CHUBU Electric Power

NIPPON KOEI

VRE forecast

Contents

1. Overview of the VRE forecast model

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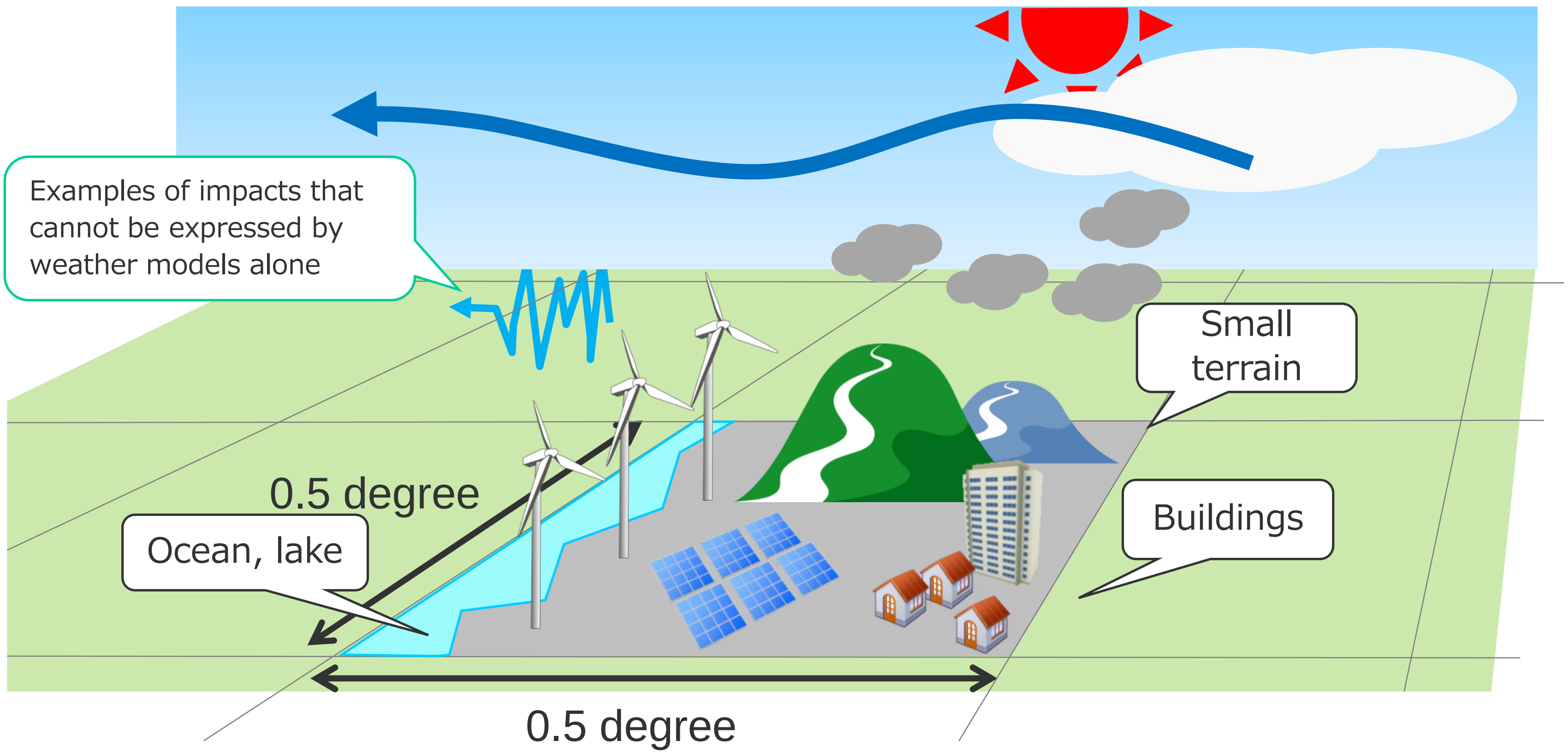
It is said that the meteorological phenomenon that can be represented by the resolution of the numerical weather model is 5 to 8 times its size. The effect of terrain smaller than the resolution cannot be expressed.
By using the statistical method, it is possible to correct short-term fluctuations and the bias of the meteorological model, and improve the prediction accuracy.



1. Overview of the VRE forecast model

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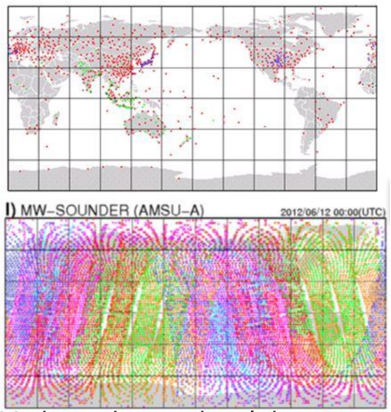
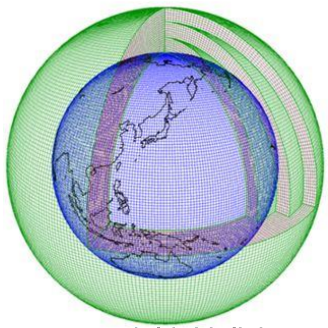
- Weather forecast for VRE can be calculated based on the weather models of the Japan Meteorological Agency and the Meteorological Organizations of each country.

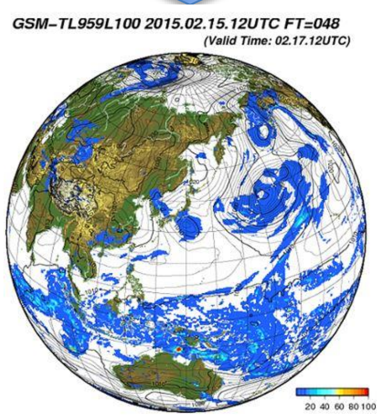
Meteorological Organizations (global / regional models, etc.)



Various observational data

（example）
Domain: Global
Frequency: once a day
Forecast range:
84 hours ahead
Time interval: 6 hours
Resolution: 0.5 degree
Variable: air pressure, wind, temperature, humidity Precipitation, etc.


Model initializing

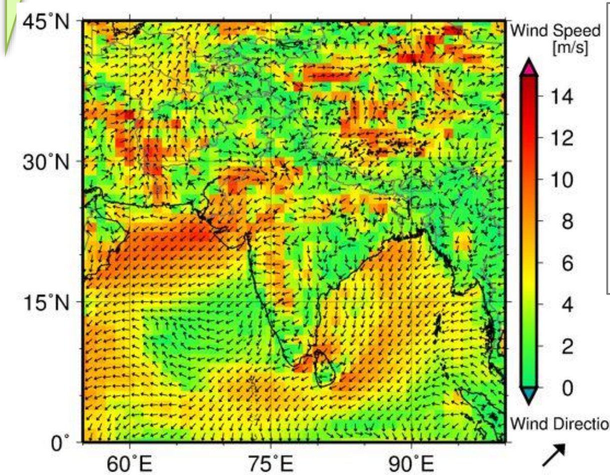


Forecasting

feed

Japan Weather Association (statistical model calculation)

Output from Weather model → Statistical model calculation → Forecast for VRE [Wind speed] [solar radiation]



（example）
Frequency: once a day
Forecast range:
72 hours ahead
Time interval: 1 hours
Variable: Wind speed
solar radiation

※Specification should be considered in detail at the time of design

1. Overview of the VRE forecast model

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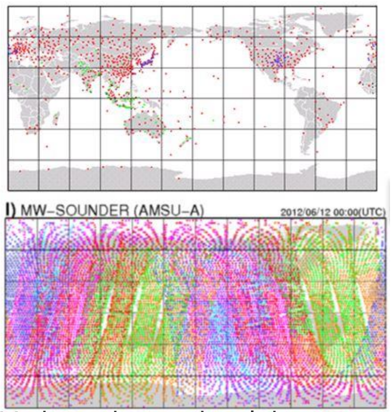
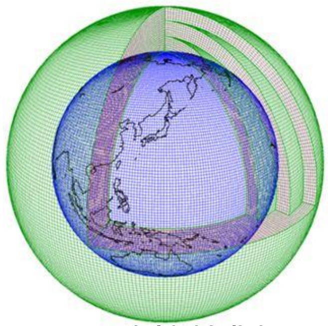


Various observational data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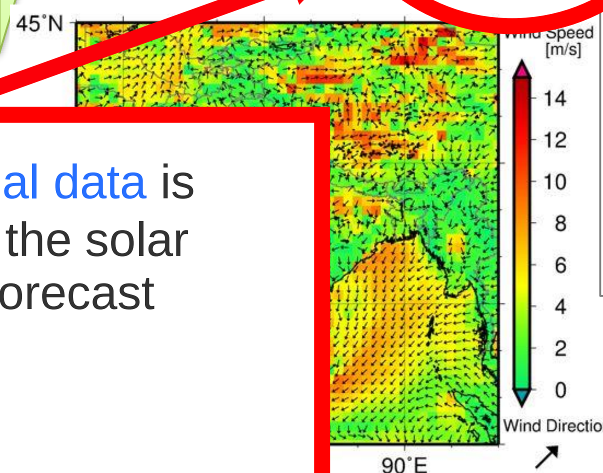

(example)
Frequency: once a day
Forecast range:
72 hours ahead
Time interval: 1 hours
Variable: Wind speed
solar radiation

※Specification should be considered in detail at the time of design

The weather observational data is required to develop both the solar irradiation and the wind forecast models.

- Analysis
- Verification of accuracy(weather)

1. Overview of the VRE forecast model

CHUBU Electric Power
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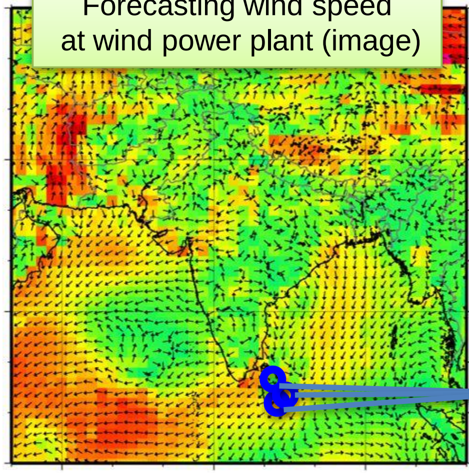
- The output of PV and wind power can be predicted from weather forecast results and specifications of facilities.

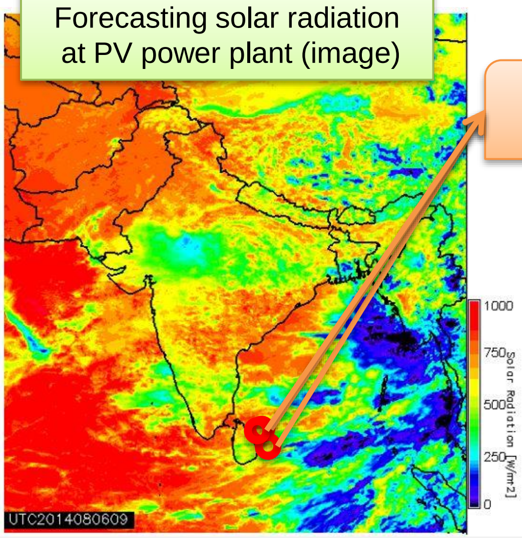
Forecasting wind speed at wind power plant (image)



Facility information
wind turbine rated capacity
wind turbine model number
number of wind turbines
wind turbine hub height
power curve, etc.

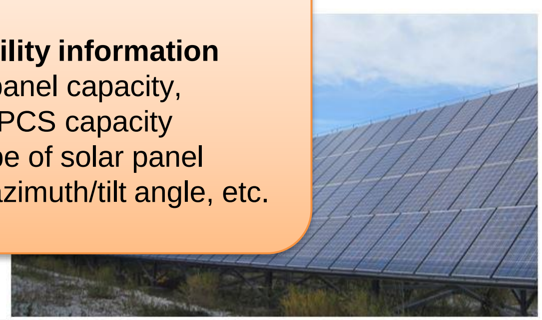
wind speed at wind power plant → statistical model → wind power generation at the plant

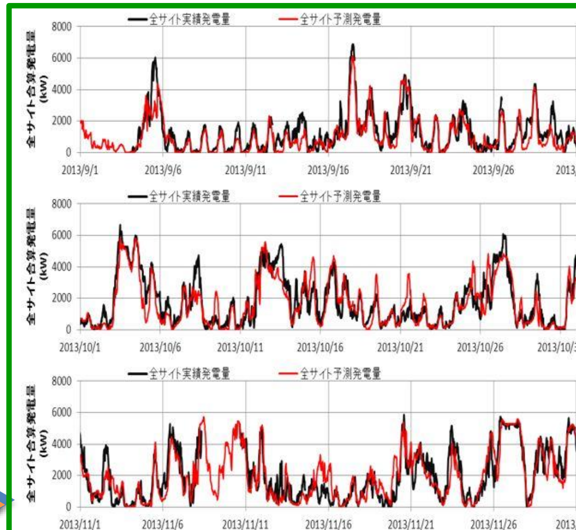
Forecasting solar radiation at PV power plant (image)



solar radiation at PV power plant → statistical model → PV power generation at the plant

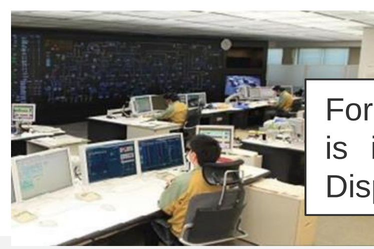
Facility information
panel capacity,
PCS capacity
type of solar panel
panel azimuth/tilt angle, etc.





X_axis: timeline [year/month/day]
Y_axis: total amount of all power output(wind+ PV) [kW]
legend: historical result (black); forecast for power generation output (red)

※Specification should be considered in detail at the time of design



Forecast system of PV output is installed at Central Load Dispatching Center in CEPCO.

1. Overview of the VRE forecast model

CHUBU Electric Power
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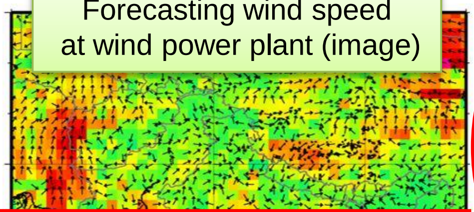
- The output of PV and wind power can be predicted from weather forecast results and specifications of facilities.

Forecasting wind speed at wind power plant (image)

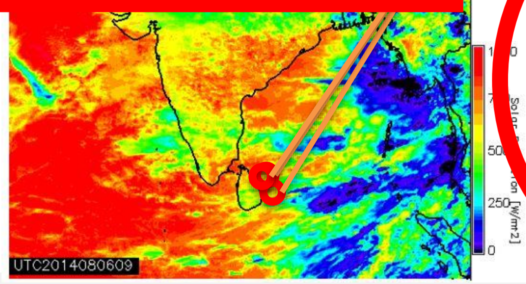


Facility information
wind turbine rated capacity
wind turbine model number
number of wind turbines
wind turbine hub height
power curve, etc.

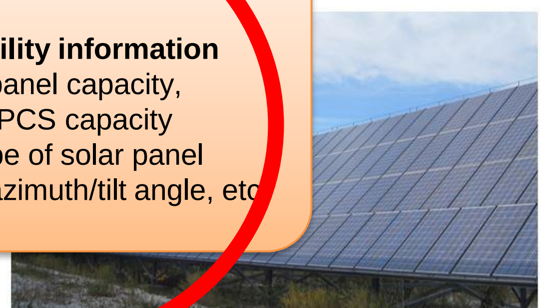
Facility information is needed for analysis to develop power generation prediction models for solar and wind output.

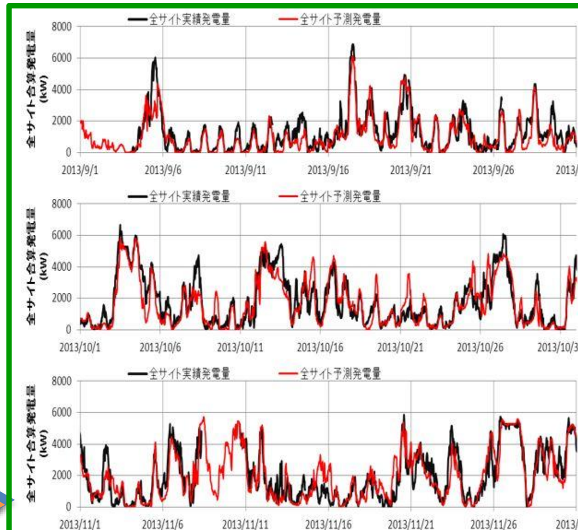
wind speed at wind power plant → statistical model → wind power generation at the plant

solar radiation at PV power plant → statistical model → PV power generation at the plant



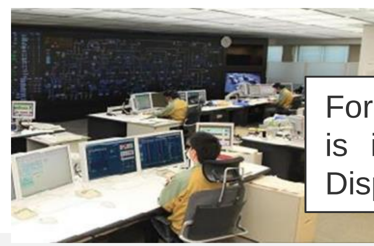
Facility information
panel capacity,
PCS capacity
type of solar panel
panel azimuth/tilt angle, etc





X_axis: timeline [year/month/day]
Y_axis: total amount of all power output(wind+ PV) [kW]
legend: ▬ historical result
▬ forecast for power generation output

※Specification should be considered in detail at the time of design



Forecast system of PV output is installed at Central Load Dispatching Center in CEPCO.

1. Overview of the VRE forecast model

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NIPPON KOEI

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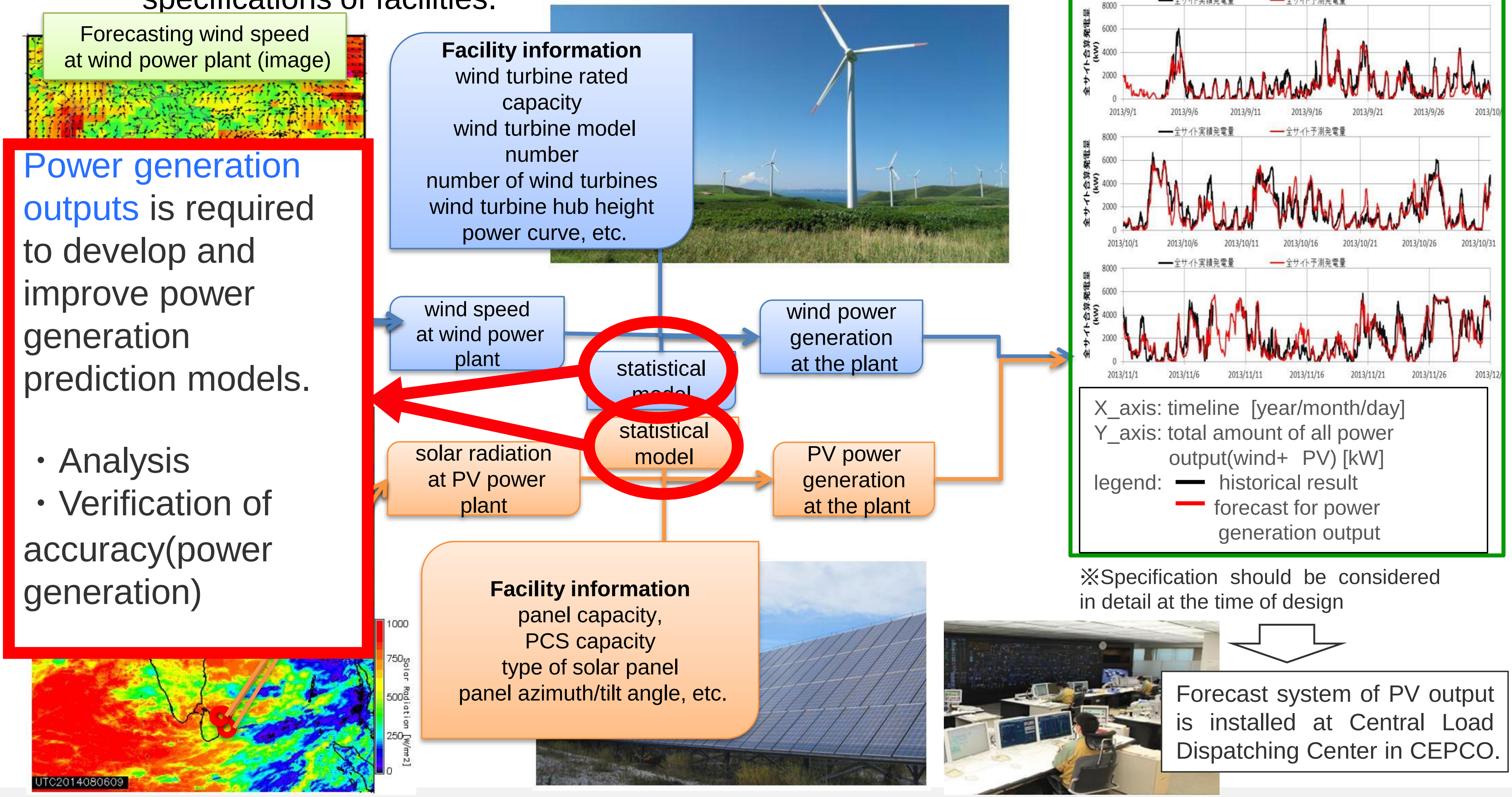
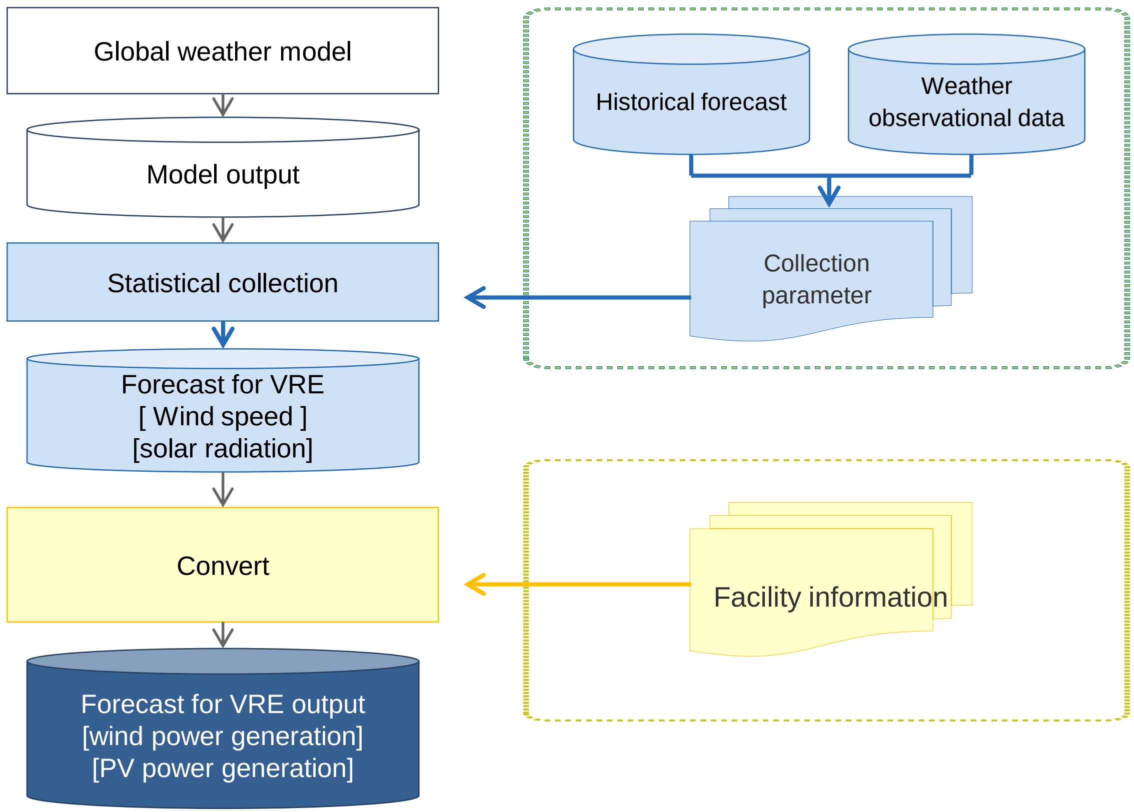


