Smart Inverters

ФАКУЛТЕТ ТЕХНИЧКИХ НАУКА

САША ШТАТКИЋ

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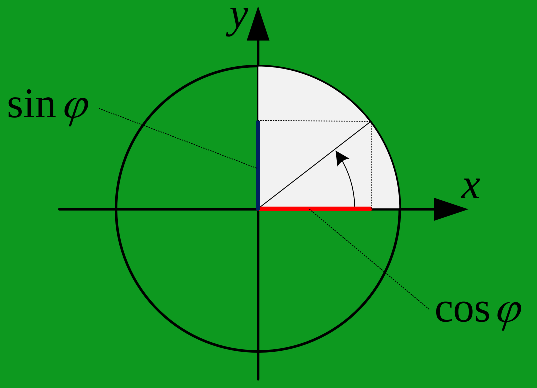
Producer Reference Frame (PRF) conventions power factor sign – quadrant I



$$\underline{U} = Ue^{j\varphi}$$

$$0 < \varphi < 90^{\circ}$$

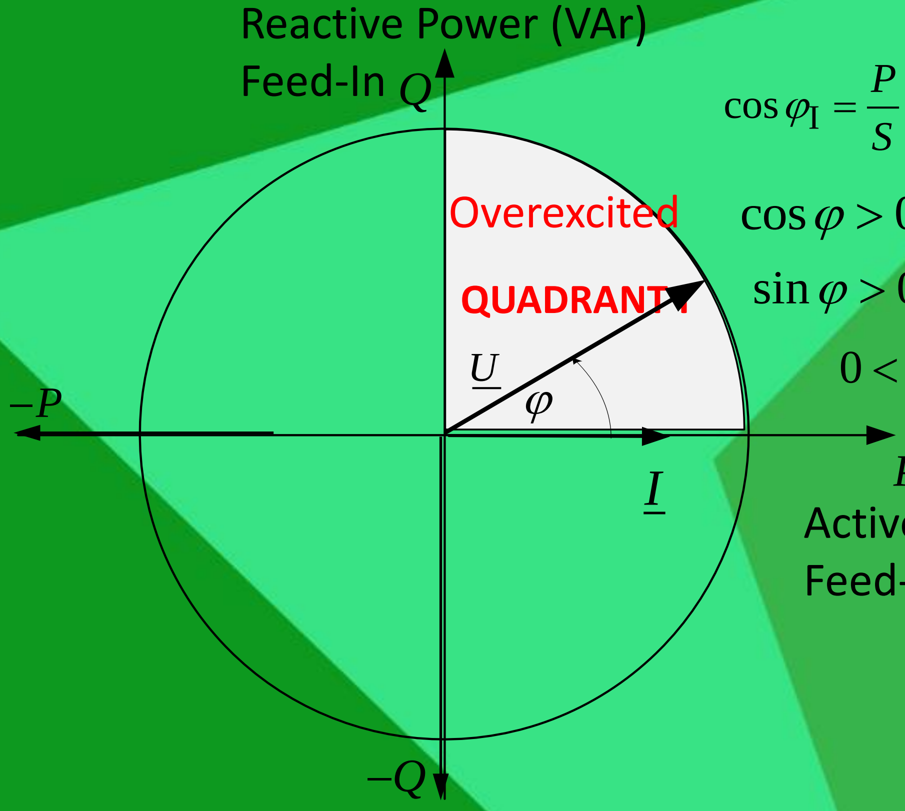
$$\underline{I} = Ie^{j\psi} = Ie^{j0^{\circ}} = I\cos 0^{\circ} + jI\sin 0^{\circ} = I$$

$$\underline{S} = \underline{U} \cdot \underline{I}^{*} = Ue^{j\varphi} \cdot \left(Ie^{j0}\right)^{*} = UIe^{j\varphi} =$$

$$= UI\left(\cos\varphi + j\sin\varphi\right) = UI\cos\varphi + jUI\sin\varphi = P + jQ$$

$\cos\varphi > 0$ $\quad P = UI\cos\varphi > 0$

$\sin\varphi > 0$ $\quad Q = UI\sin\varphi > 0$



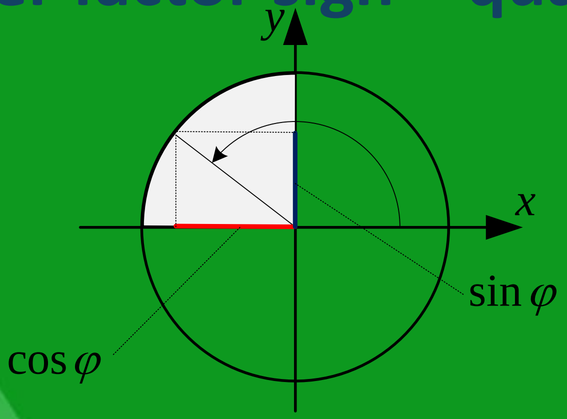
$$\cos\varphi_{I} = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}} > 0$$

$\cos\varphi > 0$ $\quad P = UI\cos\varphi > 0$

$\sin\varphi > 0$ $\quad Q = UI\sin\varphi > 0$

$$0 < \varphi < 90^{\circ}$$

Producer Reference Frame (PRF) conventions power factor sign – quadrant II

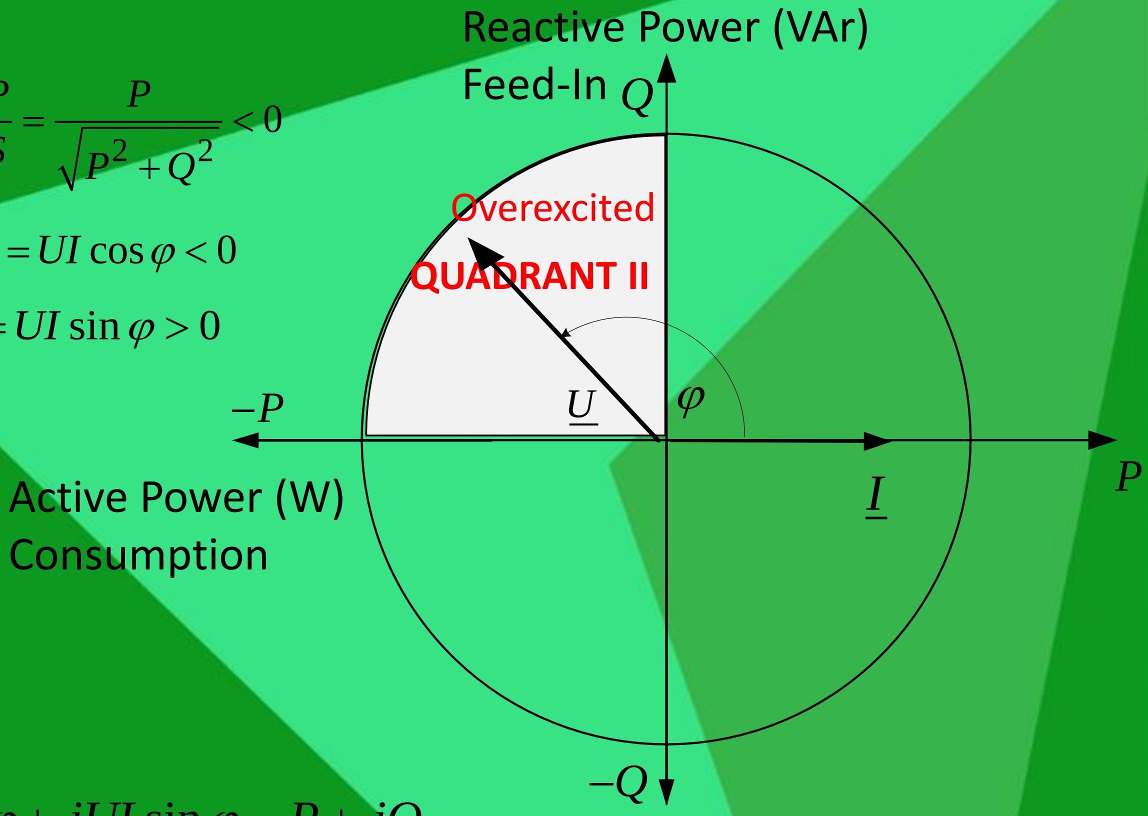


$$\cos\varphi_{II} = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}} < 0$$

$\cos\varphi < 0$ $\qquad P = UI\cos\varphi < 0$

$\sin\varphi > 0$ $\qquad Q = UI\sin\varphi > 0$

$90^\circ < \varphi < 180^\circ$



$$\underline{I} = Ie^{j\psi} = Ie^{j0^\circ} = I\cos 0^\circ + jI\sin 0^\circ = I$$

$$\underline{U} = Ue^{j\varphi} \qquad 90^\circ < \varphi < 180^\circ$$

$$\underline{S} = \underline{U}\cdot\underline{I}^* = Ue^{j\varphi}\cdot\left(Ie^{j0}\right)^* = UIe^{j\varphi} = UI\left(\cos\varphi + j\sin\varphi\right) = UI\cos\varphi + jUI\sin\varphi = P + jQ$$

