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A scheme for operating electrolysis system powered by a photovoltaic generation cooperated with a hydrogen refueling station

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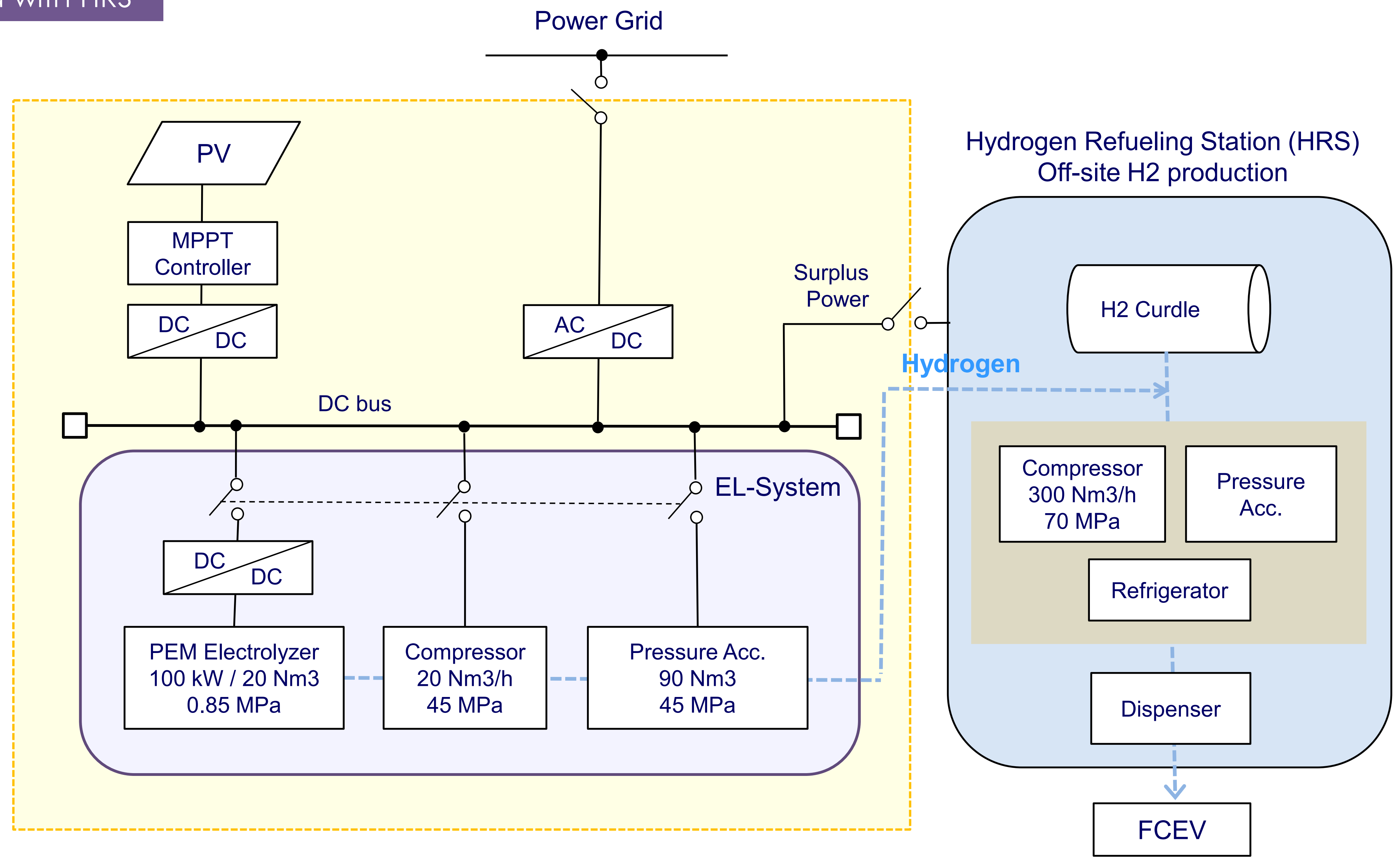
Contents

- Until March 2018, we developed an electrolysis system (EL-System),
  - ✓ A brief history on the EL-System
- Since April 2018, the second stage focuses on “Daily Operation Planning”,
  - ✓ Overlook a scheme for operating the EL-System
  - ✓ Defined an Operation Planning
  - ✓ Design a deriving method of the threshold X_{day}
  - ✓ Propose “Review & Revise” for daily operation scenarios
  - ✓ Survey an outlook of the Review & Revise

PV-powered Electrolysis System (Configuration)

Cooperated with HRS



EL-System and HRS (built up in March 2017)

Takasago Works, Kobe Steel Ltd.

KOBELCO
KOBE STEEL GROUP

Source: “Kobe Steel Ltd. Proposes Hydrogen Refueling Station using Renewable Energy Resources,” Leaflet of Kobe Steel Group

Small-scale experimental system (set up in June 2017)