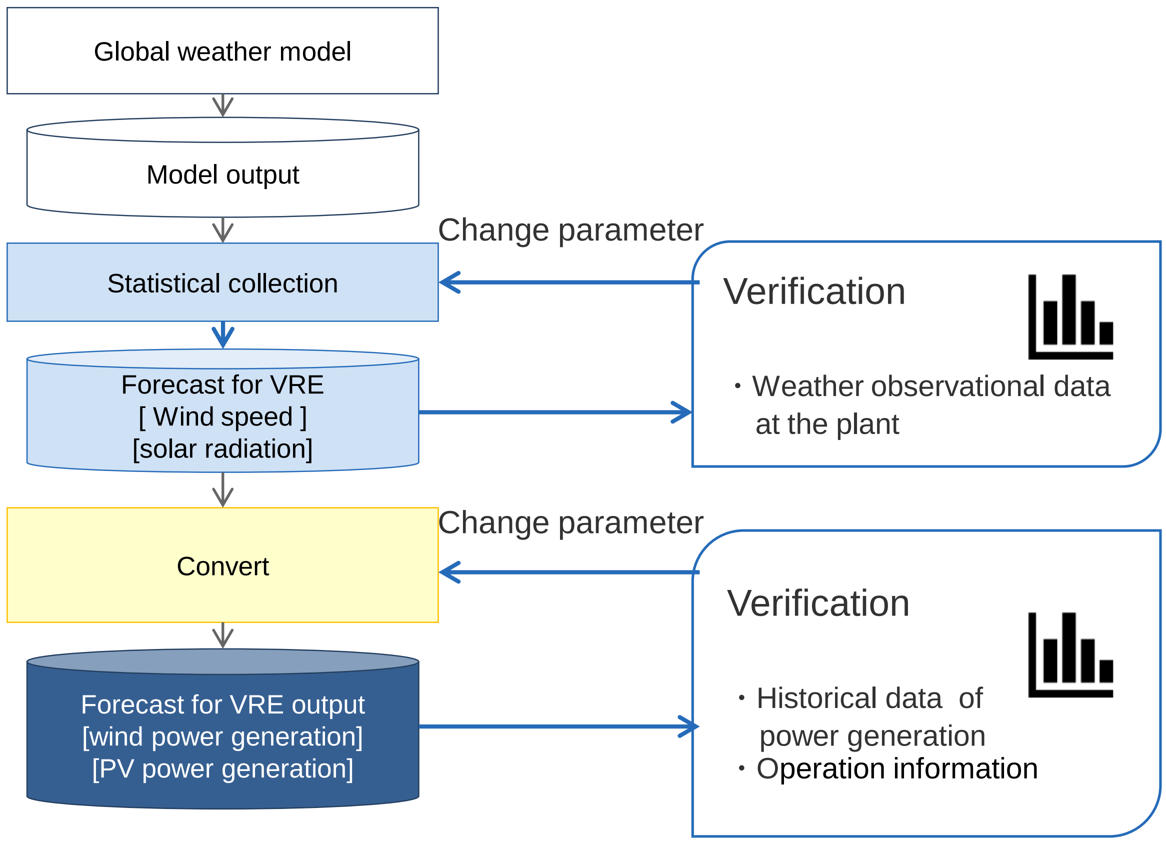
2. Developing method of the VRE forecast model

This flow diagram shows an example approach for predicting power output using weather forecasts. The overall flow is the same for PV and wind power. Facility information is mandatory to power generation.



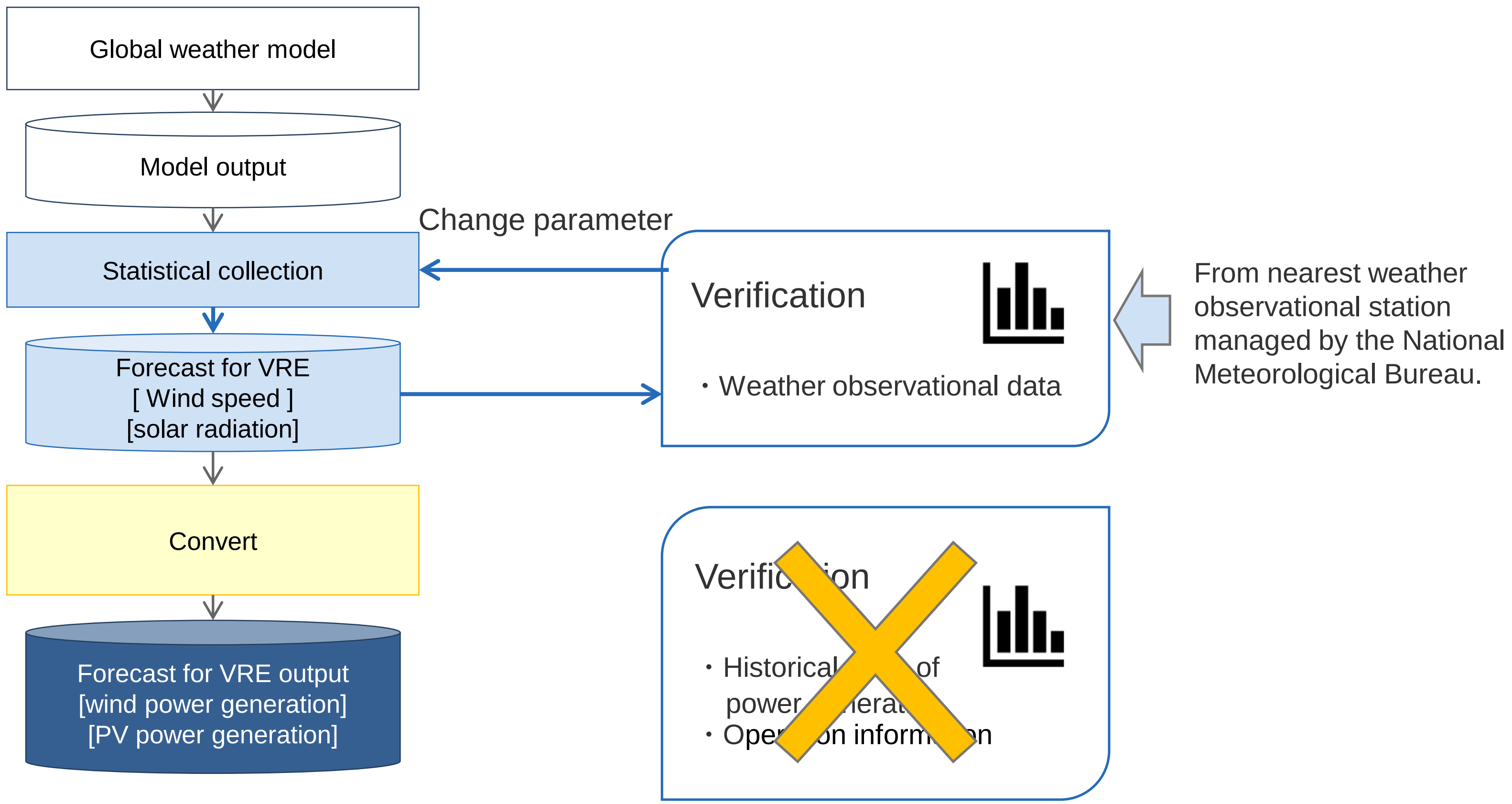
2. Developing method of the VRE forecast model

Verification with historical data is ideal. Optimal parameters are adjusted by verification using weather observational data and power generation data. This will give you a more accurate forecast.



2. Developing method of the VRE forecast model

When forecasting future planned plants, historical power generation data cannot be obtained. At this time, it is desirable to verify the prediction accuracy using the nearest weather observational data managed by the National Meteorological Bureau.

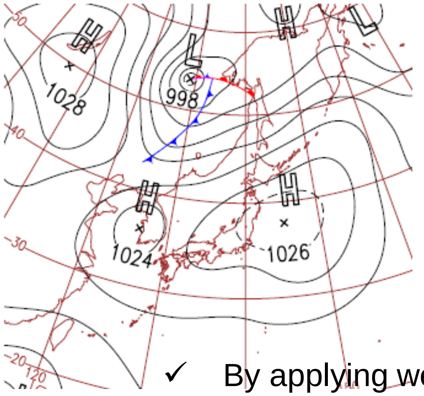


Contents

1. Procedure for PV Forecasting

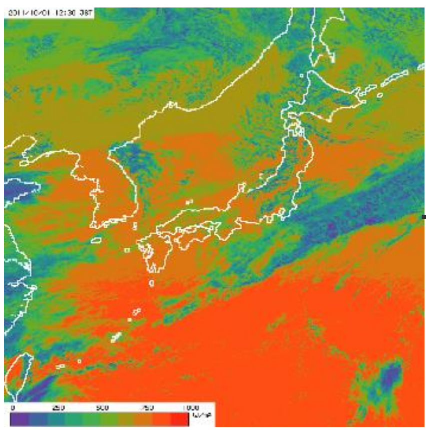
2. Irradiation Measurement System for PV Forecasting

1. Procedure for PV Forecasting



Weather Information (e.g. Atmospheric Pressure Distribution)

- ✓ By applying weather forecasting technologies, the thickness, height and size of clouds is predicted.
- ✓ In addition, irradiation on the ground is predicted based on the forecast of atmospheric conditions such as moving direction and velocity of clouds.



Japan Weather Association

Irradiation on the Ground※1

Temperature※1

(Source: Japan Weather Association)

Date, Time, Panel Angle

Panel Capacity

Transmission/ Distribution loss

Irradiation on PV Panel Surface

Temperature Loss of PV Panel

PV Forecasting※2

Hydro

Thermal

Total Supply

Central Load Dispatching Center
Chubu Electric Power Grid Co., Inc.

(Source: CEPCO)

※1 All of Electric Power Companies in Japan receive the weather data from Japan Weather Association.
※2 Some part of Electric Power Companies receive the PV Forecasting Data from Japan Weather Association.

2. Irradiation Measurement System for PV Forecasting

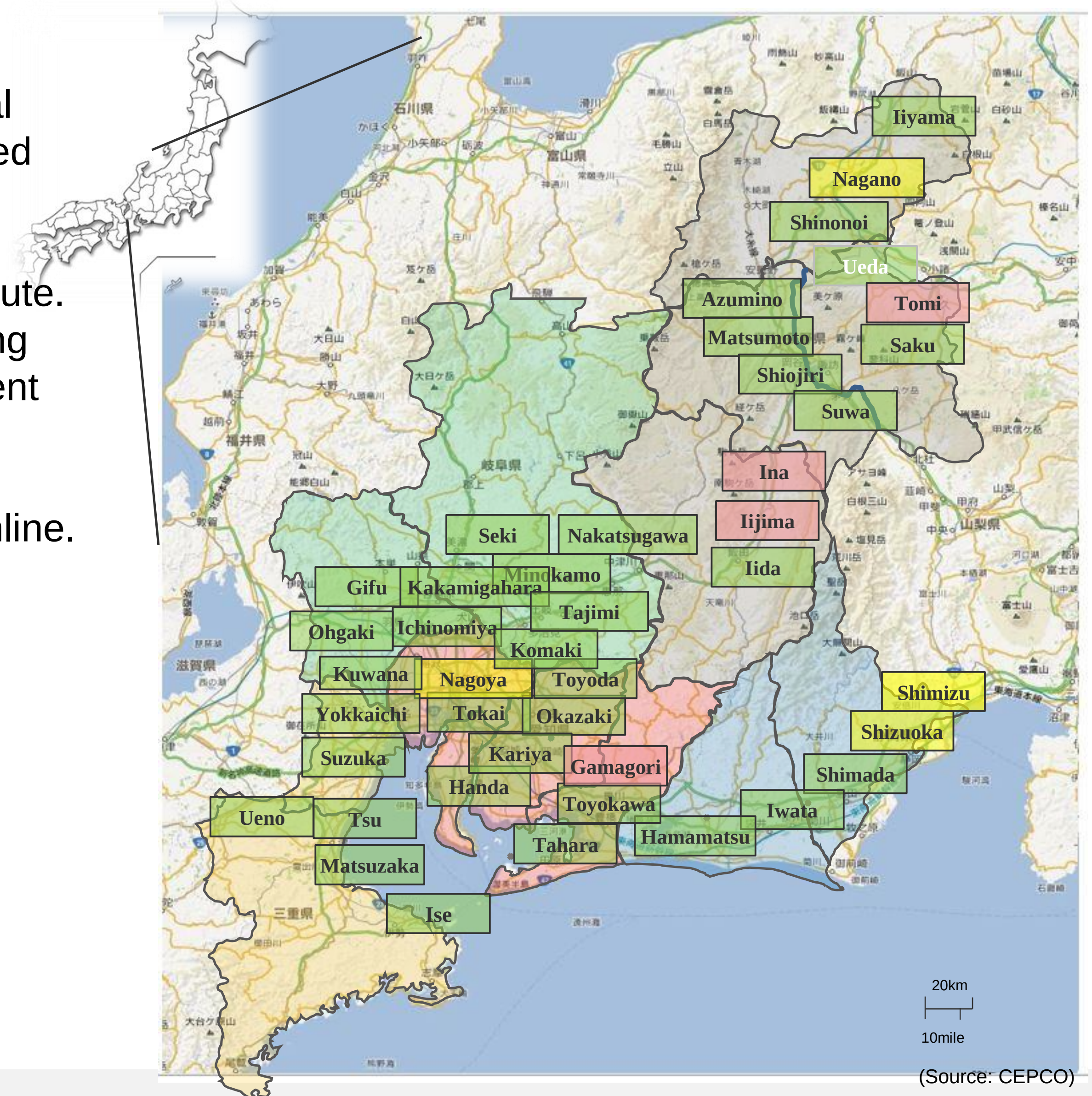
- ✓ Measurement area in service area is divided into 14 areas based on regional irradiation characteristics and introduced PV capacity.
- ✓ Irradiation is measured by instrument ,called PV300, at every minute.
- ✓ The number of the Irradiation measuring points is 3 or more in each measurement area.
- ✓ Measurement data is transmitted to Central Load Dispatching Center by online.

◆PV300 (Installed by CEPCO)

Pyranometer	・・・ 39 locations

◆Facilities of Meteorological Agency

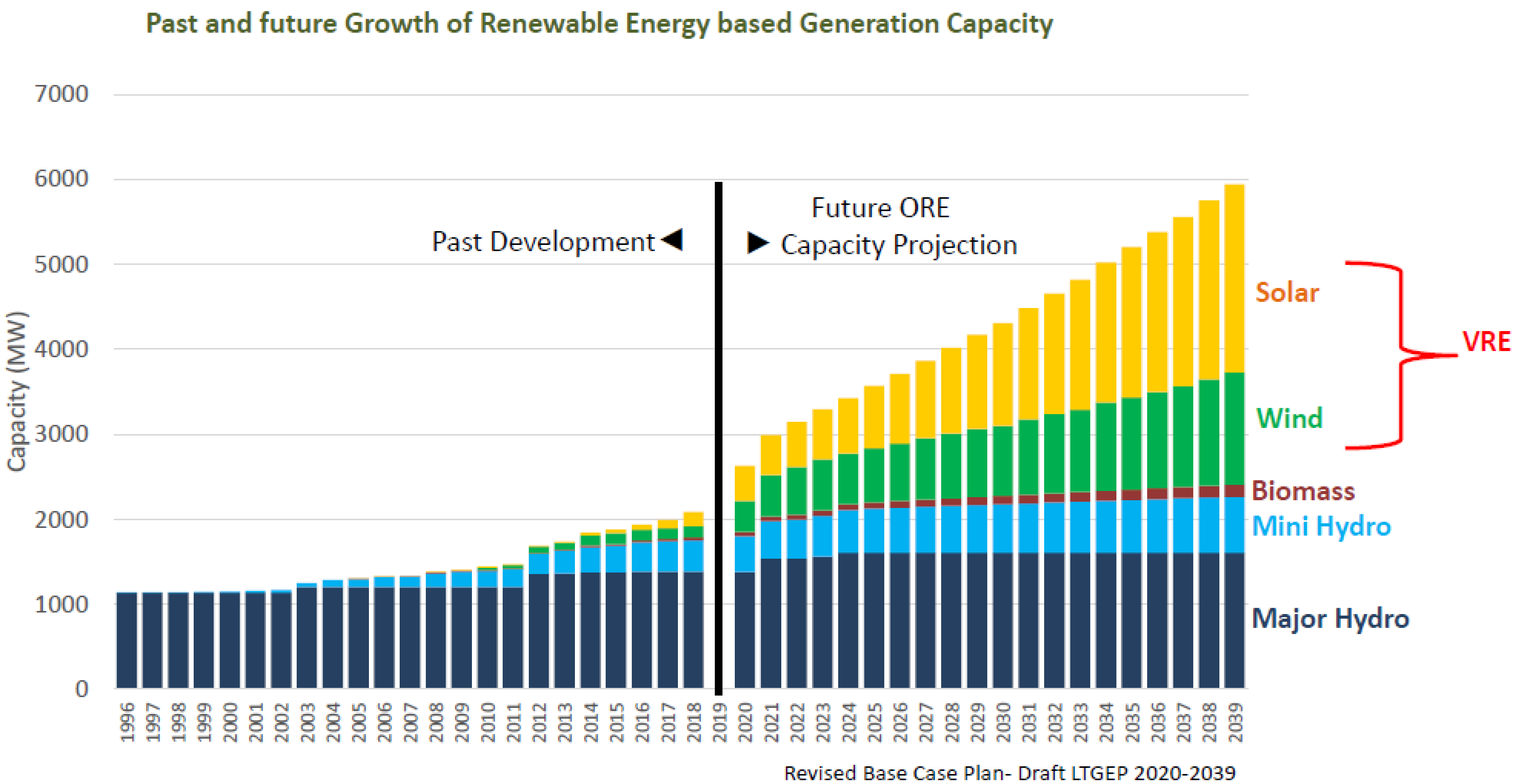
Pyranometer	・・・ 3 locations
Estimated Irradiation	・・・ 5 locations



(Source: CEPCO)