$\cos\varphi < 0$ $\qquad P = UI\cos\varphi < 0$

$\sin\varphi > 0$ $\qquad Q = UI\sin\varphi > 0$

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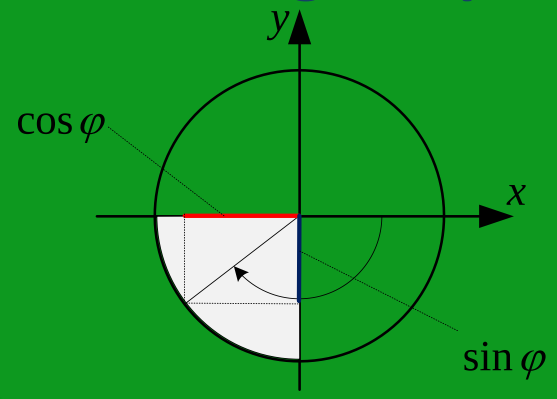
Producer Reference Frame (PRF) conventions power factor sign – quadrant III



$$\underline{I} = Ie^{j\psi} = Ie^{j0^\circ} = I\cos 0^\circ + jI\sin 0^\circ = I$$

$$\underline{U} = Ue^{j\varphi} \quad 180^\circ < \varphi < 270^\circ$$

$$\underline{S} = \underline{U}\cdot\underline{I}^* = Ue^{j\varphi}\cdot\left(Ie^{j0}\right)^* = UIe^{j\varphi} =$$

$$= UI\left(\cos\varphi + j\sin\varphi\right) = UI\cos\varphi + jUI\sin\varphi = P + jQ$$

$$\cos\varphi < 0 \qquad P = UI\cos\varphi < 0$$

$$\sin\varphi > 0 \qquad Q = UI\sin\varphi > 0$$

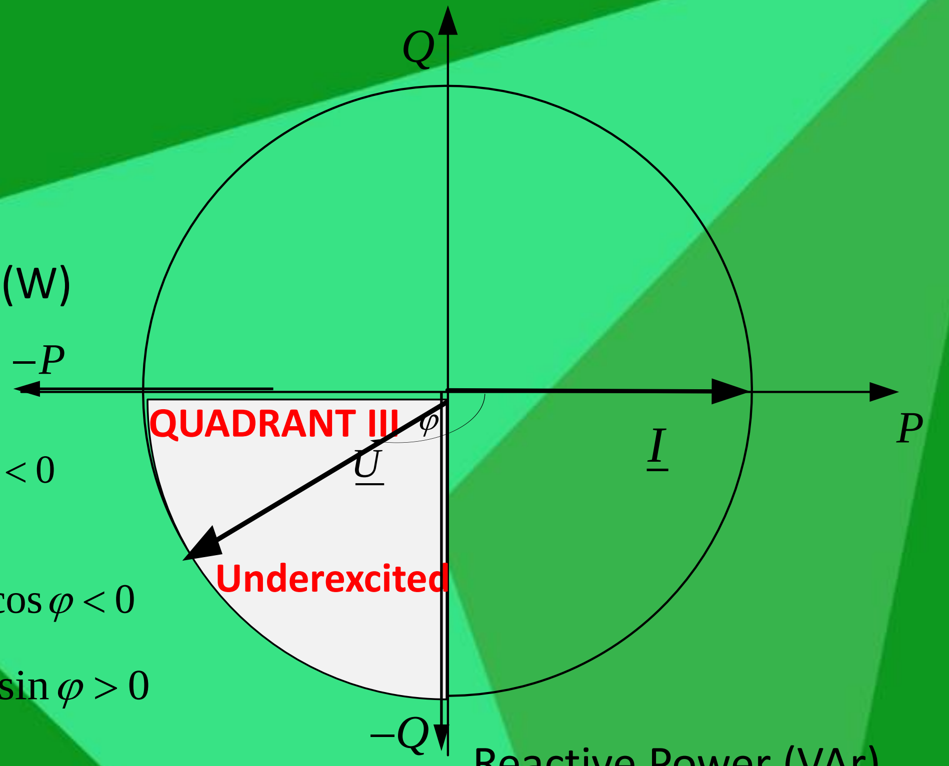
$$\cos\varphi_{\mathrm{III}} = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}} < 0$$

$$\cos\varphi < 0 \qquad P = UI\cos\varphi < 0$$

$$\sin\varphi > 0 \qquad Q = UI\sin\varphi > 0$$

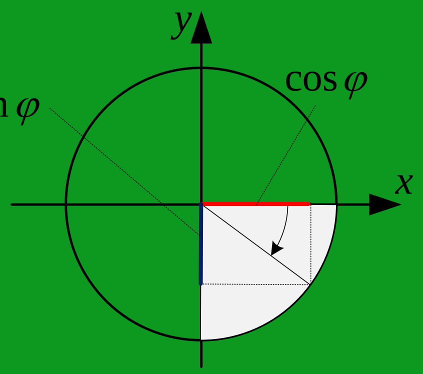
$$180^\circ < \varphi < 270^\circ$$

Active Power (W) Consumption



Reactive Power (VAr) Consumption

Producer Reference Frame (PRF) conventions power factor sign – quadrant IV



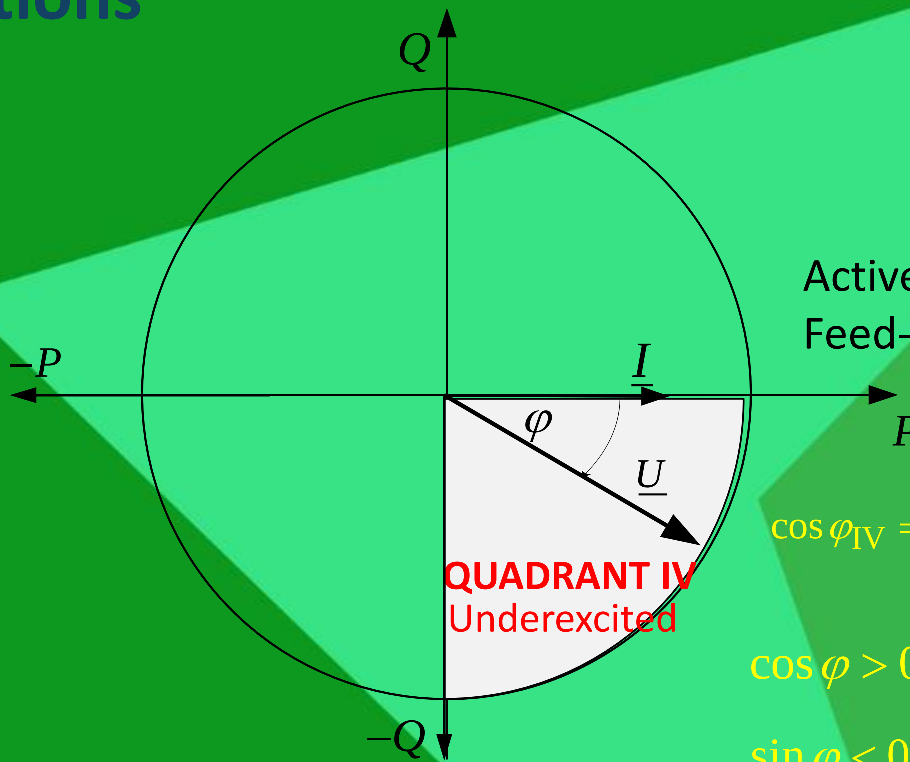
$$\underline{I} = Ie^{j\psi} = Ie^{j0^\circ} = I\cos 0^\circ + jI\sin 0^\circ = I$$

$$\underline{U} = Ue^{j\varphi} \qquad 270^\circ < \varphi < 360^\circ$$

$$\underline{S} = \underline{U}\cdot\underline{I}^* = Ue^{j\varphi}\cdot\left(Ie^{j0}\right)^* = UIe^{j\varphi} =$$
$$= UI\left(\cos\varphi + j\sin\varphi\right) = UI\cos\varphi + jUI\sin\varphi = P + jQ$$

$$\cos\varphi > 0 \qquad P = UI\cos\varphi > 0$$

$$\sin\varphi < 0 \qquad Q = UI\sin\varphi < 0$$



Active Power (W) Feed-In

Reactive Power (VAr) Consumption

$$\cos\varphi_{IV} = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}} > 0$$

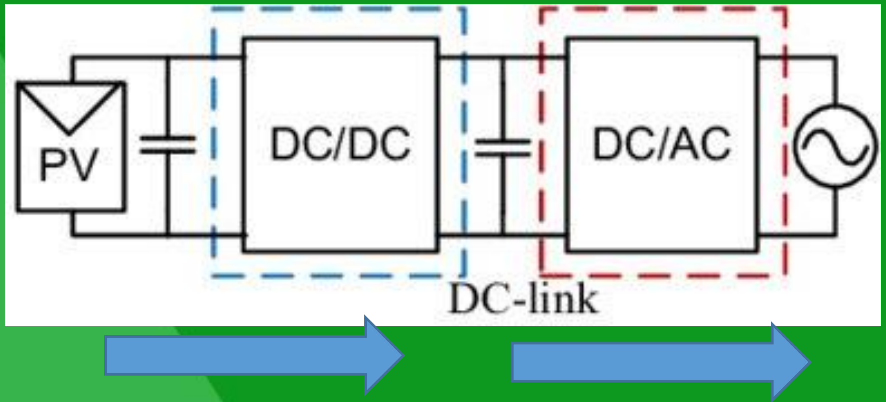
$$\cos\varphi > 0 \qquad P = UI\cos\varphi > 0$$

$$\sin\varphi < 0 \qquad Q = UI\sin\varphi < 0$$

$$270^\circ < \varphi < 360^\circ$$

Photovoltaic inverters working area 2 quadrants, I and IV

Photovoltaic inverters

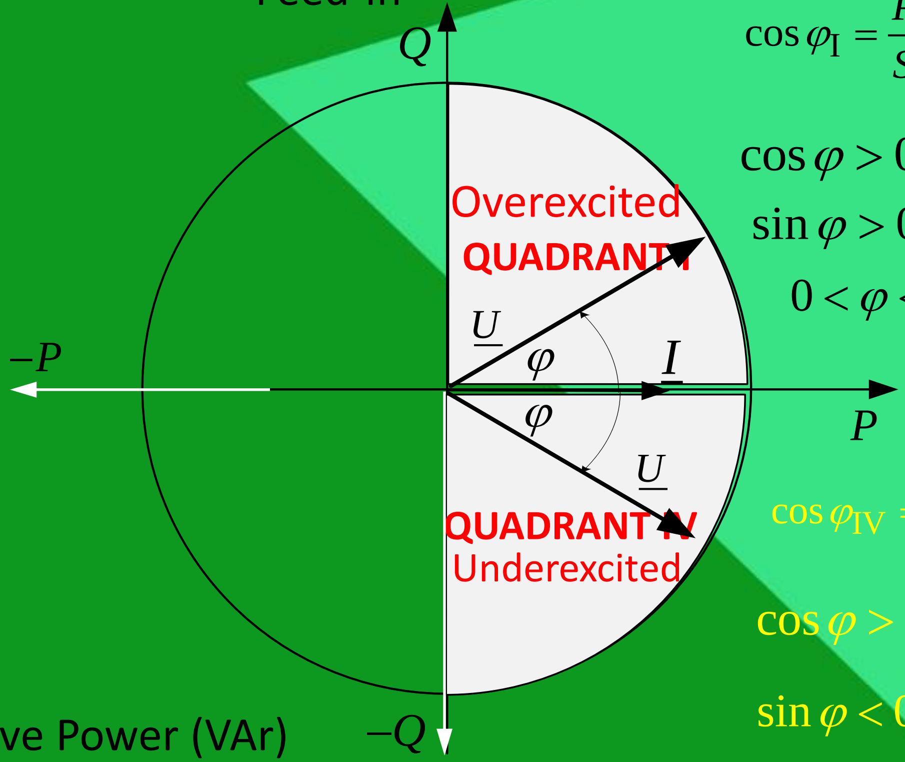


One Direction Active Power Flow

Active Power (W) Feed-In

Producer Reference Frame (PRF)