Algae Biomass and Energy System R&D Center in Univ. of Tsukuba

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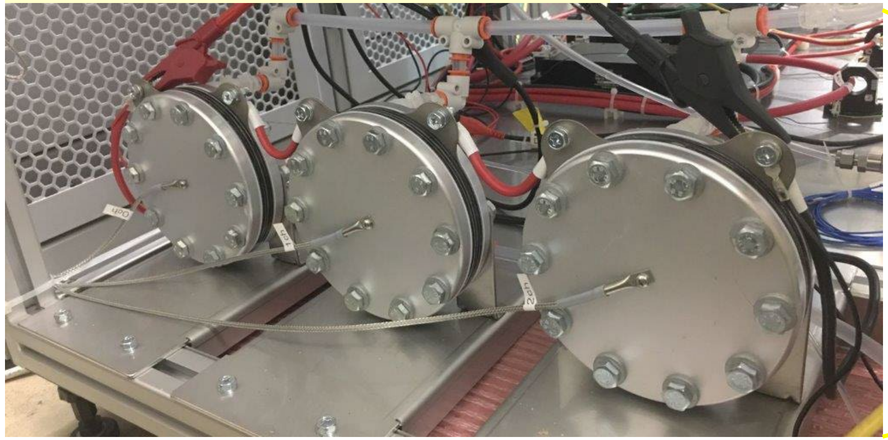
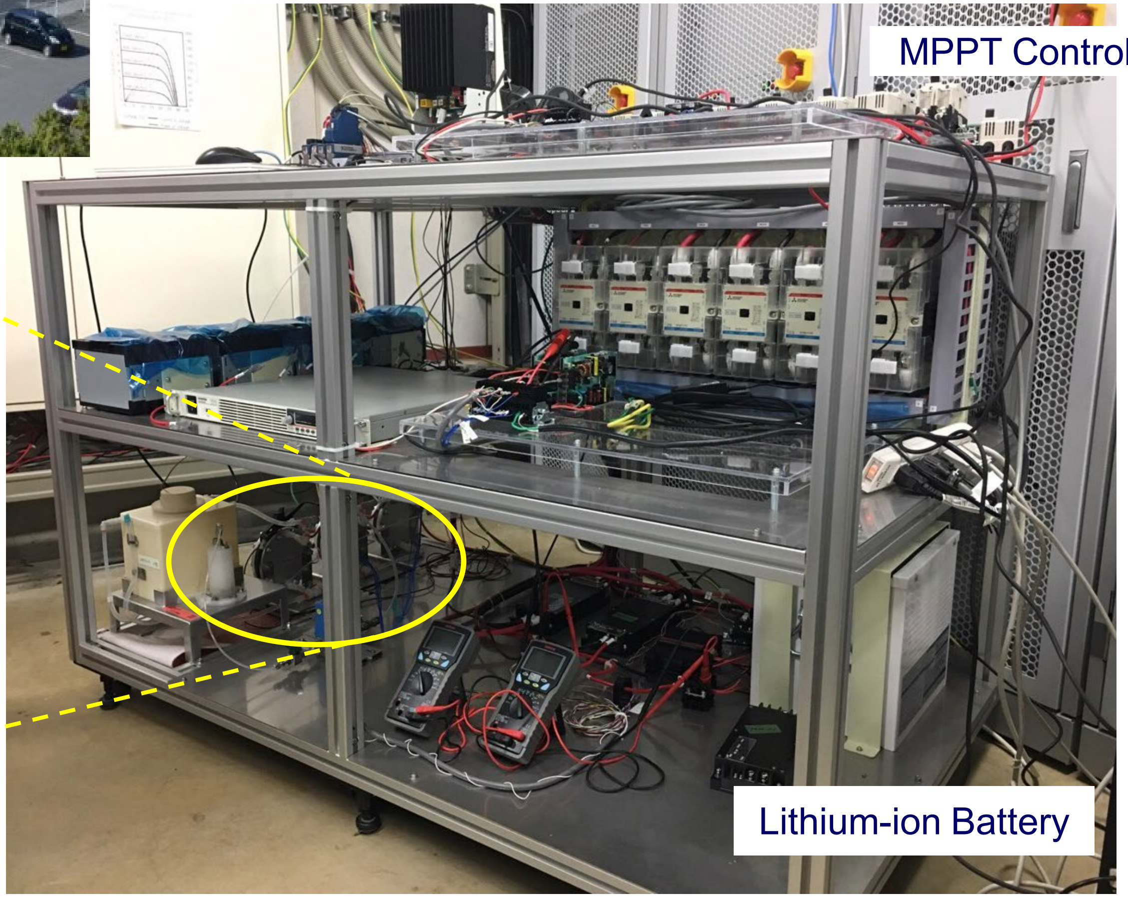
(Specifications)

PV System	**180 W × 2 (Ser.) × 4 (Pal.)**
PEM El. Stacks	**3 Stacks (2 Cells/Stack) 1.5 L/min**
Lithium Battery	**1.2 kWh (12 V)**
MPPT Controller	**Max 60 A (48 V)**

