PV PLANT OPTIMIZATION BY REGULATING LOCAL VOLTAGE

TO INCREASE YIELD AND REDUCE SYSTEM COST

DFBEW/OFATE - Konferenz zu den Kosten von PV-Freiflächenanlagen

06/06/2023, Armin Vielhauer, Maschinenfabrik Reinhausen

AGENDA

MASCHNENFABRIK REINHAUSEN AT A GLANCE

Leading globally in niches of electrical power engineering

- Founded in 1868, Trademark established 1901
- Independent, majority family ownership in fifth generation
- World market leader in transformer switching
- 3,600 employees, 70% located in Germany
- 90% of production in Germany
- 30 subsidiaries and 11 affiliated companies
- Group turnover of 730 million EUR, highest available rating (banks)

>50%
of worldwide electricity consumption passes through our products.

>80%
of all our products ever delivered are still in operation today.

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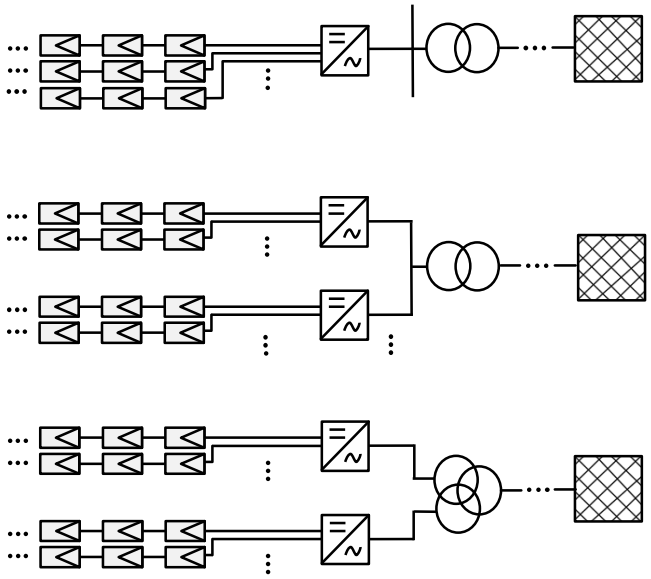
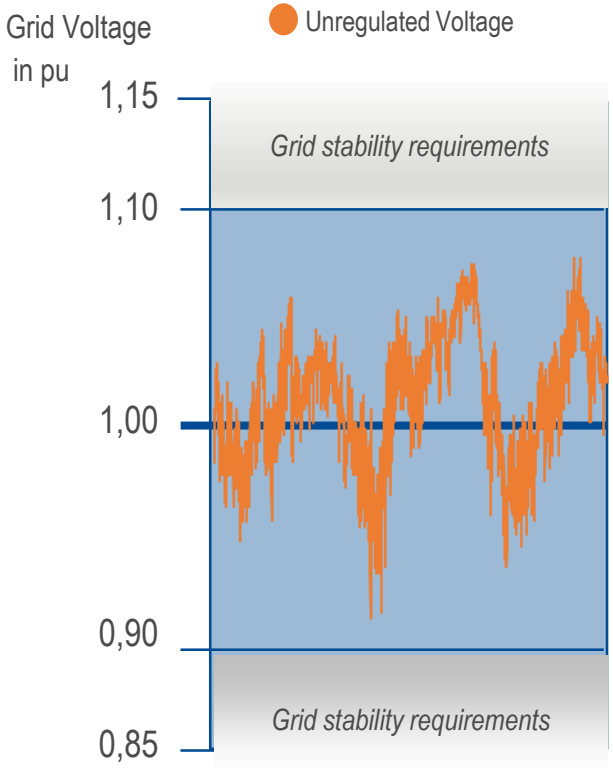
01 INTRODUCTION

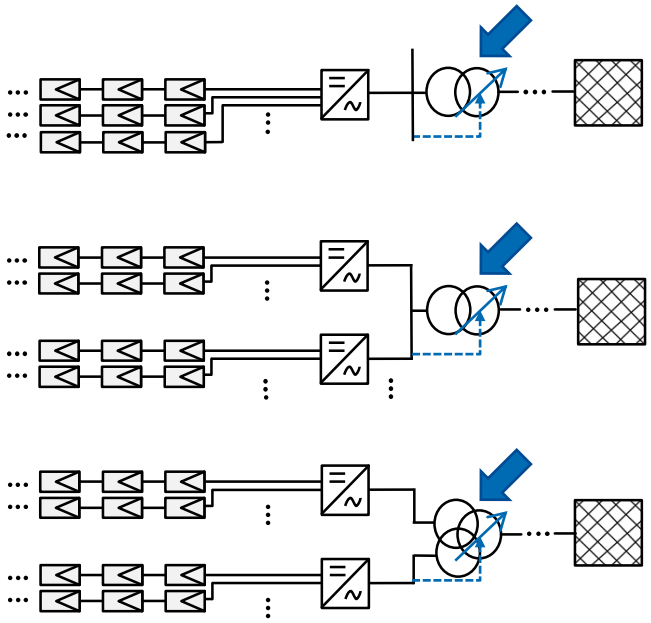
KEY PRINCIPLE FOR PV PLANT OPTIMIZATION: REGULATION OF AC-VOLTAGE AT THE INVERTER TRANSFORMER...





