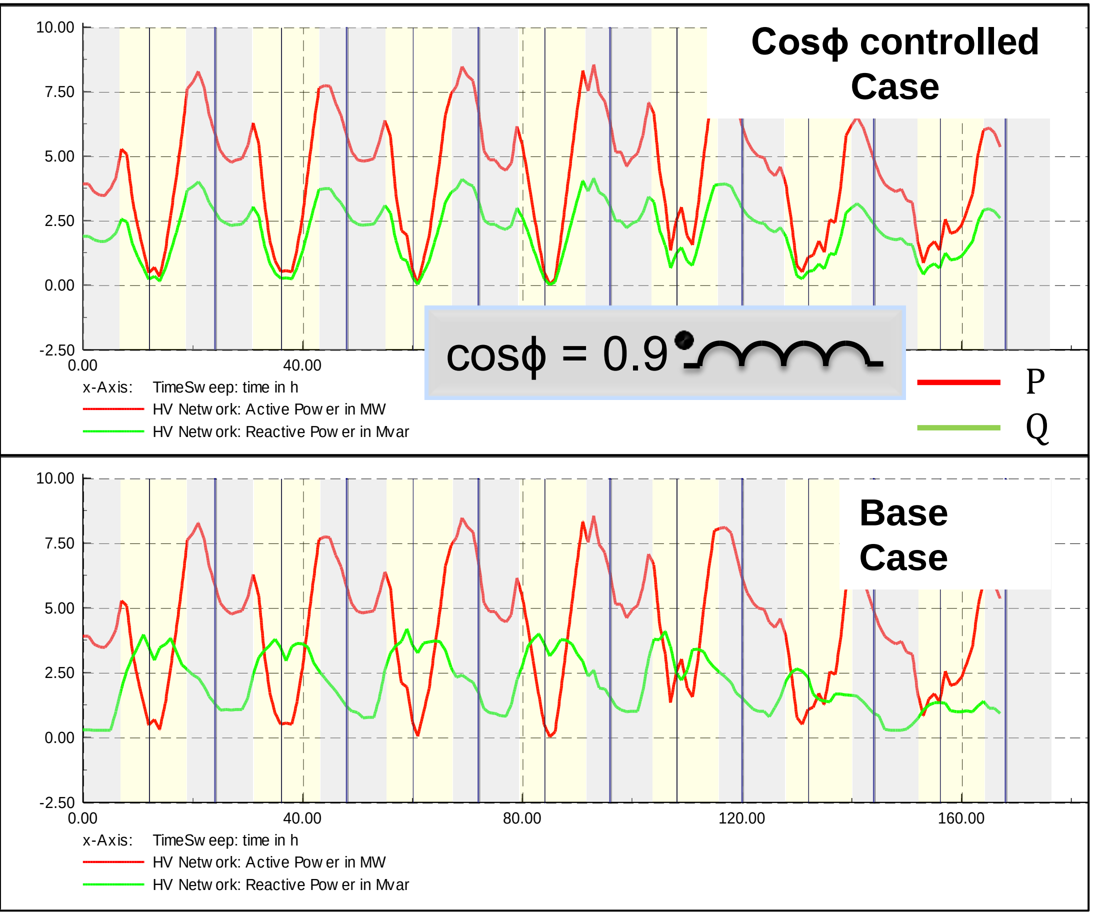
Simulated P-Q load profile of PV plant "Cavriglia 1": reactive power modulated at the level required to maintain a fixed PF at HV/MV transformer (0.9)

- During daytime the plant supply also reactive capacitive power to the grid
- During night time the plant is working as an inductive load



- Inverter only plots

Case study
Scenario 2- Constant Cos(φ) at HV/MV Transformer



New HV/MV Transformer power flow:
Run time cos(φ)= 0.9: low inductive load profile during day-time
-High inductive profile during night-time
-Direct partecipation to the Voltage control on HV Grid (global view)

Base case		**Cos(φ) ctrl case**
Variable cos(φ)	**Vs.**	Constant cos(φ)
High reactive power at low load		High reactive power at high load

