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Cloud Passing Forecasting for PV Power Plant Output Power Smoothing

Primož SUKIČ
Gorazd ŠTUMBERGER

PV power plants
















Advantages

Disadvantages

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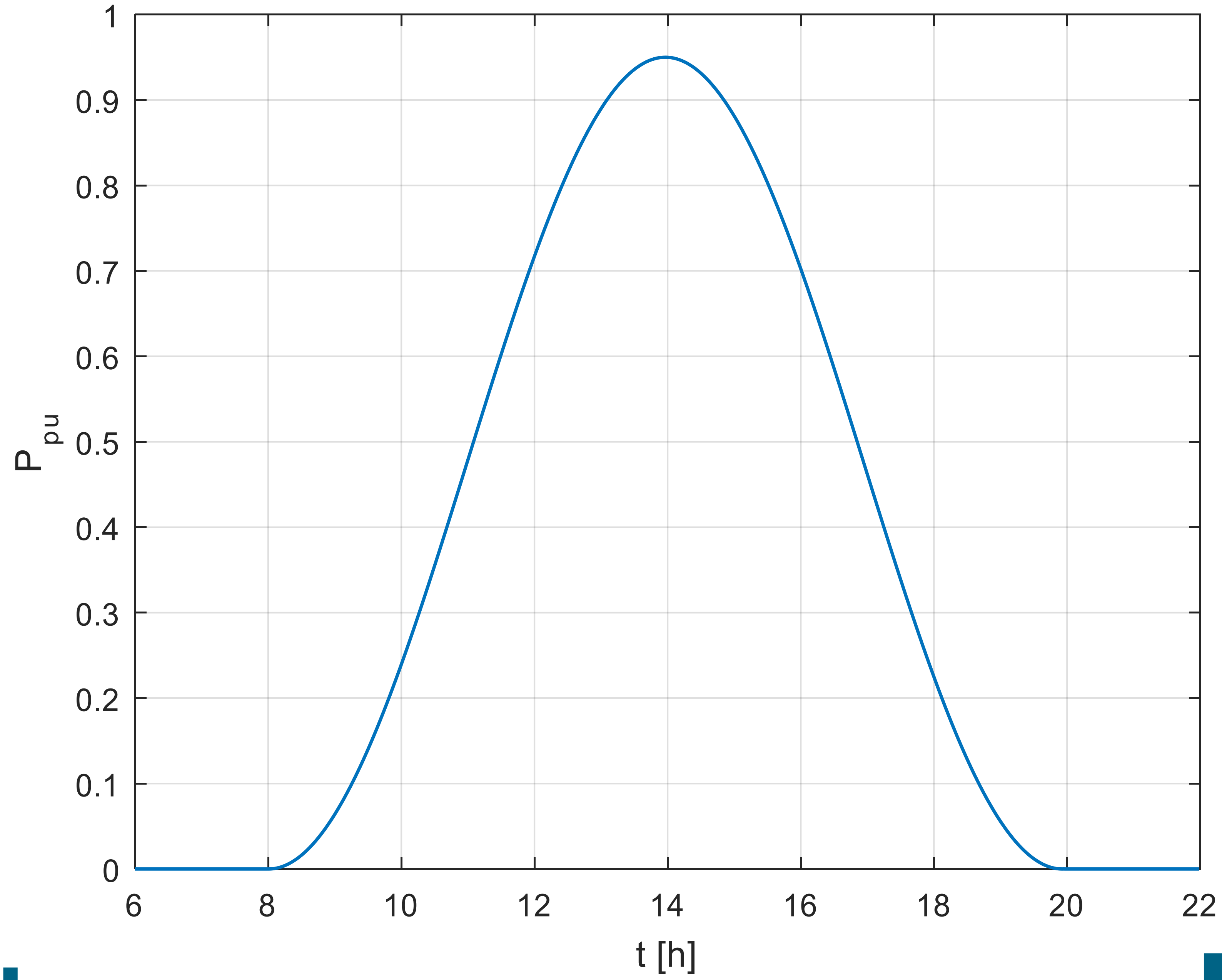
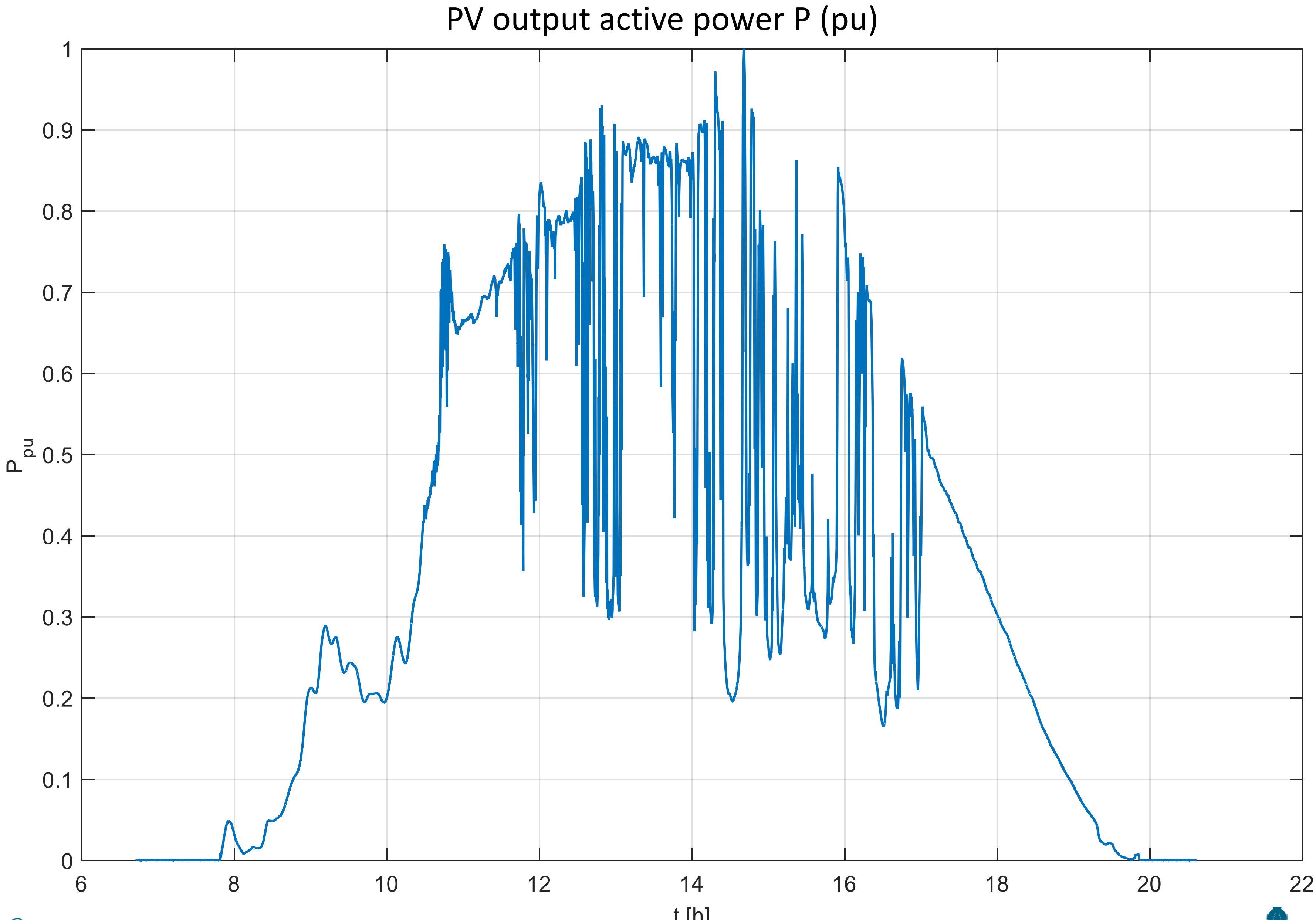
PV power plant output power?


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
P_{pu}
6
8
10
12
14
16
18
20
22
t [h]



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Problems?

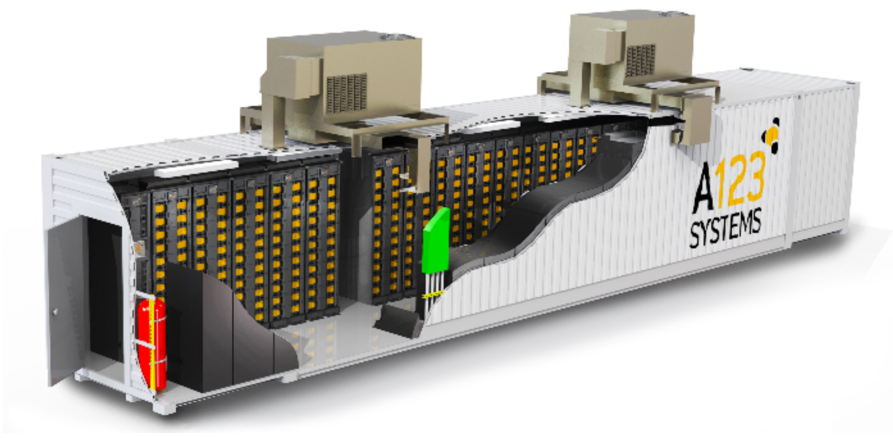
- Voltage fluctuations
- Network grid elements can work incorrectly
  - Tap changer
  - Protecting elements
  - Capacitor banks

Solutions ?