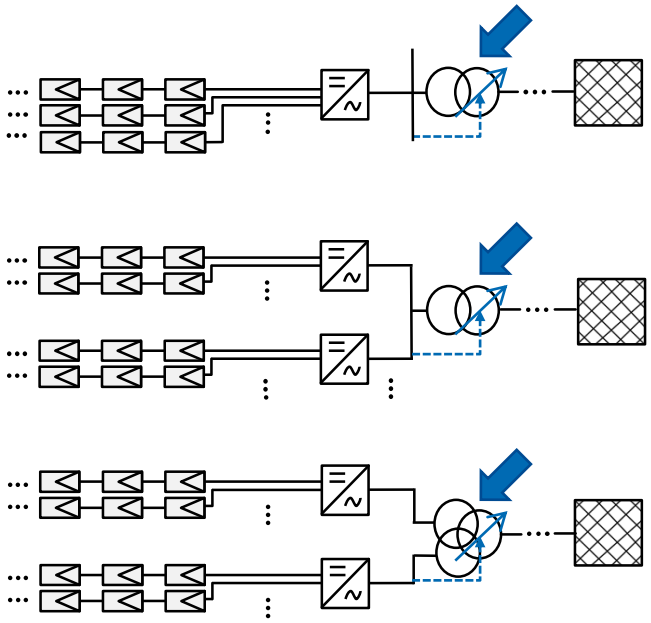
- Steady state voltage is the operational bandwidth with respect to nominal voltage
- Inverters are designed to match these operational conditions

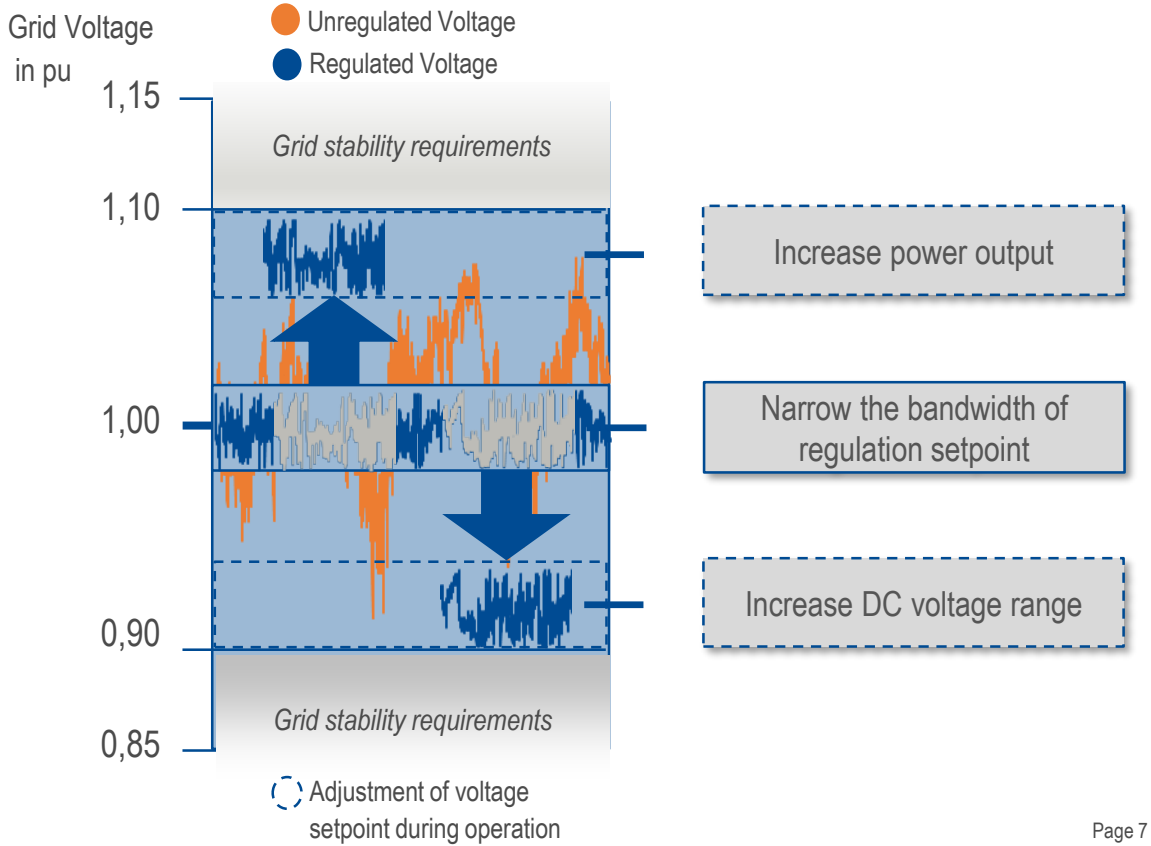
KEY PRINCIPLE FOR PV PLANT OPTIMIZATION: REGULATION OF AC-VOLTAGE AT THE INVERTER TRANSFORMER…