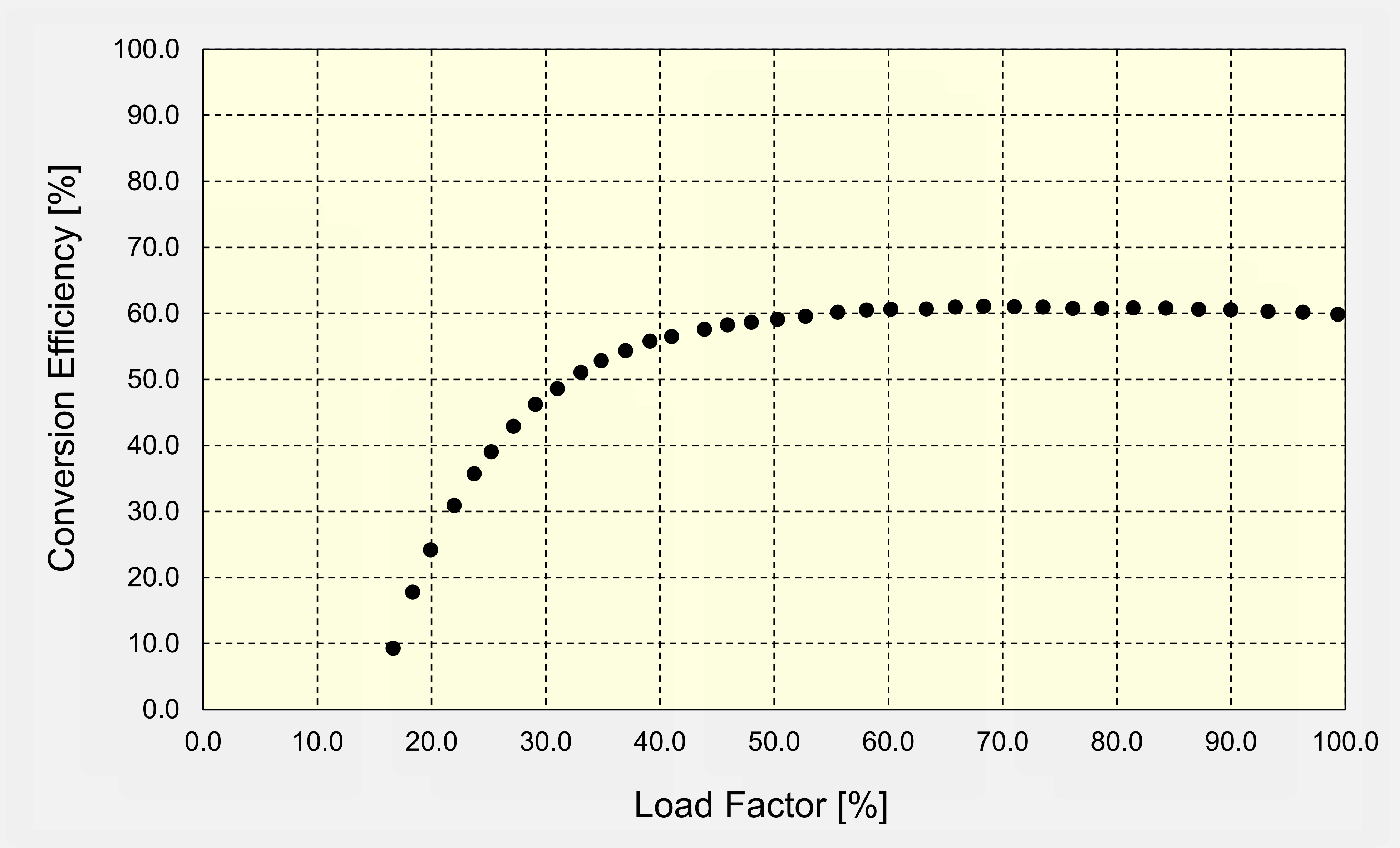
PEM Electrolysis Stacks





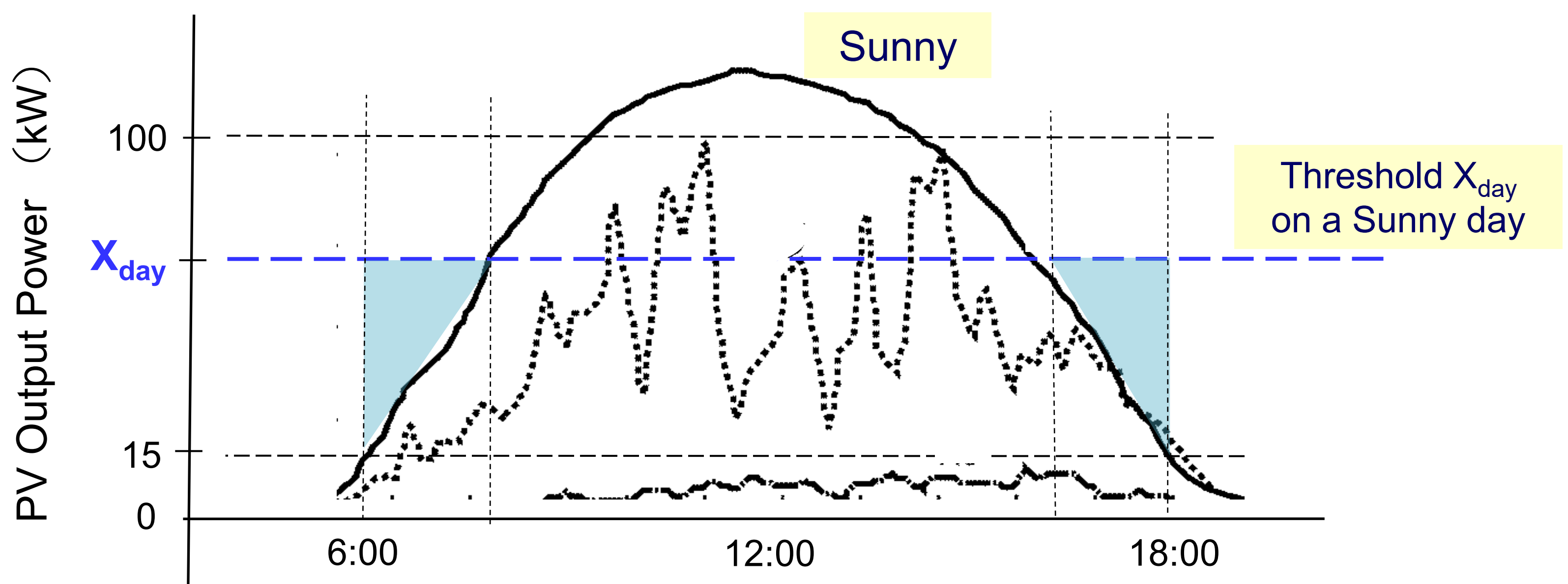
Characteristics of EL-System (modeling in January 2018)

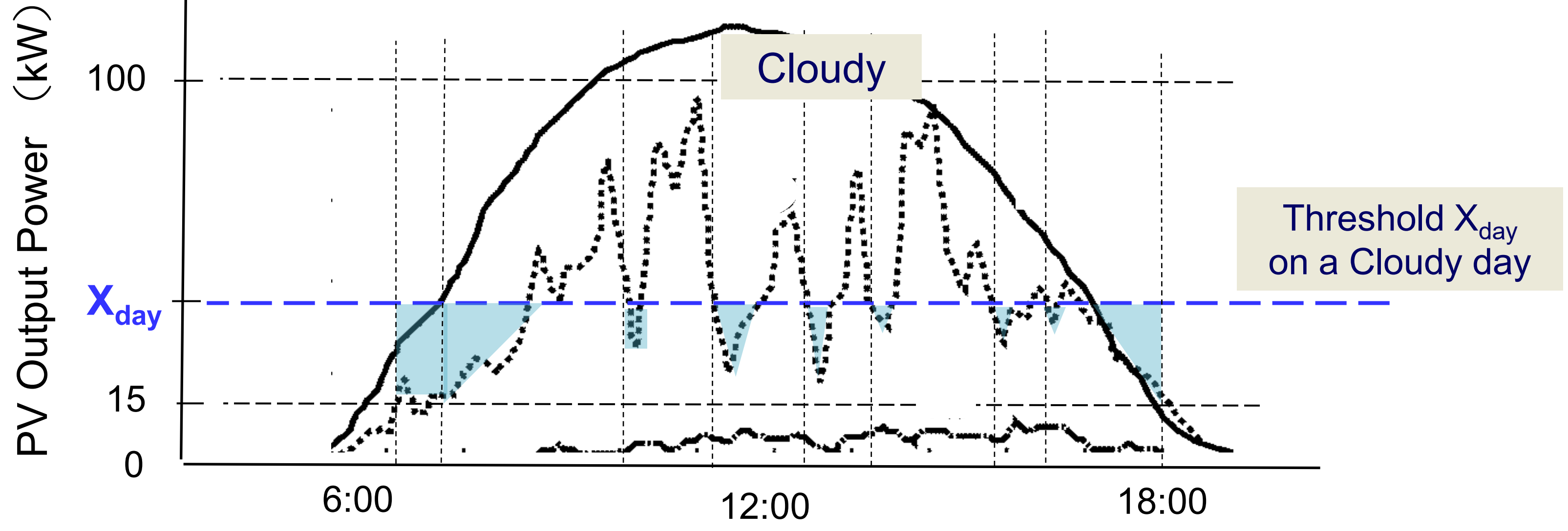
Estimated Conversion Efficiency based on measured data of the EL-System



An operational strategy, “Power Leveling” (proposed in Jan. 2018)