Reactive Power (VAr) Feed-In



Active Power (W) Feed-In

Reactive Power (VAr) Consumption

$$\cos\varphi_{I} = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}} > 0$$

$\cos\varphi > 0 \quad P = UI\cos\varphi > 0$

$\sin\varphi > 0 \quad Q = UI\sin\varphi > 0$

$0 < \varphi < 90^\circ$

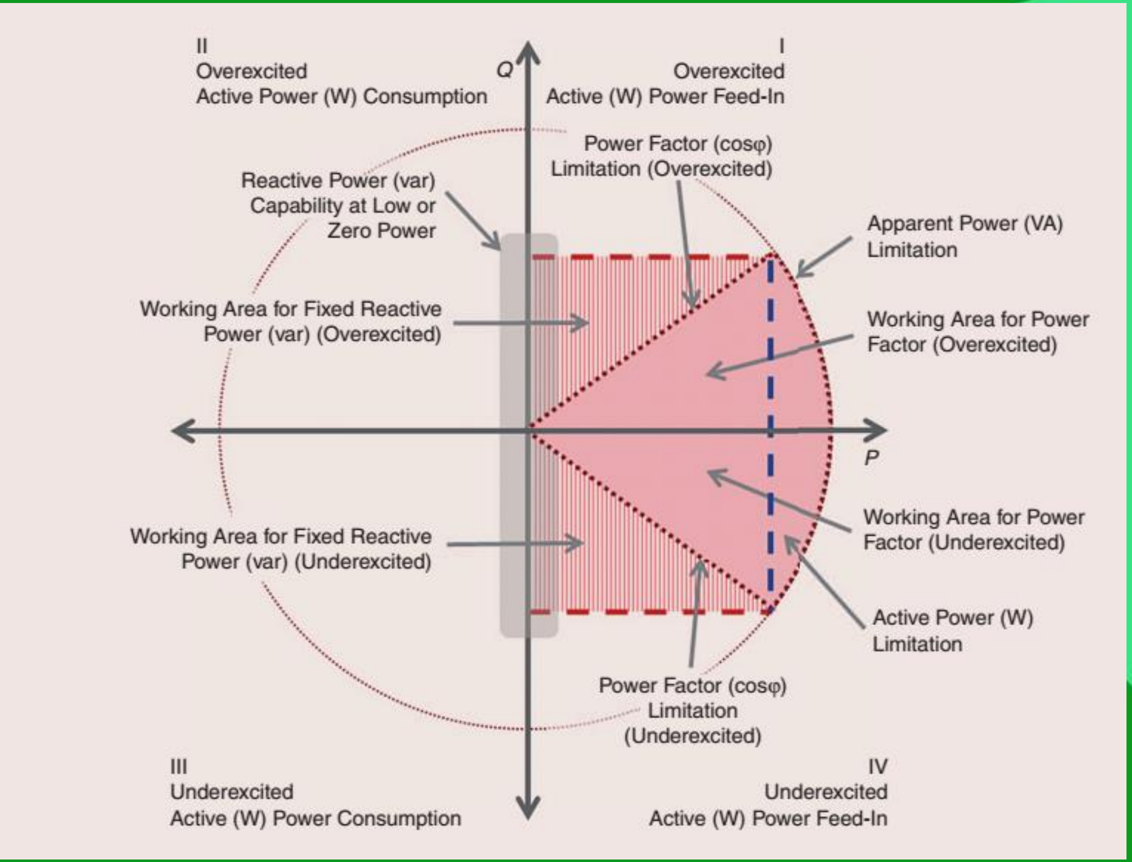
$$\cos\varphi_{IV} = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}} > 0$$

$\cos\varphi > 0 \quad P = UI\cos\varphi > 0$

$\sin\varphi < 0 \quad Q = UI\sin\varphi < 0$

$270^\circ < \varphi < 360^\circ$

A P-Q diagram of an inverter in Producer Reference Frame (PRF)

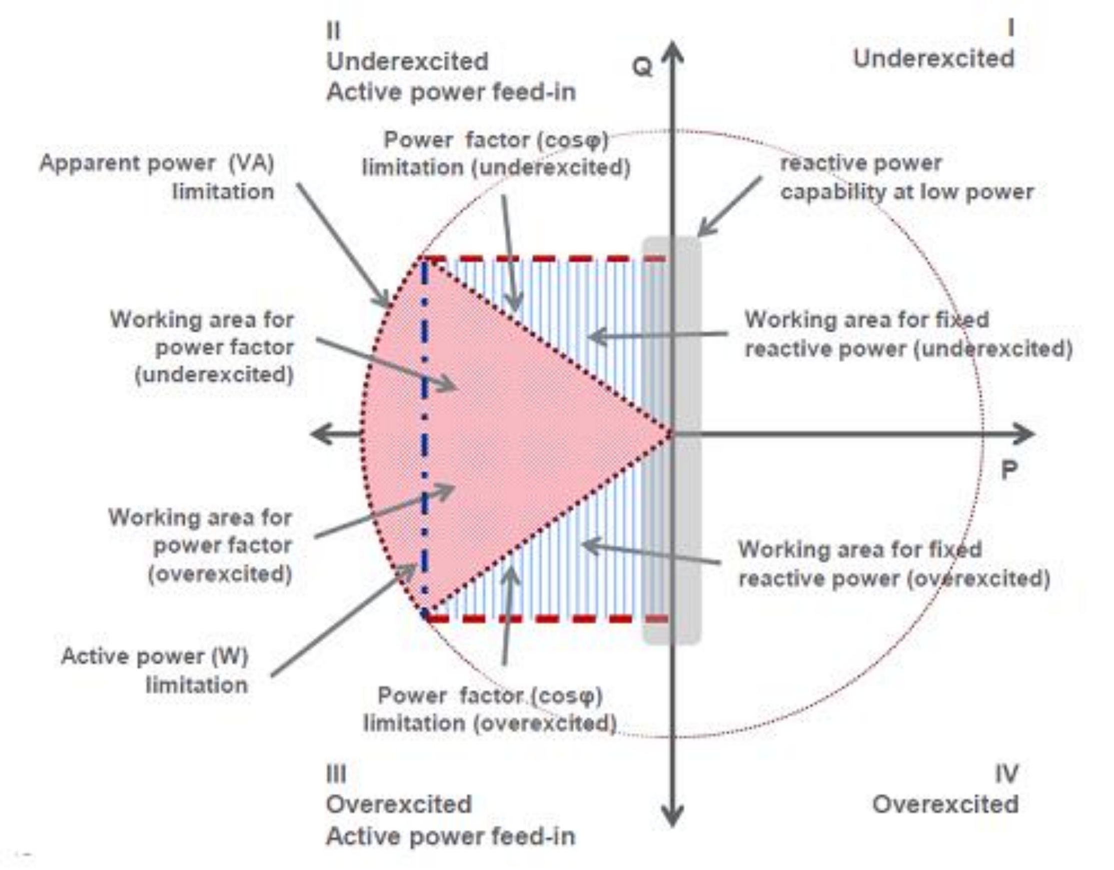


A P-Q diagram of an inverter, showing the device's working areas in terms of active and reactive power and different control modes, in the producer reference frame (PRF)

Producer Reference Frame (PRF)

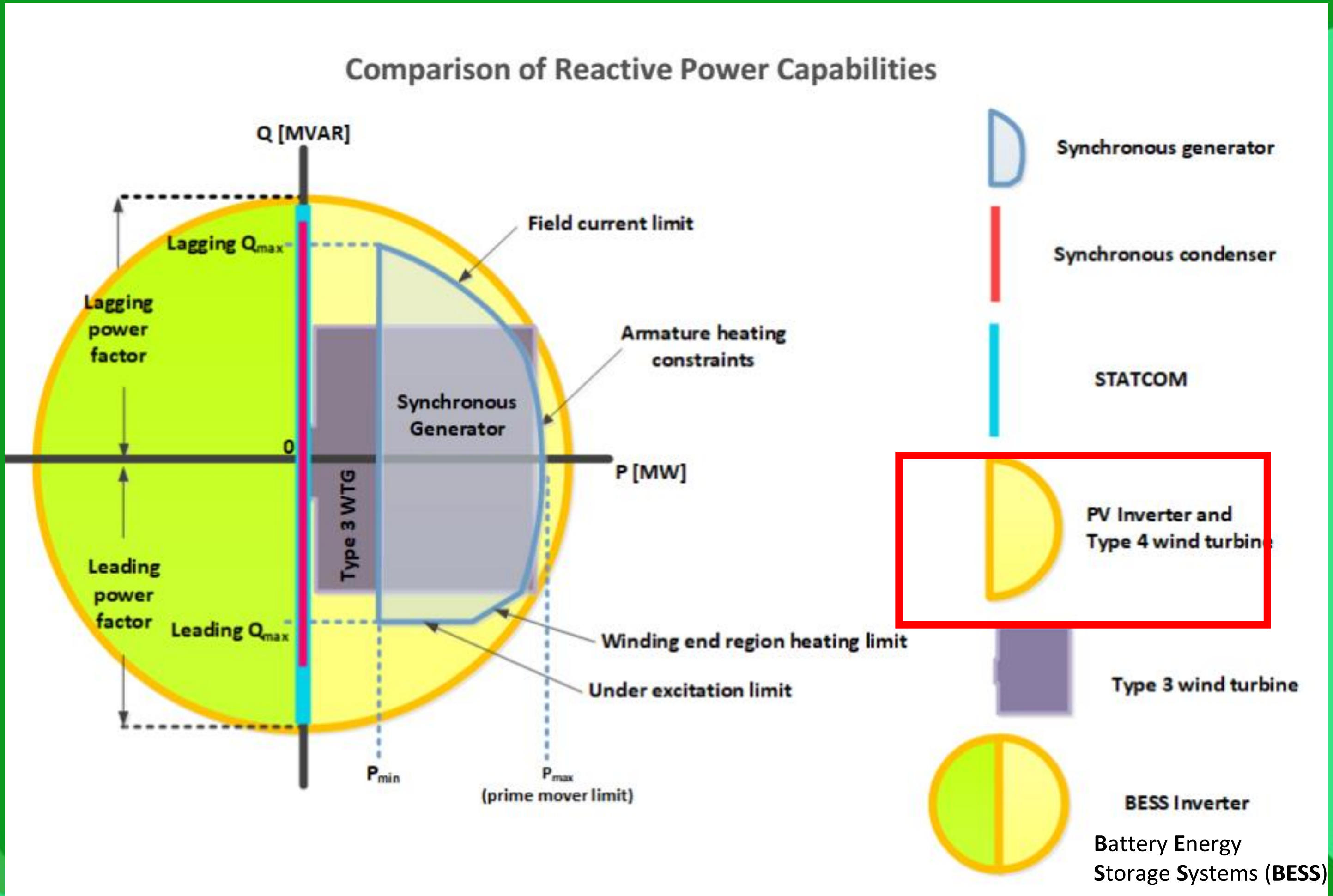
A P-Q diagram of an inverter in Consumer Reference Frame (CRF)