Narrow the bandwidth of regulation setpoint

KEY PRINCIPLE FOR PV PLANT OPTIMIZATION: REGULATION OF AC-VOLTAGE AT THE INVERTER TRANSFORMER…





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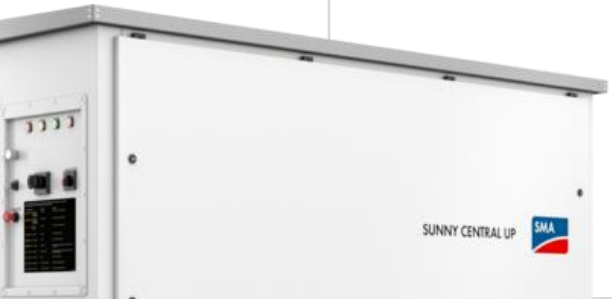
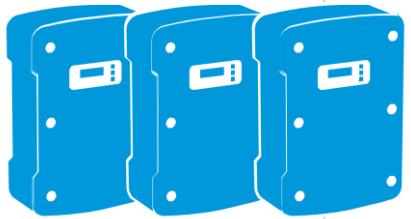
02 PV INVERTERS & AC VOLTAGE DEPENDENCY





CENTRAL INVERTER EXAMPLE: SMA SUNNY CENTRAL UP

RELATION BETWEEN AC VOLTAGE, DC/MPP VOLTAGE AND RATED OUTPUT

Four models operating at different AC voltages:

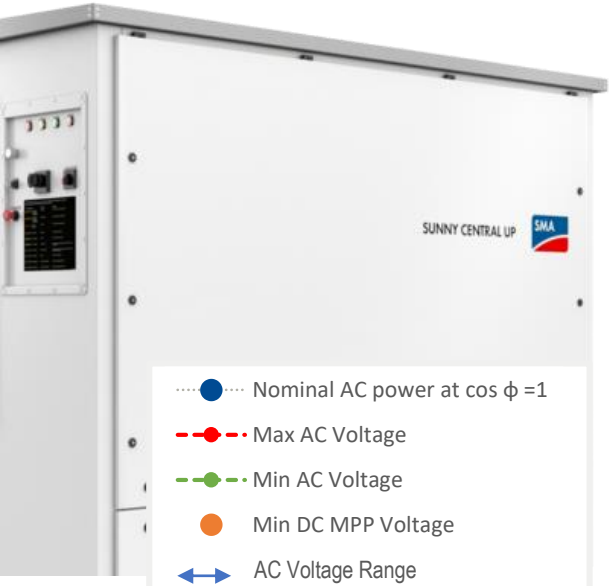
600V, 630V, 660V, 690V

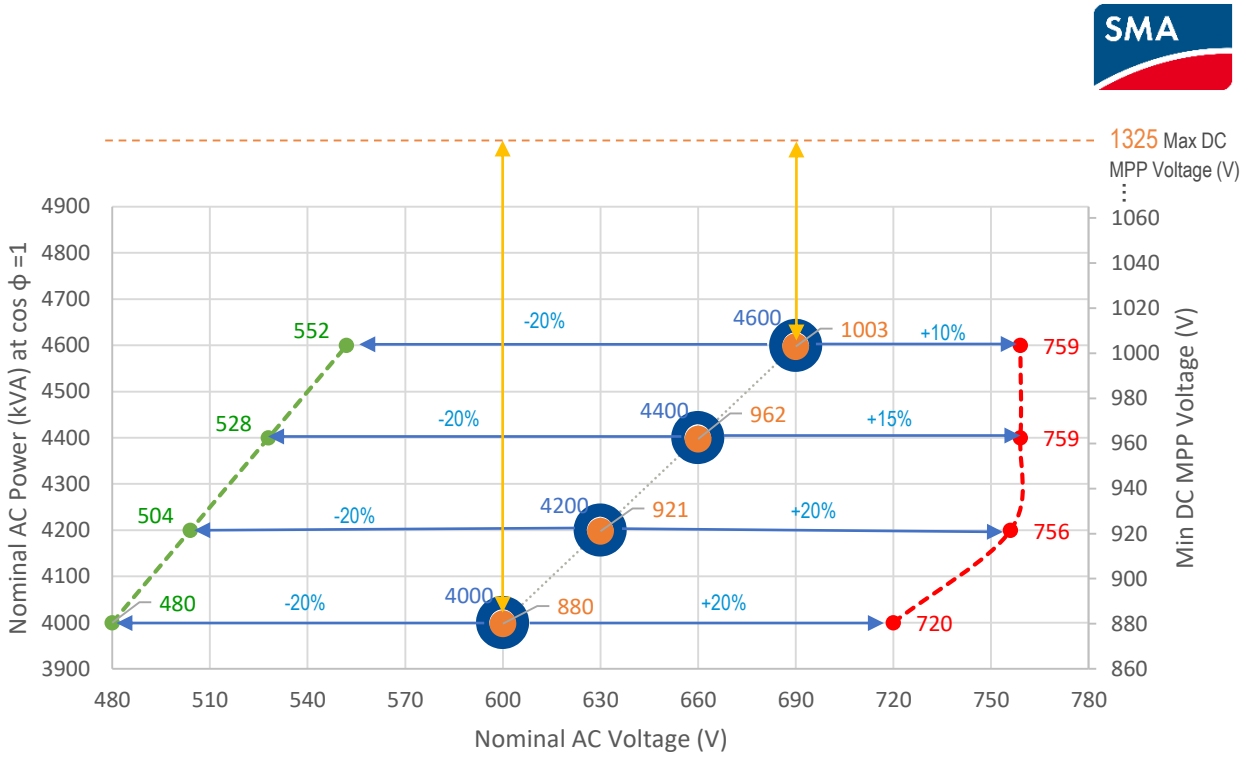
1. **Dependency 1:** Min DC Voltage dependent on operating nominal AC Voltage by a factor of √2. This defines the Start Voltage and MPP range
2. **Dependency 2:** Max AC current limit same for all models: 3850A at 35°C / 3465A at 50°C. Nominal AC power is defined by operating nominal AC voltage at this max AC current

Technical Data	SC 4000 UP	SC 4200 UP	SC 4400 UP	SC 4600 UP
DC side				
MPP voltage range V_{DC} (at 25 °C / at 50 °C)	880 to 1325 V / 1100 V	921 to 1325 V / 1050 V	962 to 1325 V / 1000 V	1003 to 1325 V / 1040 V
Min. DC voltage $V_{DC, min}$ / Start voltage $V_{DC, Start}$ (1)	849 V / 1030 V	891 V / 1071 V	934 V / 1112 V	976 V / 1153 V
Max. DC voltage $V_{DC, max}$	1500 V	1500 V	1500 V	1500 V
Max. DC current $I_{DC, max}$	4750 A	4750 A	4750 A	4750 A
Max. short-circuit current $I_{DC, SC}$	8400 A	8400 A	8400 A	8400 A
AC side				
Nominal AC power at cos φ =1 (at 35°C / at 50°C)	4000 kVA[12] / 3600 kVA	4200 kVA[13] / 3780 kVA	4400 kVA[13] / 3960 kVA	4600 kVA[14] / 4140 kVA
Nominal AC active power at cos φ =0.8 (at 35°C / at 50°C)	3200 kW[12] / 2880 kW	3360 kW[13] / 3024 kW	3520 kW[13] / 3168 kW	3680 kW[14] / 3312 kW
Nominal AC current $I_{AC, nom}$ (at 35°C / at 50°C) (2)	3850 A / 3465 A	3850 A / 3465 A	3850 A / 3465 A	3850 A / 3465 A
Max. total harmonic distortion	< 3% at nominal power	< 3% at nominal power	< 3% at nominal power	< 3% at nominal power
Nominal AC voltage / nominal AC voltage range[1) 8)]	600 V / 480 V to 720 V	630 V / 504 V to 756 V	660 V / 528 V to 759 V	690 V / 552 V to 759 V