- Electricity network reinforcements

- Energy storage

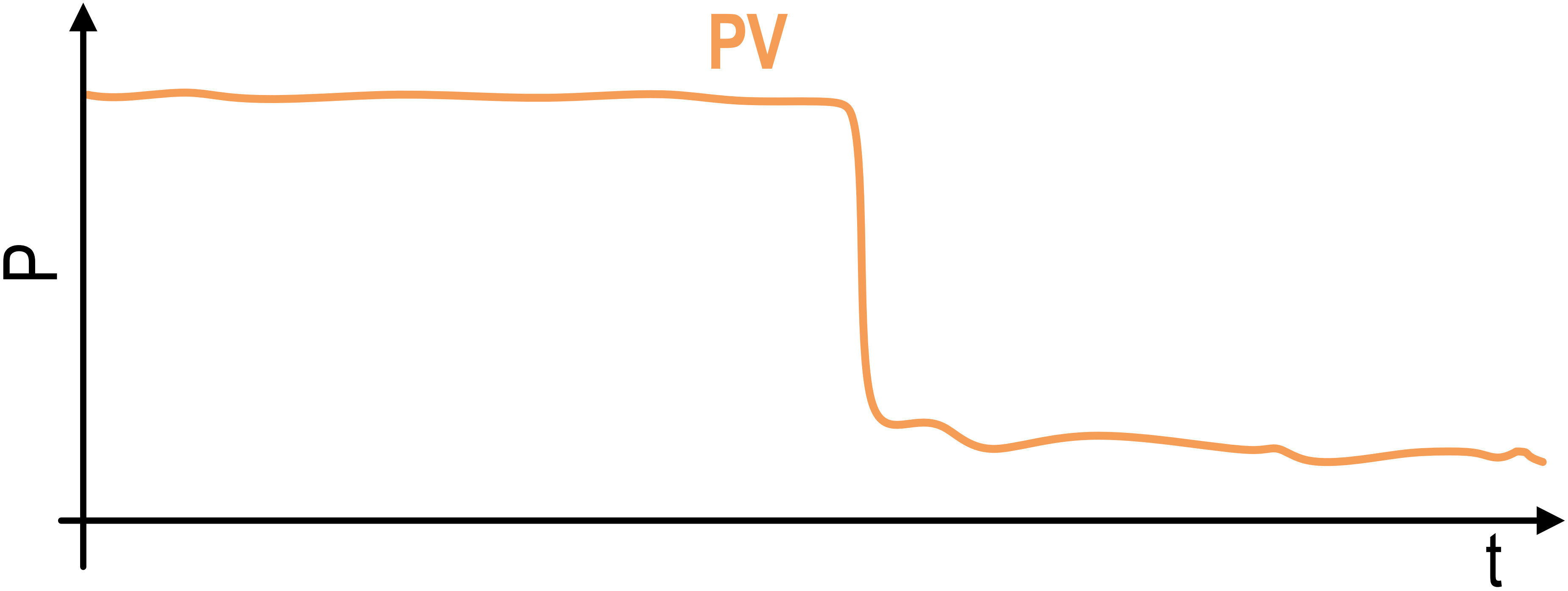

HITACHI
Hitachi, Ltd.,
ENERGY STORAGE SYSTEM
CrystEna
1MW Li-ion Battery

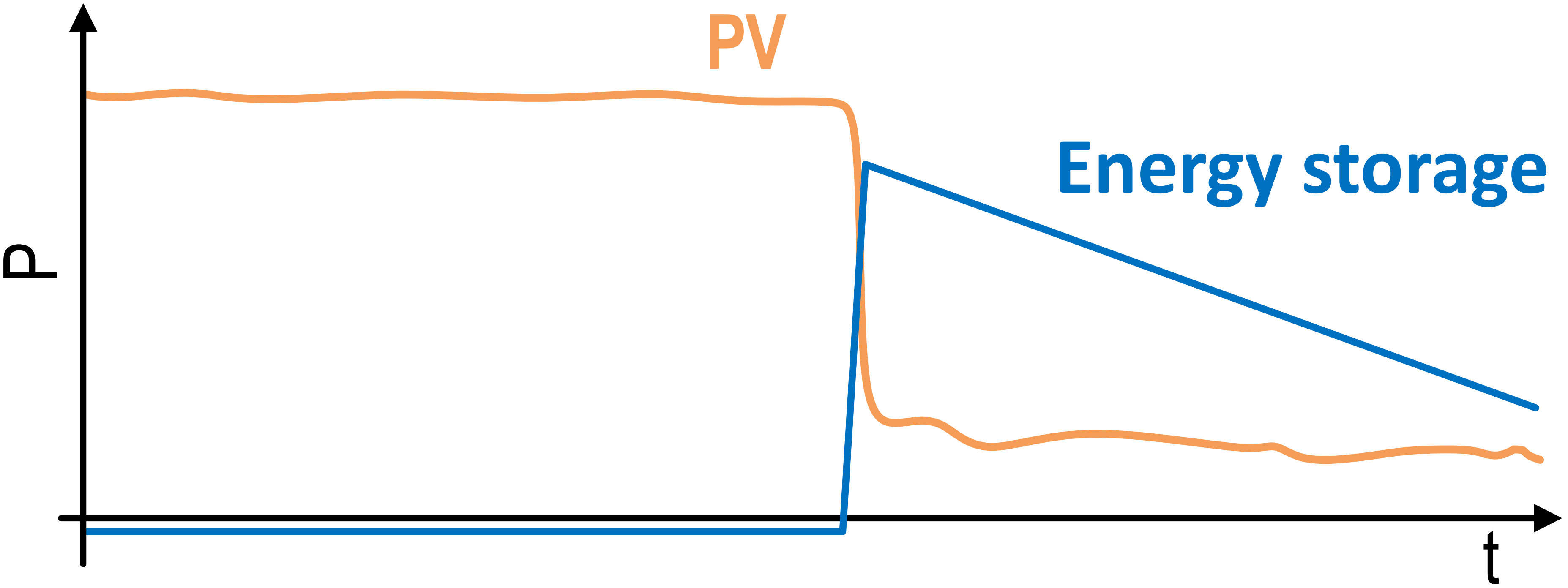

A123
SYSTEMS

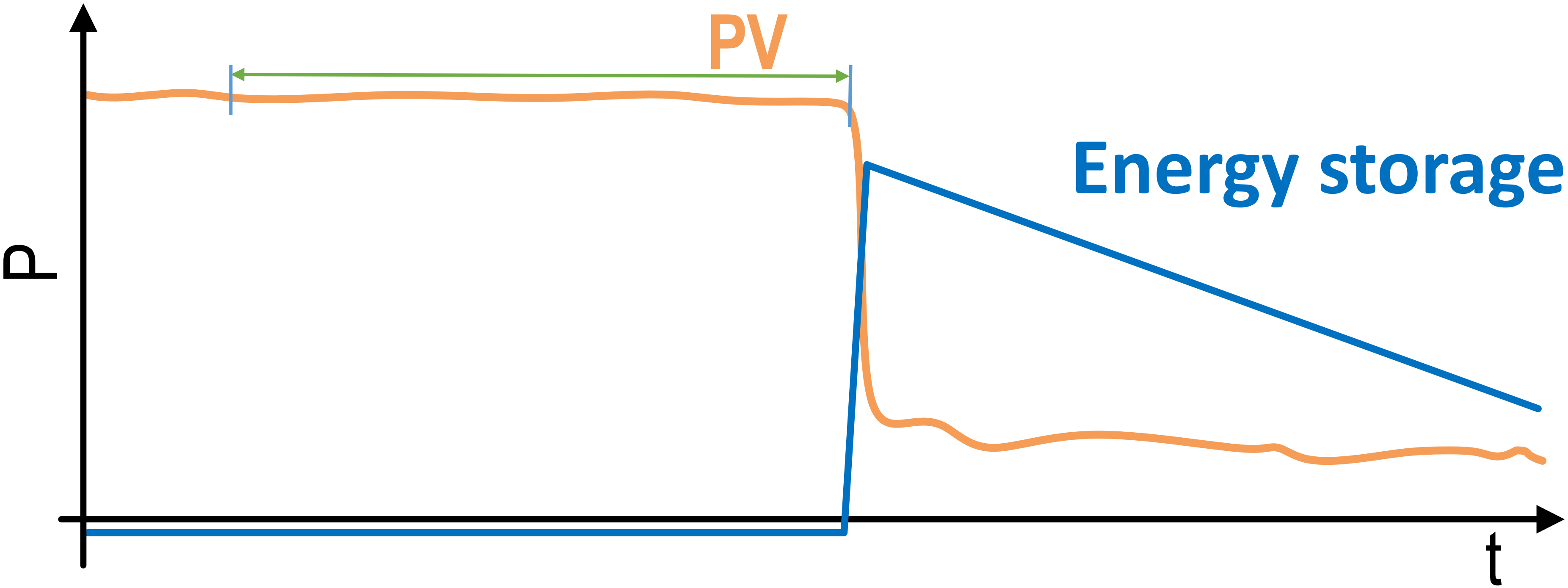
Cost!
Battery energy system