<u>Benefits</u>

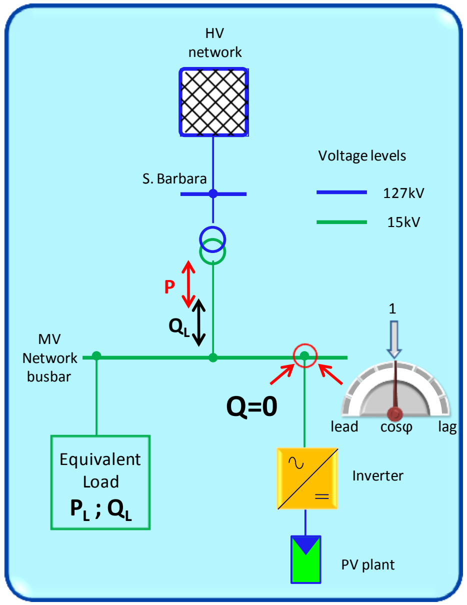
DAY: auto production and consumption of reactive power during daytime at MV node level: **no HV grid engaged.**

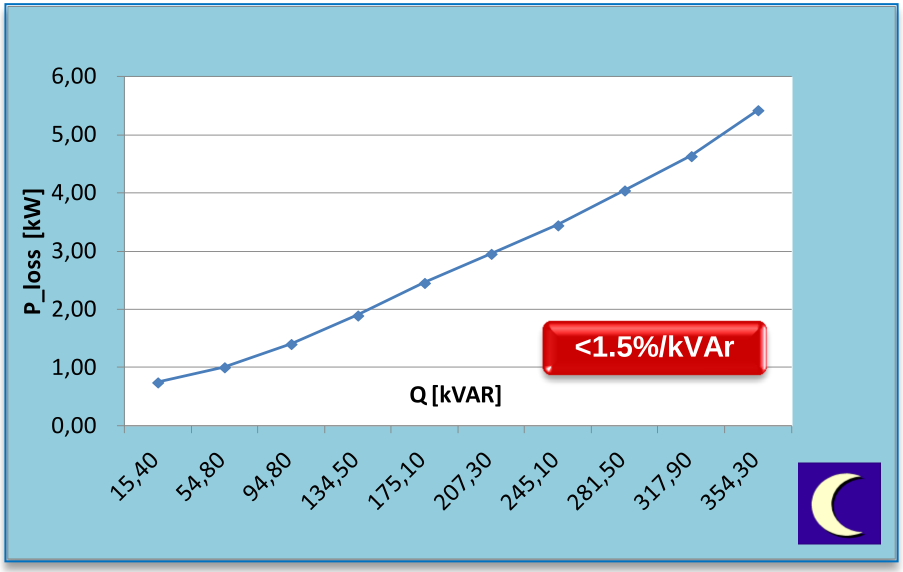
NIGHT: HV grid support (global view) to reduce the typical capacitive behavior of the unloaded system.