A P-Q diagram of an inverter, showing the device's working areas in terms of active and reactive power and different control modes, in the consumer reference frame (CRF)



Consumer Reference Frame (CRF)

Comparison of Reactive Power Capabilities



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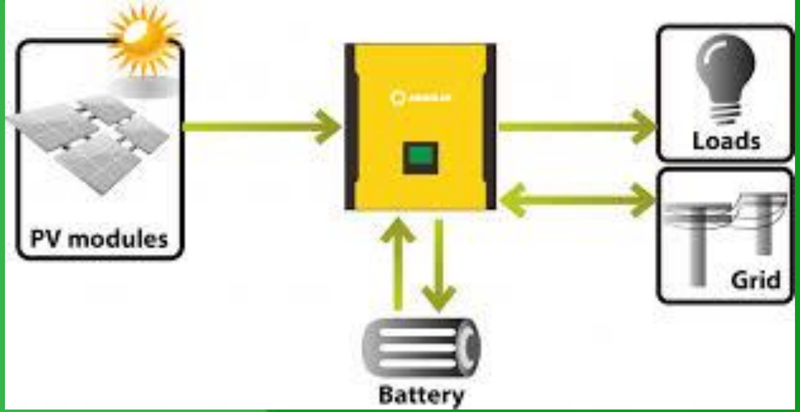
Battery storage system inverters working area 4 quadrants, I, II, III and IV

Producer Reference Frame (PRF)

Reactive Power (VAr) Feed-In

Hybrid Photovoltaic Inverter



Bi-Direction Active Power Flow

Active Power (W) Feed-In

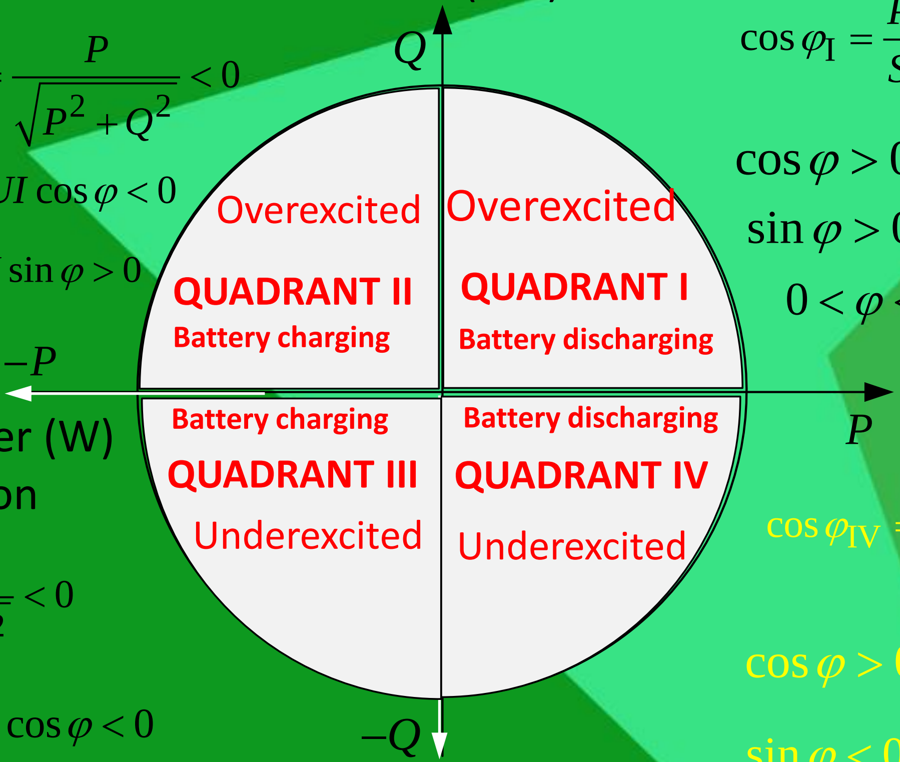
Active Power (W) Consumption

$$\cos\varphi_{II} = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}} < 0$$

$\cos\varphi < 0 \quad P = UI\cos\varphi < 0$

$\sin\varphi > 0 \quad Q = UI\sin\varphi > 0$

$90^\circ < \varphi < 180^\circ$



Active Power (W) Consumption

$$\cos\varphi_{III} = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}} < 0$$

$\cos\varphi < 0 \quad P = UI\cos\varphi < 0$

$\sin\varphi > 0 \quad Q = UI\sin\varphi > 0$

$180^\circ < \varphi < 270^\circ$

Reactive Power (VAr) Consumption

$$\cos\varphi_{I} = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}} > 0$$

$\cos\varphi > 0 \quad P = UI\cos\varphi > 0$

$\sin\varphi > 0 \quad Q = UI\sin\varphi > 0$

$0 < \varphi < 90^\circ$

Active Power (W) Feed-In

$$\cos\varphi_{IV} = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}} > 0$$

$\cos\varphi > 0 \quad P = UI\cos\varphi > 0$

$\sin\varphi < 0 \quad Q = UI\sin\varphi < 0$

$270^\circ < \varphi < 360^\circ$

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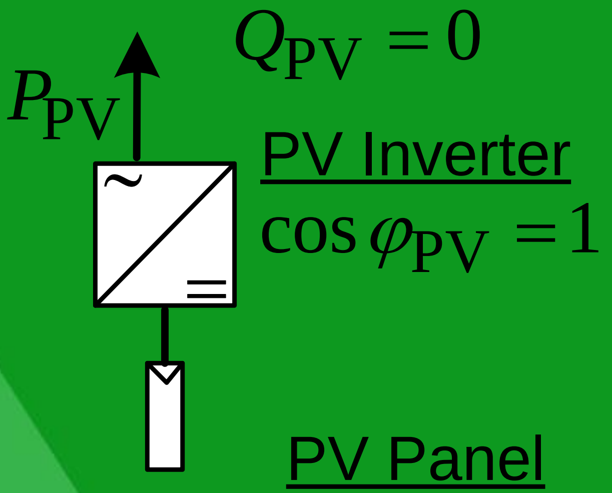
COMPARASION TWO PV INVERTORS ON ONE PV SOURCE WITH SAME CHATACTERSTICS