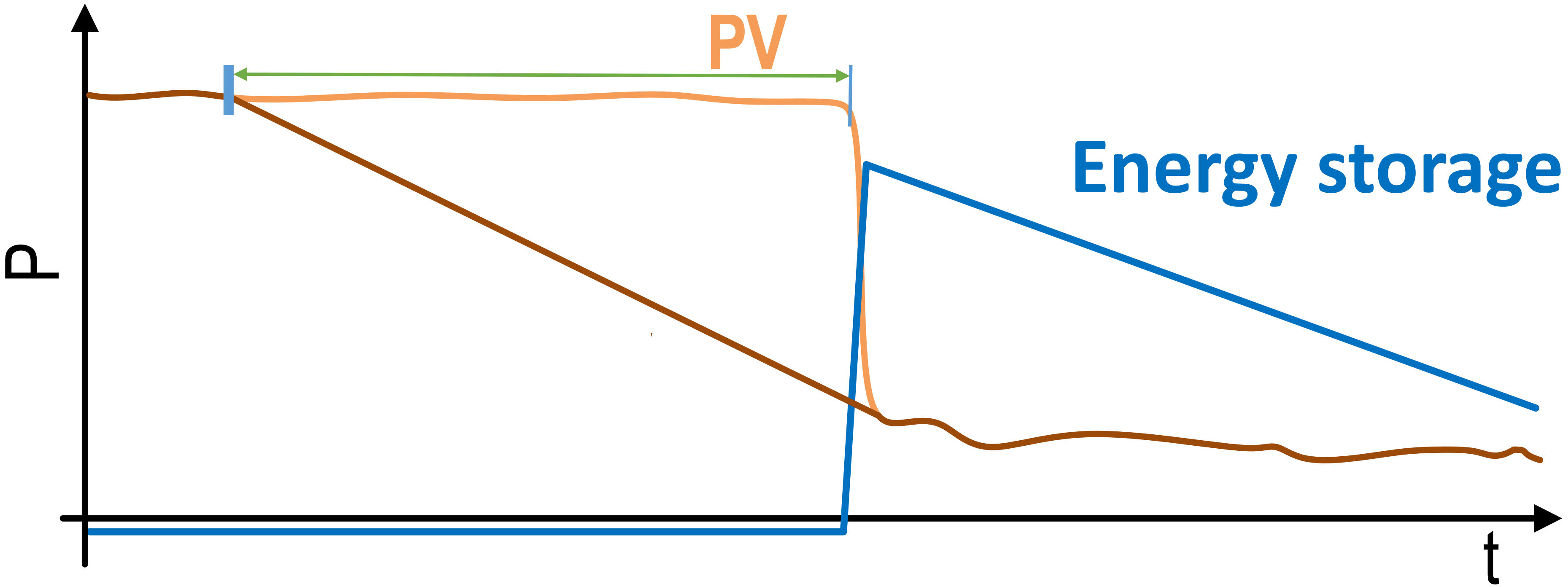
(1 – 3) €/W/Wh

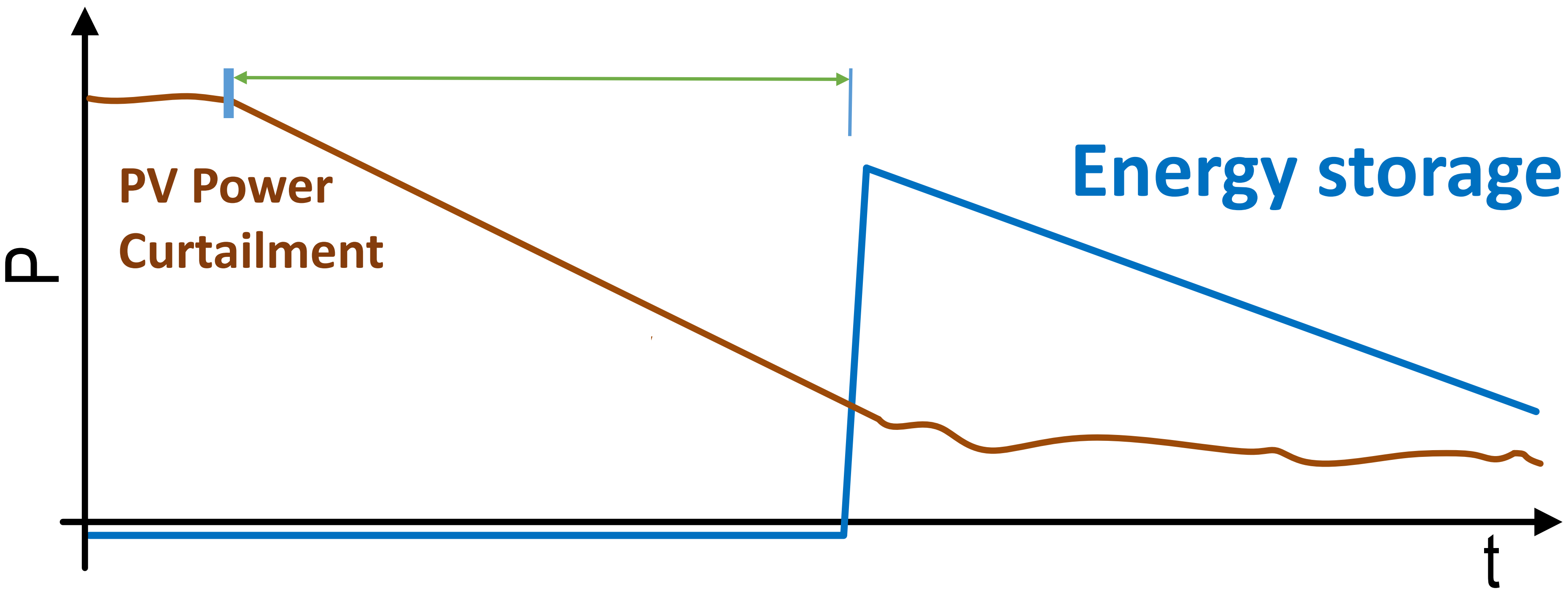
MW → M€


PV
P
t


PV
Energy storage
P
t

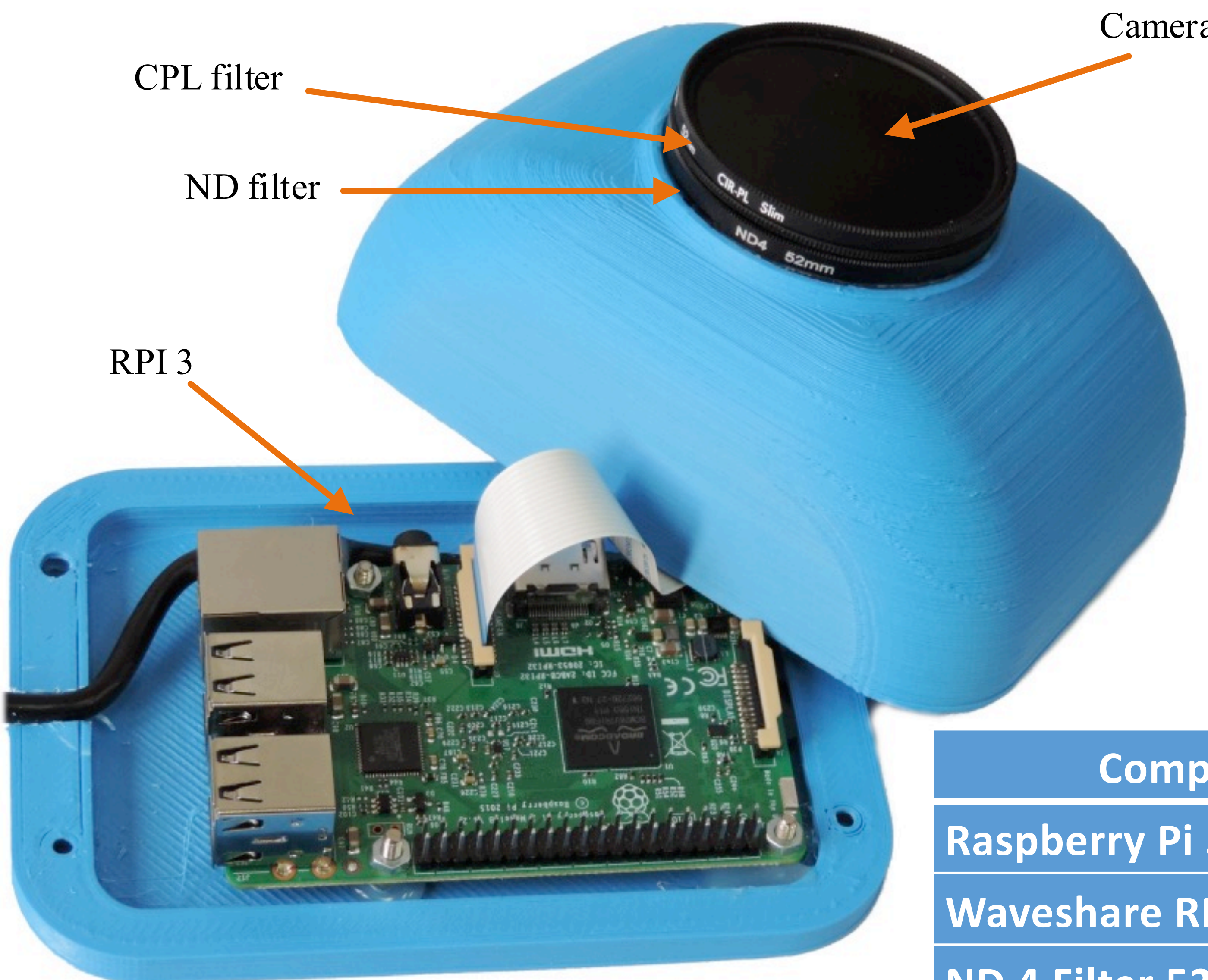

PV
Energy storage
P
t


PV
Energy storage
P
t

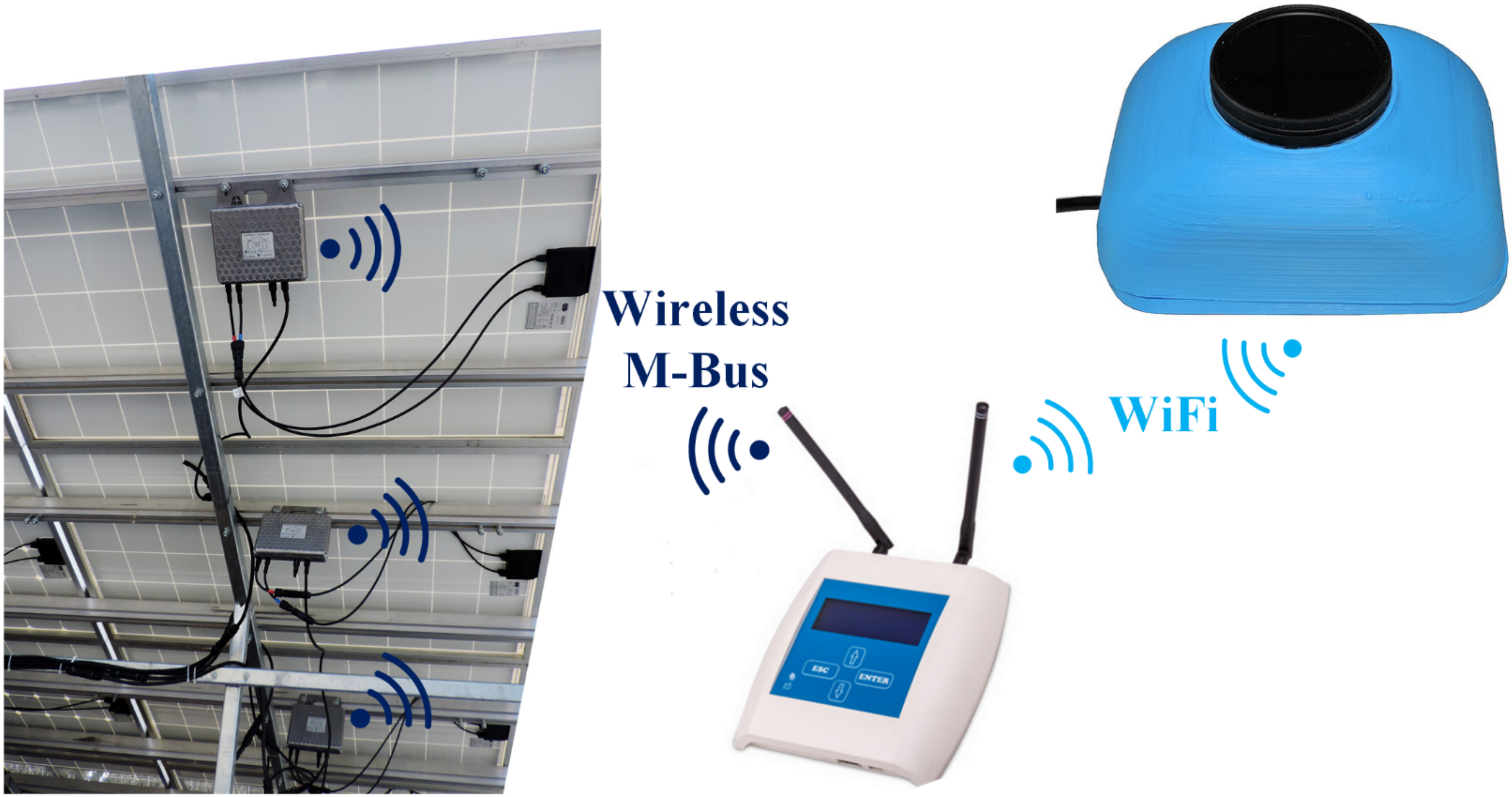

P
PV Power
Curtailment
Energy storage
t

Solution?