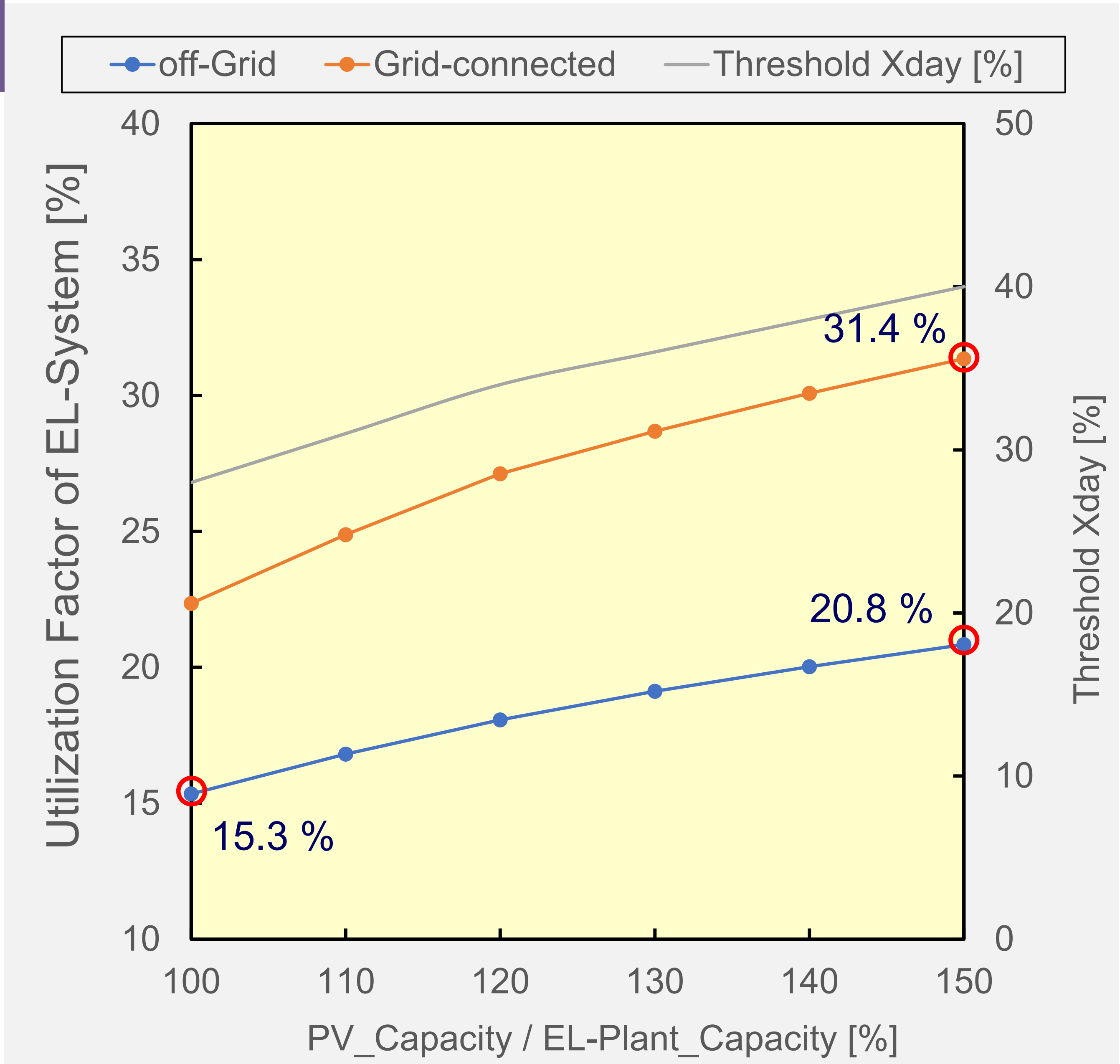
By the power grid





Effects of Capacity Planning and Power Leveling (in March 2018)

Improving the utilization factor

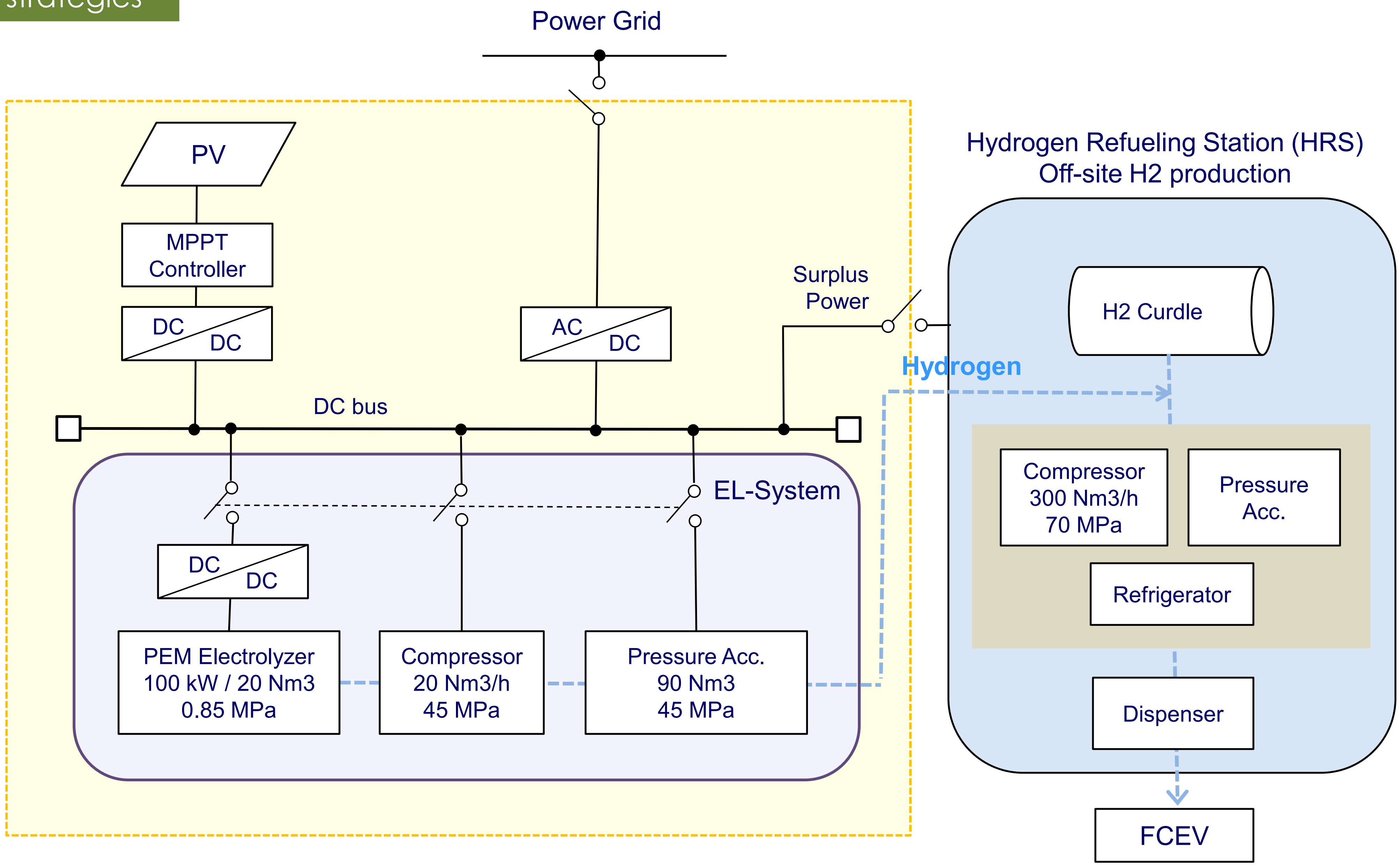


Effect of Power Leveling reducing CO2 emissions

Effect of Oversizing the PV capacity

The second stage, Daily Operation Planning (since April 2018)

To meet the strategies



Overlook a scheme for operating EL-System

A framework of energy conversion system

Layers		*Options*	*EL-System*
Operation Strategy		Min. CO2 Emission / Max. Utilization Factor / Min. Levelized Cost of Energy	Max. Utilization Factor restricted by CO2 Emission
Plan / Assess / Amend	Before the operation	Planning with predicting Insolation / Planning with Weather forecast	Planning according to prediction data
	Under the operation	Based on the insolation between Sunrise and Culmination, Review & Revise the plan	At the time of Culmination Review & Revise
	After the operation	Based on the insolation between Sunrise and Sunset, Review the plan, and Calculate “Weighting-Factor (WF)”	After the work Daily review
Grid Interconnection		One-way flow / Two-way flow (Reverse power flow)	One-way flow compensating PV by the grid
Operation Mode	Running Time	Continuous Operation / Daily Start-and-Stop (DSS) Op.	DSS including Cold start
	Operating Load	Full-load (ON/OFF) Operation / Part-load Op.	Part-load including Hot-standby
Energy Conversion		Power-to-Hydrogen ［Alkaline / PEM / SOEC］	PEM Electrolysis (100 kW / 20 Nm3/h)
Input Energy Resources		PV / Wind / ・・・・・ / Power Grid	PV & Power Grid including radiation-power factor