- Utility Plots

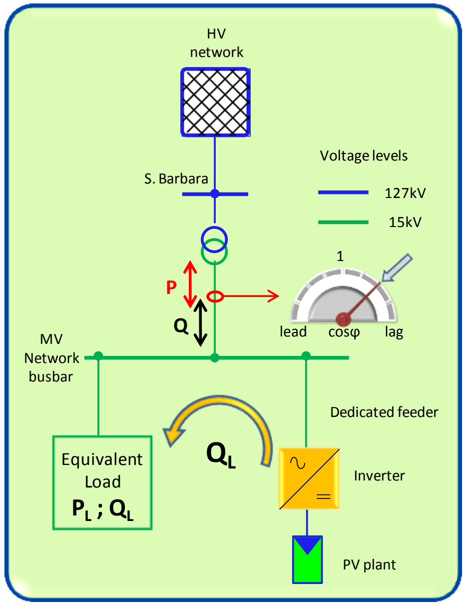
Night time performance:
Scenario 1 & 2

PV Line feeder compensation





Cos(φ) control at HV level



Significant network contribution at minimum cost

PV Line feeder compensation / 250kVAr

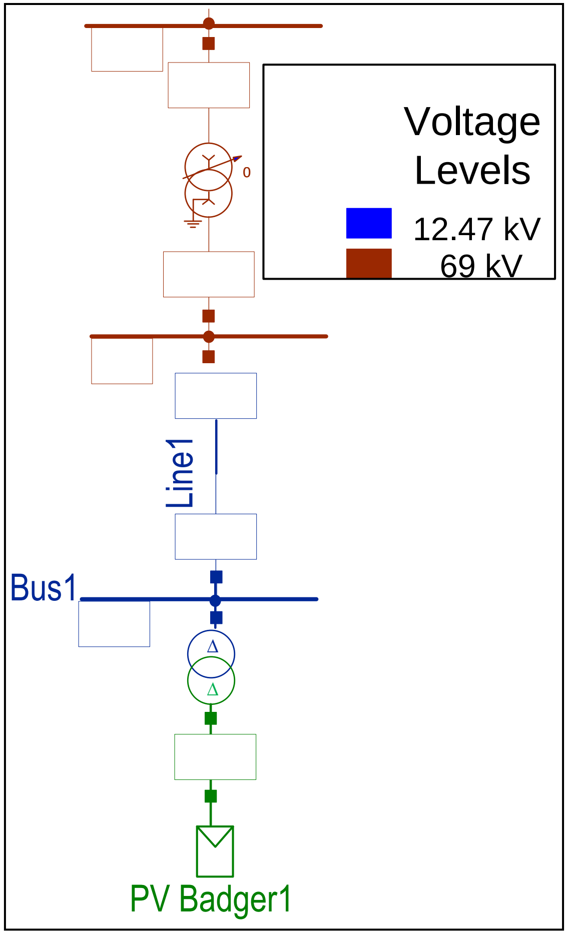
- Active power consumption during reactive power compensation is negligible.
- Low impact on PV plant lifecycle costs
- 10MW PV →1x 390kVA module operate overnight to compensate feeder capacitance

Cos(φ) control at HV level / 1.5MVAr

- Negligible active power consumption
- More intensive use of inverter capability to achieve desired Cos(φ) profile
- Compensation scheme shall count for O&M and inverter replacement costs.

Case Study 2- NA

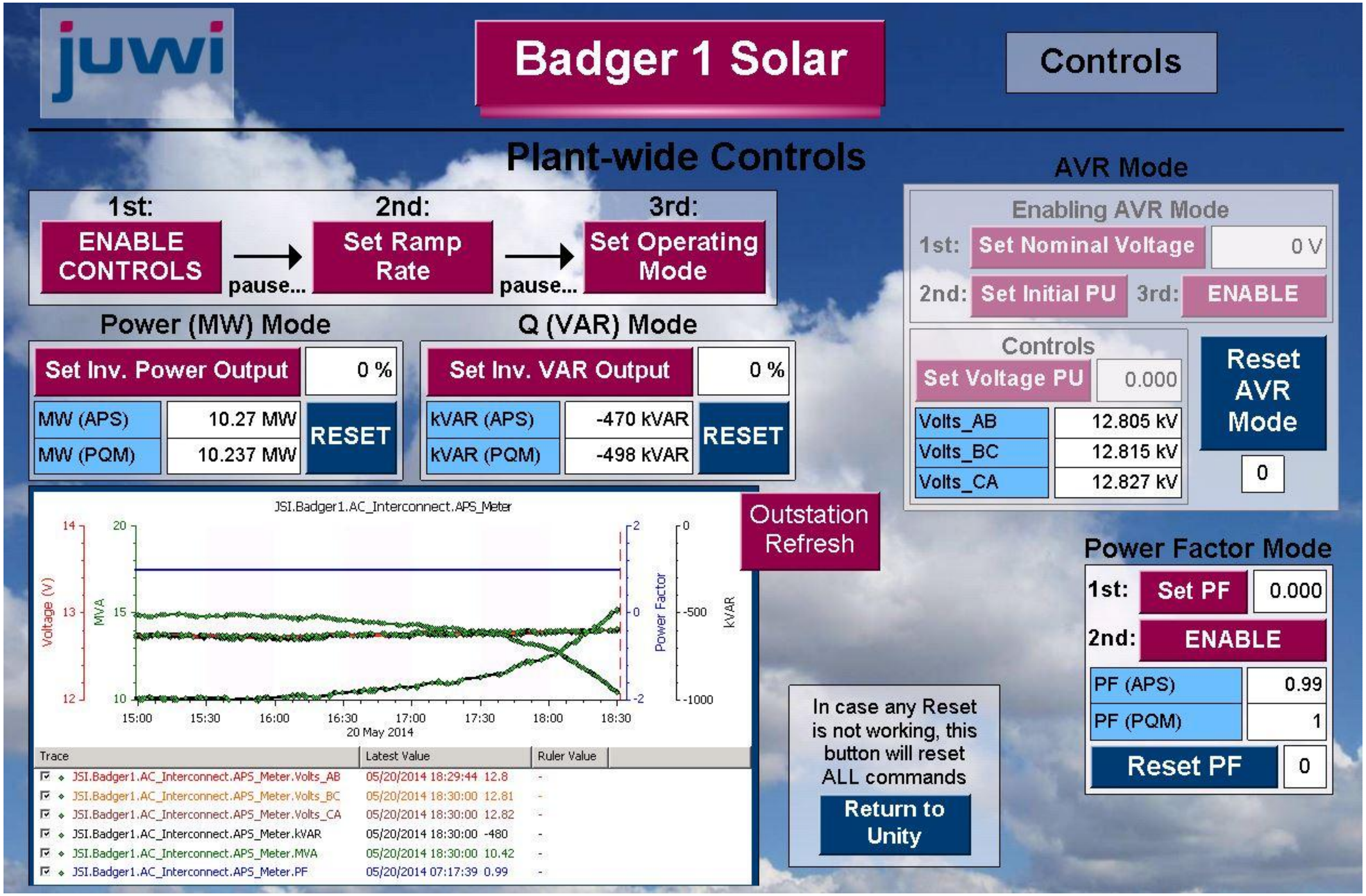
Case study 2
PV plant Badger – Plant level support