Cloud passing forecast system



Component	price
Raspberry Pi 3 Model B	34 €
Waveshare RPi Camera (G)	29 €
ND 4 Filter 52 mm	3 €
CPL Filter 52 mm	4 €
Sum	70 €



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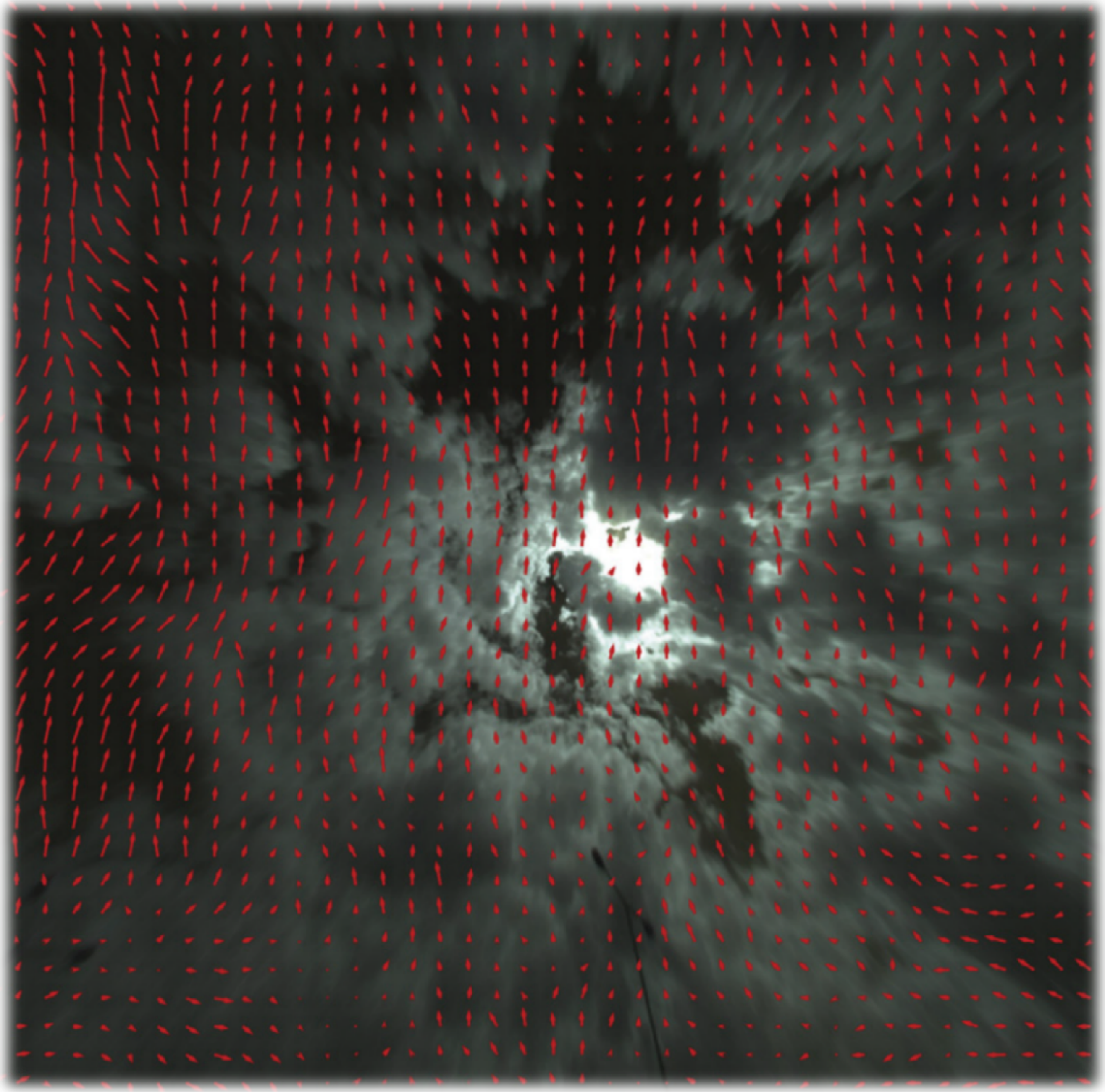
Algorithm



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Voltage fluctuations

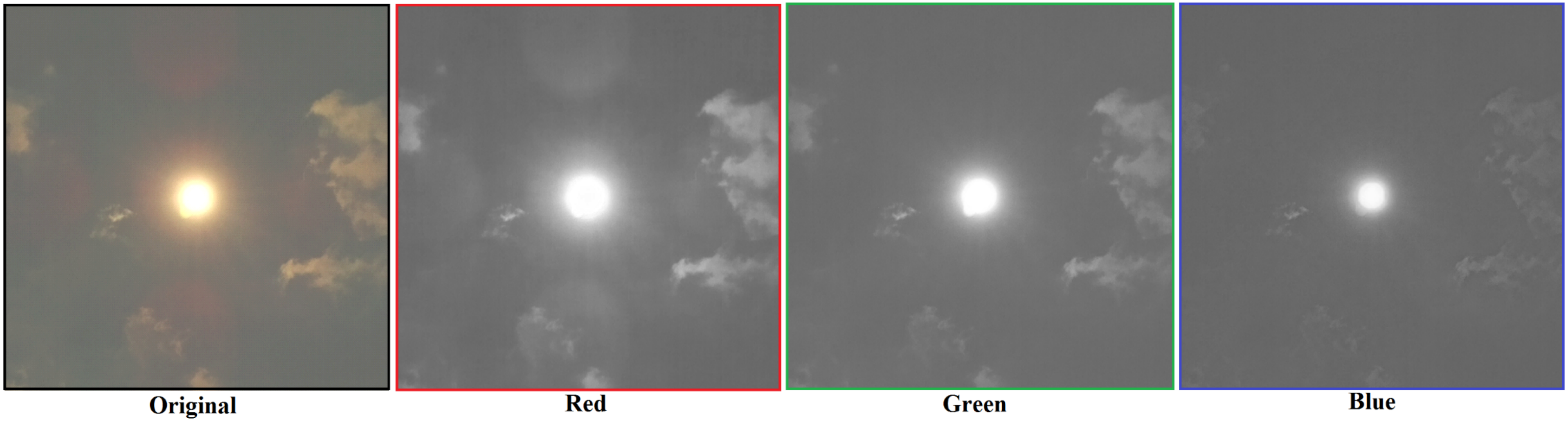
Sun recognition

$$green(x,y)+blue(x,y)>500$$

$$x_{ave\_sun}=\frac{\sum_{x_{start}}^{x_{end}} x_{p\_sun}}{n_{p\_sun}}$$

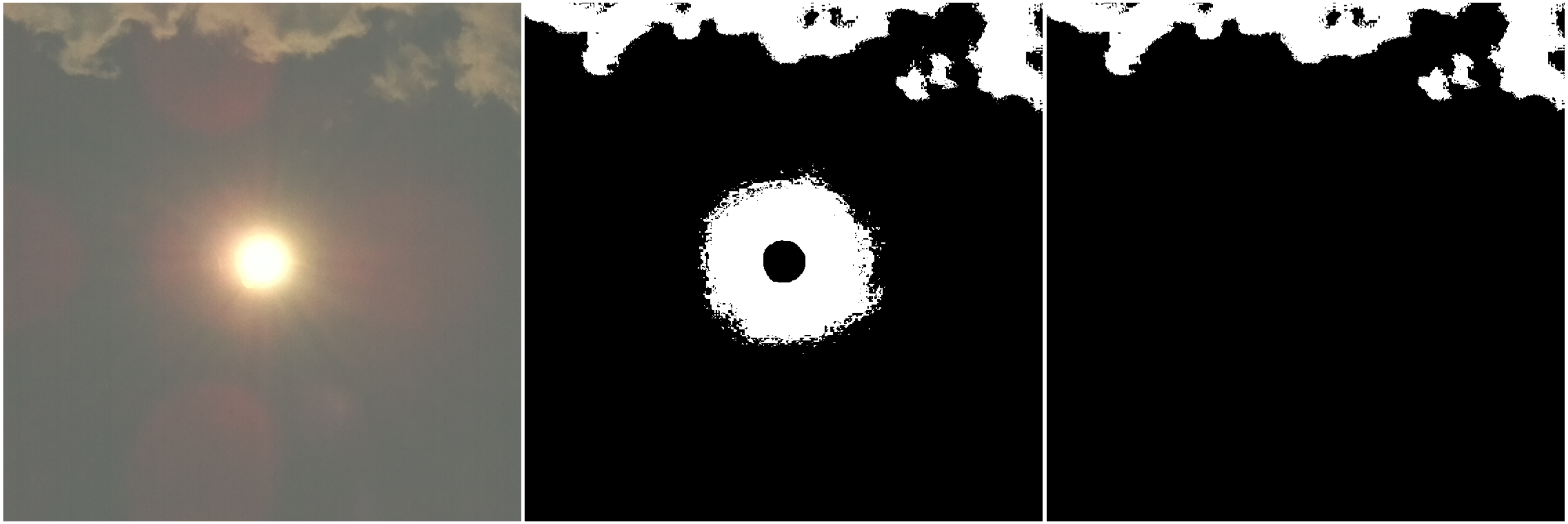
$$y_{ave\_sun}=\frac{\sum_{y_{start}}^{y_{end}} y_{p\_sun}}{n_{p\_sun}}$$