Contents

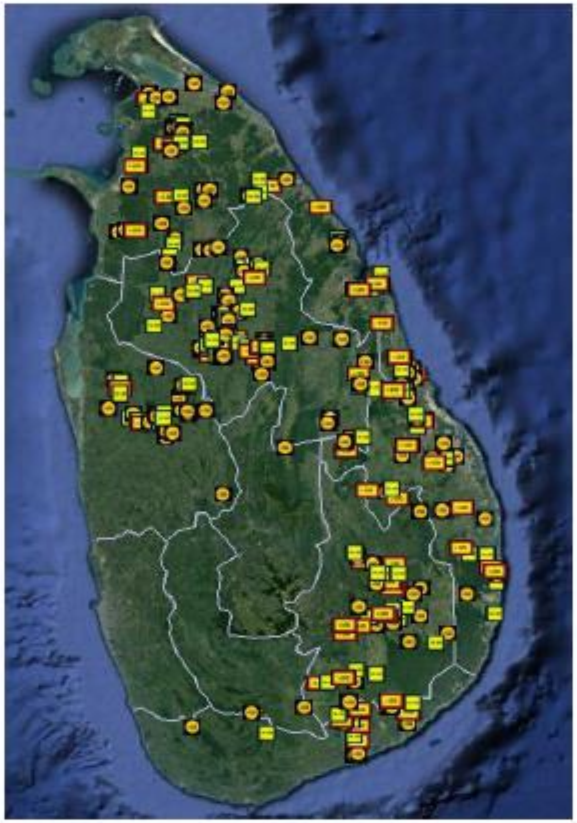
1.VRE Resource Development



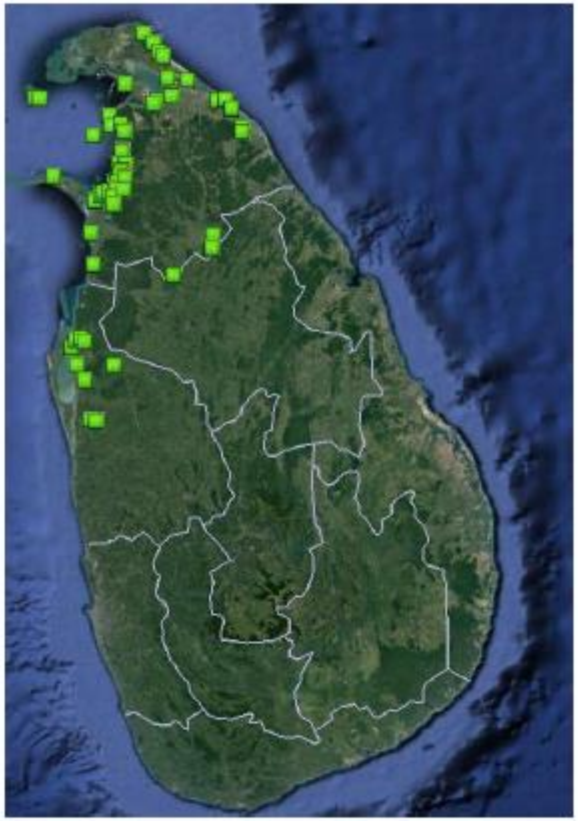
Source: Made by CEB

2. Resource Potential

Solar Resource



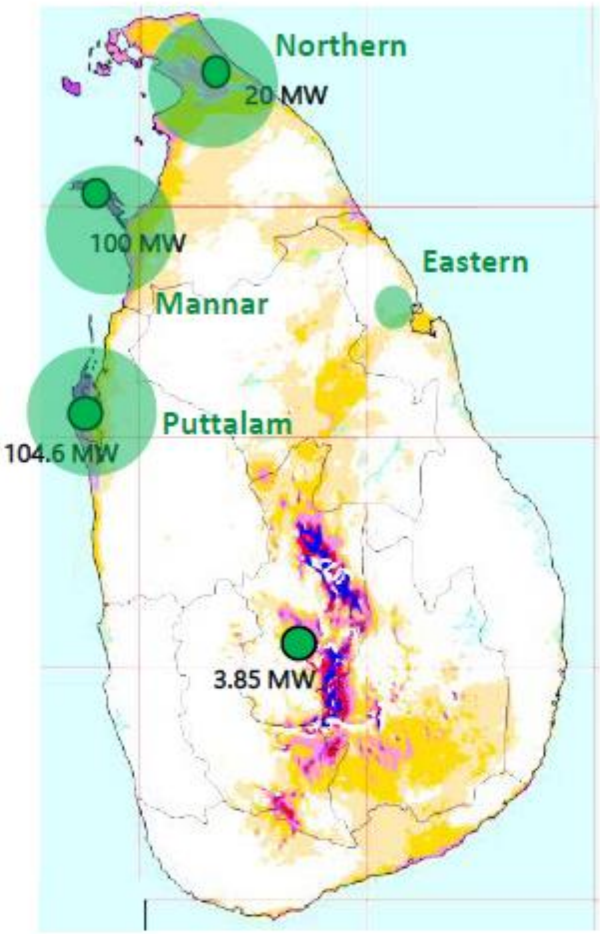
Wind Resource



VRE Resources mapped by Sri Lanka Sustainable Energy Authority (SLSEA) in 2020

Source: Made by CEB

3. Wind Resource Development



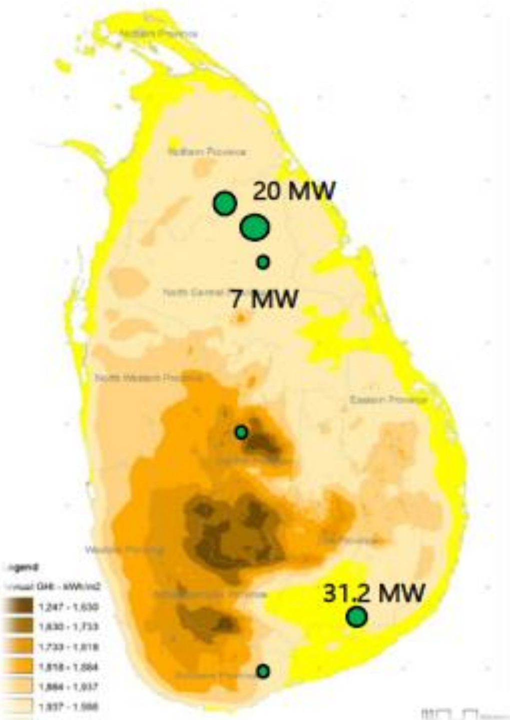
Source: Made by CEB

Existing and Future Clusters

- Northwestern Cluster
- Mannar Cluster
- Northern Cluster
- Eastern Cluster

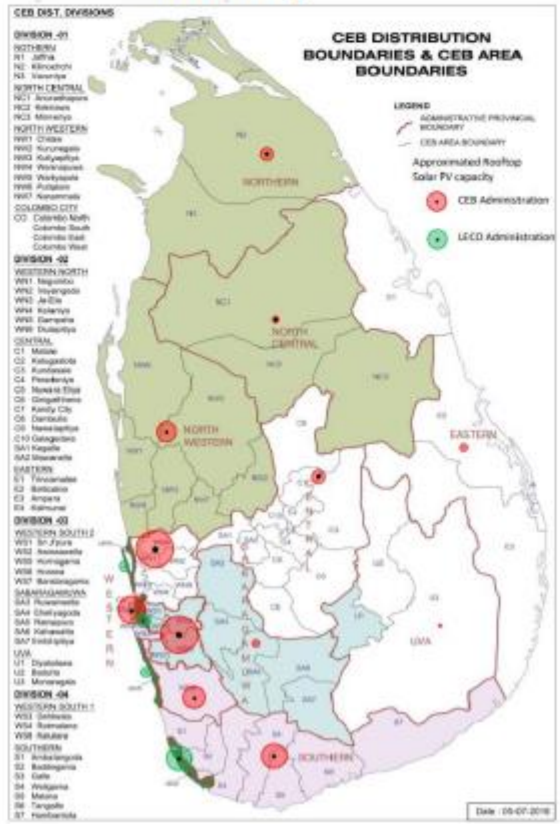
4. Solar Resource Development

Grid Scale and Small Scale



Existing plants

Rooftop



Rooftop Capacity

Future Development

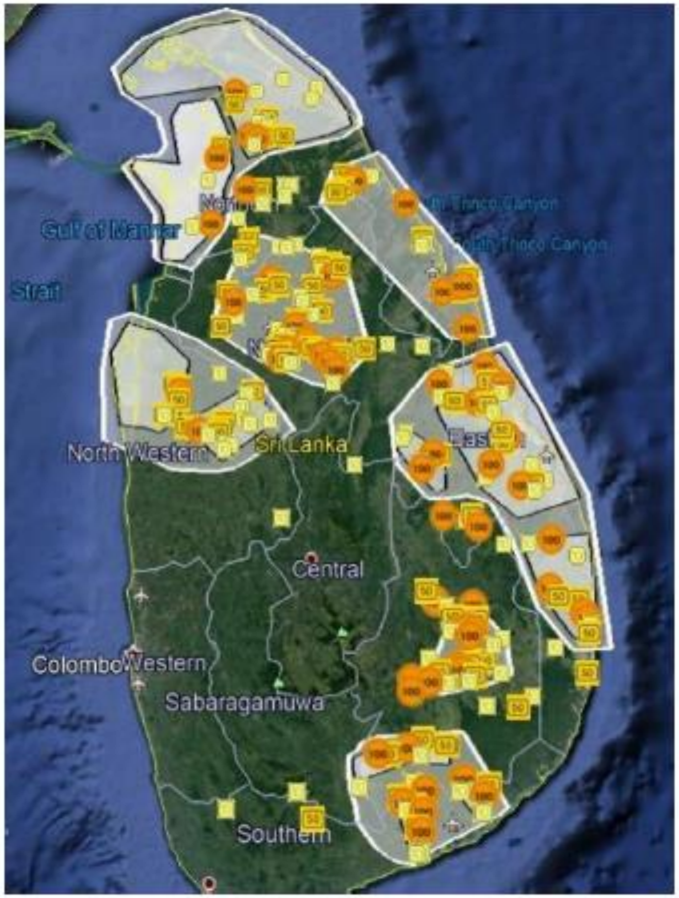
1. **Ground Mounted Solar**
   a. Large and Medium scale solar parks (10-100MW)
   b. Scattered small scale solar parks (1-10MW)
   c. Scattered small scale solar parks connected to LV Network

2. **Rooftop Solar (Net Metering, Net Plus & Net Accounting)**

Source: Made by CEB

4. Solar Resource Development

Large/Grid Scale Development



1. **Resource Development Zones have been identified**
2. **Small scale geographically scattered development Programs will continue**

Source: Made by CEB

5. Future plan of VRE output forecast in CEB

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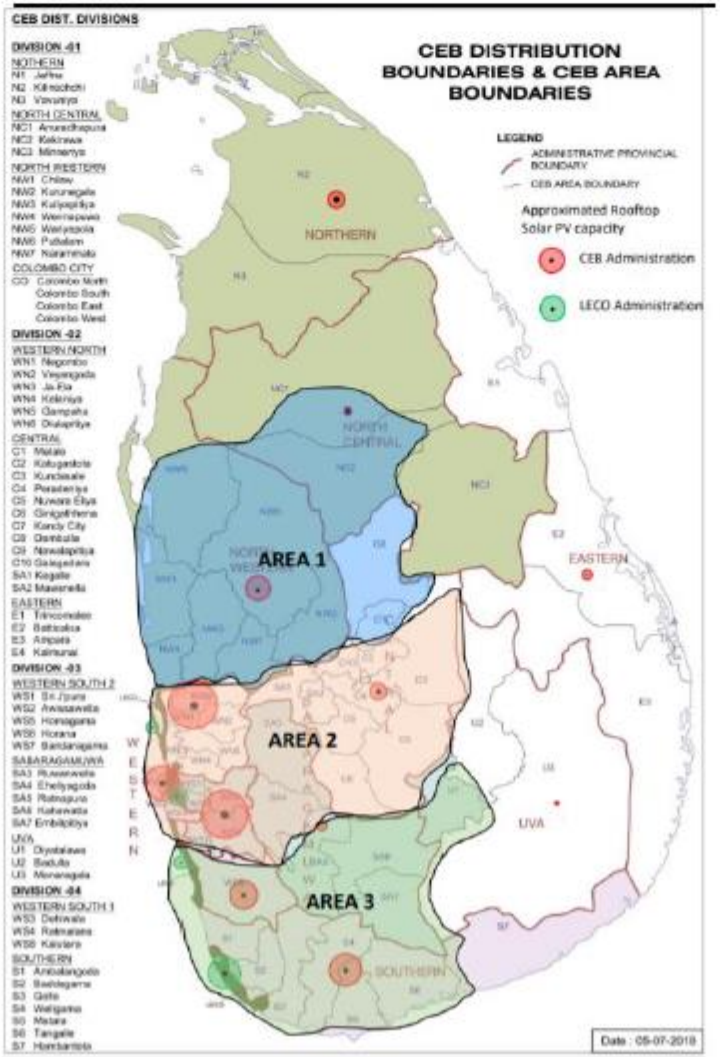
- A centralized forecasting system providing a system wide forecasting is preferred

- Scale and the locations of future VRE resource development to be considered appropriately for developing the forecasting system

4. Solar Resource Development



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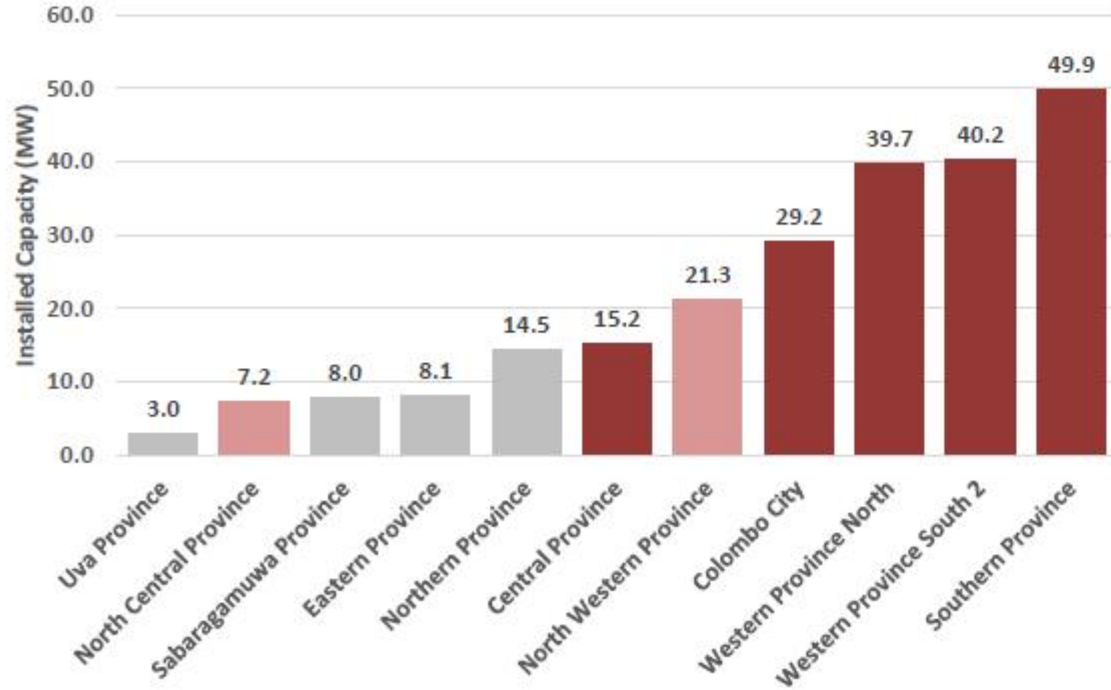

Three Areas account for nearly 77% of the Total installed rooftop PV Capacity

6.2.1 Outline of VRE forecast model

Contents

1. Forecast points of VRE
2. Overview of the VRE forecast for weather
3. Overview of the VRE forecast for output
4. The process of the VRE forecast model
5. Collected Data on developing the model
6. Delivery method of VRE forecast

1. Forecast Points of VRE

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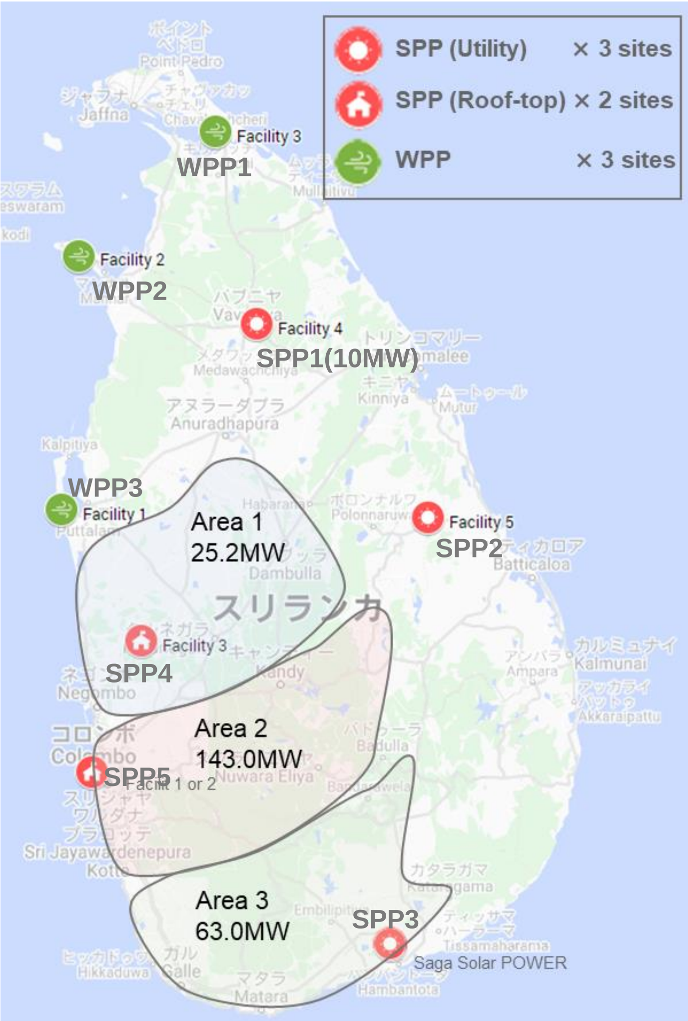
Forecast points



Information on forecast point

Forecast site	Information on forecast site	Lat/Lon
WPP1	Northern Wind Power Plant	9.55/80.35
WPP2	Mannar Wind Power Plant	9.050124, 79.792038
WPP3	Mampuri Wind Power Plant	8°0'36.37"N, 79°43'24.09"E
SPP1	Vydexa solar Power Plant	8°46'9.49"N, 80°31'39.88"E
SPP2	Solar One Ceylon Power	7°58'31.38"N 81°14'18.23"E
SPP3	Saga Solar Power	6.22/81.085
SPP4	Kuliyapitiya Area	7.5/80.05
SPP5	CEB Head office	6.9/79.8

2. Overview of the VRE forecast for Weather

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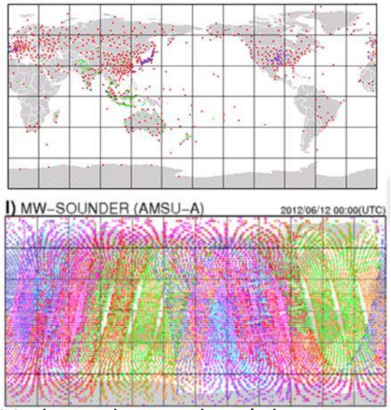
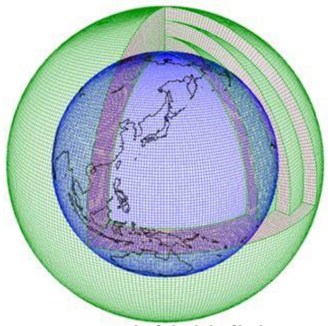
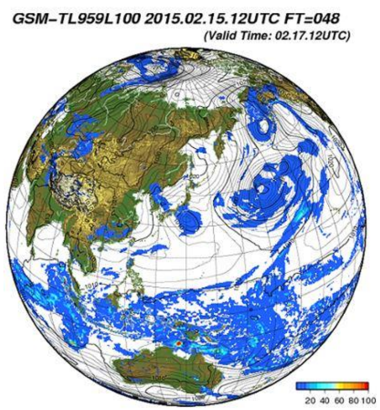
Meteorological Organizations (global / regional models, etc.)



Various observational data


Model initializing



Forecasting

（example）
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feed

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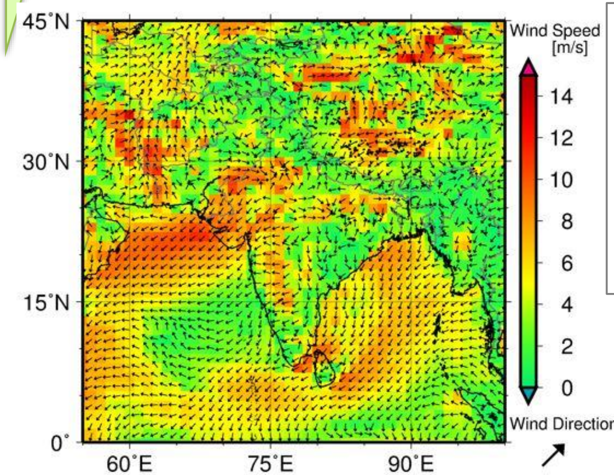
Output from Weather model → Statistical model calculation → Forecast for VRE [Wind speed] [solar radiation]



（example）
Frequency: once a day
Forecast range:
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Variable: Wind speed
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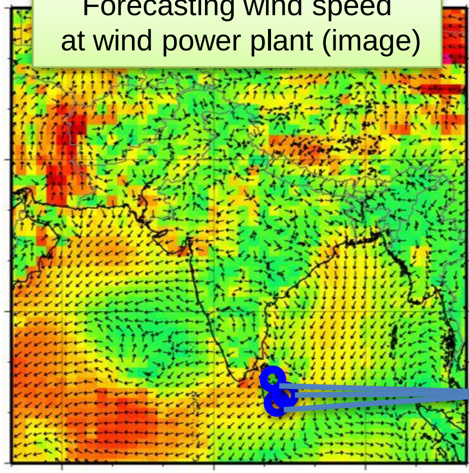
3. Overview of the VRE forecast for output

- The output of PV and wind power can be predicted from weather forecast results and specifications of facilities.