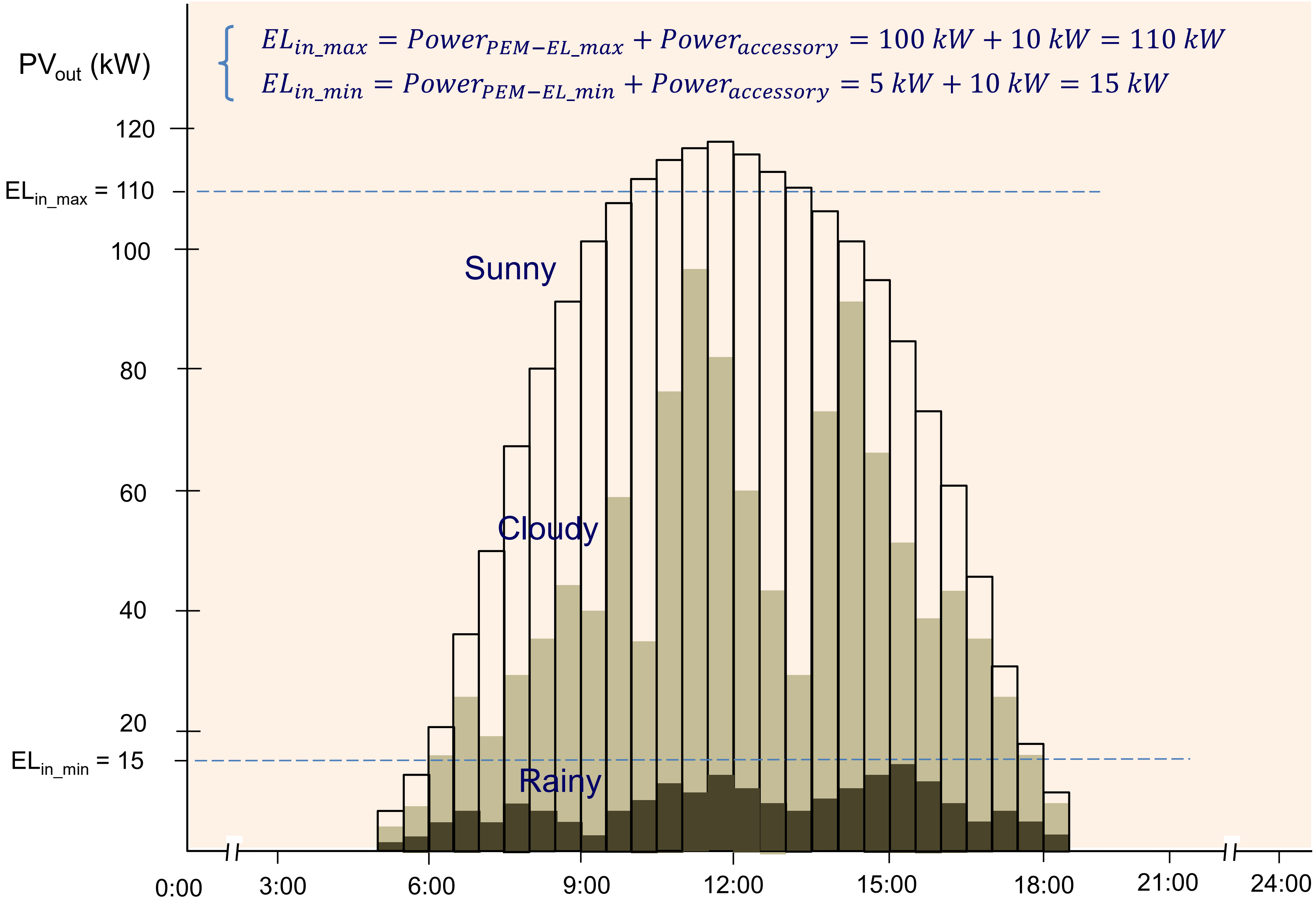
Prediction Data (Insolation, Weather forecast)

Estimate a PV generation profile next day

Prediction Data (Example)	Insolation Prediction (Commercial Service)	Weather Forecast (JMA)
Types of information	Total Solar Irradiance (TSI)	temperature, wind, precipitation, cloudiness, etc.
Delivery time and frequency	At 4:00, 10:00, 16:00, 22:00 o'clock 4 times per day	At 5:00, 11:00, 17:00 o'clock 3 times per day
Time range	Within 65 hours every 30 minutes	Within 24 hours every 3 hours
Spatial range	Reginal area (in Japan)	Prefectural area (in Japan)
Delivery method	Online service	Broadcasting

Estimate a "PV generation profile" based on the prediction data

Using Insolation prediction data



Operation planning is to fix the threshold X_{day}

Mathematical model of Power Leveling

Relations between Input power (EL_{in}) and Threshold X_{day}

$EL_{in}(t, X_{day})$: Input power of the EL-System in the case of threshold X_{day} (%) (kW)

$PV_{out}(t)$: PV generation power (kW)

$Grid(t)$: Input power from the grid (kW)

$$Threshold = X_{day}\ (\%)$$

$$EL_{in}(t, X_{day}) = \begin{cases} EL_{in\_max} & : PV_{out}(t) > EL_{in\_max} (= 110\ kW) \\ PV_{out}(t) & : X_{day} \cdot EL_{in\_max} < PV_{out}(t) \leq EL_{in\_max} \\ X_{day} \cdot EL_{in\_max}{}^{(*)} & : EL_{in\_min} < PV_{out}(t) \leq X_{day} \cdot EL_{in\_max} \\ 0\ kW & : PV_{out}(t) \leq EL_{in\_min} (= 15 kW) \end{cases}$$