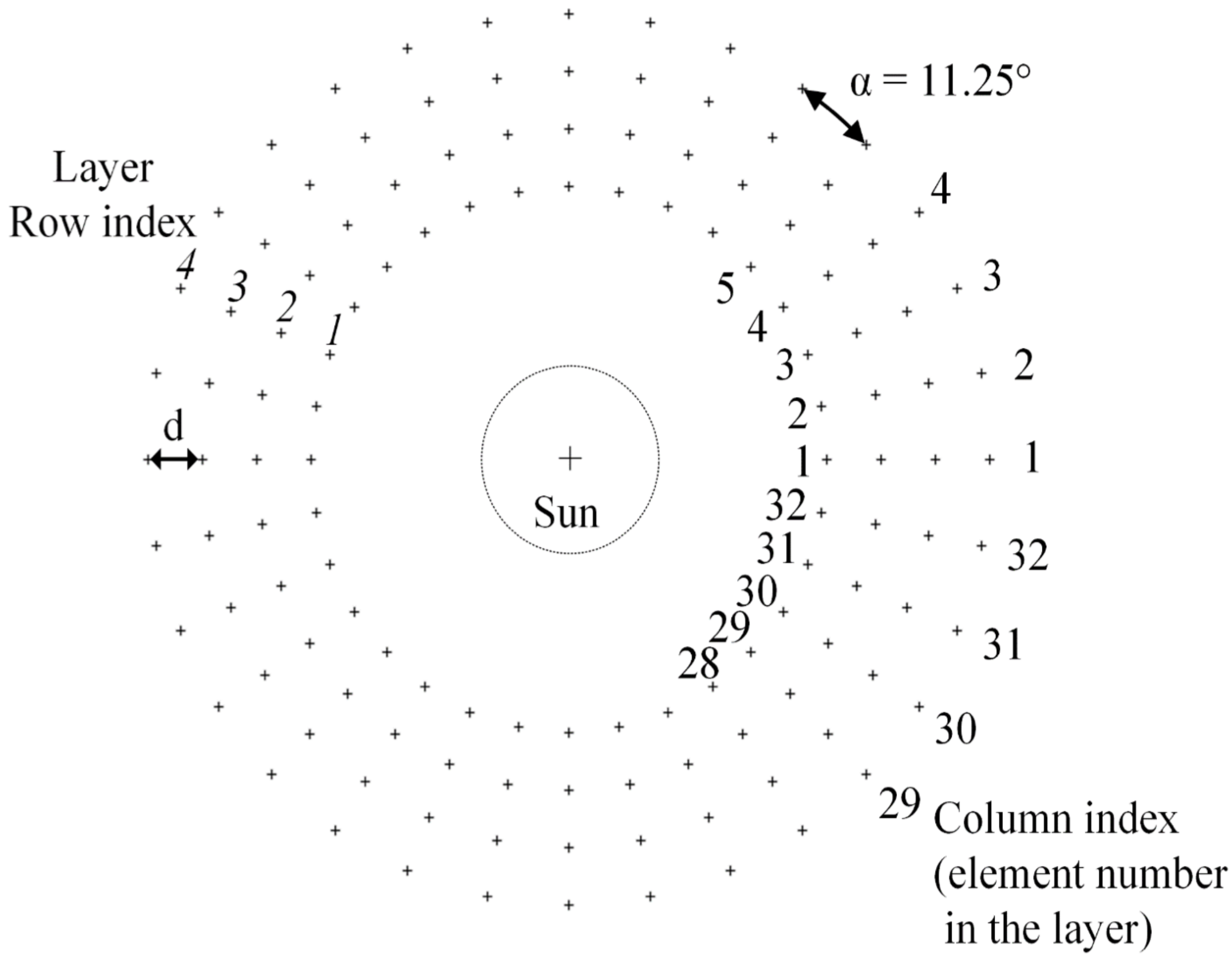
Cloud recognition

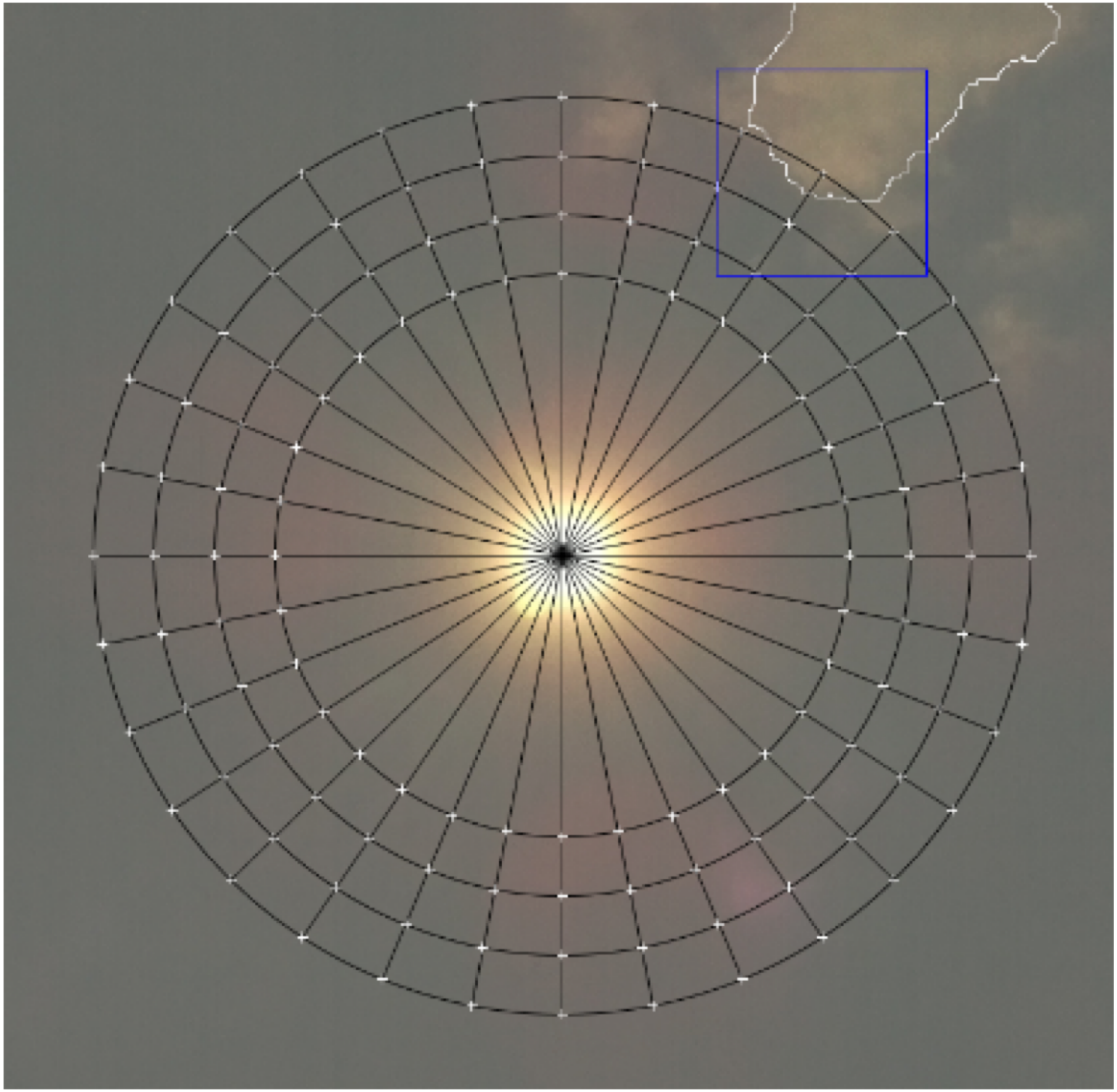


$$\frac{R}{B} > RBR_{lim}$$

$$\frac{G}{B} > GBR_{lim}$$




α = 11.25°
Layer
Row index
4
3
2
1
d
Sun
5
4
3
2
1
32
31
30
29
28
4
3
2
1
32
31
30
29
Column index
(element number
in the layer)



$$x_{ave\_p} = \frac{\sum_{x_{start}}^{x_{end}} x_p}{n_p}$$

$$y_{ave\_p} = \frac{\sum_{y_{start}}^{y_{end}} y_p}{n_p}$$

$$x_{ave_{p\_r}}(i-1) = x_{ave_p}(i-1) - x_{sun}$$

$$y_{ave_{p\_r}}(i-1) = y_{sun} - y_{ave_p}(i-1)$$

$$x_{ave_{p_r}}(i) = x_{ave_p}(i) - x_{sun}$$

$$y_{ave_{p_r}}(i) = y_{sun} - y_{ave_p}(i)$$

$$x_v = x_{ave_{p\_r}}(i-1) - x_{ave_{p_r}}(i)$$

$$y_v = y_{ave_{p\_r}}(i-1) - y_{ave_{p_r}}(i)$$

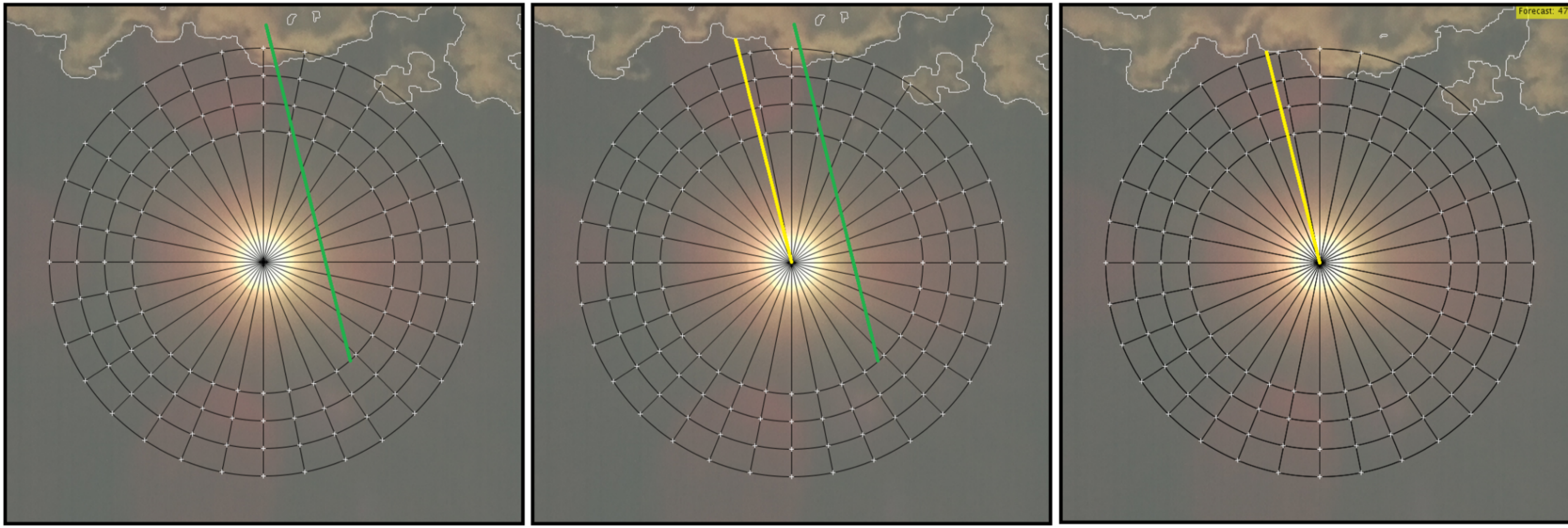
$$\gamma = \arctan\left(\frac{y_v}{x_v}\right) \cdot \frac{180}{\pi} \qquad ; x_v > 0$$

$$\gamma = (\arctan\left(\frac{y_v}{x_v}\right) + \pi) \cdot \frac{180}{\pi} \qquad ; (x_v < 0) \;\&\; (y_v \geq 0)$$

$$\gamma = (\arctan\left(\frac{y_v}{x_v}\right) + \pi) \cdot \frac{180}{\pi} \qquad ; (x_v < 0) \;\&\; (y_v < 0)$$