"Badger 1 Solar" PV Plant:
-15 MW PV plant connected to dedicated MV feeder
-SEL-735 PQM meter

Primary Substation:
-15MVA HV/MV transformer 69kV / 12.47kV;

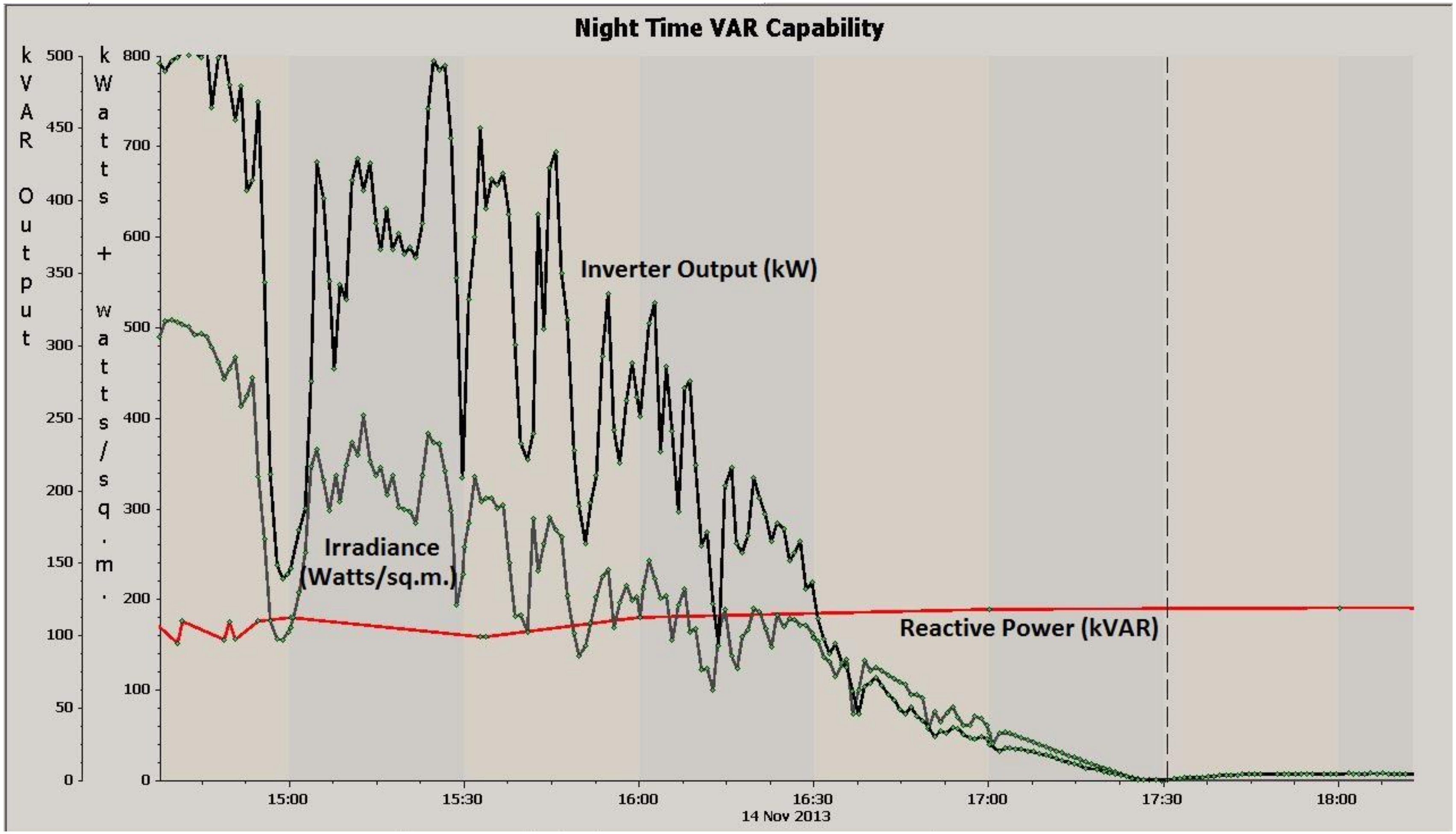
Plant Controller



Source: Juwi Solar Inc.

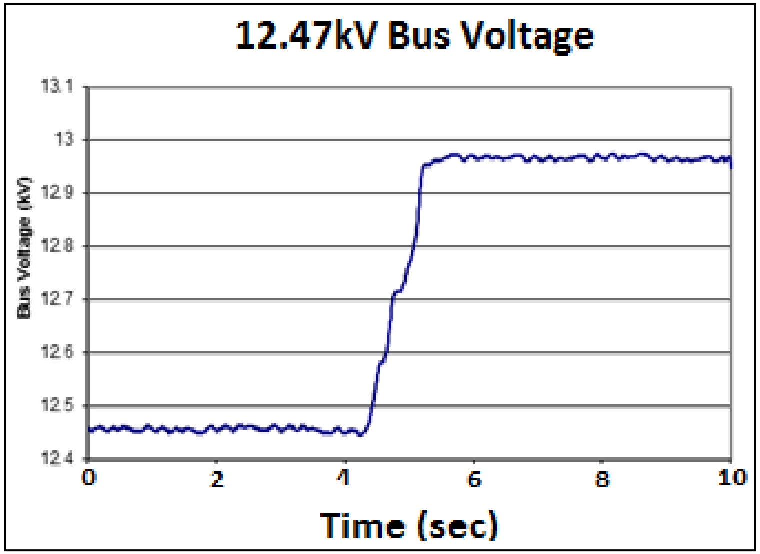
ABB

Nighttime Support



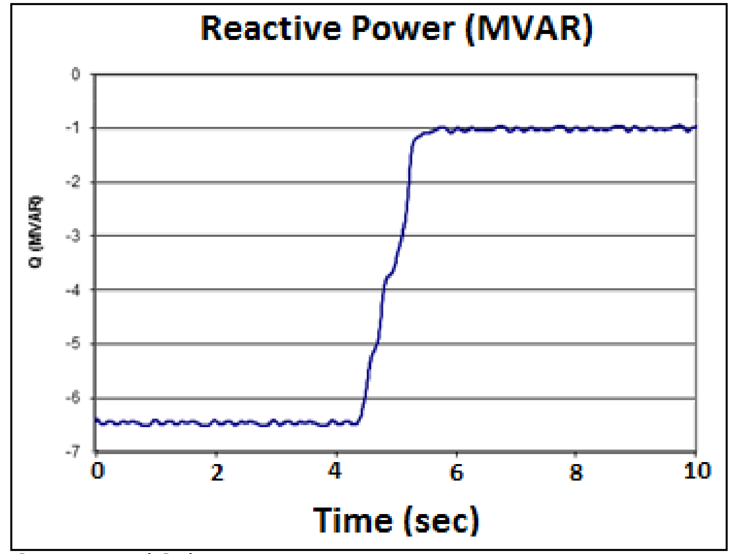
Source: Juwi Solar Inc.

Voltage DROOP Support



Source: Juwi Solar Inc.

Bus voltage transient response to 4% voltage step change



Source: Juwi Solar Inc.

MVAR output change in response to 4% voltage step change

Case Study 2
Credits

Conclusions and further developments

- A set of load flow simulations based on actual P/Q transit at a HV-MV substation with significant PV capacity connected via a dedicated line feeder was performed to identify possible reactive power control scenarios with relevance at local (MV) as well as at the system level (HV)
- PV system reactive power demands for 2 different control schemes have been calculated, providing realistic set-points as a reference for assessing the impact on inverter performance
- The effectiveness of the PV Inverter to offer VAR control at night was showcased
- Inverters have been tested in the exemplary VAR control modes, confirming the ability to meet the required grid support tasks at minimum cost and with marginal impact over system performance
- Field testing results confirm inverter performance

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