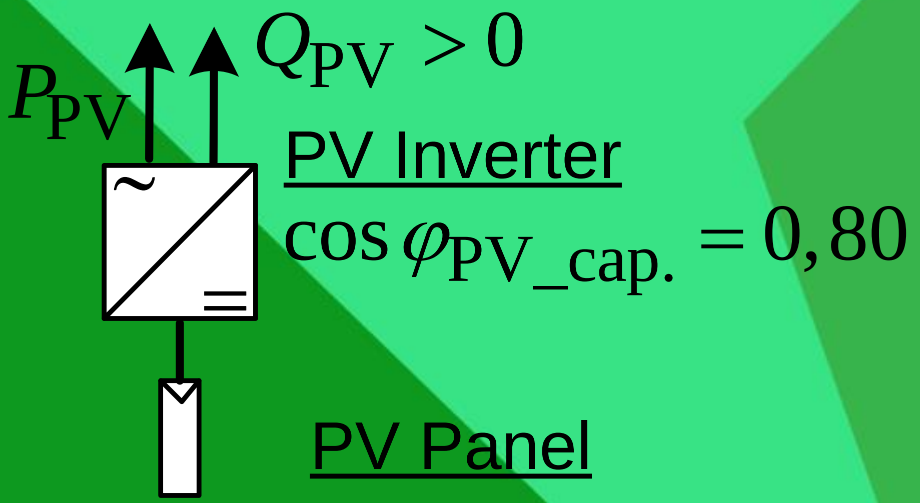
EXAMPLE 1

OLD PV INVERTER



EXAMPLE 2

PV SMART INVERTER



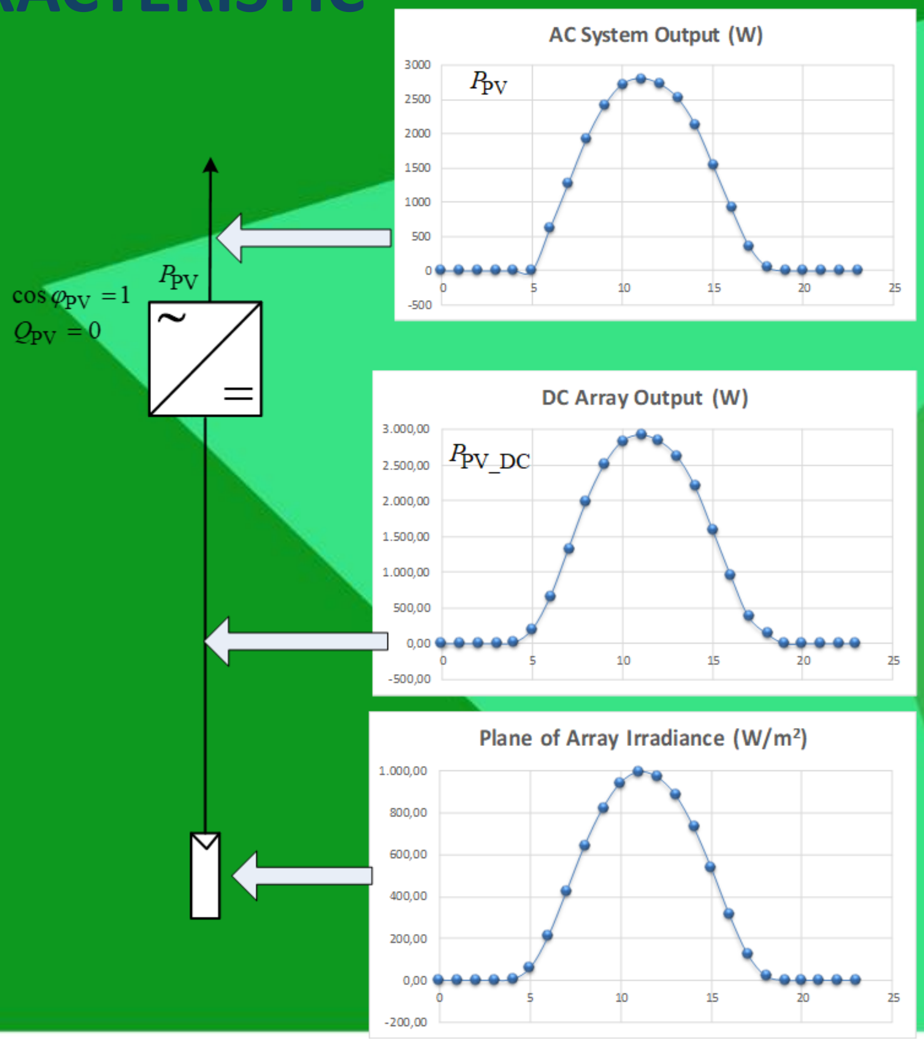
EXAMPLE 1 AND 2 - PV SOURCE CHARACTERISTIC
Daily diagram of POWER generation

SAME DATA FOR EXAMPLE 1 AND 2

PVWatts: Hourly PV Performance Data	
Requested Location:	44.708, 20.455
Location:	BELGRADE, SERBIA
Lat (deg N):	44.82
Long (deg E):	20.28
Elev (m):	99
DC System Size (kW):	4
Module Type:	Standard
Array Type:	Fixed (open rack)
Array Tilt (deg):	20
Array Azimuth (deg):	180
System Losses:	14.08
Invert Efficiency:	96
DC to AC Size Ratio:	1.2

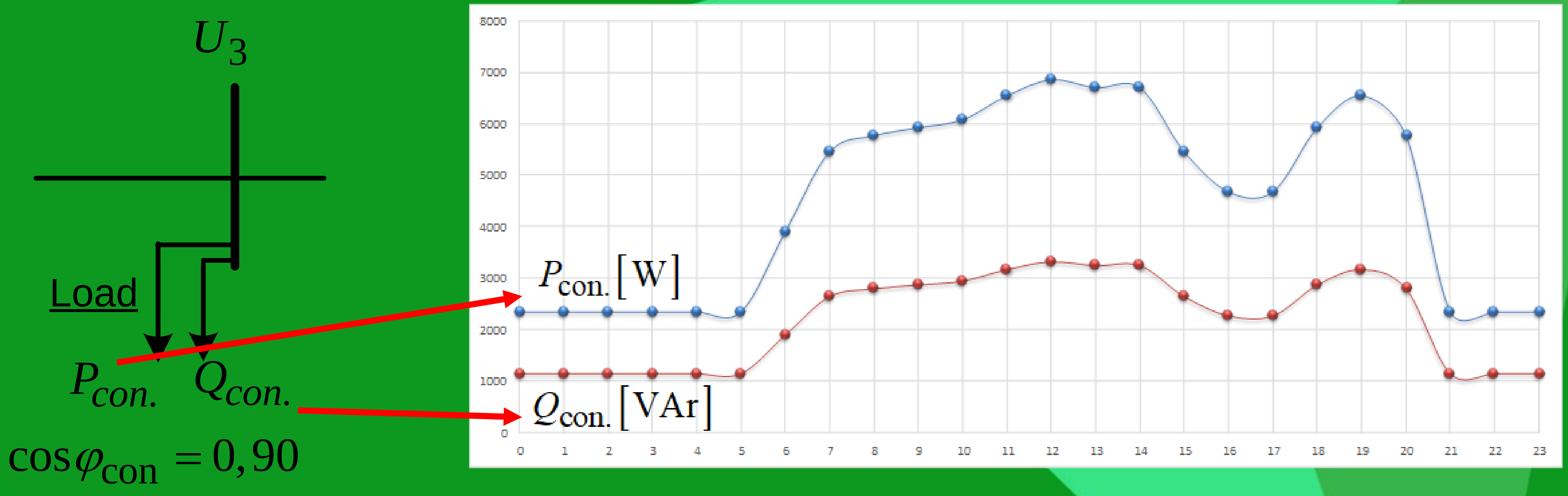
Month	Day
8	1

PVWatts: Hourly PV Performance Data

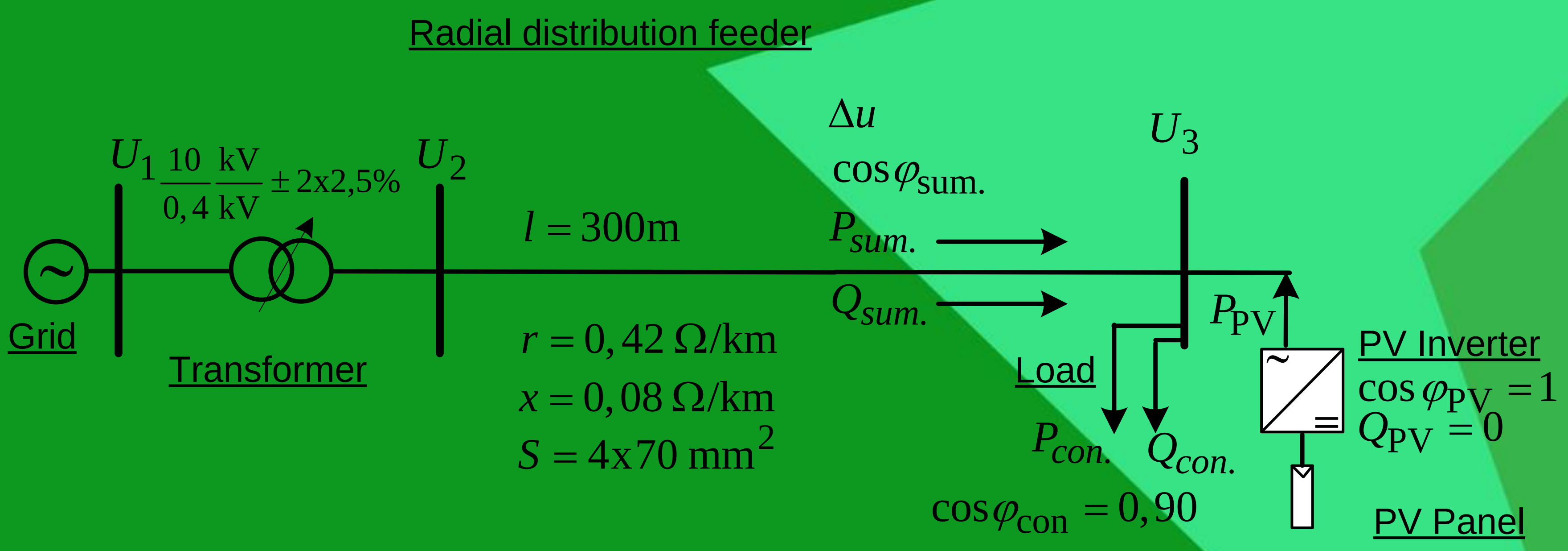


EXAMPLE 1 AND 2 – Daily diagram of POWER consumption

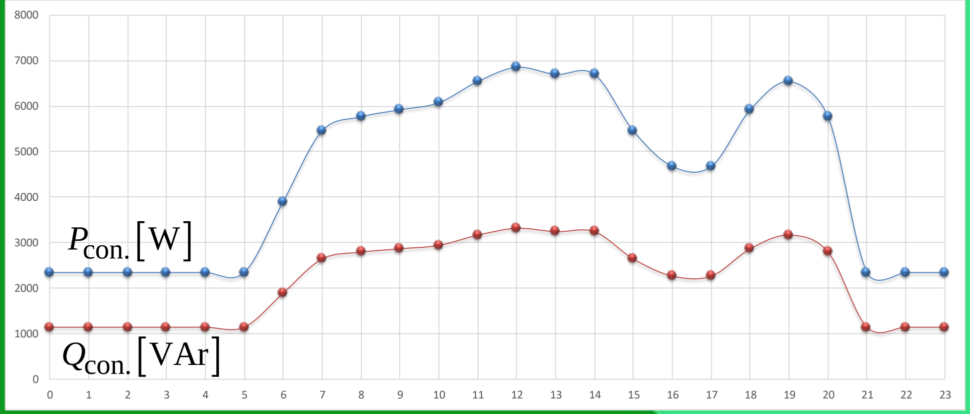
SAME DATA FOR EXAMPLE 1 AND 2



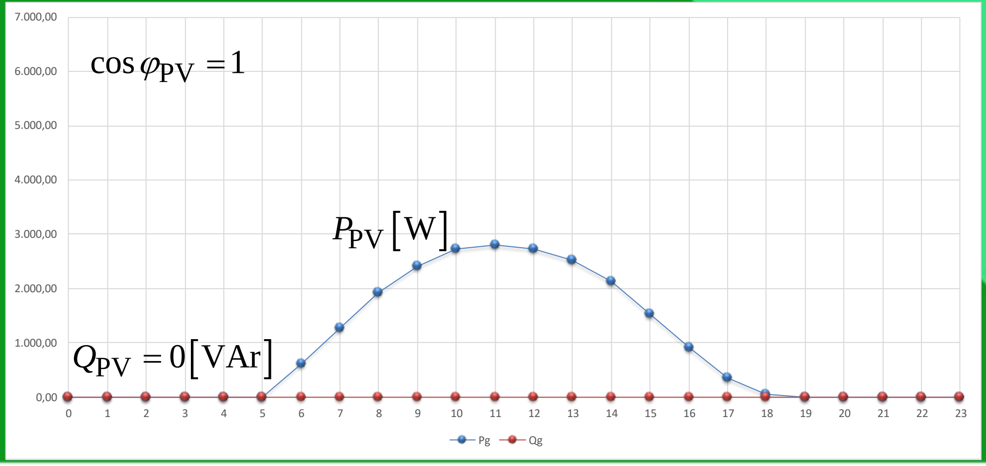
EXAMPLE 1 - RADIAL DISTRIBUTION FIDER
PV INVERTER (OLD INVERTER) WITH POWER FACTOR 1