Forecasting wind speed at wind power plant (image)



Facility information
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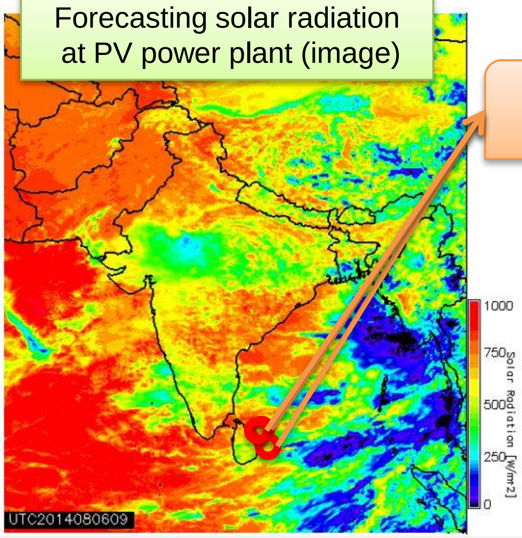
wind turbine model number
number of wind turbines
wind turbine hub height
power curve, etc.

wind speed at wind power plant → statistical model → wind power generation at the plant

Forecasting solar radiation at PV power plant (image)



solar radiation at PV power plant → statistical model → PV power generation at the plant

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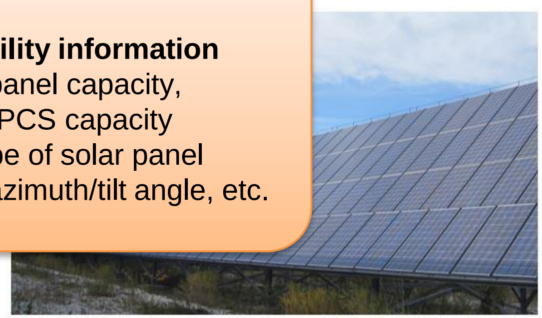

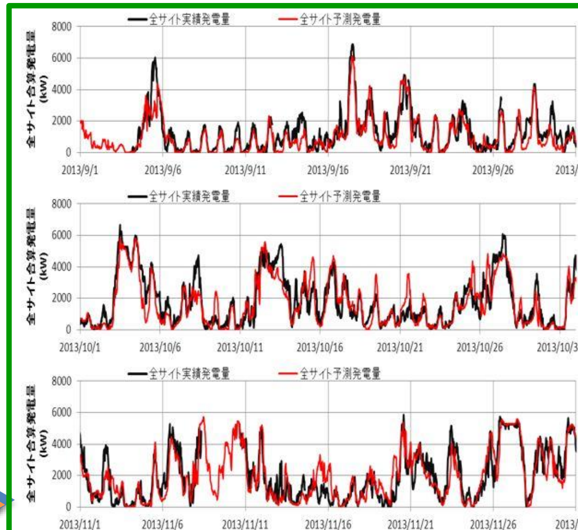

X_axis: timeline [year/month/day]
Y_axis: total amount of all power output(wind+ PV) [kW]
legend: ▬ historical result
▬ forecast for power generation output

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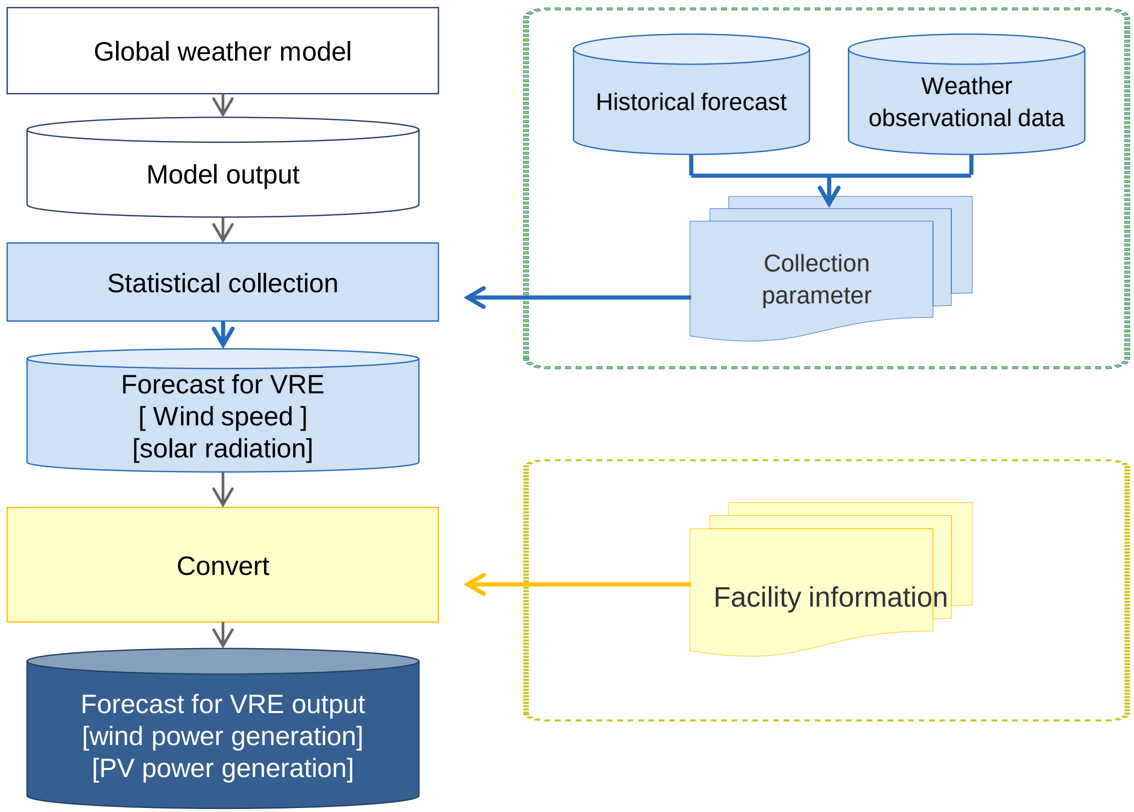
4. The Process of the VRE forecast model

This flow diagram shows an example approach for predicting power output using weather forecasts. The overall flow is the same for PV and wind power. Facility information is mandatory to power generation.



5. Collected Data on developing the model

Historical data(as of Sep. 9, 2022)

Historical Data	WPP1	WPP2	WPP3
	Northern Wind Power Plant 10MW	Mannar Wind Power Plant 103.5MW	Mampuri Wind Power Plant 10MW
Weather (Wind Speed and direction)	From Jun 1,2021 to September 30,2021	From Jun 21,2021 to Jun 13,2022	-
VRE Output	From July 1, 2021 to Jun 13, 2022 From September 1, 2022 to September 9, 2022	From July 1,2021 to June 13,2022 From September 1,2022 to September 9,2022	From July 6,2021 to Jun 13,2022

Historical Data	SPP1	SPP2	SPP3
	Vydexa solar Power Plant 10MW	Solar One Ceylon Power 12.5MW	Saga Solar Power 10MW
Weather (Irradiation)	From July 1,2021 to October 21,2021	From Jun 1,2021 to October 21,2021	-
VRE Output	From July 1,2021 to Jun 13,2022	From Jun 1,2021 to June 13,2022	From July 1, 2021 to Jun 13, 2022 From September 1, 2022, to September 9, 2022

Historical Data	SPP4	SPP5	
	Kuliyapitiya Area 50kW	CEB Head office 90.9kW	
Weather (Irradiation at the nearest area of the installed location)	-	-	
VRE Output	From July 1, 2021 to September 12, 2022	From July 1,2021 to Jun 13,2022	

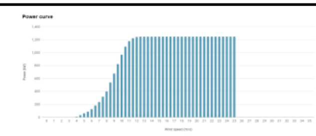
5. Collected Data on developing the model

Facility Information of VRE forecast (SPP)

	Utility PV			Roof-top PV	
	SPP1	SPP2	SPP3	SPP4	SPP5
Facility No.	Facility 4	Facility 5	Saga Solar POWER	Facility 3	Facility 1
Information/Site	10 MW Solar Power plant (Vydexa solar power plant)	Solar One Ceylon Power (Pudukadumalai) SPP	SAGA SOLAR POWER		Rooftop PV Colombo
Area	Vavuniyava	Welikanda	Hambantota	Kuliyapitiya	Slave Island
Premises	Privately Owned	Privately Owned			CEB Head office
Location (Lat/lon)	8°46'9.49"N, 80°31'39.88"E	7°58'31.38"N 81°14'18.23"E	6.22 , 81.085	7.469655377230161, 80.05004525435352	6.930312772873491, 79.84709213773222
Period of Installation	Jul-17	Dec-16	2015-2016	09/02/2018	installed 2019-jun-25
Panel Azimuth Angle			0	90°	30 degree
Panel Tilt Angle	Single-Axis Tracking	Single-Axis Tracking	5 degrees to 15	35°	8 degree
Type of Installation	Gound Mounted	Gound Mounted	GMFT	roof	on small structure
Type of PV Module	350p Monocrystalline	315Wp & 320Wp Polycrystalline	MULTI CRYSTALINE	Monocrystalline	MONO PERC
Total Panel Capacity	**10 MW**	**12.5 MW**	**10MW**	**50 KW**	**90.9 KW**
PCS or Inverter model			ABB	SMA Gmbh STP 25000 TL-30	TR10-20.0-TL-OUTD-S2X-400 X 1 no /TR10-27-6-TL-OUTD-400 X 3 No
PCS or Inverter Capacity			1MW*10	25kVA	20kW X 1 No and 27kW X 3 No
Online Data Availability (If possible)				Yes	Yes
Past Data availability (If possible)				Yes	Yes

5. Collected Data on developing the model

Facility Information of VRE forecast (WPP)

	WPP1	WPP2	WPP3
Facility No.	Facility 3	Facility 2	Facility 1
Information	Northern Wind power plant	Mannr Wind power plant	Wind plant from cluster in Puttalam
Site	Vallimunai 10MW Wind Power plant	Thambapavani Wind Power plant (CEB)	Mampuri Wind Power Plant– Stage I
Area	Jaffna	Mannar Island	Puttalam
Premises	Beta Power (Pvt) Ltd	Thambapavani Wind Power plant	Mampuri Wind Power Plant
Location (Lat/lon)	9.556760792037888, 80.35954521288103	9.050124, 79.792038	8°0'36.37"N, 79°43'24.09"E
Period of Installation	December 2014	End 2020- Being Commissioned	2010
Number of wind turbines	8	30	8
Wind turbine rated capacity per unit	1,500 kW (ReGen VENSYS 82V82)	3,450kW	1,250kW
Total amount of wind turbine capacity	**12 MW**	**103.5 MW**	**10 MW**
Wind turbine hub height	85m	80 m	60m
Power curve (includes cut-in, rated, cut-out wind speed)	Cut-in wind speed: 2.5 m/s Rated wind speed: 13 m/s Cut-off wind speed: 22.5 m/s http://www.regenpowertech.com/104/wind-turbine	Rated power: 3,450 kW Cut-in wind speed: 3 m/s Cut-out wind speed: 22.5 m/s Re cut-in wind speed: 20 m/s Wind class IEC IIIA/IEC IIB https://www.vestas.com/en/products/4-mw-platform/v136-_3_45_mw#!technical-specifications	 Power Curve Data- https://www.thewindpower.net/turbine_en_220_suzlon_s64-1250.php
Past Data availability (If possible)			

Important items for Building VRE forecast model

Request more information

6. Delivery method of VRE forecast

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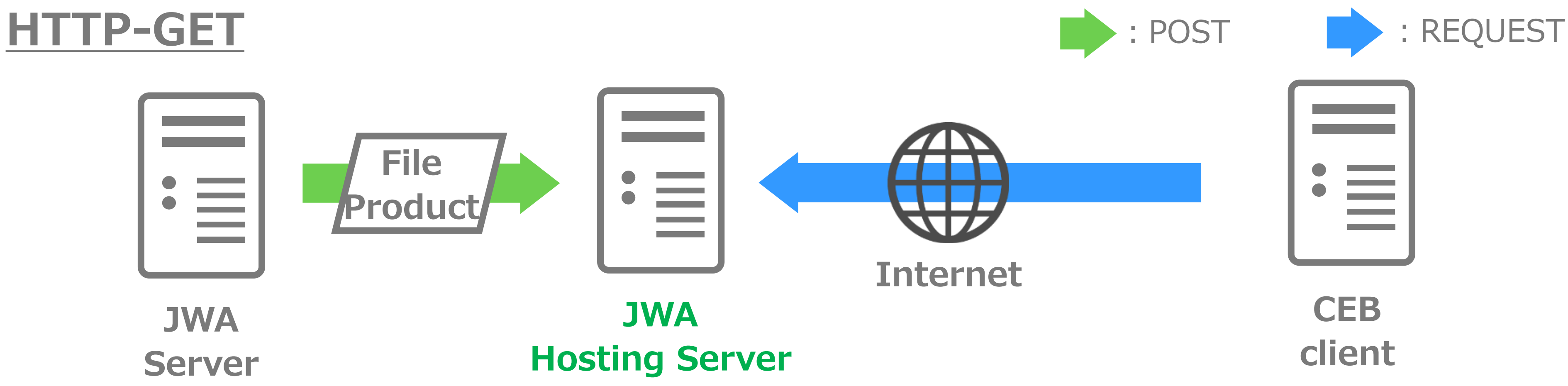
Specification of the VRE forecast

Category	Contents
Data distribution periods	From July 1, 2021, to February 28, 2023
Forecast range	Up to maximum 78 hours ahead from initial time
Frequency	Twice a day (6 AM and 4 PM in Sri Lanka Standard Time)
Timestep	Every 15 min (※Interpolated value)
Data variables	PV ①Total amount of solar radiation(W/㎡) ②PV power output(kW) WF ③wind speed(m/s) and direction ④WF power output (kW)
Forecasting point	8 points set by Latitude/longitude
File format	XML(two files, weather and VRE output)
Data access	HTTP-GET

6. Delivery method of VRE forecast



The data size of 2 XML file to be sent is expected to be about 200KB per delivery
Data for the past 1 week is stored on JWA Hosting Server, if old data is needed

6. Delivery method of VRE forecast

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【File format (example of VRE output)】

The following is an image of the forecast information provided in XML format.

Point number

Time of forecast target (local time: SLST)

Forecast of VRE output


```
<point code=“714401001”>
  <forecast time=“2022-03-28T06:15">
    <generatedEnergy_kw rank="">670</generatedEnergy_kw>
  </forecast>
  <forecast time="2022-03-28T06:30">
    <generatedEnergy_kw rank="">658</generatedEnergy_kw>
  </forecast>
  <forecast time=“2022-03-28T06:45”>
    <generatedEnergy_kw rank=“”>645</generatedEnergy_kw>
  </forecast>
  <forecast time="2022-03-28T07:00">
    <generatedEnergy_kw rank="">633</generatedEnergy_kw>
  </forecast>
・・・
```

Contents

1. The viewpoints of candidate sites selection

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When considering the candidate sites of the VRE forecast, the following viewpoints shall be taken into account

- ✓ Facility information availability(mandatory condition)
- ✓ Larger generation capacity (100MW>10MW>1MW)
- ✓ Availability of measured data (output and weather> output > weather)
- ✓ Sites to represent the north, south, east, and west regions of Sri Lanka

* The above inequality sign (>) indicates the priority.

2. Facility information

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【PV, Utility-scale】

Using the following facility information, the amount of solar radiation is converted into PV power generation output This information should be organized by site.

PV facility information	example
Site name	Saga PV Site
Location(latitude/longitude)	Lat: 7.94YYYYY,　Lon: 81.25XXXX
Period of installation	1 year and 3 months since installation
panel azimuth angle	180°　　(due south)
panel tilt angle	10°
type of installation	Utility-scale
types of PV module	Monocrystalline Silicon, Polycrystalline Silicon, etc
Total amount of panel capacity（kW)	100,000kW
PCS series-name（manufacturer)	PCS-ABC1200E (produced by ABC solar Co.,Ltd.)
Total amount of PCS rated capacity（kW)	100,000kW

2. Facility information

【PV, Rooftop】

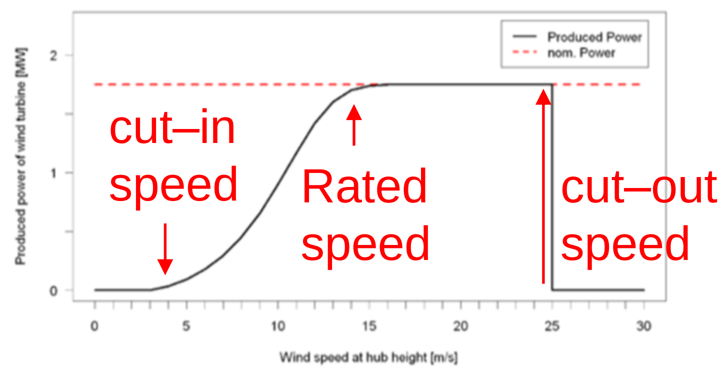
Using the following facility information, solar radiation is converted into Rooftop PV power generation per resident(household). These information should be organized by area.

Rooftop PV facility information	example
Area name	Rooftop South
Representative Location(latitude/longitude)	Lat: 7.94YYYYY, Lon: 81.25XXXX
Period of installation	(If possible)
Representative panel azimuth angle	180° (due south)
Representative panel tilt angle	10°
type of installation	Rooftops
Representative types of PV module	Monocrystalline Silicon, Polycrystalline Silicon, etc
Representative panel capacity kW) **※per resident(household)**	4.5kW
PCS series-name（manufacturer）	(If possible)
Total amount of PCS rated capacity（kW）	(If possible)

2.Facility information

【Wind power】

Using the following facility information, wind speed and direction is converted into Wind power generation output. This information should be organized by site as in the table below.

Wind facility information	example
Site name	ZZZZ WPP Site
Location(latitude/longitude)	Lat: 7.94YYYYY,　Lon: 81.25XXXX
Period of installation	8 months since installation
number of wind turbines	11
wind turbine rated capacity per unit（kW）	1,700 kW
Total amount of wind turbine capacity（kW）	18,700 kW
wind turbine hub height	60m
power curve (includes cut–in, rated, cut–out wind speed) ※please refer to product catalog of wind turbine.	