$$\gamma = 90 \qquad ; (x_v = 0) \;\&\; (y_v > 0)$$

$$\gamma = 270 \qquad ; (x_v = 0) \;\&\; (y_v < 0)$$

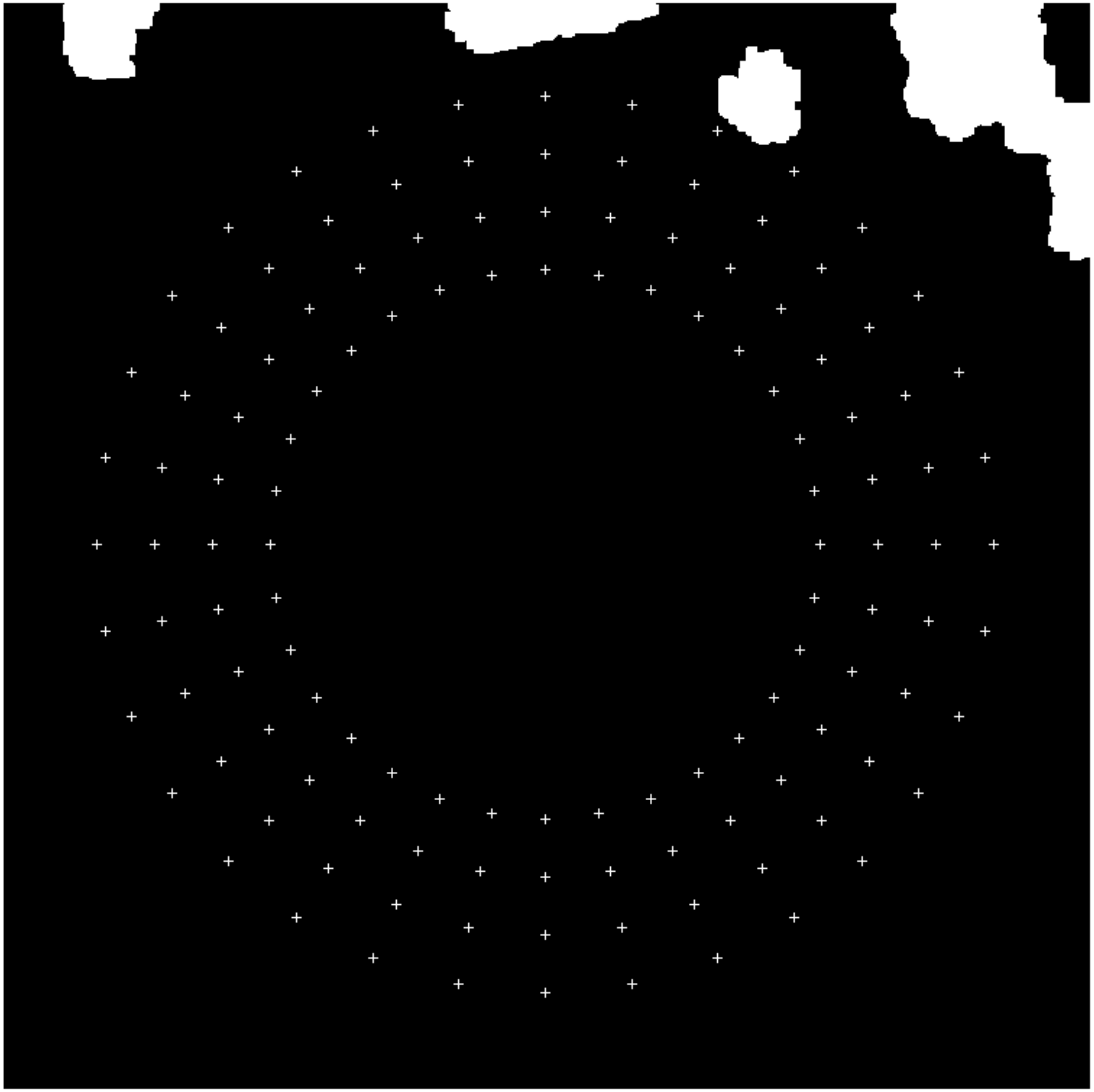

Forecast: 47

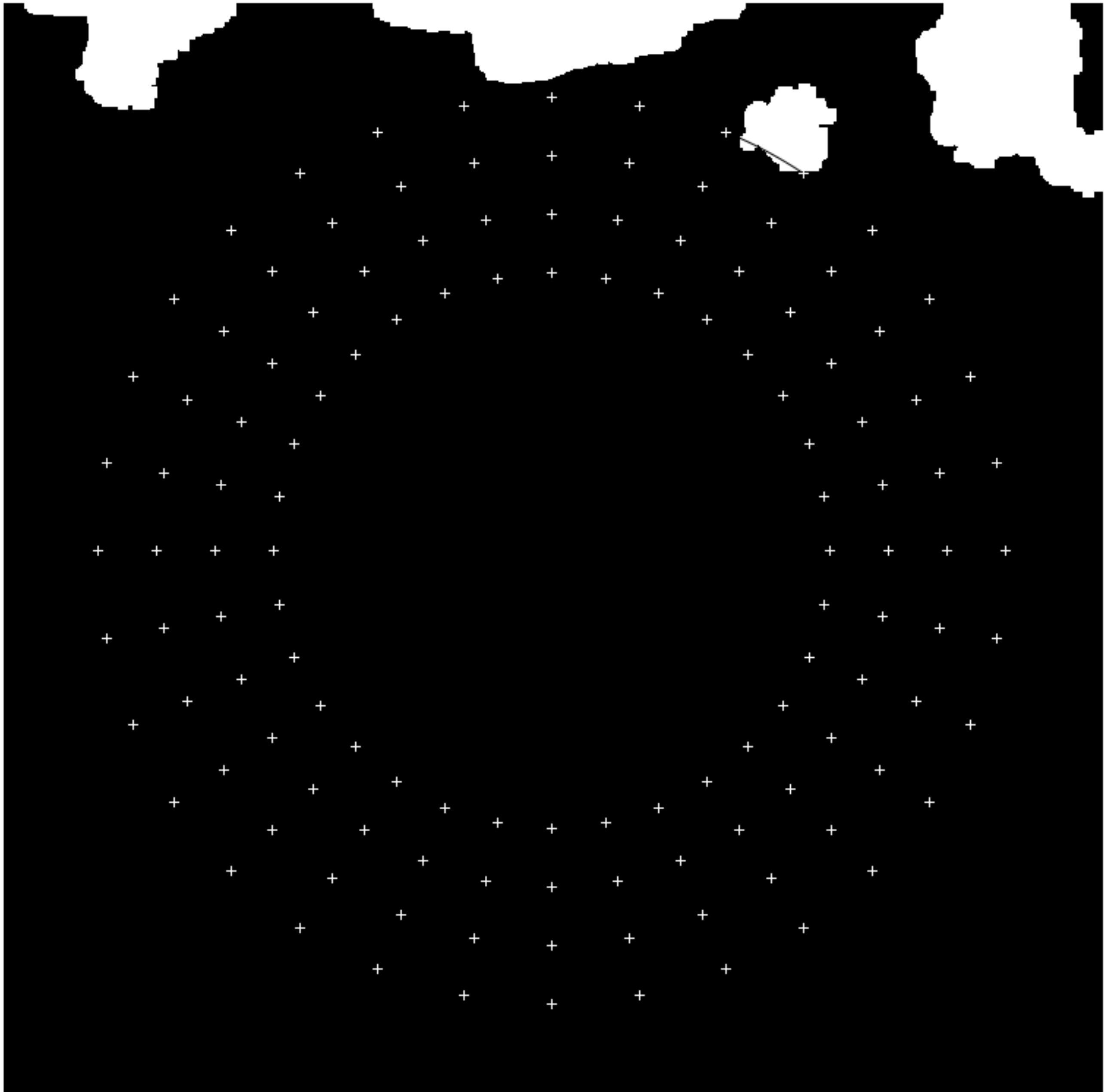
$$x_{cloud} = x_{sun} + \left\| \mathrm{d} \cdot \cos(\gamma) \right\|$$
$$y_{cloud} = y_{sun} + \left\| \mathrm{d} \cdot \sin(\gamma) \right\|$$

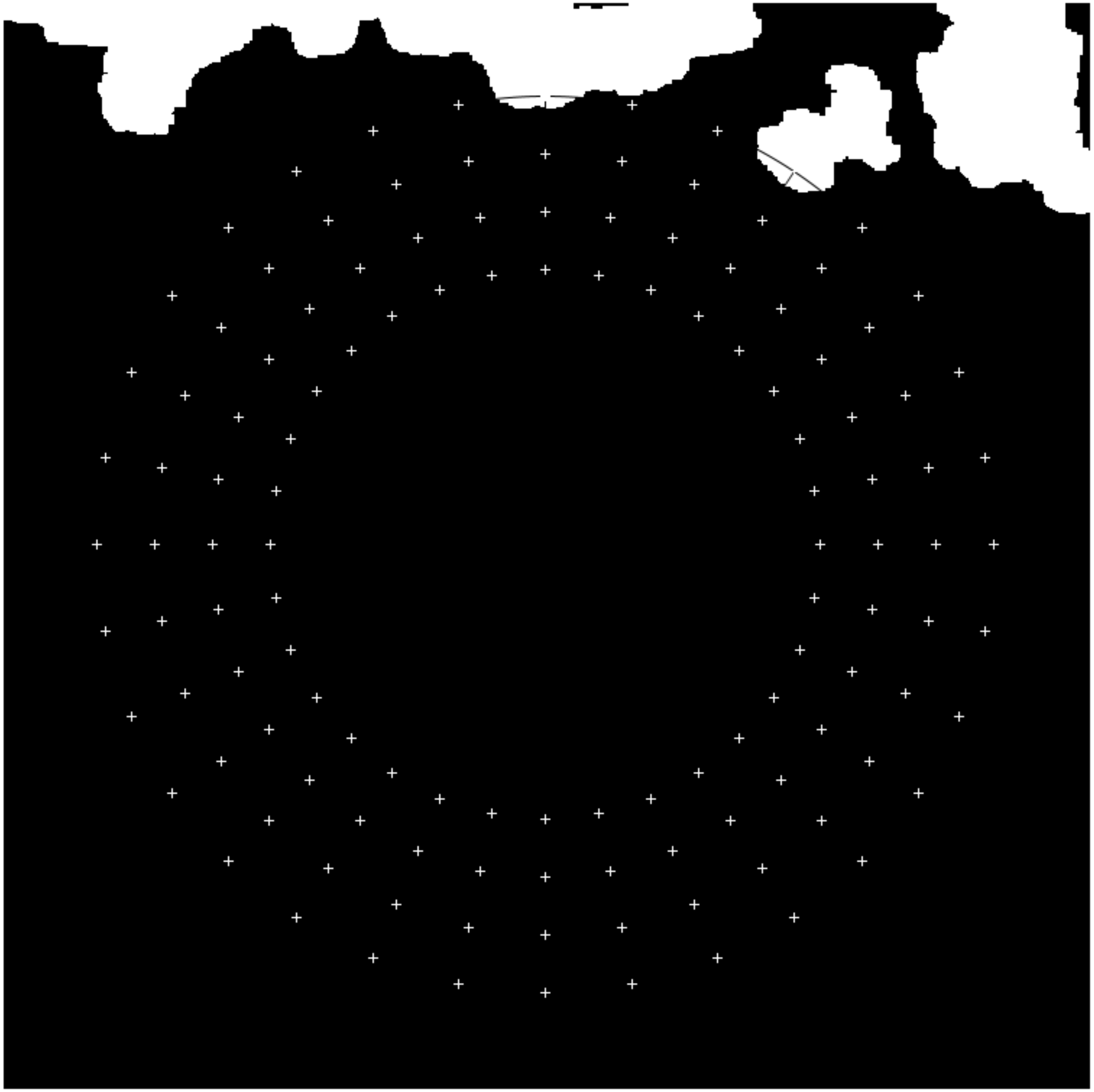
$$\left(d = r_{ignore},\ r_{ignore} + 1,\ \ldots,\ r_{lim} \right)$$