CENTRAL INVERTER EXAMPLE: SMA SUNNY CENTRAL UP

RELATION BETWEEN AC VOLTAGE, DC/MPP VOLTAGE AND RATED OUTPUT





Datasheet values at 25°C

INVERTER OPERATING RANGE & DAILY PRODUCTION PROFILE

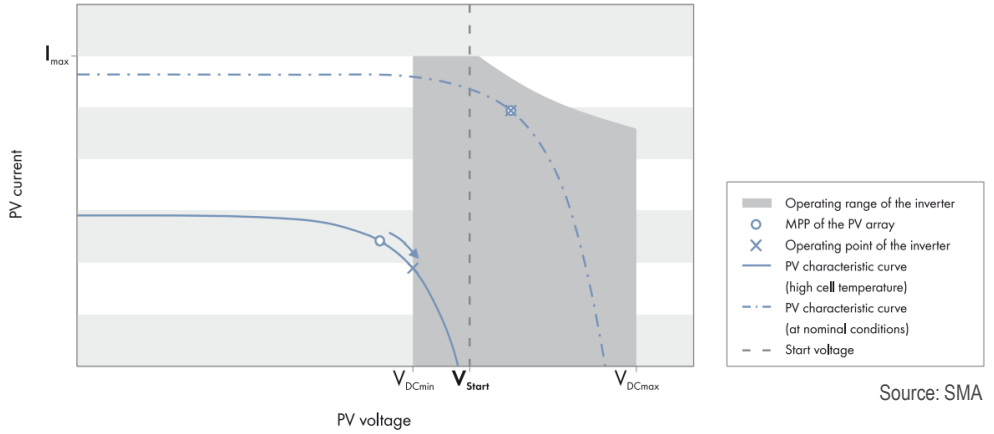
LOW DC VOLTAGE LOSSES & PEAK POWER CLIPPING LOSSES

Low DC Voltage/MPP Losses will occur:

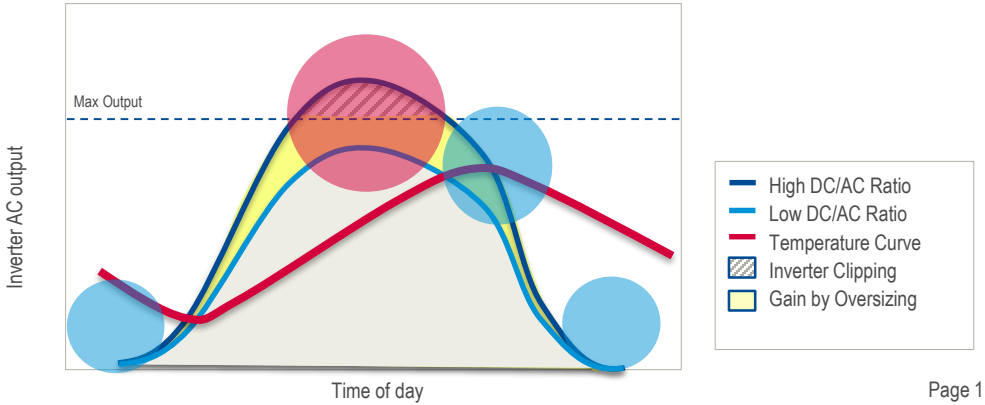
- Early morning or end of day at low irradiance conditions
- Afternoon because of derating at high temperature
- Further increased with high reactive power demand and at sites with low Short Circuit Ratio (SCR)

Peak Power Clipping Losses will occur:

- Around midday at peak production times in high DC/AC ratio plants
- At low temperature and high irradiance situations or at high temperature under derated conditions
- Further increased with high reactive power demand and at sites with low SCR