3. Examine existing sites at the preparation stage

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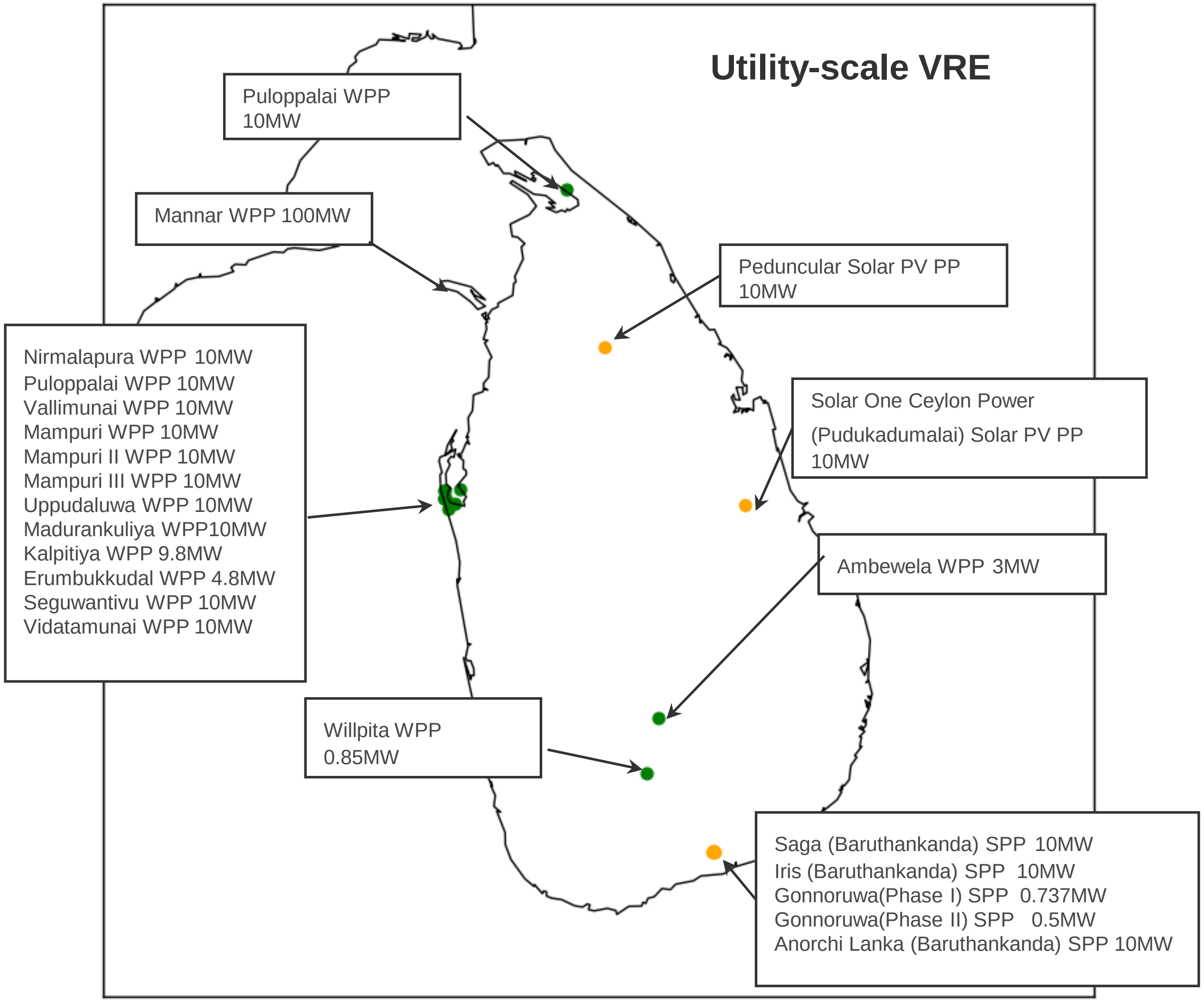
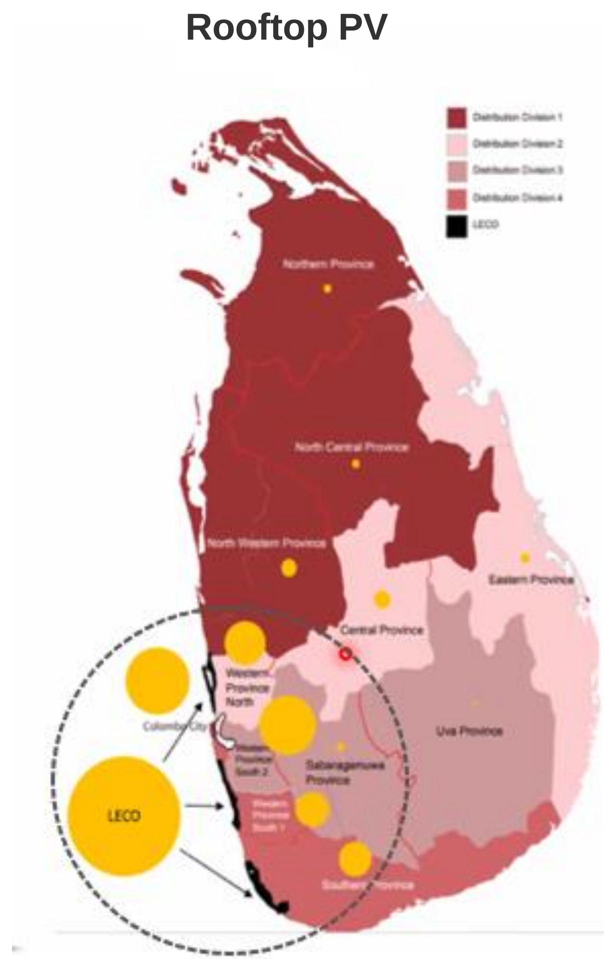




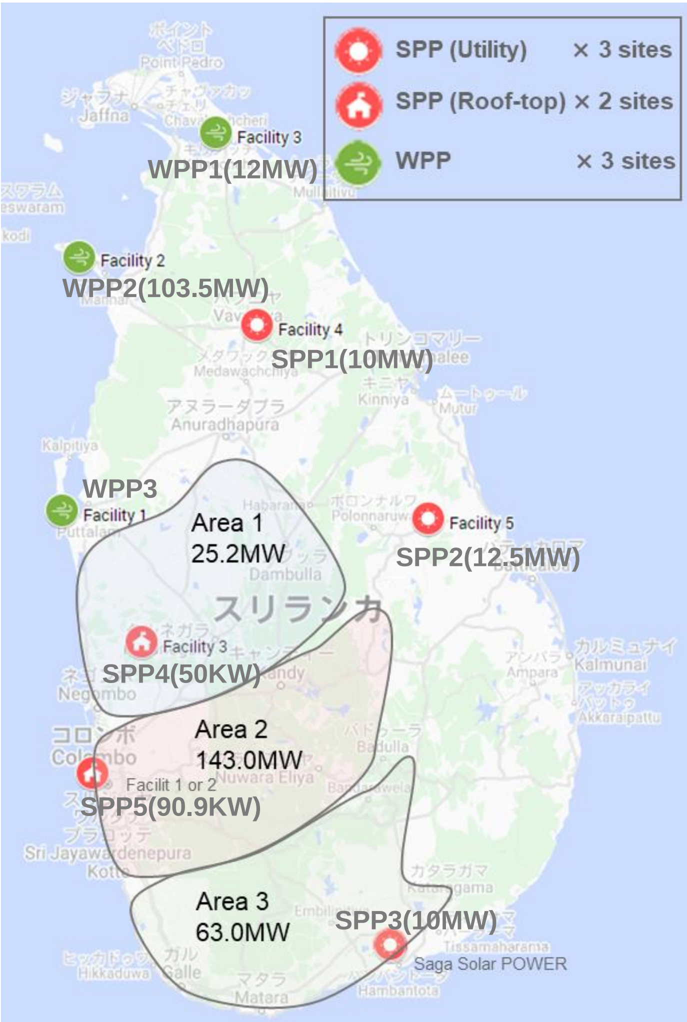
Distribution of the Existing VRE Sites as of 2020.Sep

4. Method to decide the forecast points for rooftop PV

#	Points of view to decide the points of rooftop PV
1	Please set appropriate points (latitude and longitude) for forecasting. Concerning a distribution map of Rooftop PV with capacity level, it is better to select a capacity-intense area as a forecast location.
2	Please investigate and create "Representative average facility information" for each area. Panel azimuth angle, tilt angle, types of PV module, and panel capacity are mandatory parameters.
3	Please create a profile of power consumption per resident to calculate surplus power generation from forecast output.
4	Please prepare the parameter of the number of Rooftops by area to reflect its rapid-growing. (e.g. monthly number of Rooftop PV, etc)
5	Is it possible to obtain data records of "all-quantity power generation per resident(household)"? It will be useful to verify the forecast accuracy.

5. Determination of Forecast Points of VRE

Forecast points



Information on forecast point

Forecast site(Capacity)	Information on forecast site	Lat/Lon
WPP1(12MW)	Northern Wind Power Plant	9.55/80.35
WPP2(103.5MW)	Mannar Wind Power Plant	9.050124, 79.792038
WPP3(10MW)	Mampuri Wind Power Plant	8°0'36.37"N, 79°43'24.09"E
SPP1(10MW)	Vydexa solar Power Plant	8°46'9.49"N, 80°31'39.88"E
SPP2(12.5MW)	Solar One Ceylon Power	7°58'31.38"N 81°14'18.23"E
SPP3(10MW)	Saga Solar Power	6.22/81.085
SPP4(50KW)	Kuliyapitiya Area	7.5/80.05
SPP5(90.9KW)	CEB Head office	6.9/79.8

Contents

1.Necessary data on developing the VRE forecast model

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The priority of collecting data for the development of the VRE forecast model

Target Site	Weather data Wind speed & direction for Wind power Solar irradiation for Solar power	Output data of VRE	Facility information
Existing Site (Data source)	○ (CEB/IPP/DOM)	○ (CEB/IPP/etc.)	◎ (CEB/IPP/etc.)
Planning Site (Data source)	○ (DOM/etc.)	× (CEB/IPP/etc.)	◎ (CEB/IPP/etc.)

◎ : Mandatory, ○ : Desirable, × : Not available
DOM : Department of Meteorology, Sri Lanka

1.Necessary data on developing the VRE forecast model

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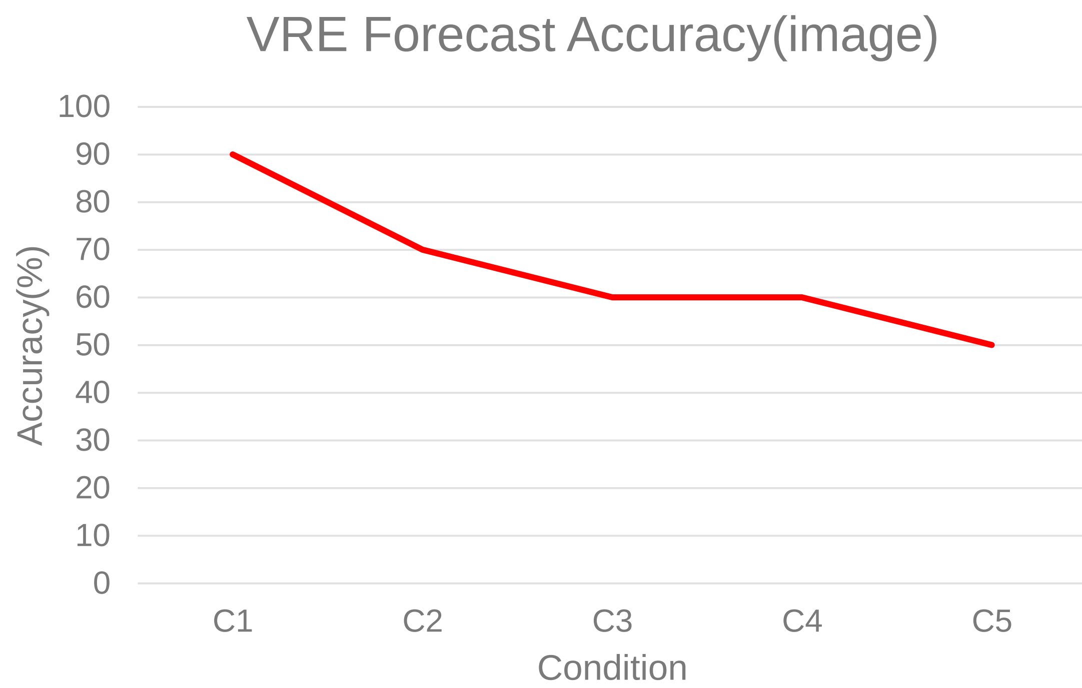
Data acquisition condition

Condition	Weather data (CEB,IPP)	Weather data (DOM)	Output data of VRE	Facility information
C1	〇	×	〇	〇
C2	×	〇	〇	〇
C3	×	×	〇	〇
C4	×	〇	×	〇
C5	×	×	×	〇

〇：Available,×：Not available
DOM：Department of Meteorology, Sri Lanka



The Accuracy of the VRE forecast model depends on the condition of data acquisition

2. Acquisition method for the development of the VRE forecast model

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【Weather observation data】

Location, available variables, and any other additional information are also important for weather observational data.

additional information	example
station name (ID)	●● station 001
administrator	CEB (or Department of Meteorology)
Location(latitude/longitude)	Lat: 7.94YYYYY, Lon: 81.25XXXX
Variables	solar irradiation, wind speed/ direction, daily maximum/ minimum temperature, precipitation, hours of daylight etc.
observation frequency	every ten (10) minutes
period	available since Mar.2017

2. Acquisition method for the development of the VRE forecast model

【Weather observation data】

Observational data (temperature, precipitation, solar radiation, etc)

timeline

年月日時	気温(°	気温(°	気温(°	降水量	降水量	降水量	降水量	降雪(c	降雪(c	降雪(c	降雪(c	積雪(c	積雪(c	積雪(c	積雪(c	日照時	日照時	日照時	日照時	風速(r	風速(r	風速(r	風速(r	風速(r	日射量	日射量	日射量
																						風向	風向				
		品質情	均質番号		現象な	品質情	均質番号		現象な	品質情	均質番号		現象な	品質情	均質番号		現象な	品質情	均質番号		品質情報		品質情	均質番号		品質情	均質番
2020/1/1 1:00	3.7	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	6	8	北西	8	1	0	8	1
2020/1/1 2:00	3.5	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	4.3	8	北北西	8	1	0	8	1
2020/1/1 3:00	3.6	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	4.8	8	北北西	8	1	0	8	1
2020/1/1 4:00	4	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	4.7	8	北西	8	1	0	8	1
2020/1/1 5:00	4.2	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	4.2	8	北北西	8	1	0	8	1
2020/1/1 6:00	4.1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	4.7	8	北西	8	1	0	8	1
2020/1/1 7:00	3.8	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	0	8	1	4.2	8	北北西	8	1	0	8	1
2020/1/1 8:00	4.4	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0.2	0	8	1	2.4	8	北	8	1	0.18	8	1
2020/1/1 9:00	5.2	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0.6	0	8	1	1.8	8	北北西	8	1	0.71	8	1
2020/1/1 10:00	5.8	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0.3	0	8	1	2	8	北北東	8	1	0.98	8	1
2020/1/1 11:00	7	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1	0	8	1	2.1	8	北北西	8	1	1.77	8	1
2020/1/1 12:00	9.4	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1	0	8	1	1.9	8	北北東	8	1	1.93	8	1
2020/1/1 13:00	8.7	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1	0	8	1	1.5	8	東北東	8	1	1.87	8	1
2020/1/1 14:00	9.6	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1	0	8	1	2.2	8	北	8	1	1.58	8	1
2020/1/1 15:00	8.8	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1	0	8	1	0.7	8	西	8	1	1.13	8	1
2020/1/1 16:00	7.9	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1	0	8	1	2.2	8	南南東	8	1	0.55	8	1
2020/1/1 17:00	5.6	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0.3	0	8	1	2.3	8	南	8	1	0.07	8	1
2020/1/1 18:00	5.5	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	3	8	南	8	1	0	8	1
2020/1/1 19:00	5.5	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1.1	8	南南西	8	1	0	8	1
2020/1/1 20:00	4.9	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0.7	8	西南西	8	1	0	8	1
2020/1/1 21:00	4.3	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0.6	8	南南東	8	1	0	8	1
2020/1/1 22:00	5	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	2.3	8	西北西	8	1	0	8	1
2020/1/1 23:00	4.3	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1.3	8	北西	8	1	0	8	1
2020/1/2 0:00	4.1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	2.1	8	北西	8	1	0	8	1
2020/1/2 1:00	4.7	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1.8	8	北北西	8	1	0	8	1
2020/1/2 2:00	4.2	8	1	0	1	8	1	0	1	8	1	0	1	8	1	0	1	8	1	1.9	8	北	8	1	0	8	1

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【Facility information(PV, Utility-scale)】

Using the following facility information, the amount of solar radiation is converted into PV power generation output This information should be organized by site.

PV facility information	example
Site name	Saga PV Site
Location(latitude/longitude)	Lat: 7.94YYYYY,　Lon: 81.25XXXX
Period of installation	1 year and 3 months since installation
panel azimuth angle	180°　　(due south)
panel tilt angle	10°
type of installation	Utility-scale
types of PV module	Monocrystalline Silicon, Polycrystalline Silicon, etc
Total amount of panel capacity（kW）	100,000kW
PCS series-name（manufacturer）	PCS-ABC1200E (produced by ABC solar Co.,Ltd.)
Total amount of PCS rated capacity（kW）	100,000kW

2. Acquisition method for the development of the VRE forecast model

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【Facility information(PV, Rooftop)】

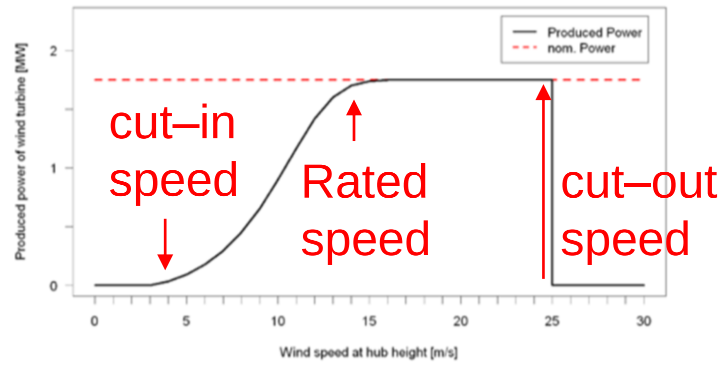
Using the following facility information, solar radiation is converted into Rooftop PV power generation per resident(household). These information should be organized by area.

Rooftop PV facility information	example
Area name	Rooftop South
Representative Location(latitude/longitude)	Lat: 7.94YYYYY, Lon: 81.25XXXX
Period of installation	(If possible)
Representative panel azimuth angle	180° (due south)
Representative panel tilt angle	10°
type of installation	Rooftops
Representative types of PV module	Monocrystalline Silicon, Polycrystalline Silicon, etc
Representative panel capacity kW） **※per resident(household)**	4.5kW
PCS series-name（manufacturer）	(If possible)
Total amount of PCS rated capacity（kW）	(If possible)

2. Acquisition method for the development of the VRE forecast model

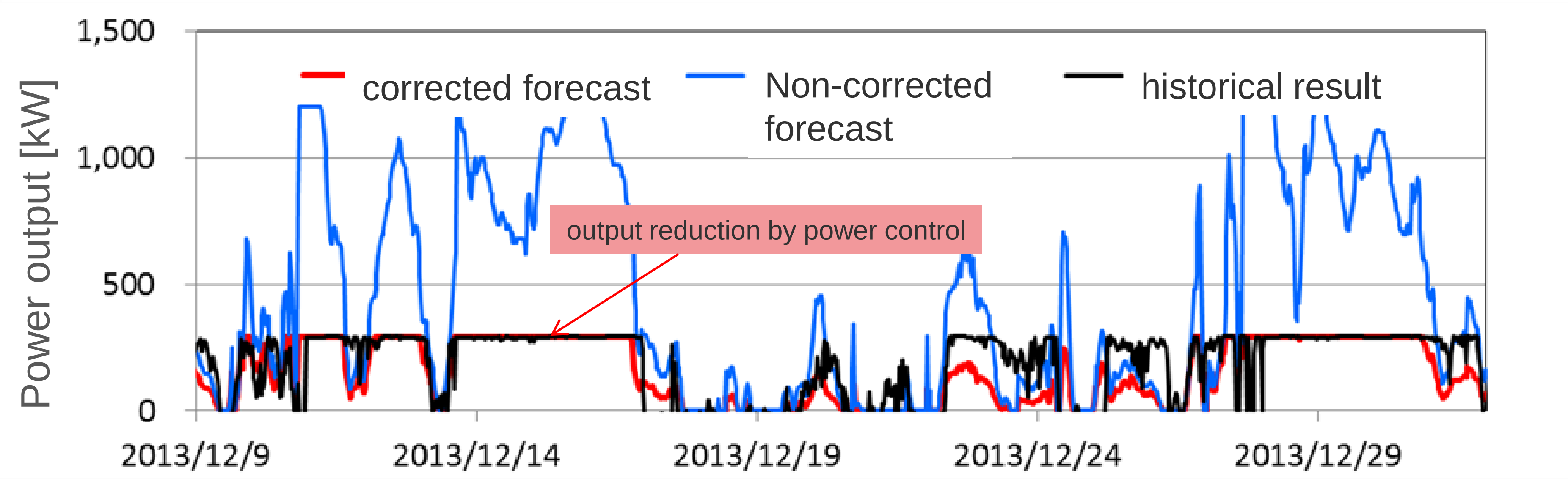
【Facility information(Wind power)】

Using the following facility information, wind speed and direction is converted into Wind power generation output. This information should be organized by site as in the table below.

Wind facility information	example
Site name	ZZZZ WPP Site
Location(latitude/longitude)	Lat: 7.94YYYYY,　Lon: 81.25XXXX
Period of installation	8 months since installation
number of wind turbines	11
wind turbine rated capacity per unit（kW）	1,700 kW
Total amount of wind turbine capacity（kW）	18,700 kW
wind turbine hub height	60m
power curve (includes cut–in, rated, cut–out wind speed) ※please refer to product catalog of wind turbine.	

【Facility information(VRE operation information)】

Operation information is useful for developing the VRE forecast model.
For example, output reduction due to power control is not due to a meteorological phenomenon. Considering such information contributes to forecasting accuracy.



Contents

1. Comparison between the observed data and the forecasted data
2. Verification result of the accuracy of the VRE forecast model

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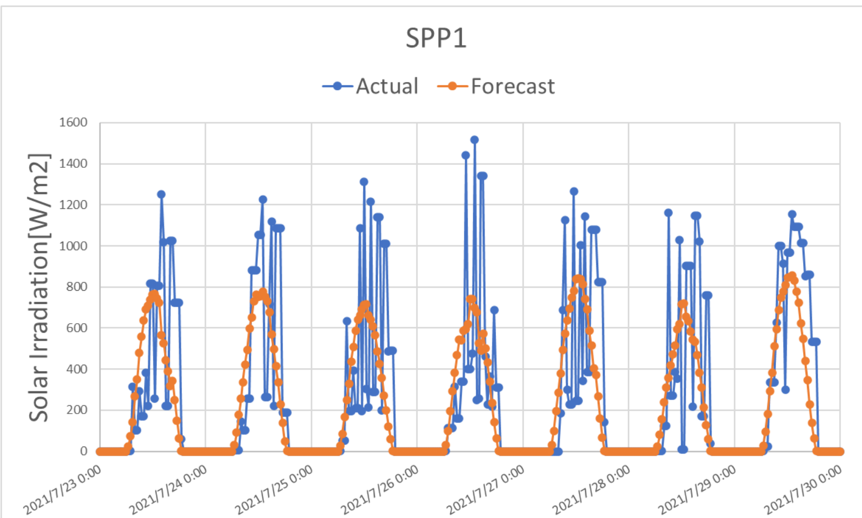
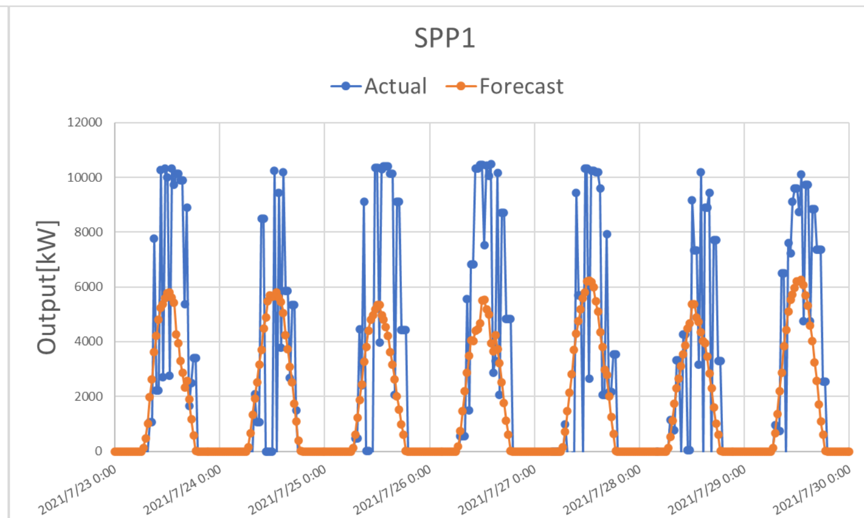
For SPP1 (Time series comparison)

① Forecasted Solar Irradiation and VRE output data tend to be underestimated.
② The fluctuation of actual data is larger than that of forecasted data.