EXAMPLE 1 - RADIAL DISTRIBUTION FIDER
PV INVERTER (OLD INVERTER) WITH POWER FACTOR 1



Daily diagram of power consumption



Daily diagram of power generation

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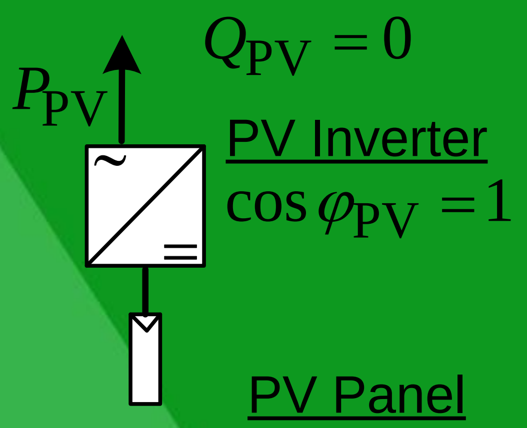
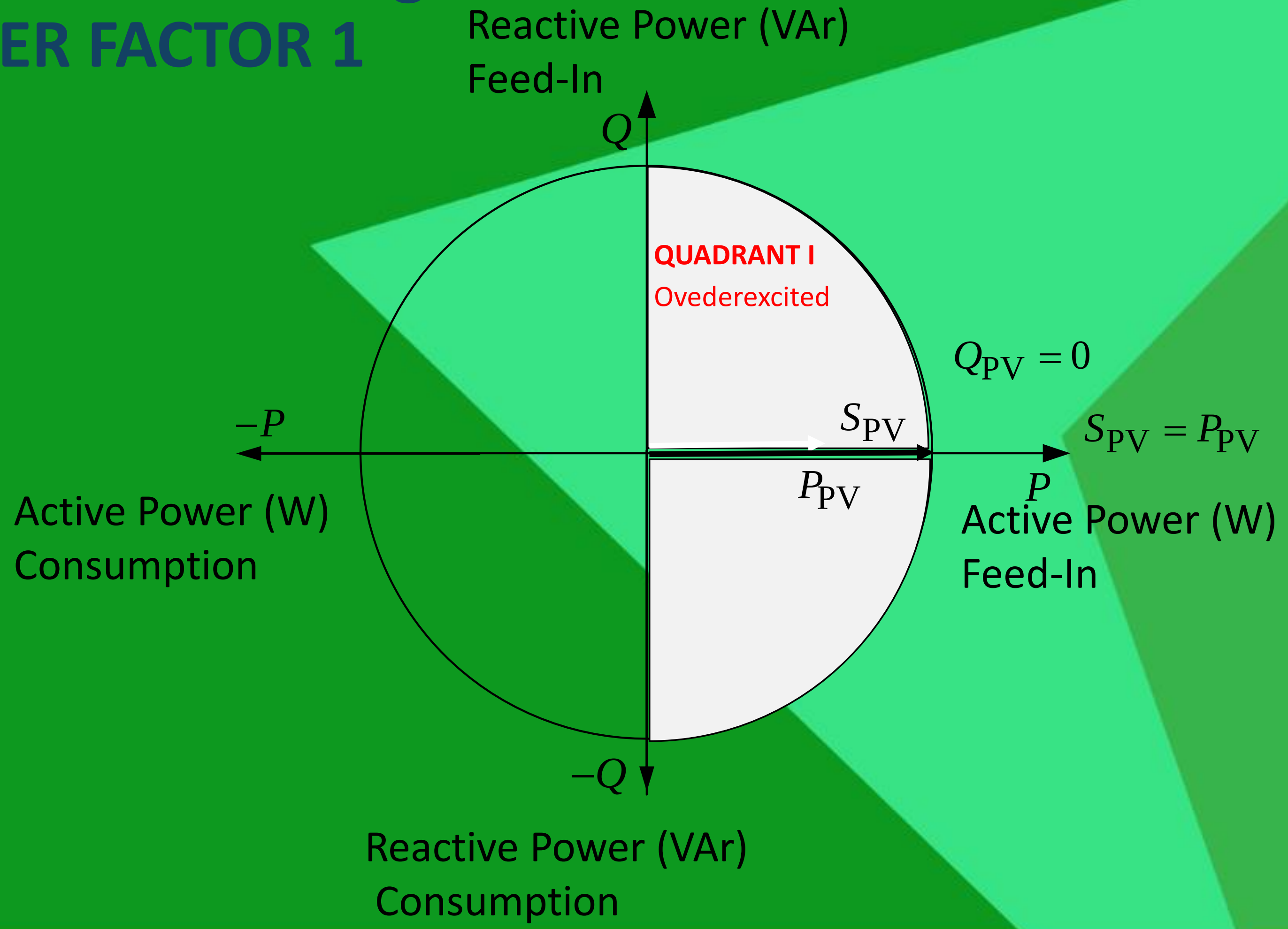
EXAPMLE 1 – work area – p axis of Q-P diagram
PV old INVERTER WITH POWER FACTOR 1

EXAMPLE 1

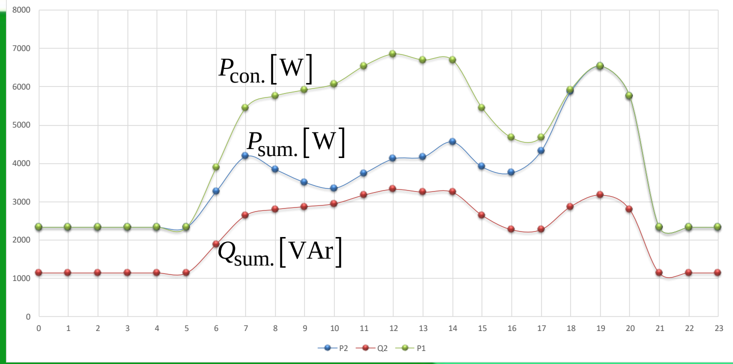
OLD PV INVERTER



Producer Reference Frame (PRF)



EXAMPLE 1 - RADIAL DISTRIBUTION FIDER PV INVERTER (OLD INVERTER) WITH POWER FACTOR 1



$P_{sum.} = P_{con.} - P_{PV}$

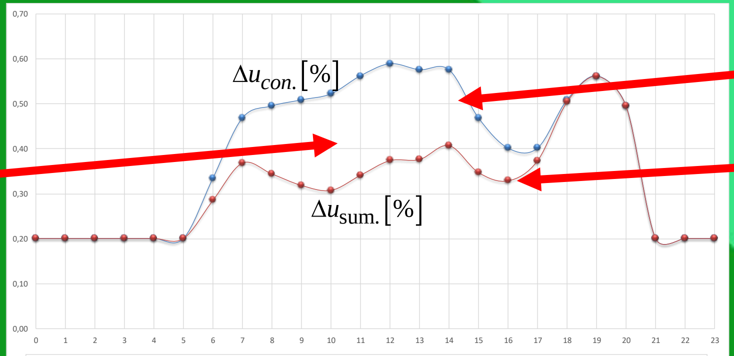
$Q_{sum.} = Q_{con.}$

Daily diagram of active power consumption

Summary Daily diagram of active power consumption

Summary Daily diagram of reactive power consumption

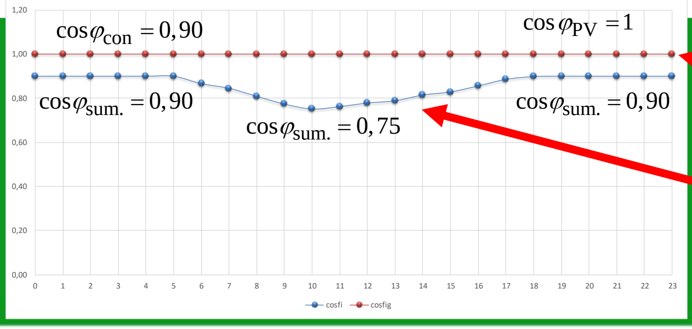
The voltage drop is smaller due to less total active power consumption on the bus 3.



Voltage drop – without PV Inverter

Voltage drop – wit PV Inverter

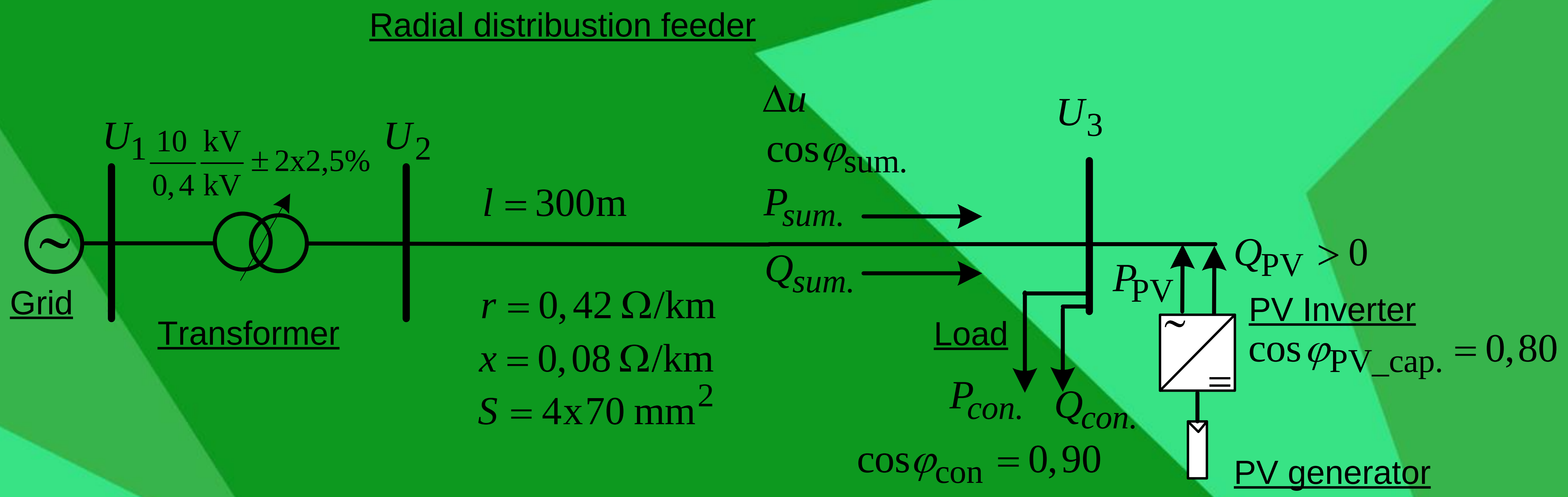
Consumer power factor decreases during the production of active power from the PV generator.