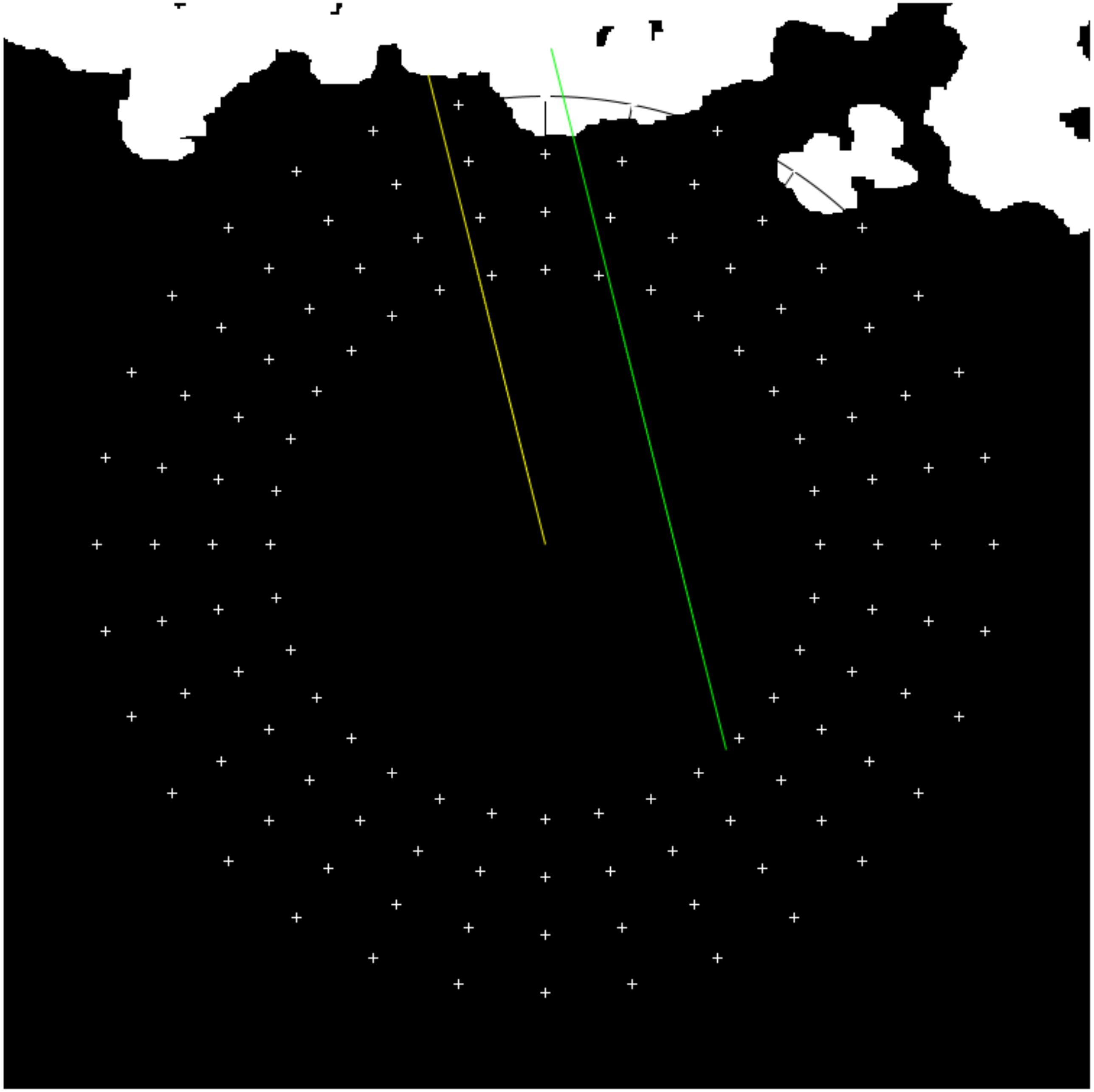
$$d_{cloud} = cloud\left(x_{cloud}, x_{cloud} \right) > 0$$

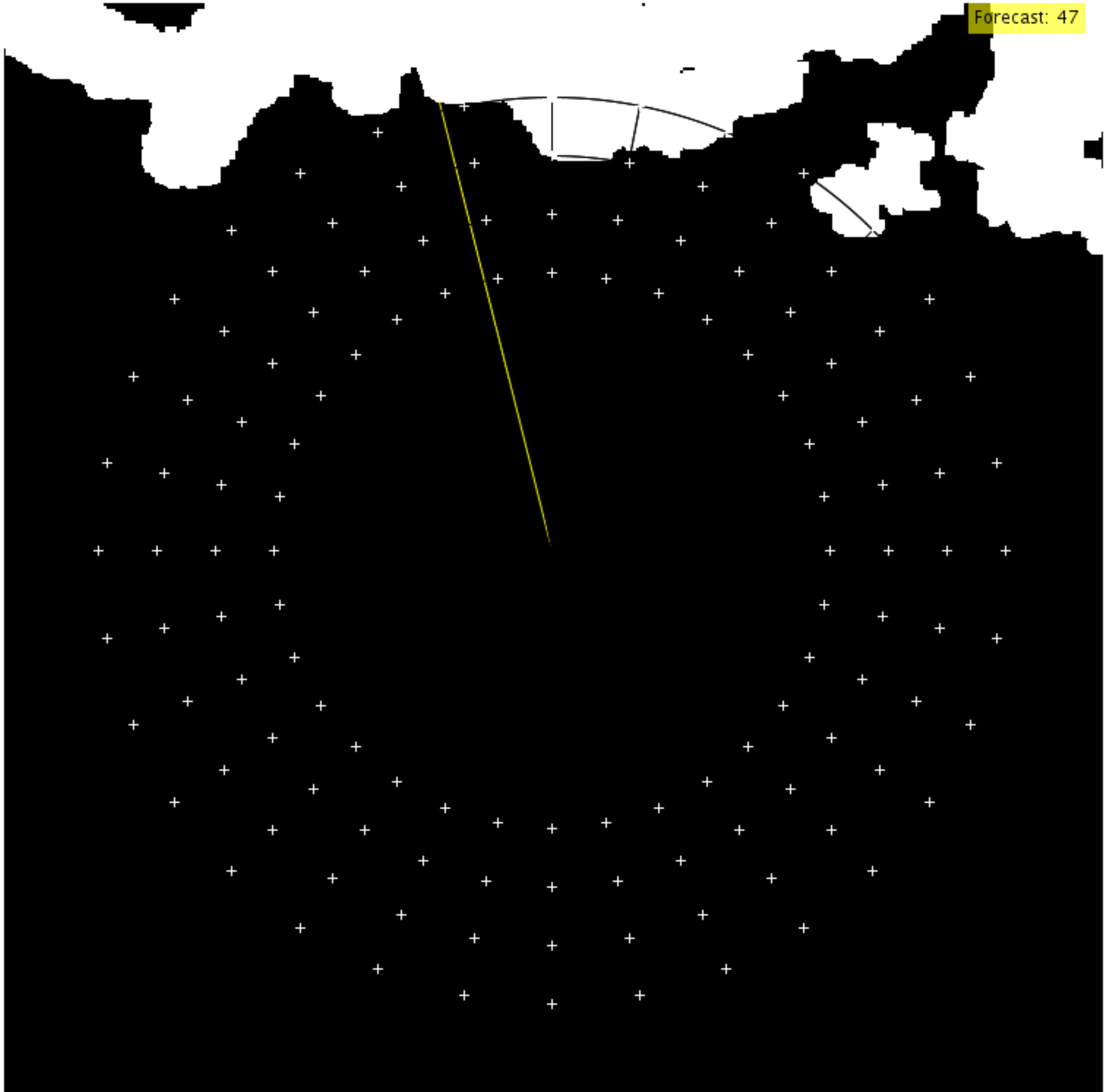
$$t_{prd} = \frac{t_p \cdot d_{(f-1)}}{d_{(f-1)} - d_{(f)}} \quad [s]$$