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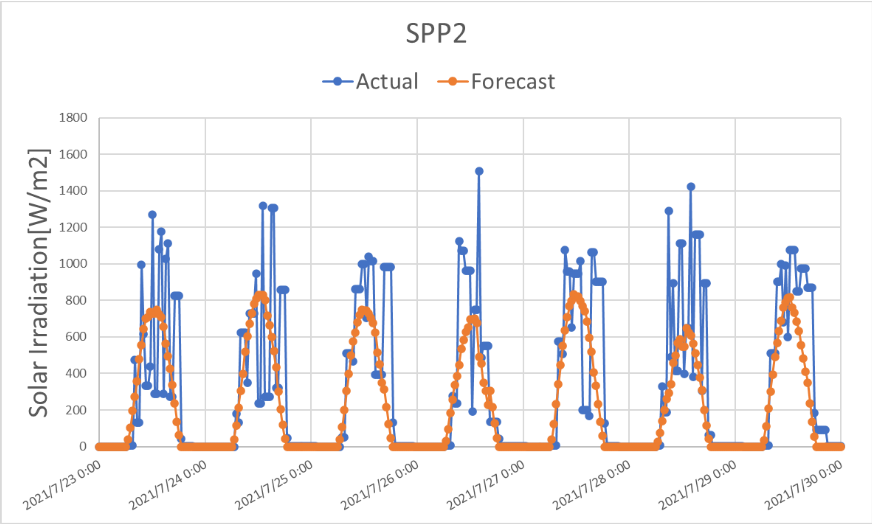
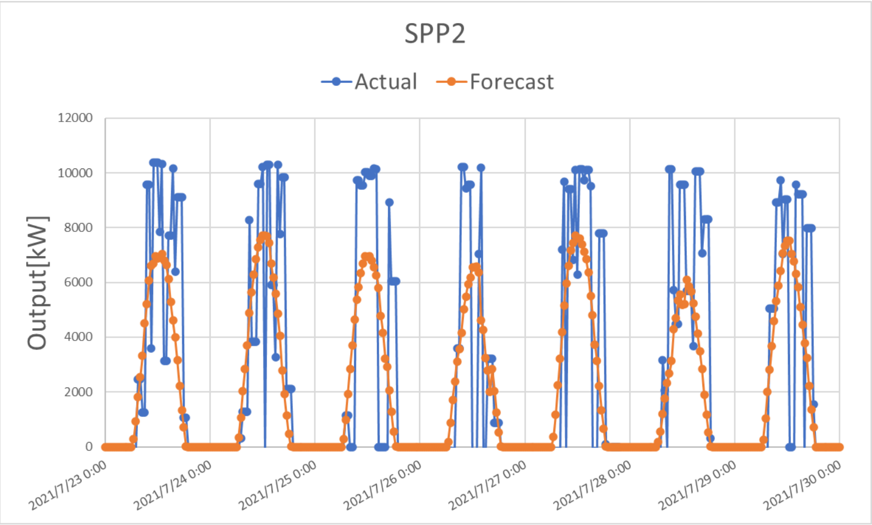
For SPP2 (Time series comparison)

① Forecasted Solar Irradiation and VRE output data tend to be underestimated.
②The fluctuation of actual data is larger than that of forecasted data





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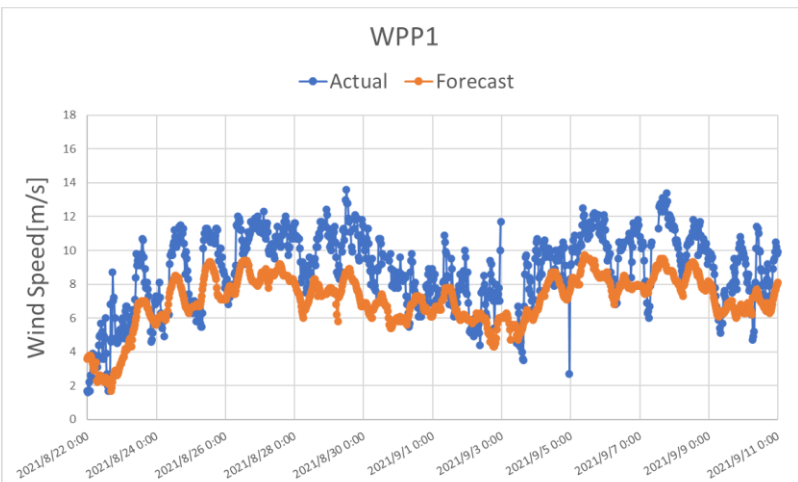
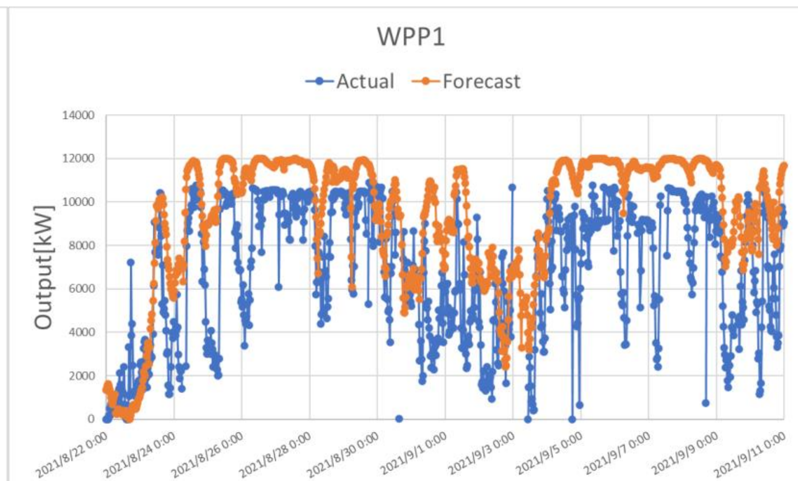
For WPP1 (Time series comparison)

① Forecasted Wind Speed data tend to be underestimated.
② Forecasted VRE output data tend to be overestimated.





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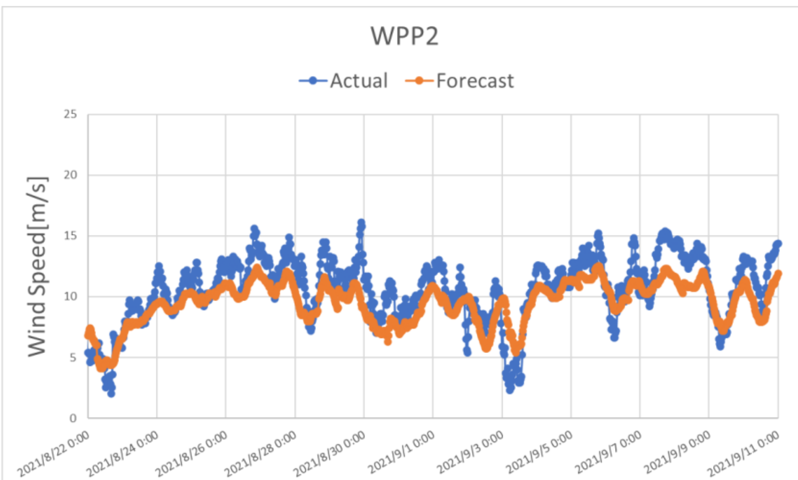
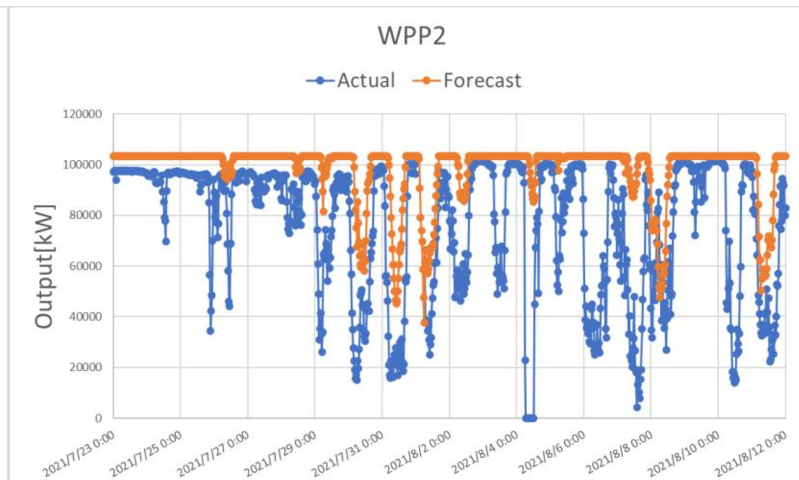
For WPP2 (Time series comparison)

① Forecasted Wind Speed data tend to be generally correct.
② Forecasted VRE output data tend to be overestimated.



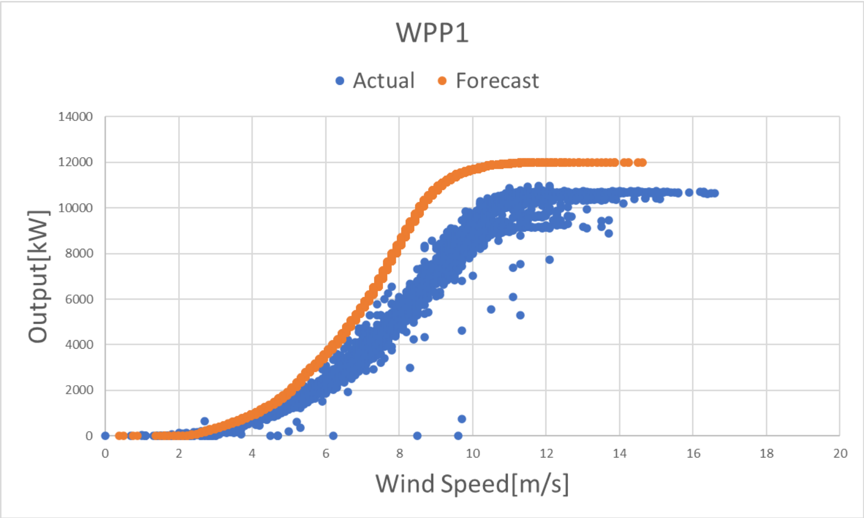


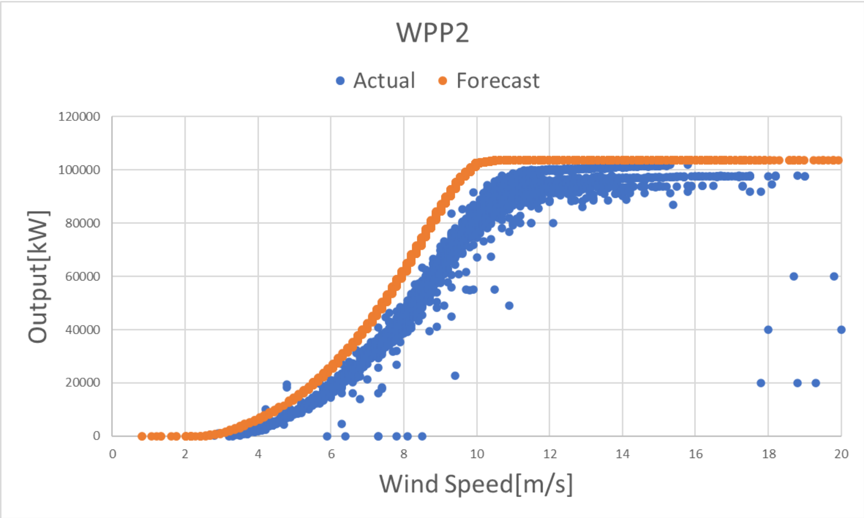
For WPP1 and WPP2 (Power Curve comparison)

① About WPP1 and WPP2,

VRE forecast model was constructed based on similar power curve, because the power curve information was not available.

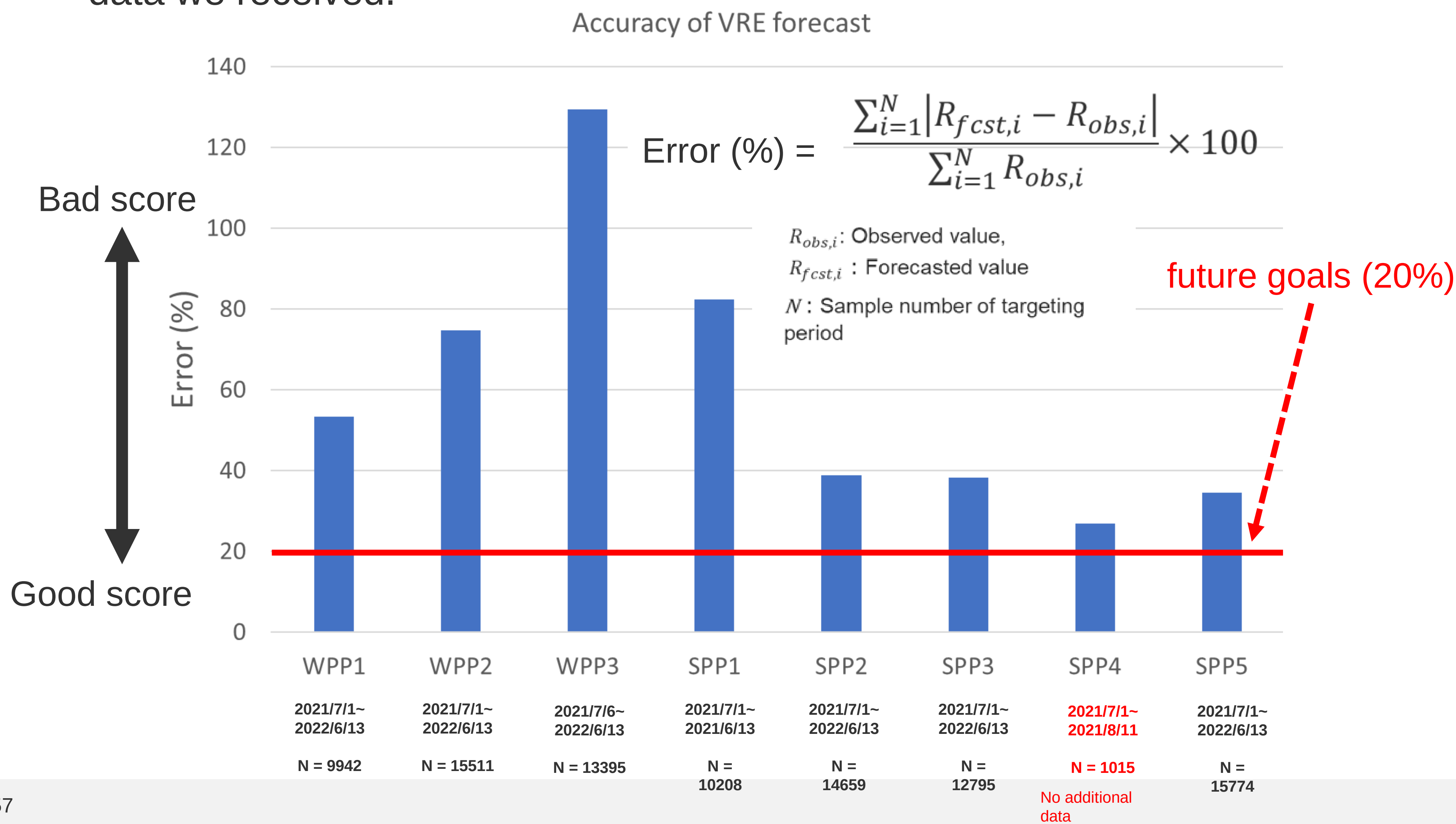
Create a power curve based on the measured values (Wind Speed and Output) and apply it to the VRE forecast model.





2. Verification result of the accuracy of the VRE forecast model

We confirmed the current VRE forecast accuracy based on the observed data we received.



Contents

1. Obtaining the historical data for VRE accuracy improvement

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CEB provided the historical data to the JICA Expert team to develop the VRE forecast model so that the JICA Expert team develop the model and evaluated the accuracy of the VRE model by using the data below.

Receipt status	SPP					WPP		
	Utility PV			Roof-top PV		WPP1	WPP2	WPP3
	SPP1	SPP2	SPP3	SPP4	SPP5			
	Vydexa solar power plant	Solar One Ceylon Power	SAGA SOLAR POWER		Rooftop PV Colombo	Vallimunai 10MW Wind Power plant	Mannar Wind power plant	Mampuri Wind Power Plant
Facility information (mainly location)	○	○	○	○	○	○	○	○
Weather observation data	○ PYRANOMETER 2021/7/1~ 2021/10/21, 15min	○ AIR TEMP, PYRANOMETER 2021/6/1~ 2021/10/21, 15min,	×	×	×	○ Wind speed 2021/6/1~ 2021/9/30, 10min, Individual (8 turbins)	○ Wind speed 2021/6/21~ 2022/6/13, 10min, Individual (33 turbins)	×
VRE output data	○ 2021/7/1~ 2022/6/13, 5min, Total	○ 2021/6/1~ 2022/6/13, 5min, Total	○ 2021/7/1~ 2022/6/13, 5min, Total	○ 2021/7/1~ 2021/8/11, 15min,	○ 2021/7/1~ 2022/6/13, 5min, Total	○ 2021/7/1~ 2022/6/13, 5min, Total	○ 2021/7/1~ 2022/6/13, 10min, Total	○ 2021/7/6~ 2022/6/13, 5min, Total

2. Improvement of the VRE forecast model

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For WPP & SPP

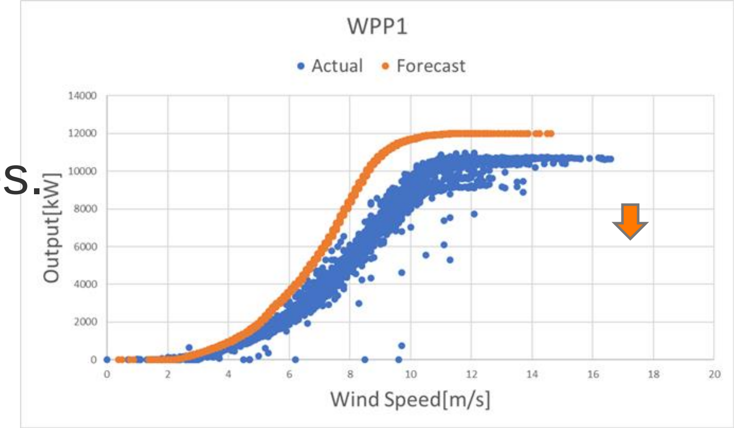
・To calculate Error rate(%) correctly, exclude outliers in the data.

・ **Create correction coefficient to reduce Error from the relationship between the Actual data and the Forecast data.**

For WPP

・Confirm the number of actual working wind turbines.

・ **Apply the power curve created by actual data to the VRE forecast model.**



Applied image.

For SPP

・ **Investigate the cause of underestimation and difference in daily variations.**

・Check the quality of observed data (solar radiation and solar power generation).

・Establish correction factors by comparing maximum values of observed and forecast data.