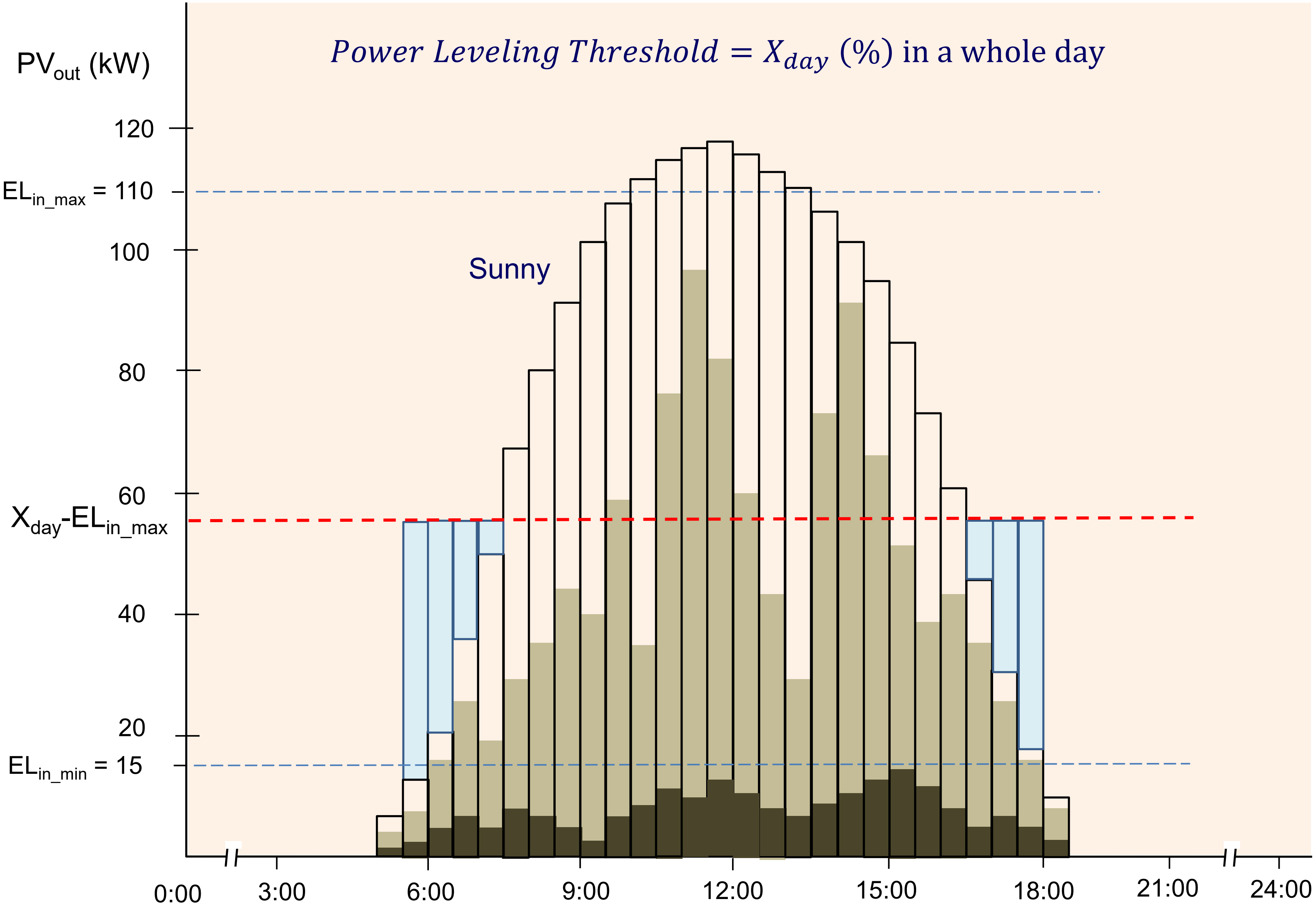
$$(*)\ X_{day} \cdot EL_{in\_max} = PV_{out}(t) + Grid(t)$$

$$EL_{in\_max} = Power_{PEM-EL\_max} + Power_{accessory} = 100\ kW + 10\ kW = 110\ kW$$

$$EL_{in\_min} = Power_{PEM-EL\_min} + Power_{accessory} = 5\ kW + 10\ kW = 15\ kW$$

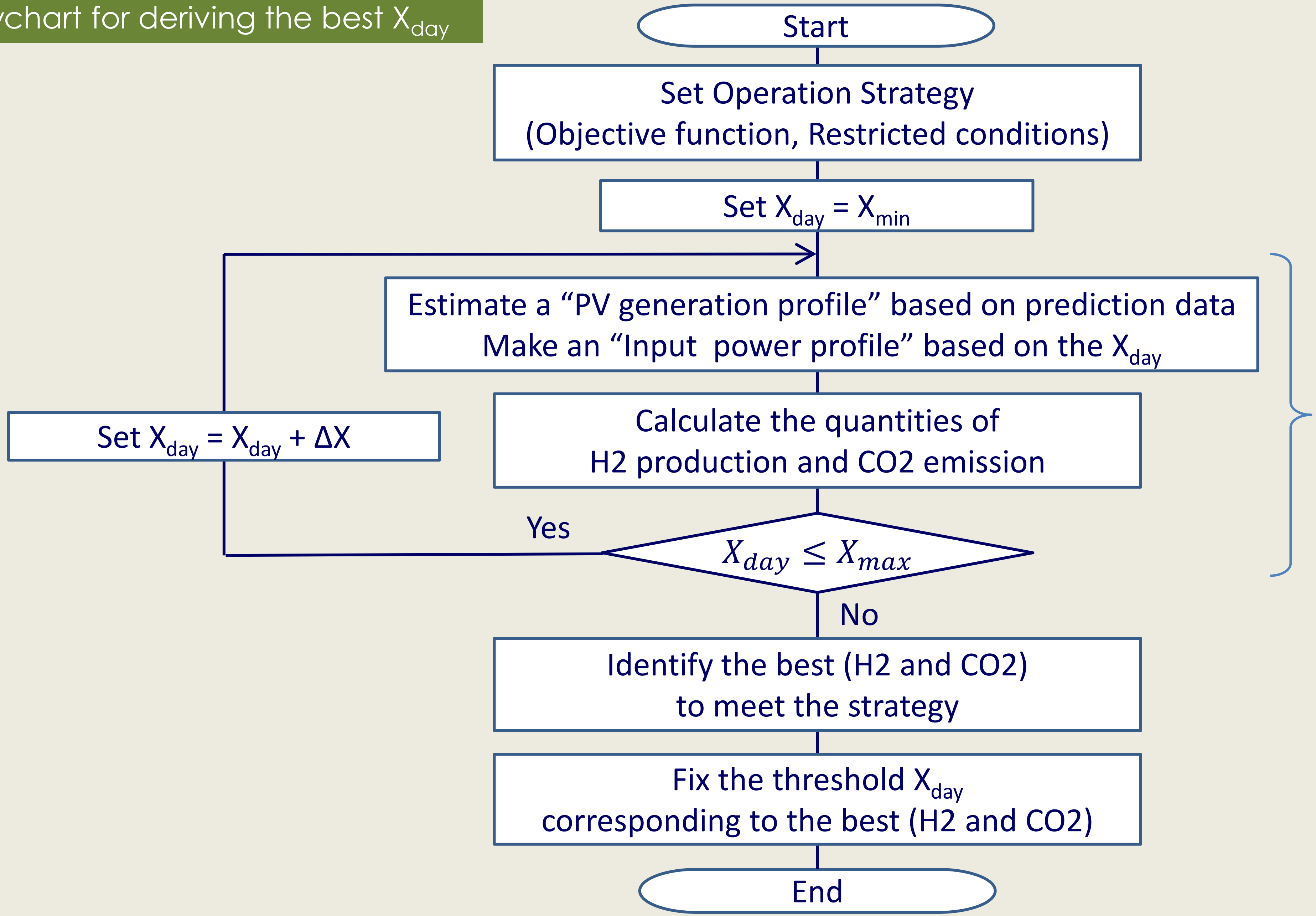
Make an "Input power profile" based on the threshold X_{day}