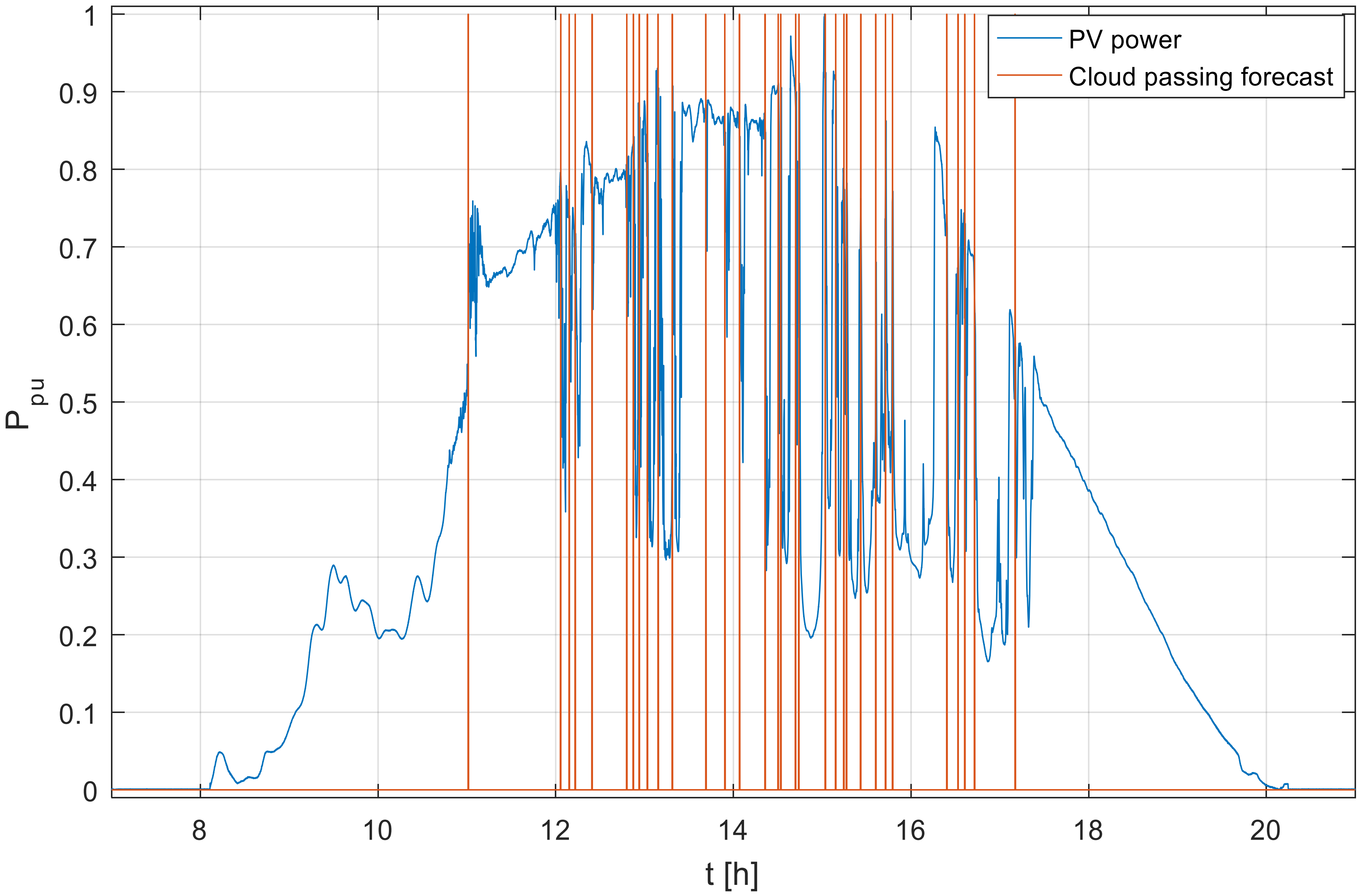




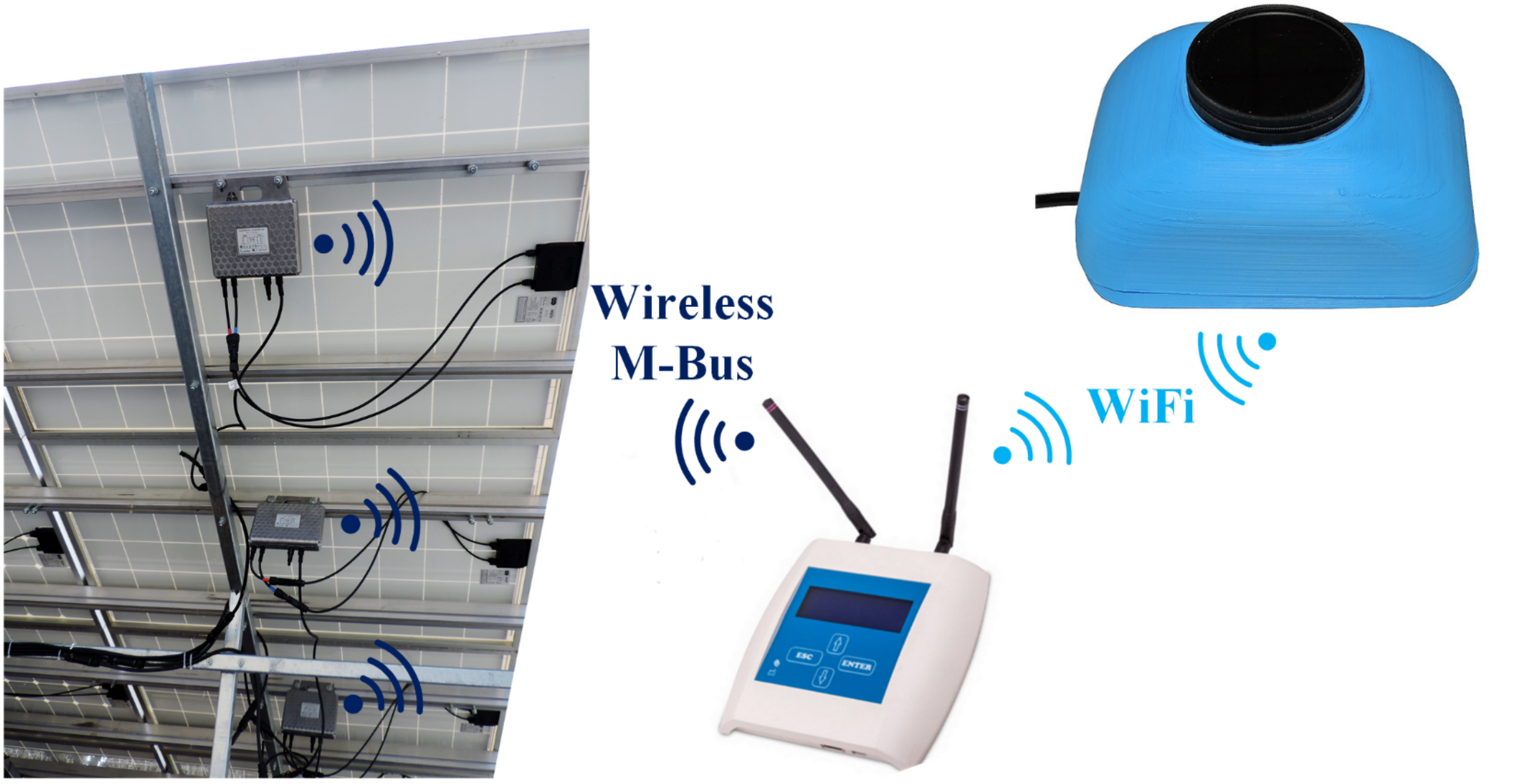


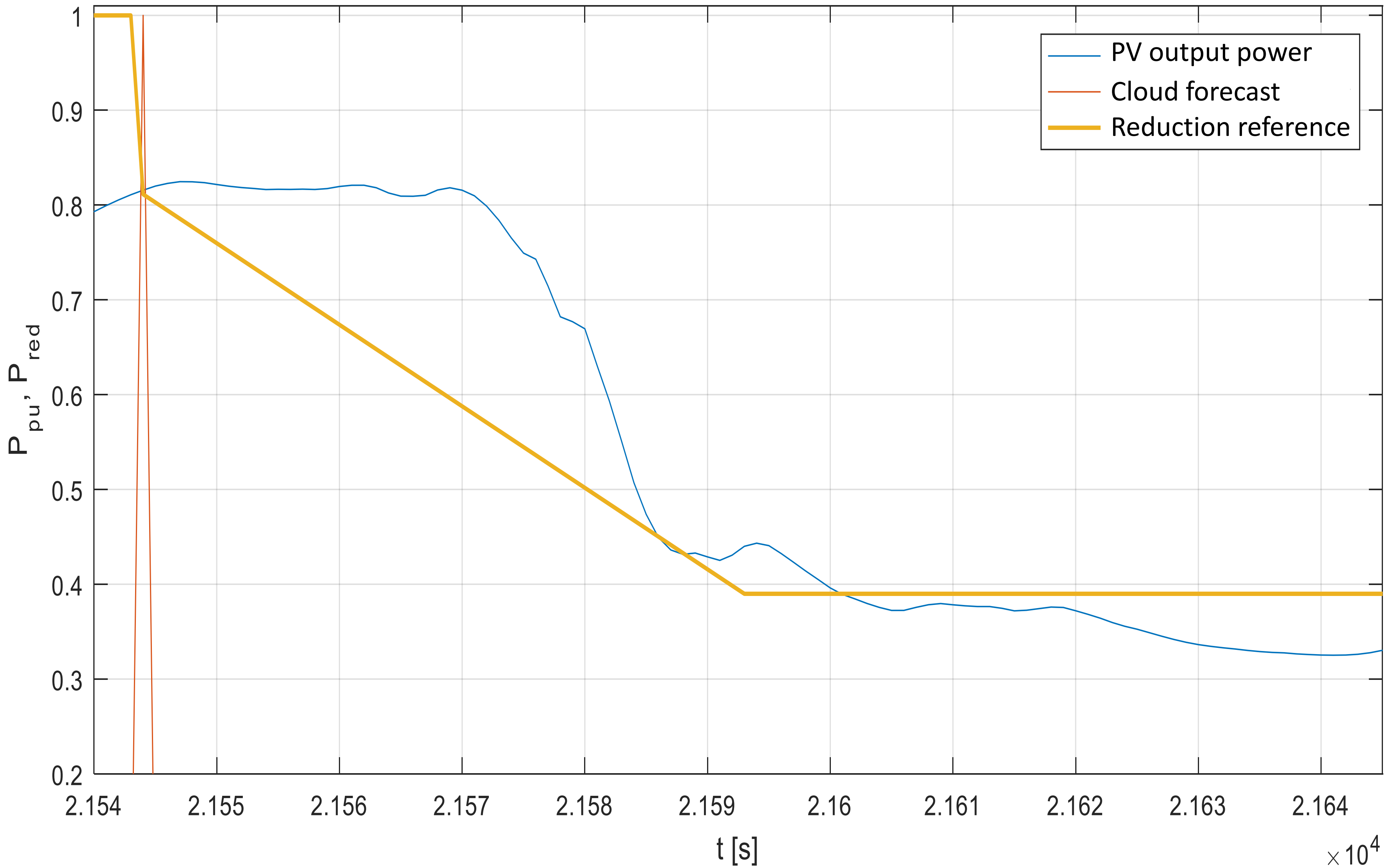



Forecast: 47


PV power
Cloud passing forecast
P_pu
t [h]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
8
10
12
14
16
18
20


HOTEL


Wireless
M-Bus
WiFi
ESC
ENTER



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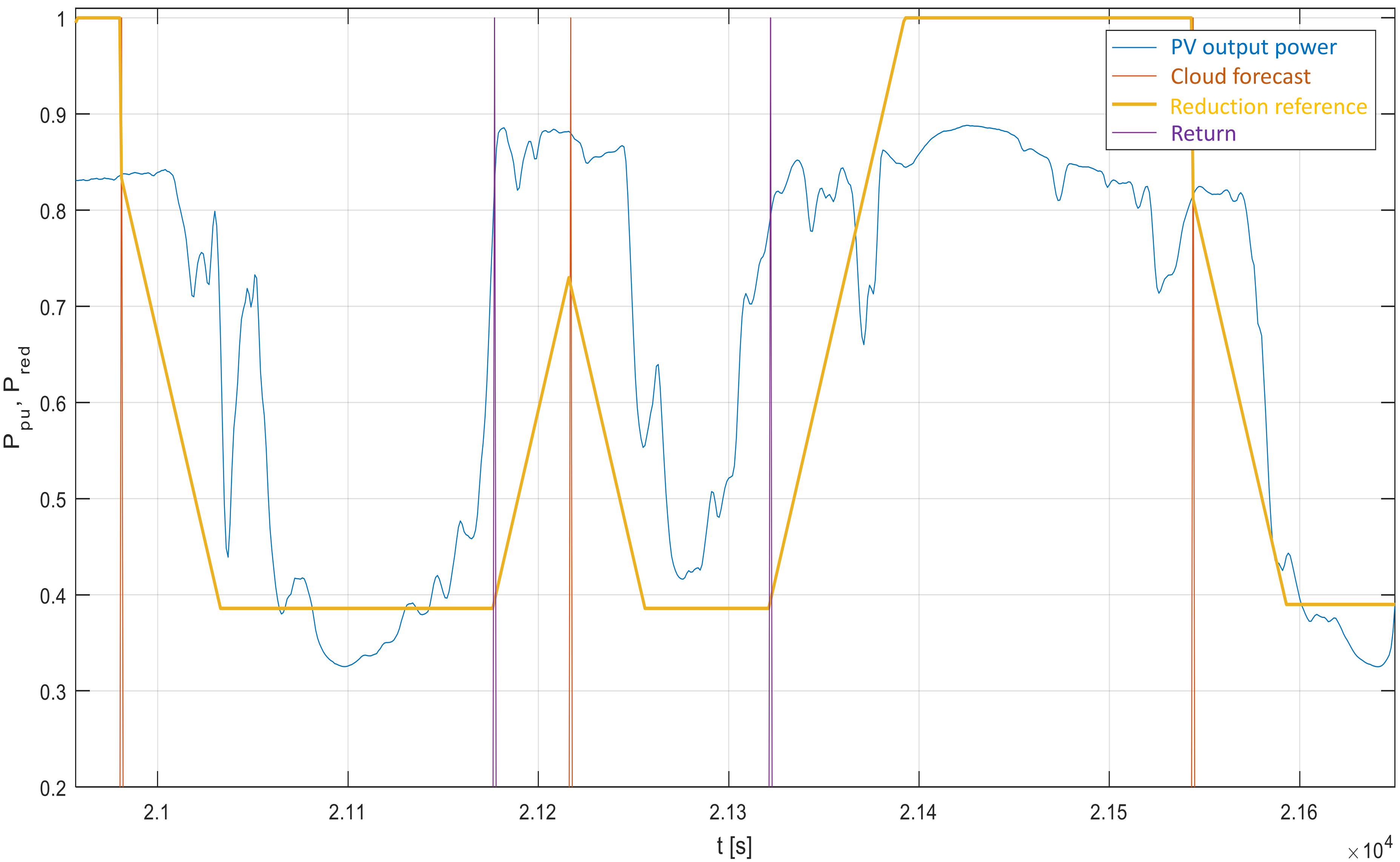
PV output power
Cloud forecast
Reduction reference
Return
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
P_{pu}, P_{red}
2.1
2.11
2.12
2.13
2.14
2.15
2.16
t [s]
$\times 10^4$

Conclusion

- Low-cost cloud passing forecast system
- Simple algorithm
- Effective solution