Source: SMA



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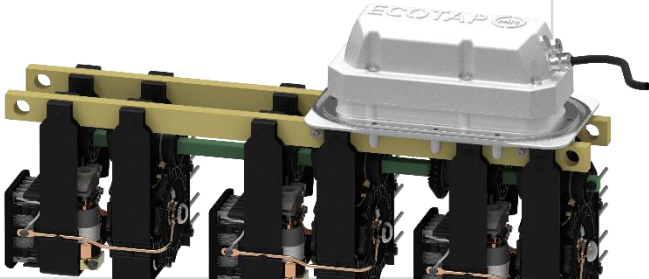
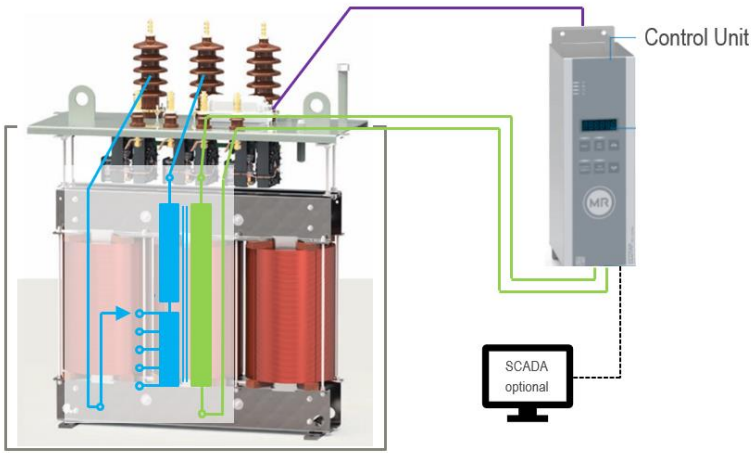
03