3. The result of improvement of the VRE forecast model

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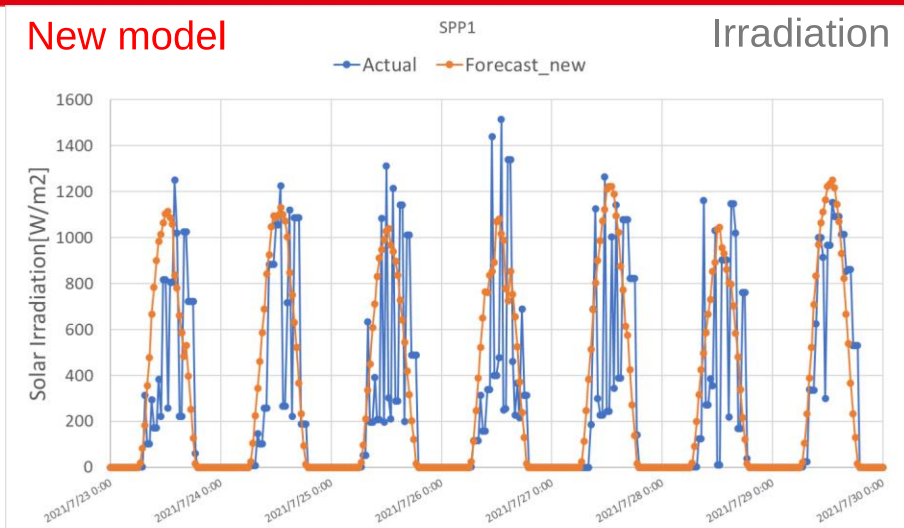
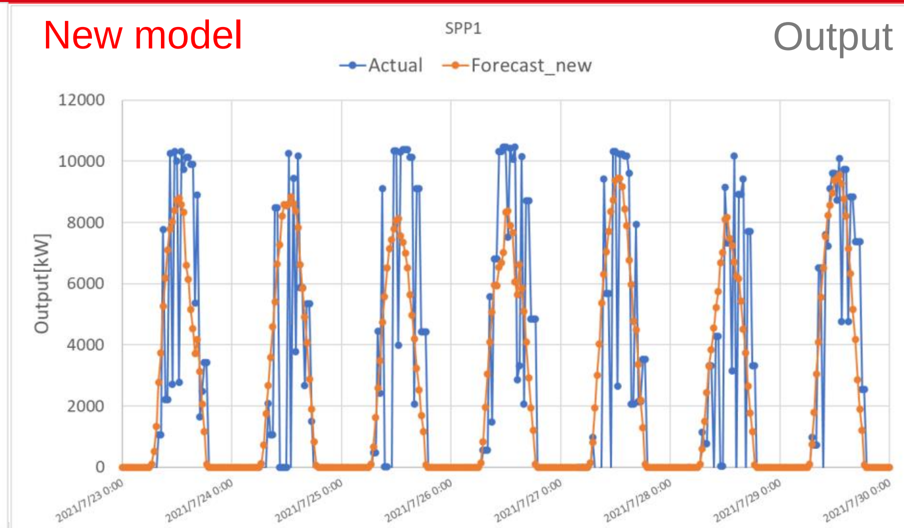
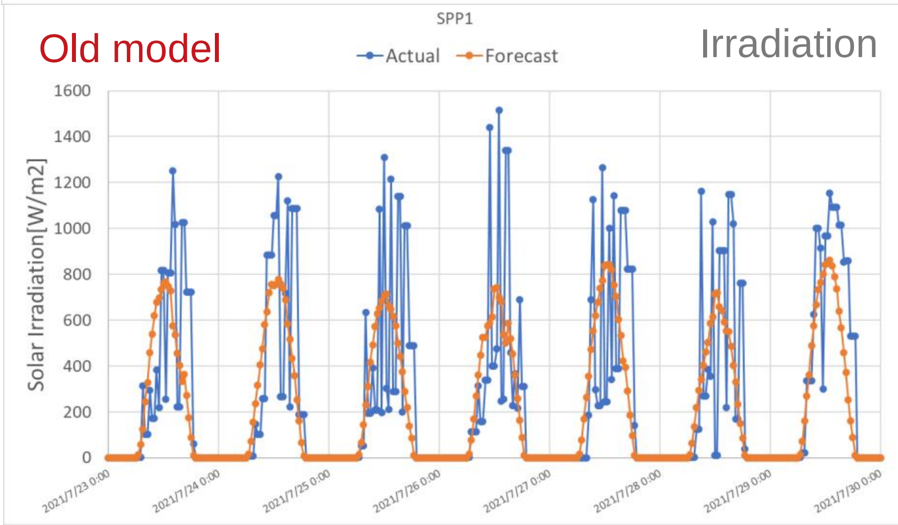
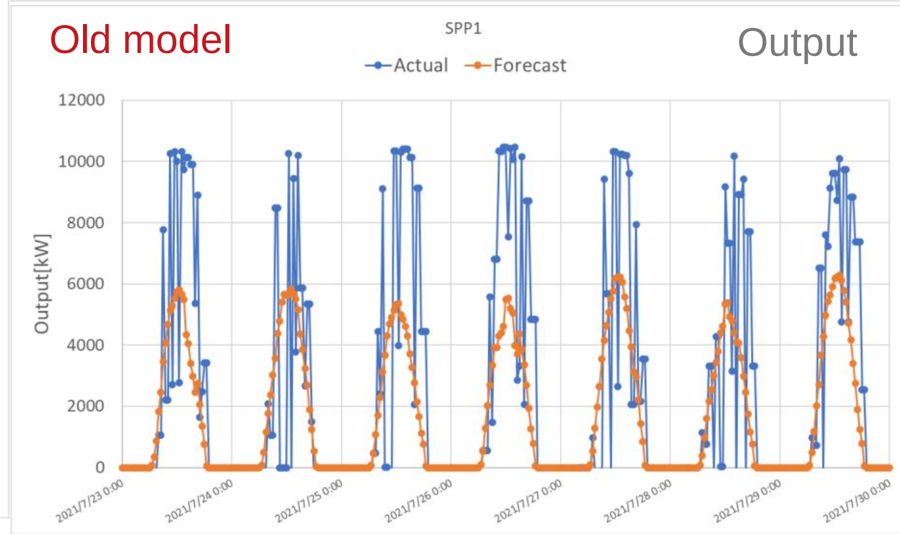
SPP1









- ✓ **The fluctuation of the actual data is much larger than that of forecasted data both irradiation and output**

3. The result of the improvement of the VRE forecast model

CHUBU Electric Power
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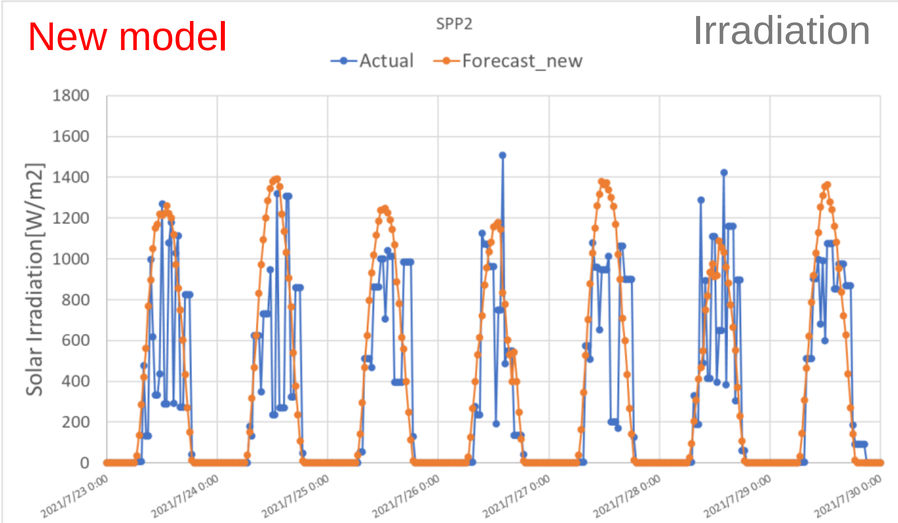
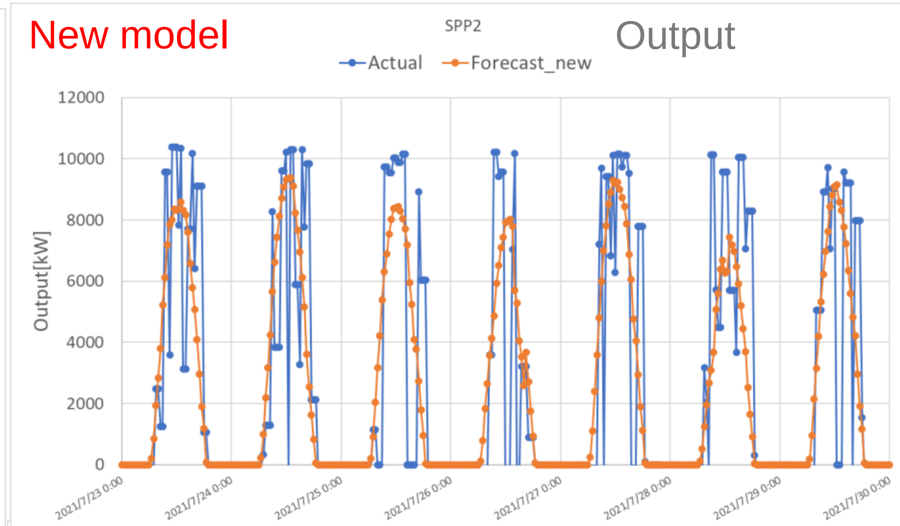
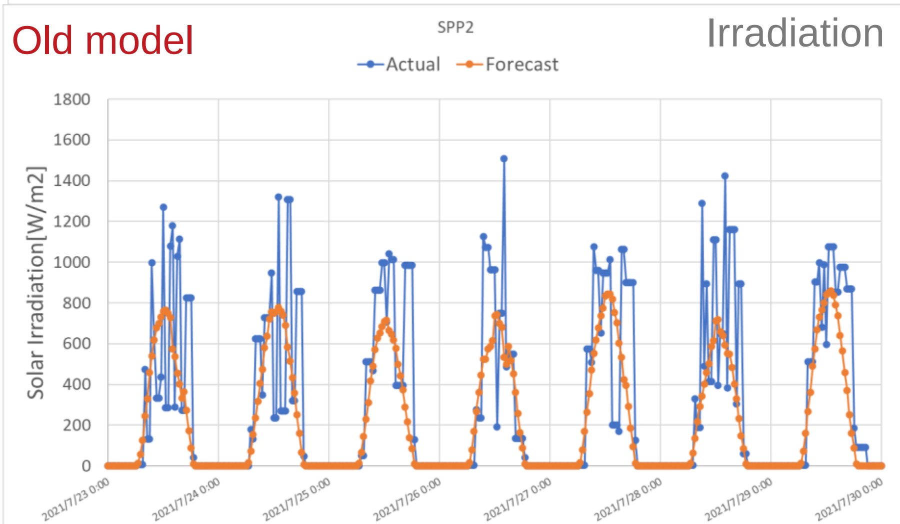
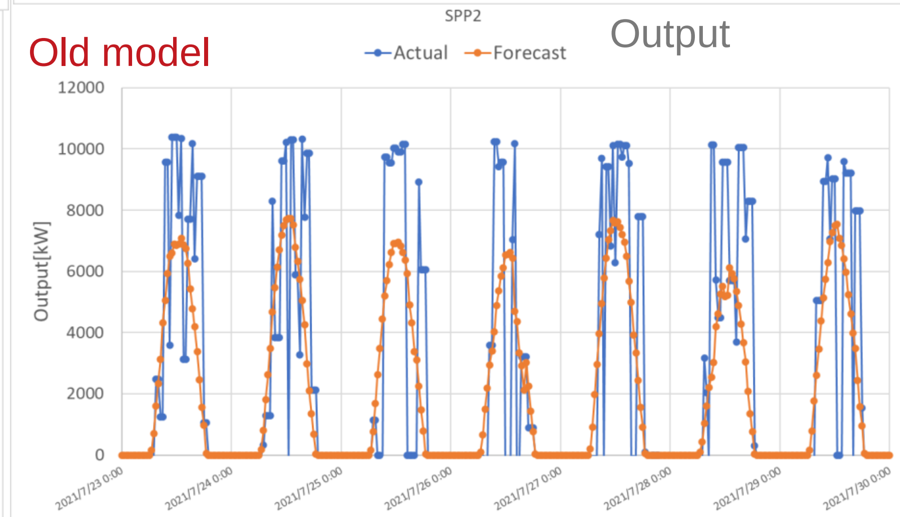
SPP2





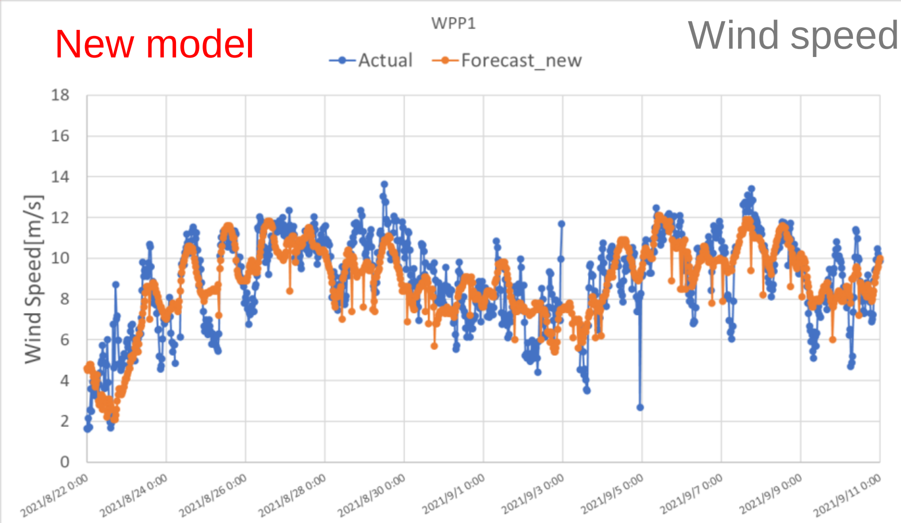


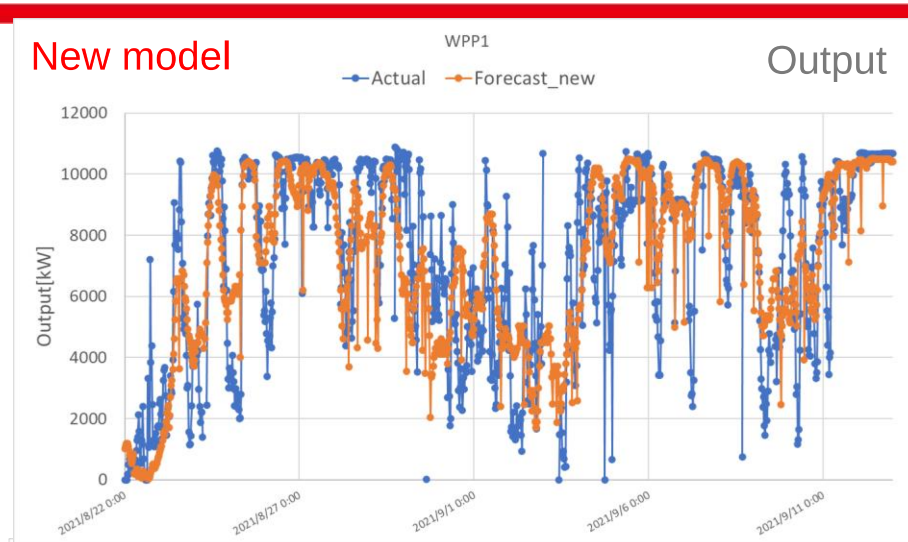


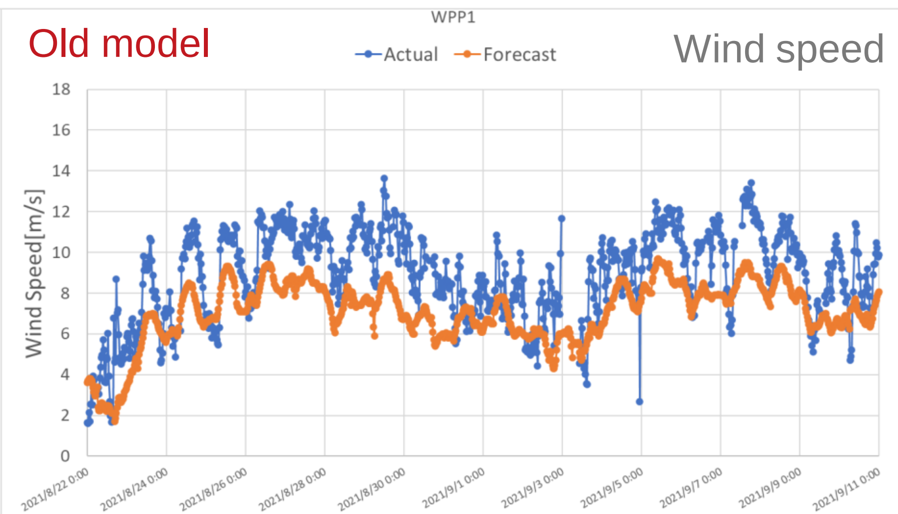
✓ **The fluctuation of the actual data is much larger than that of forecasted data both irradiation and output**

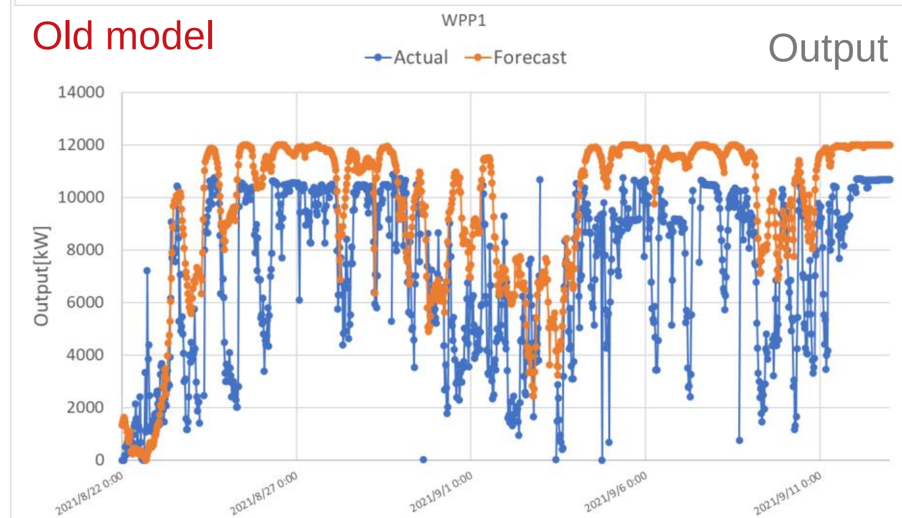
3. The result of the improvement of the VRE forecast model

WPP1





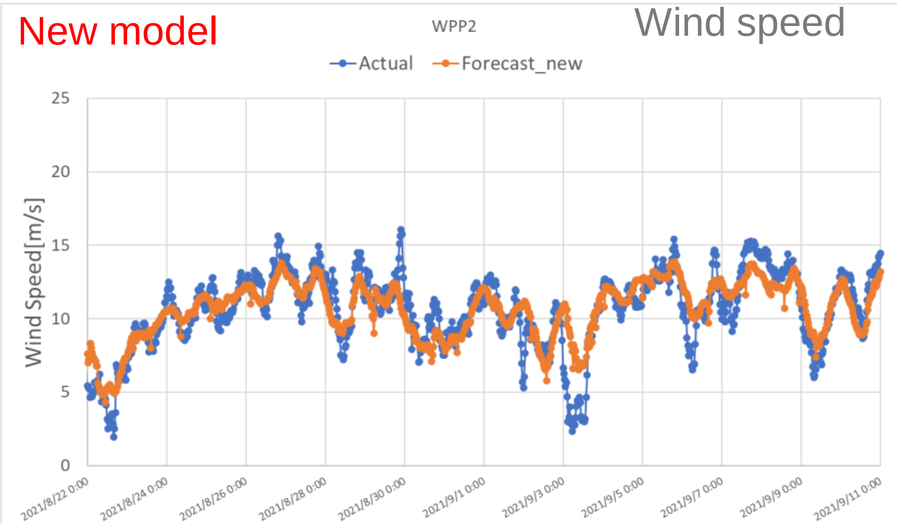


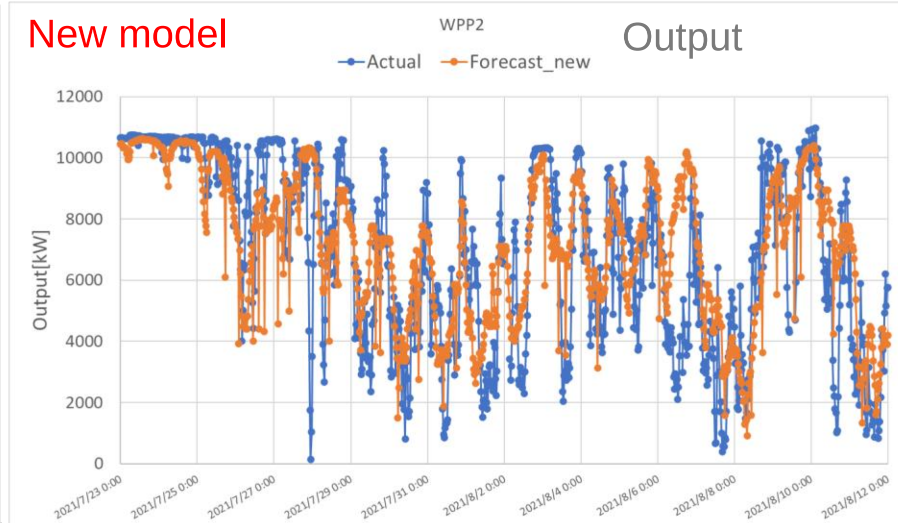


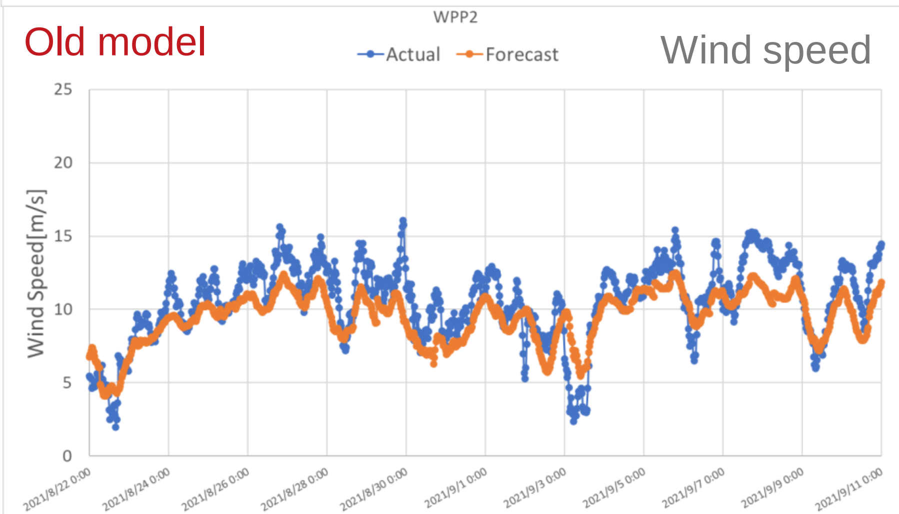
✓ **The accuracy improvement can be seen in both wind speed and output**