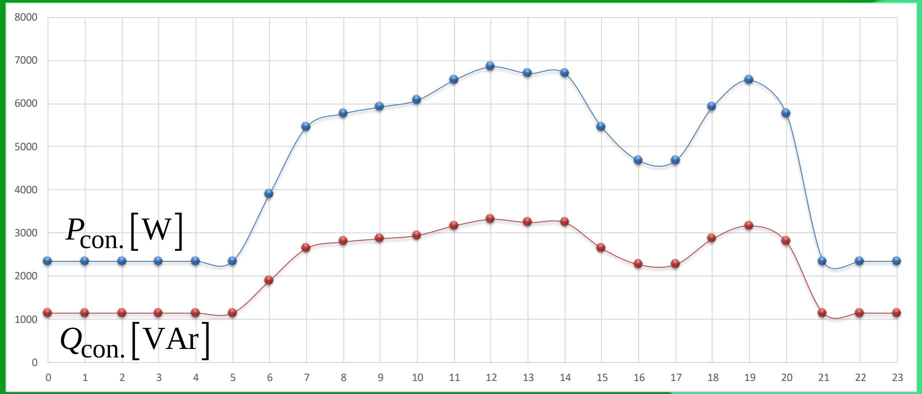
Power factor of load (0,9)

Summary Power factor of load

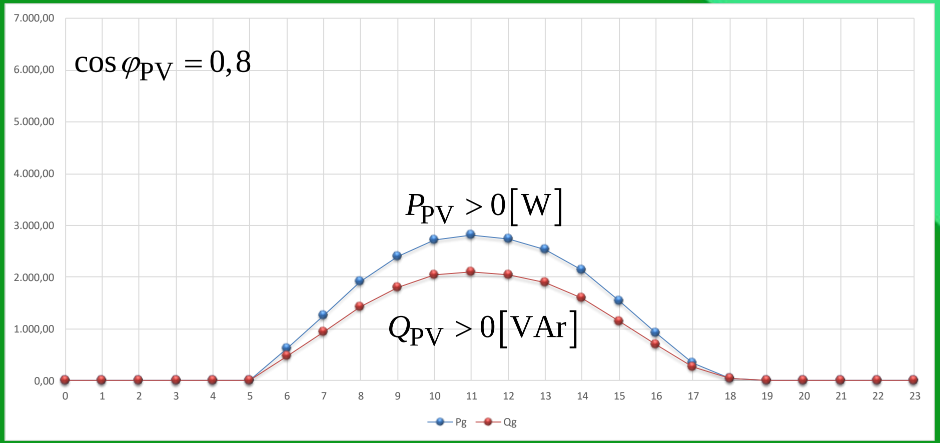
EXAPMLE 2 - RADIAL DISTRIBUTION FIDER
PV SMART INVERTER WITH CONTROLABLE POWER FACTOR



EXAPMLE 2 - RADIAL DISTRIBUTION FIDER
PV SMART INVERTER WITH CONTROLABLE POWER FACTOR



Daily diagram of power consumption

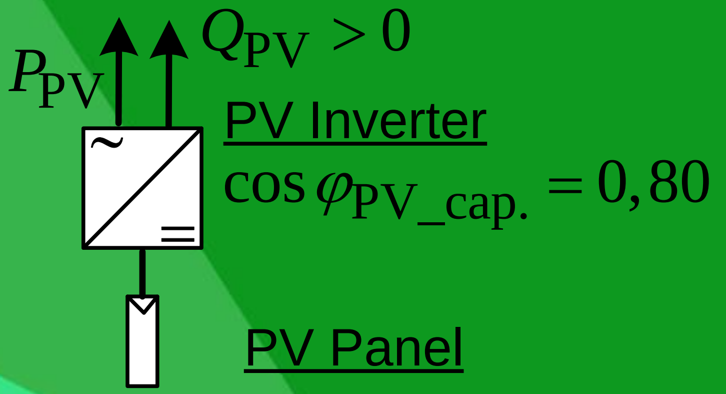


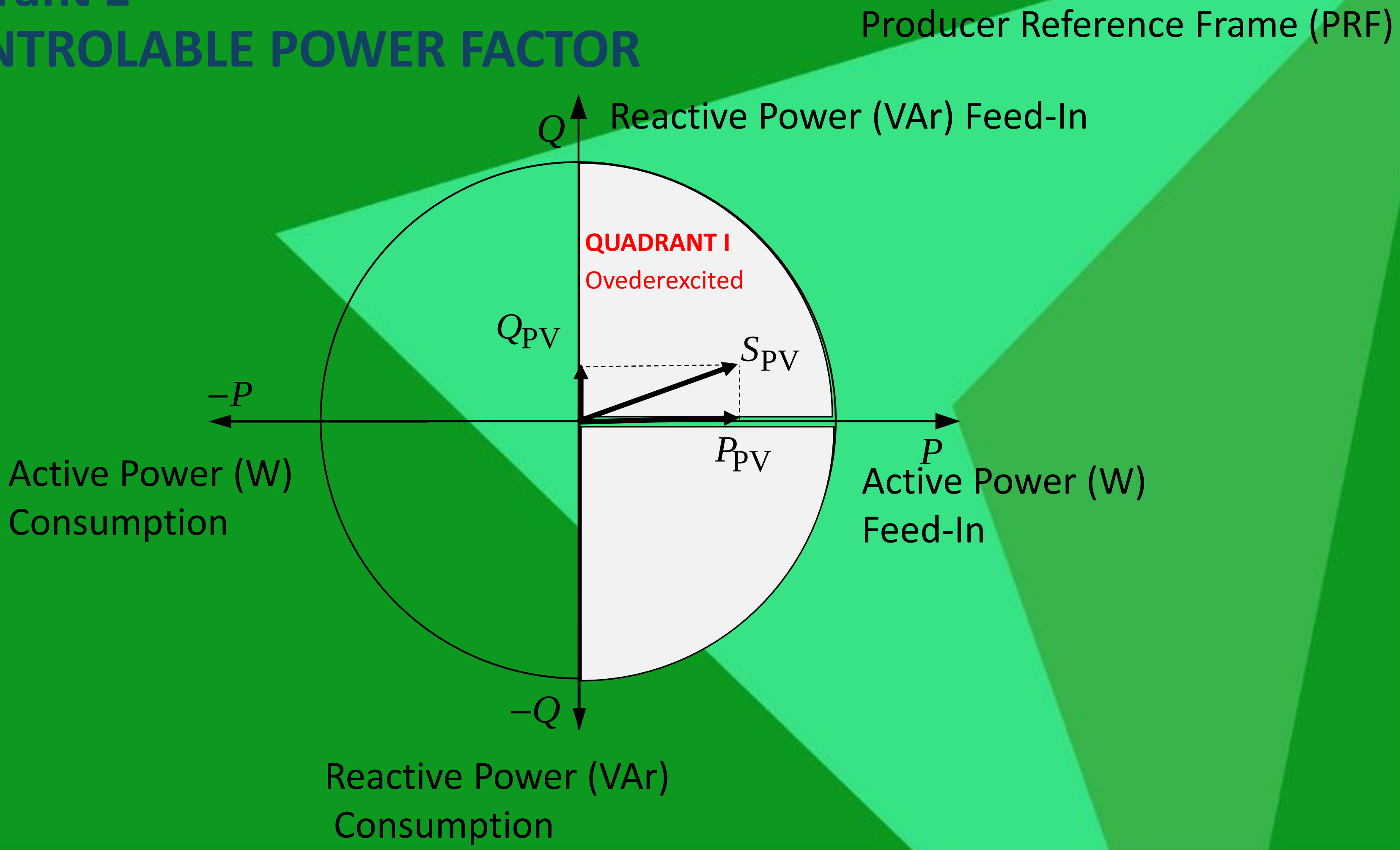
Daily diagram of power generation

EXAPMLE 2 – work area – quadrant 1
PV SMART INVERTER WITH CONTROLABLE POWER FACTOR

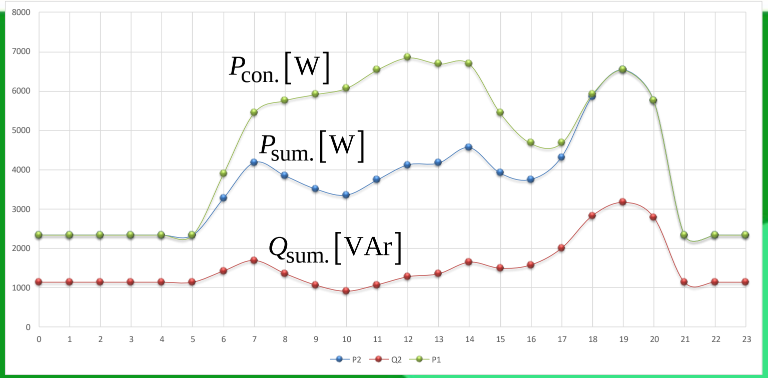
EXAMPLE 2

PV SMART INVERTER





EXAPMLE 2 - RADIAL DISTRIBUTION FIDER PV SMART INVERTER WITH CONTROLABLE POWER FACTOR



Daily diagram of active power consumption

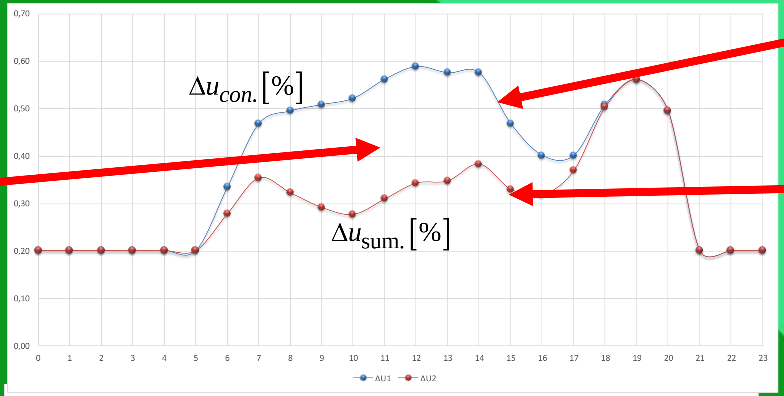
Summary Daily diagram of active power consumption