Using insolation prediction data



Design a deriving method of the threshold X_{day}

Flowchart for deriving the best X_{day}



A brute-force search

The number of iteration is almost within 200

Objective function and Restricted condition as Strategies

Maximize the utilization factor subject to a certain CO2 emissions

- Strategies

$$\begin{cases} Objective\ function \quad Max\ UF_{EL-System}(X_{day}) \\ Restricted\ condition \quad CO2EmitFactor_{EL-System}(X_{day}) \leq \alpha(=1.13) \end{cases}$$

(Def. 1) Utilization Factor

$$UF_{EL-System}(X_{day}) = \frac{\int_{t=0}^{24h} H2_{EL-System}(t, X_{day})\,dt}{H2_{EL-System\_Capacity} \times 24\,h} = \frac{1}{480\ Nm3}\int_{t=0}^{24h} H2_{EL-System}(t, X_{day})dt$$

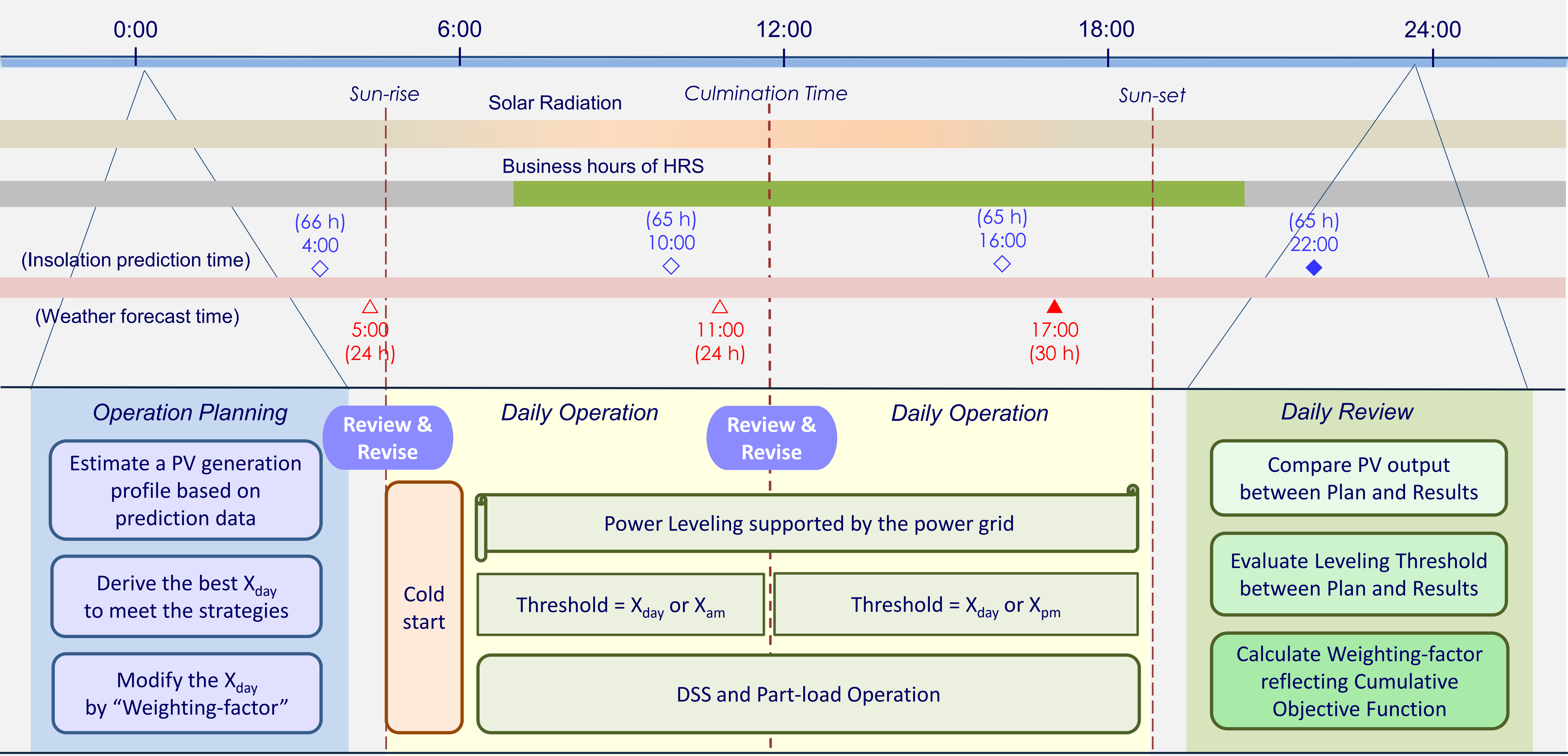
$$= \frac{1}{480\ Nm3}\int_{t=0}^{24h} \eta_{EL-System}(LoadFactor) \cdot EL_{in}(t, X_{day})dt$$

(Def. 2) CO2 Emission Factor

$$CO2EmitFactor_{EL-Plant}(X_{day}) = \frac{\beta \times \int_{t=0}^{24h} Grid(t)dt}{\int_{t=0}^{24h} \eta_{EL-Plant}(LoadFactor) \cdot EL_{in}(t, X_{day})dt}$$