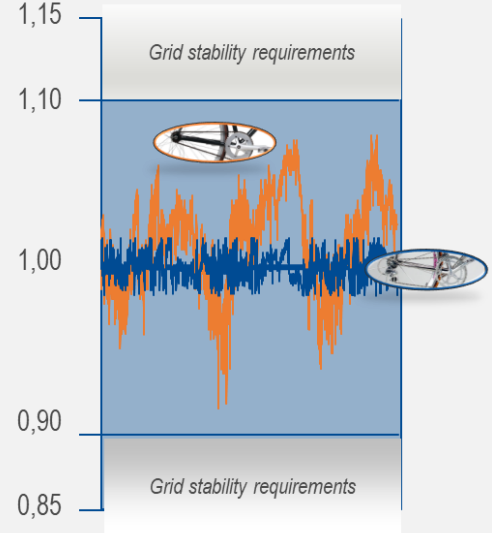
INVERTER FOCUSED USE OF ON-LOAD TAP-CHANGERS



A VRDT IS A DISTRIBUTION TRANSFORMER WITH AN ON-LOAD TAP-CHANGER TO CONTROL VOLTAGE LEVELS ON LV TERMINAL



VRDT: Distribution transformer with On-Load Tap-Changer

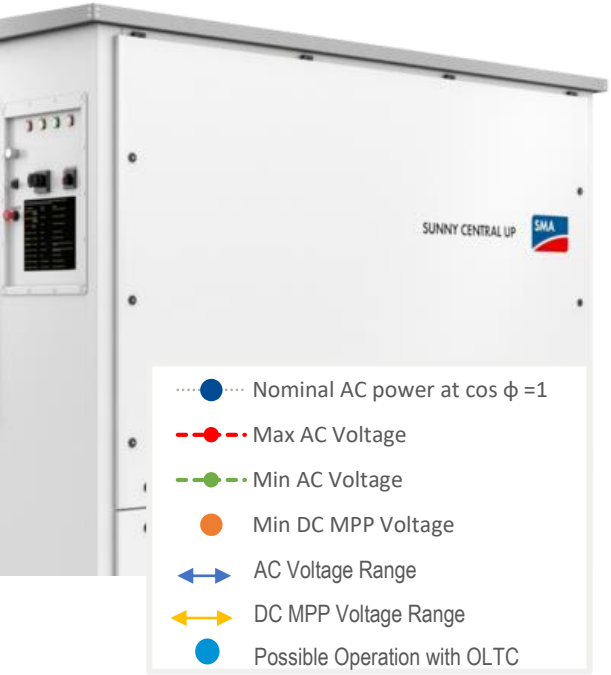


Standard DT:
fixed ratio during operation

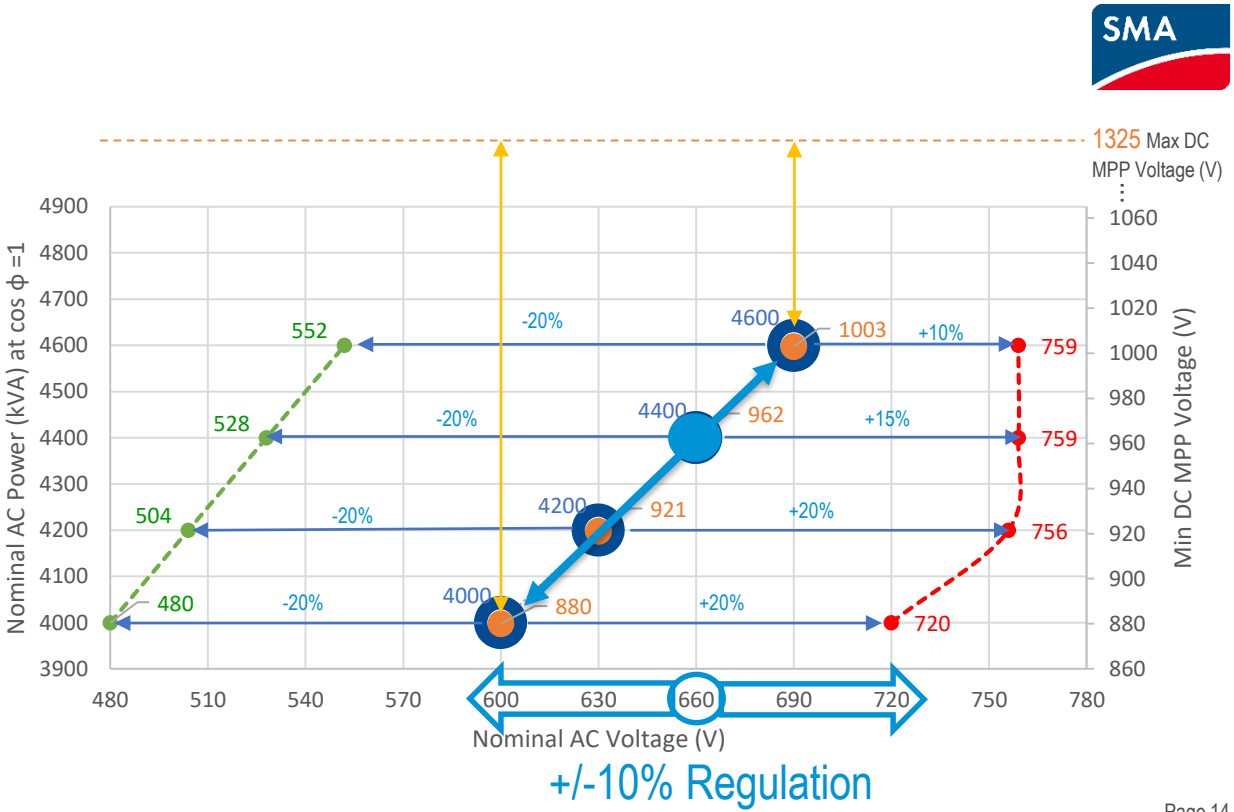
VRDT:
flexible ratio during operation

CENTRAL INVERTER EXAMPLE: SMA SUNNY CENTRAL UP

RELATION BETWEEN AC VOLTAGE, DC/MPP VOLTAGE AND RATED OUTPUT



Datasheet values at 25°C



+/-10% Regulation

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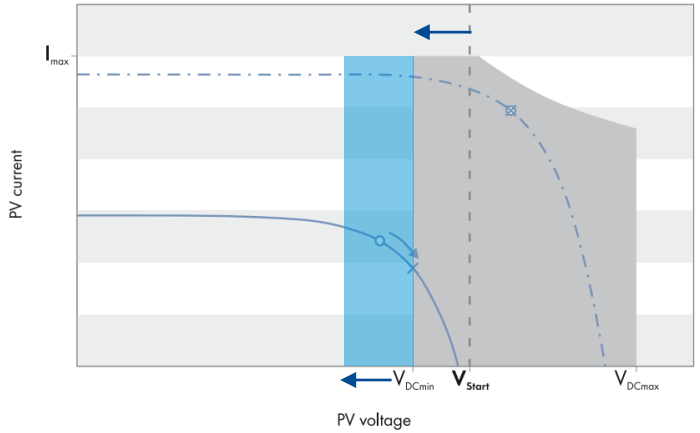
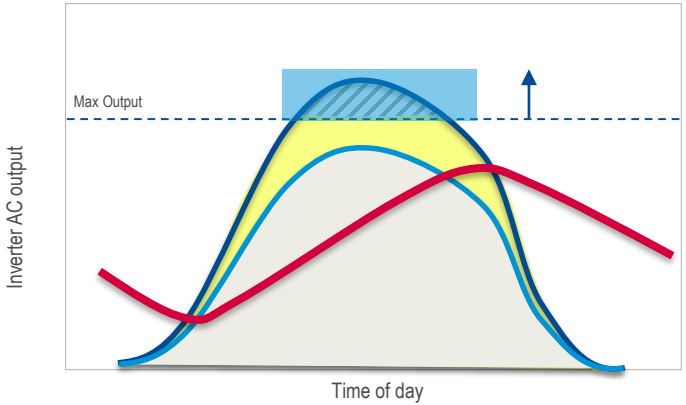