$P_{sum.} = P_{con.} - P_{PV}$

Summary Daily diagram of reactive power consumption

$Q_{sum.} = Q_{con.}$

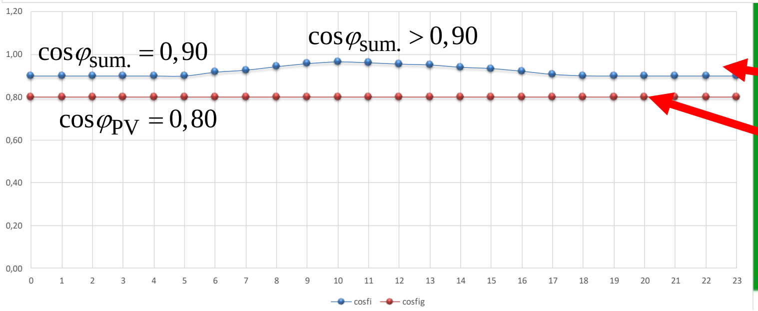
The voltage drop is smaller due to less total active and reactive power consumption on the bus 3.



Voltage drop – without PV Inverter

Voltage drop – with PV Inverter

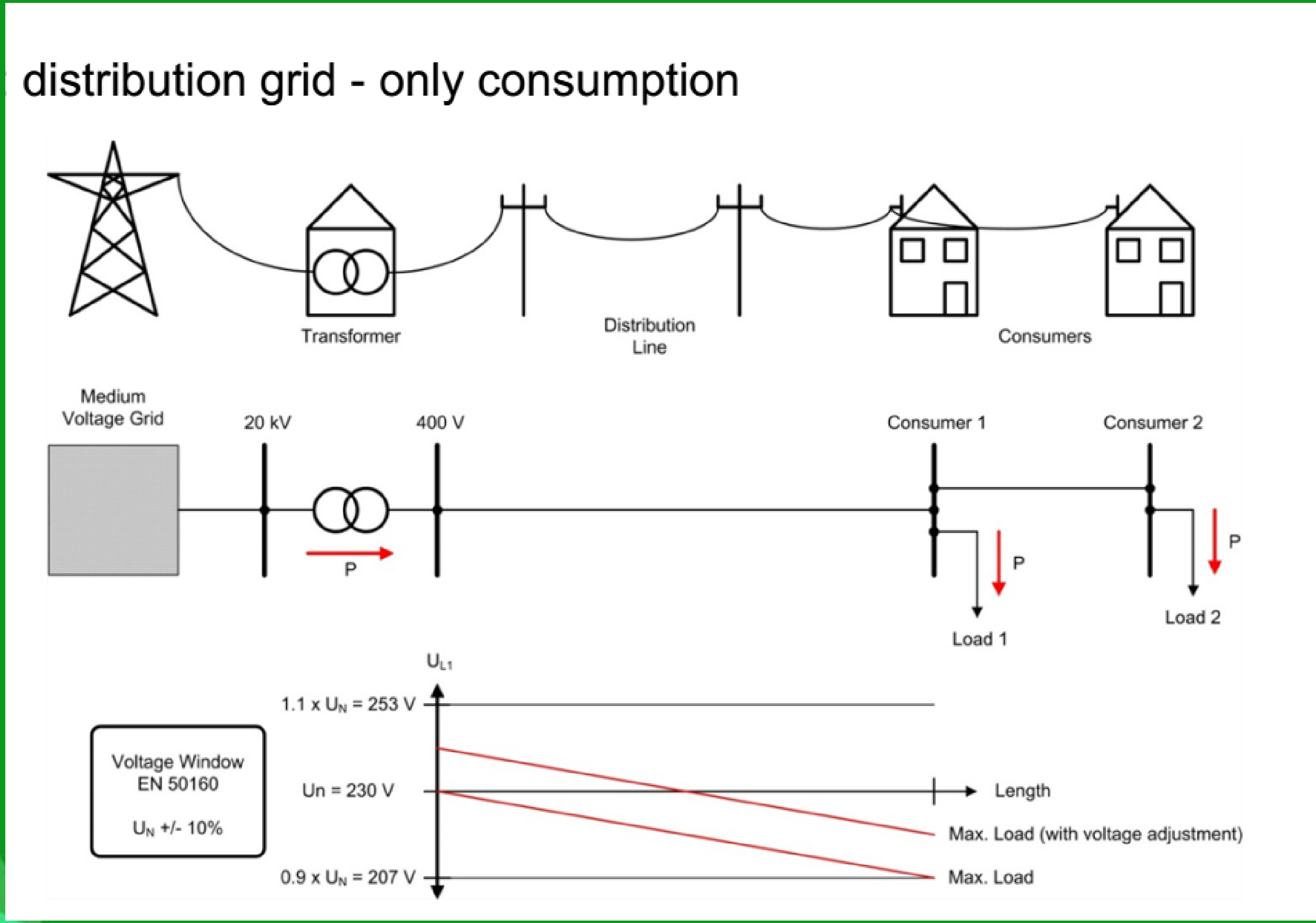
Consumer power factor increases during the production of active and reactive power from the PV generator.



Summary Power factor of load

Power factor of PV Smart Inverter (0,8)

Example: distribution grid - only consumption



KALCEA

УНИВЕРЗИТЕТ У ПРИШТИНИ КОСОВСКА МИТРОВИЦА

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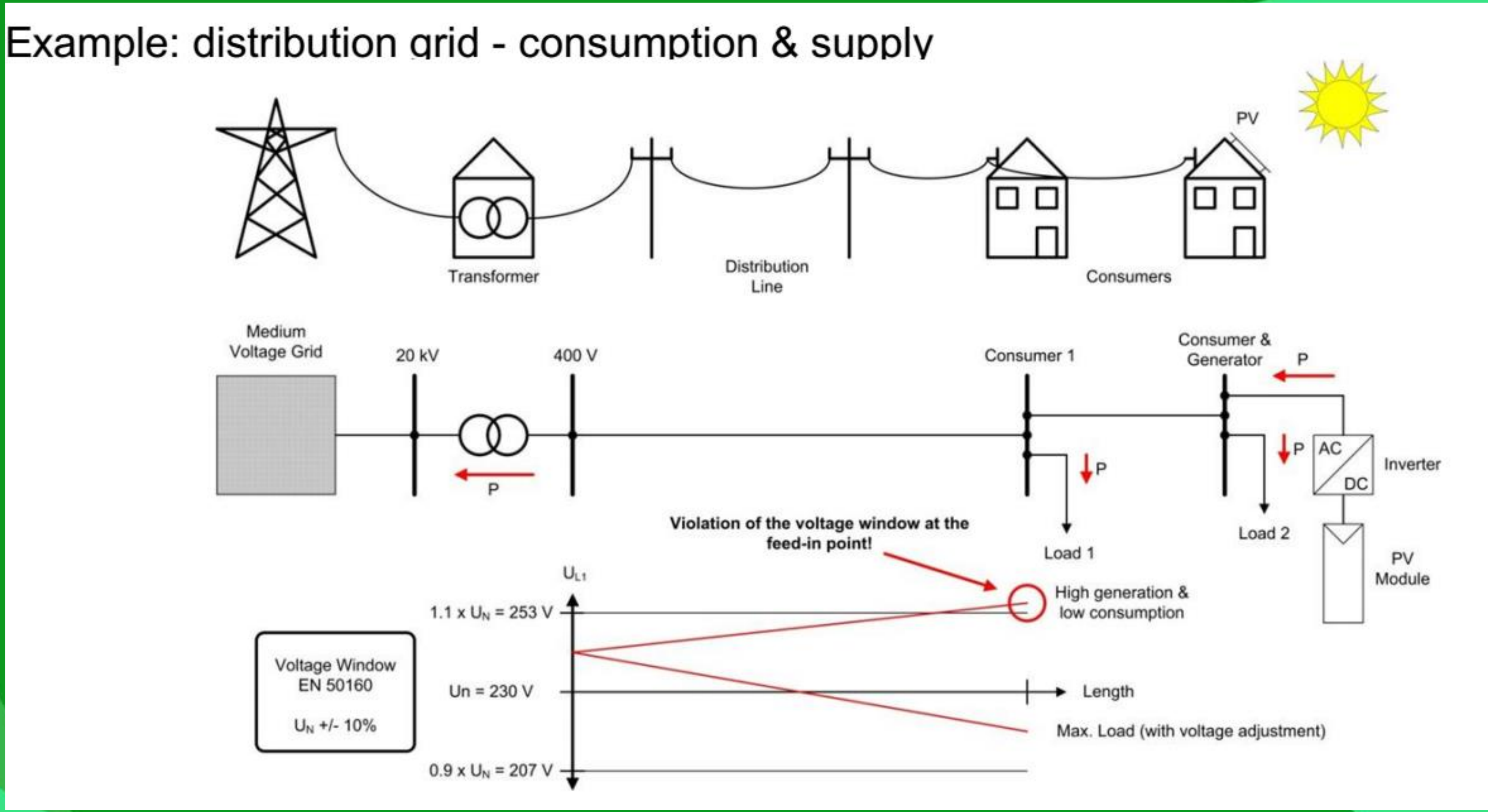
Example: distribution grid - consumption & supply



Distribution grid - consumption & supply incl. reactive power