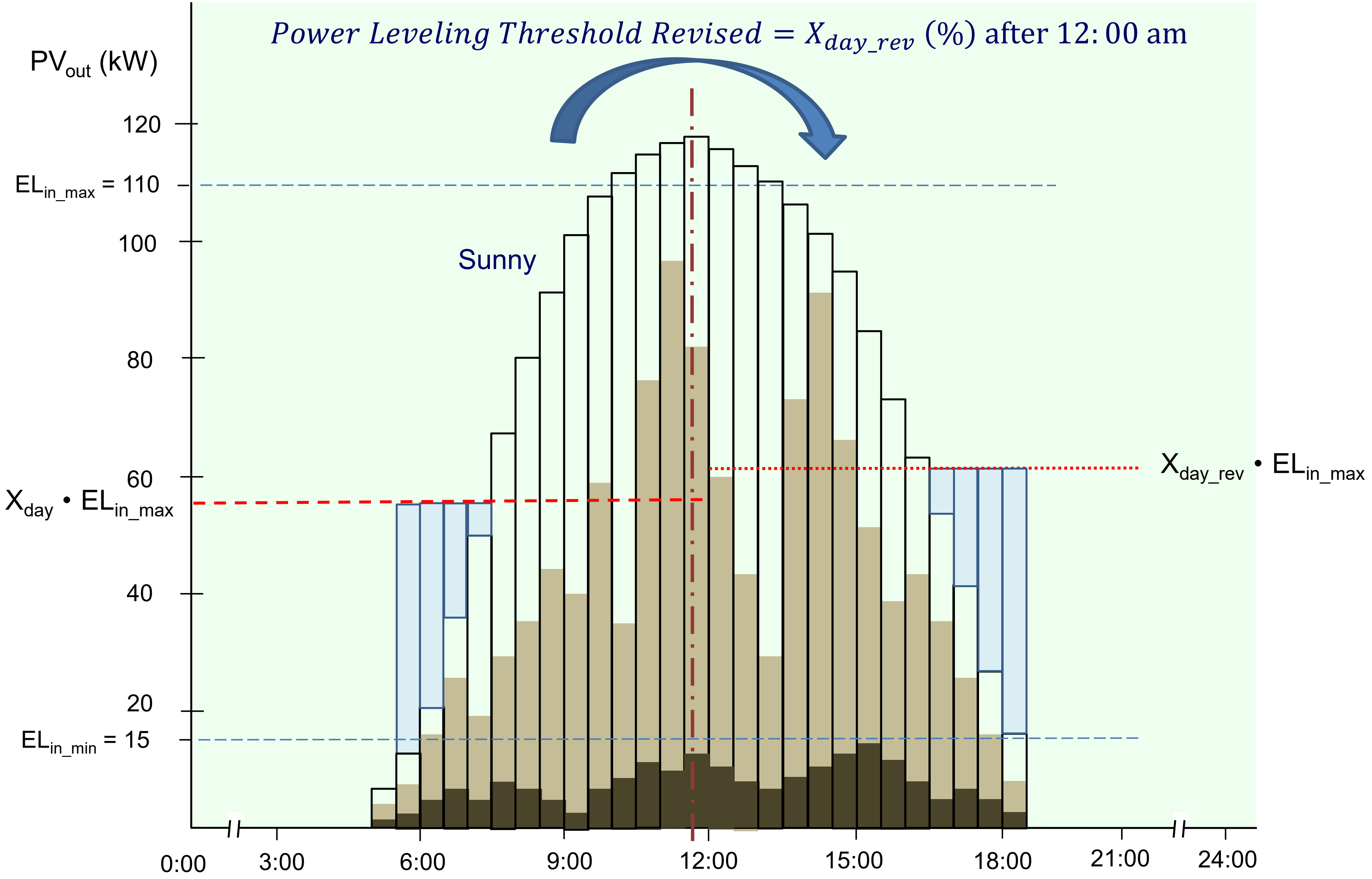
Daily Operation Scenarios（PV-powered EL-System）

Propose Review & Revise



Review & Revise at the time of culmination

Change the threshold at 12:00

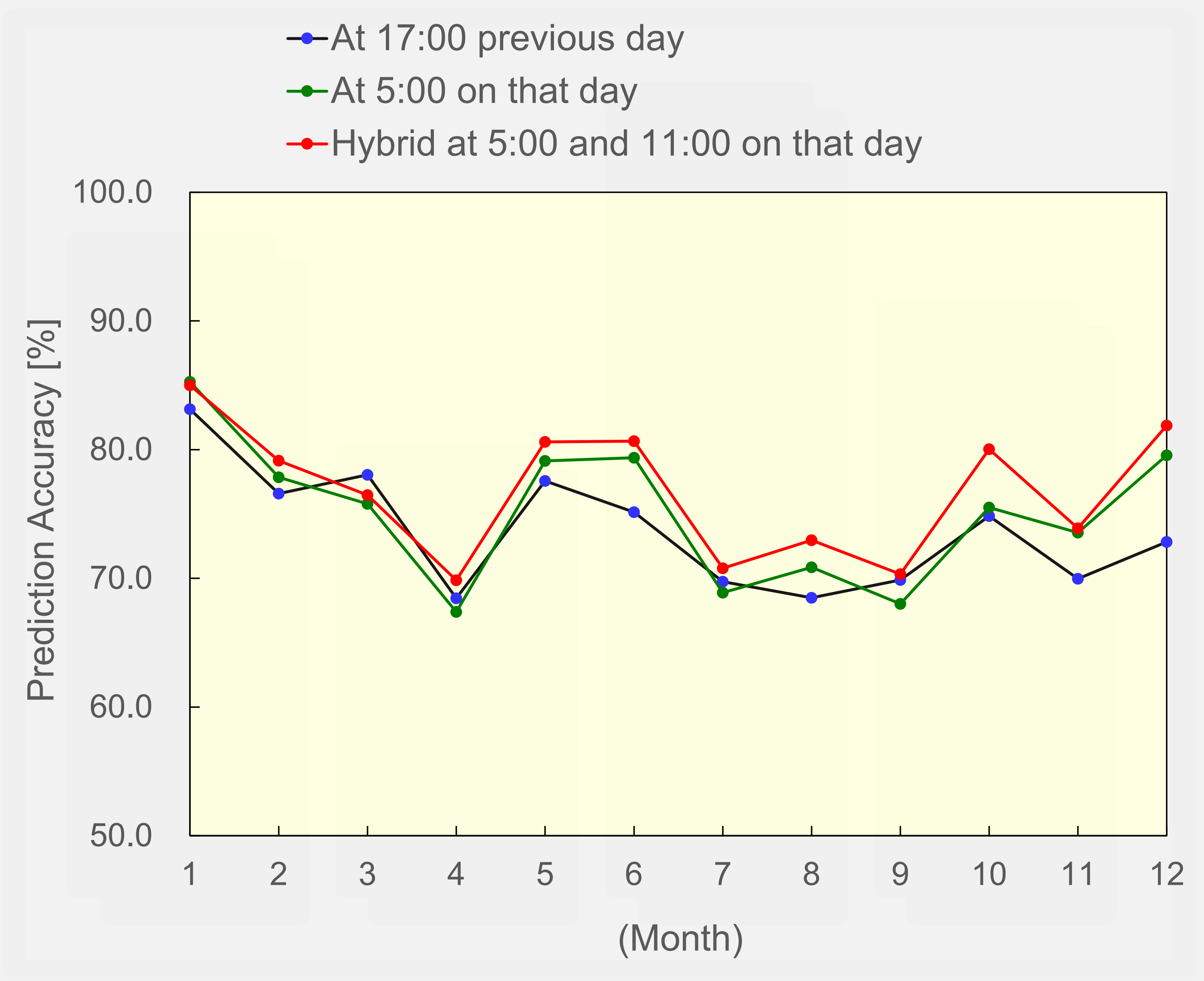


Survey an outlook of Review & Revise

Insolation Prediction using Weather Forecast

- Prediction Accuracy of Solar radiation (in 2015 at Tsukuba)

At 17:00 previous day	71.6 %
At 5:00 on that day	73.4 %
Hybrid at 5:00 and 11:00 on that day	77.0 %



Conclusions

Regarding PV-powered Electrolysis System,

we focused on the DSS (Daily Start and Stop) Operation Planning,

- Defined a parameter for Power Leveling as daily operation plan,
- Designed a solution method deriving the best threshold X_{day},
- Proposed an upgrade procedure for revising the prefixed operation plan.

The final target of this stage is to estimate the effects

of introducing solar forecast data and improving prediction accuracy.