Tap Down

Expanded operating range

- Operating range of the inverter
- MPP of the PV array
- Operating point of the inverter
- PV characteristic curve (high cell temperature)
- PV characteristic curve (at nominal conditions)
- Start voltage

Source: SMA



Tap Up

Reduced inverter clipping

- High DC/AC Ratio
- Low DC/AC Ratio
- Temperature Curve
- Inverter Clipping
- Gain by Oversizing

INVERTER FOCUSED USE OF ECOTAP® VPD®

ENHANCE CAPABILITY AND UNLOCK OPTIMIZATION POTENTIAL

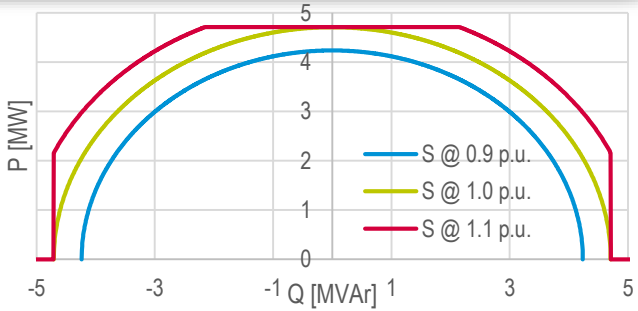
With the integration of ECOTAP® VPD® - the compact-class vacuum type on-load tap-changers by Reinhausen, capability could be improved:

- Flexible AC voltage adjustment during operation as required
  - Enhanced active and/or reactive power provision
  - Expanded DC MPPT operating range*
- Virtually no under voltage
  - Less units to comply with Grid Code requirements
- Virtually no over voltage
  - Lower minimum MPPT voltage* to comply with Grid Code requirements
  - Higher nominal AC voltage with the same PV field configuration

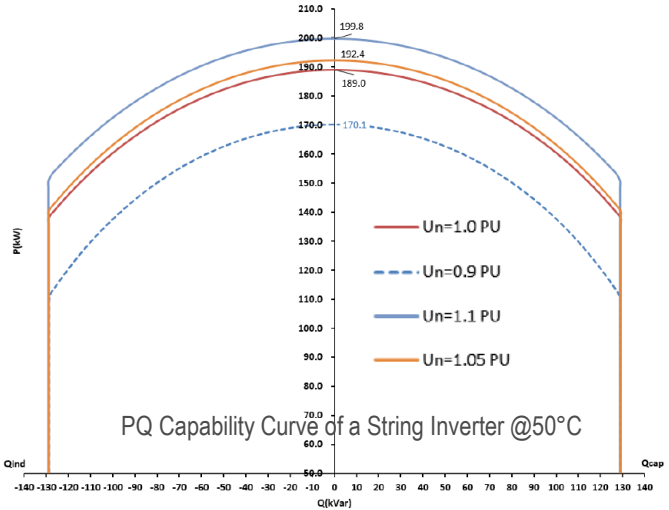
** not applicable for string inverters with additional DC-DC stage*

Enhanced Capability

Lower LCOE



PQ Capability Curve of a Central Inverter @40°C



PQ Capability Curve of a String Inverter @50°C

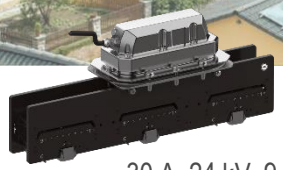
04 REFERENCES

OUR ECOTAP® VPD® FAMILY IS ALLOWING DISTRIBUTION TRANSFORMERS TO BE FLEXIBLE WHEREVER NEEDED

OPTIMIZE RENEWABLE GENERATION UNITS

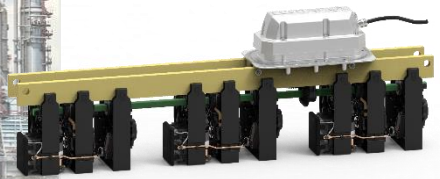
100 A, 36 kV, 9 positions

IMPROVE CAPACITIES OF DISTRIBUTION NETWORKS



30 A, 24 kV, 9 positions

OPTIMIZE AND SECURE INDUSTRIAL PROCESSES



100 A, 40,5 kV, 17 positions

VOLTAGE REGULATING DISTRIBUTION TRANSFORMERS ARE TAKING ROOT IN DISTRIBUTION NETWORKS AROUND THE WORLD

> 6,000 units delivered by the end of 2022 to

>150 transformer manufacturers

for

>300 operators worldwide

THE POWER BEHIND POWER.

www.reinhausen.com