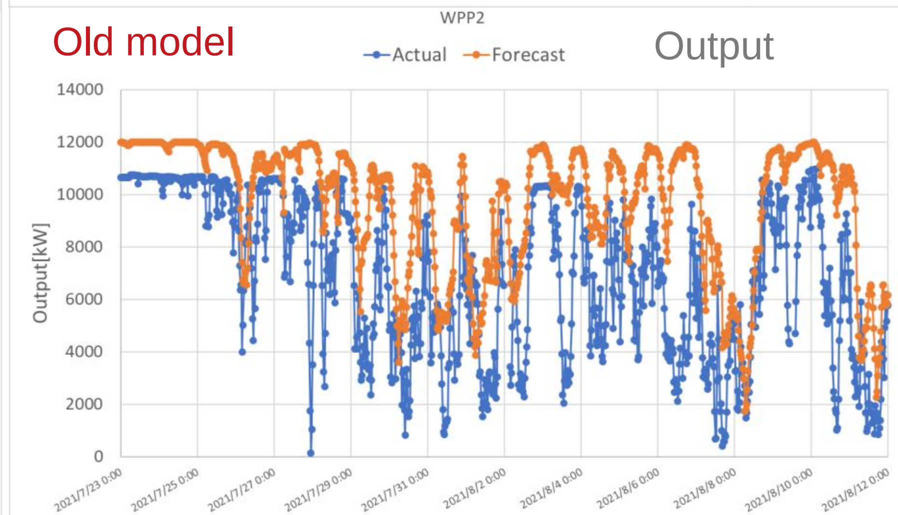
3. The result of the improvement of the VRE forecast model

WPP2









✓ **The accuracy improvement can be seen in both wind speed and output**

3. The result of the improvement of the VRE forecast model

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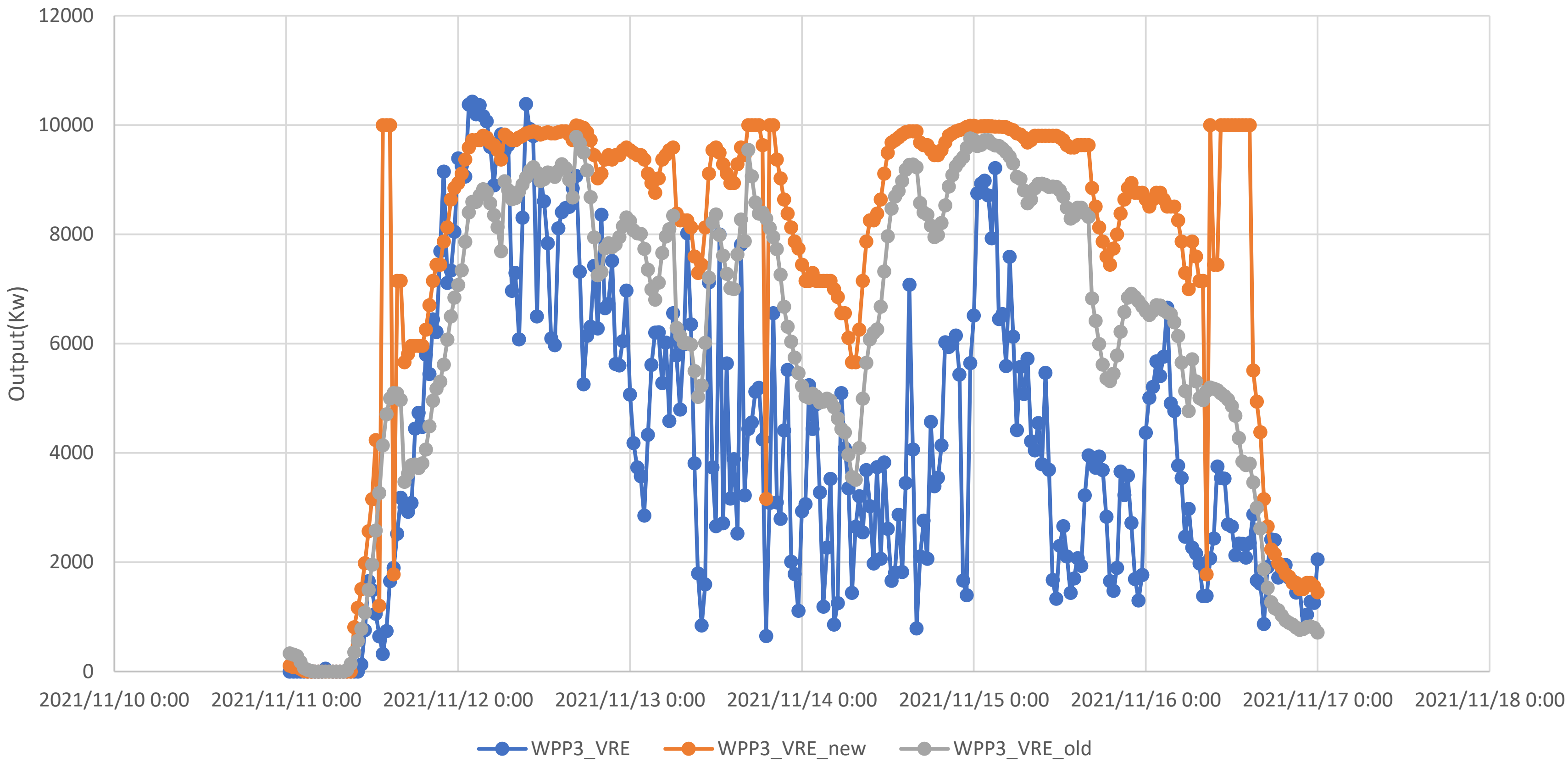
WPP3



✓ Forecast models both new and old tend to overestimation

3. The result of the improvement of the VRE forecast model

CHUBU Electric Power
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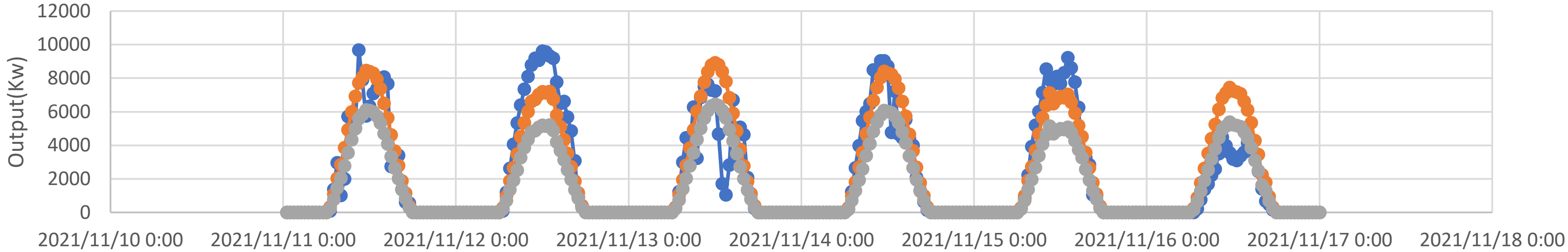
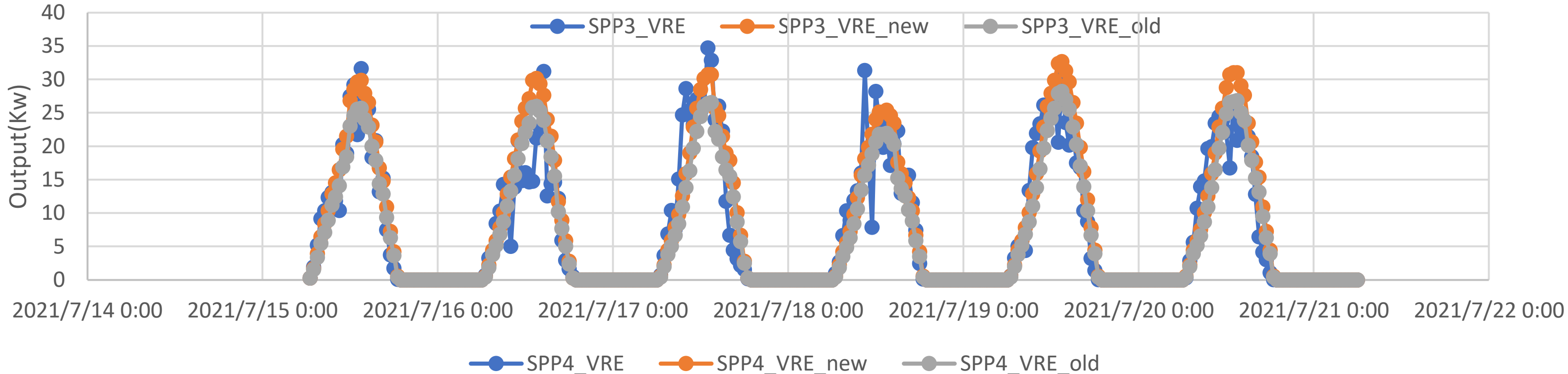
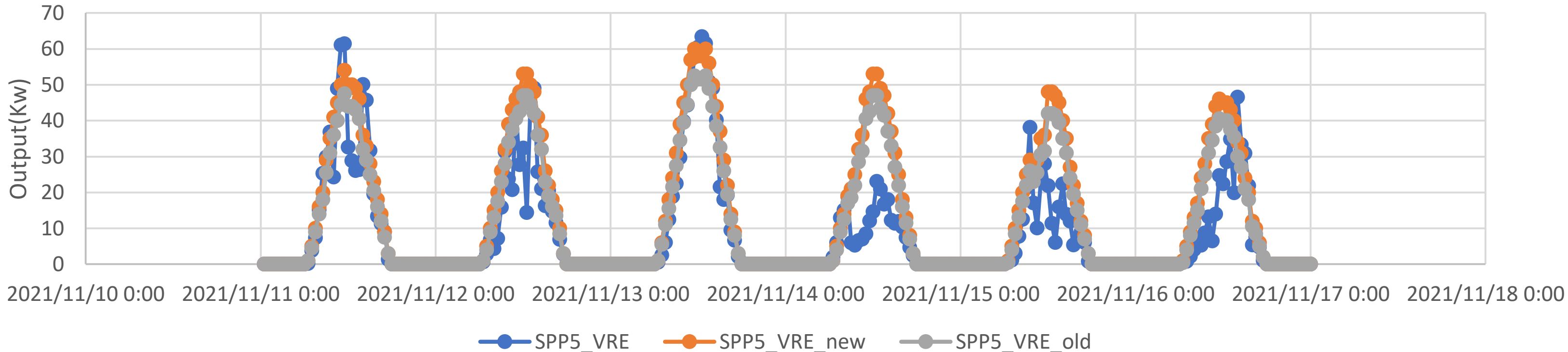
SPP3



SPP4

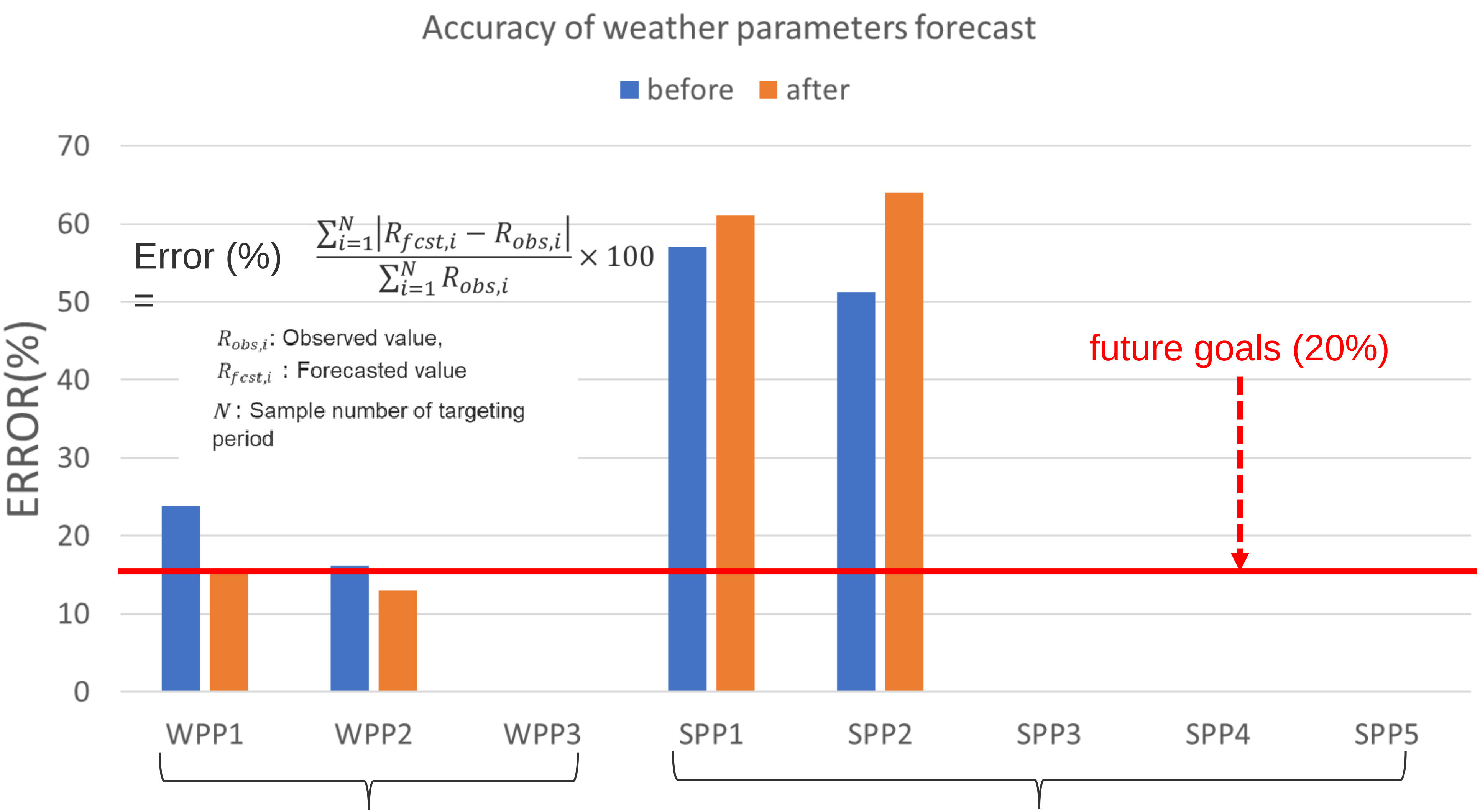


SPP5



✓ **The fluctuation of actual data is larger than that of forecasted data**

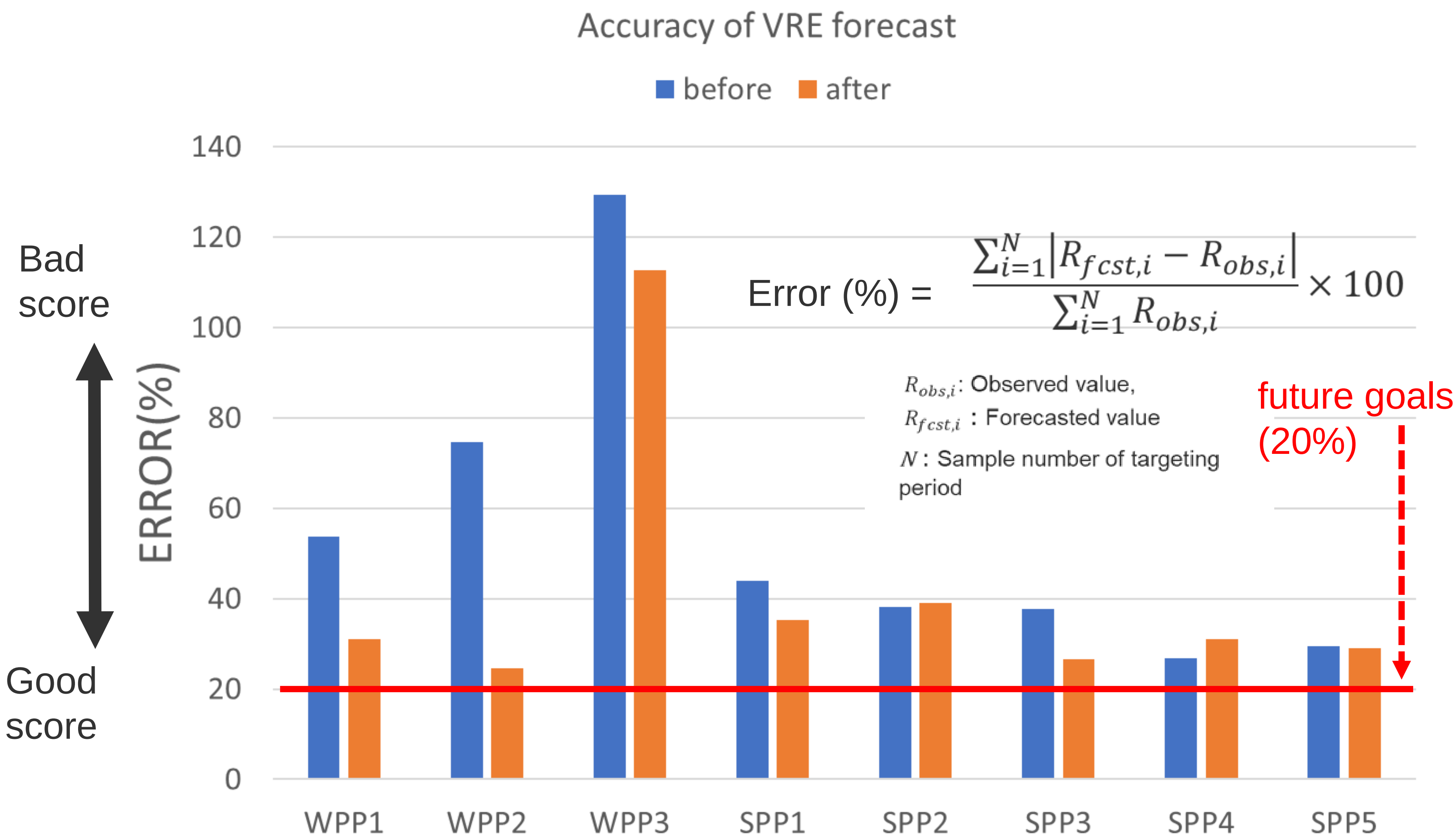
3. The result of the improvement of the VRE forecast model



Weather parameters = **Wind Speed (m/s)**

Weather parameters = **Global Horizontal Irradiation(W/m^2)**

3. The result of the improvement of the VRE forecast model



Contents

1. Methodology of approaching the area VRE forecast
2. Approach to area VRE forecast

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(1) Preliminary analysis

1)Determination of the area represented by the forecast point

2)Calculation of conversion factor(the ratio of outputs between point and area)

(2) Operational phase

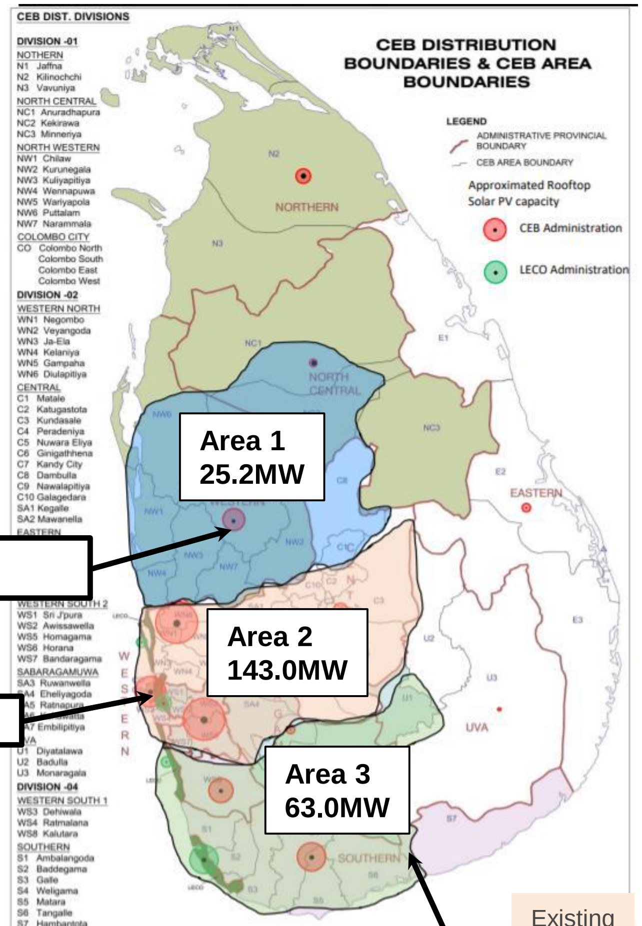
1) Forecast weather at the forecast point

2) Forecast power output at the forecast point

3) Forecast areal power output representative by each forecast point

- Multiply the power output at the forecast point by a conversion factor.
- Summation of the number of power outputs by each VRE

【Rooftop PV】



Facility 1 — 【SPP4】 Roof top PV 50KW

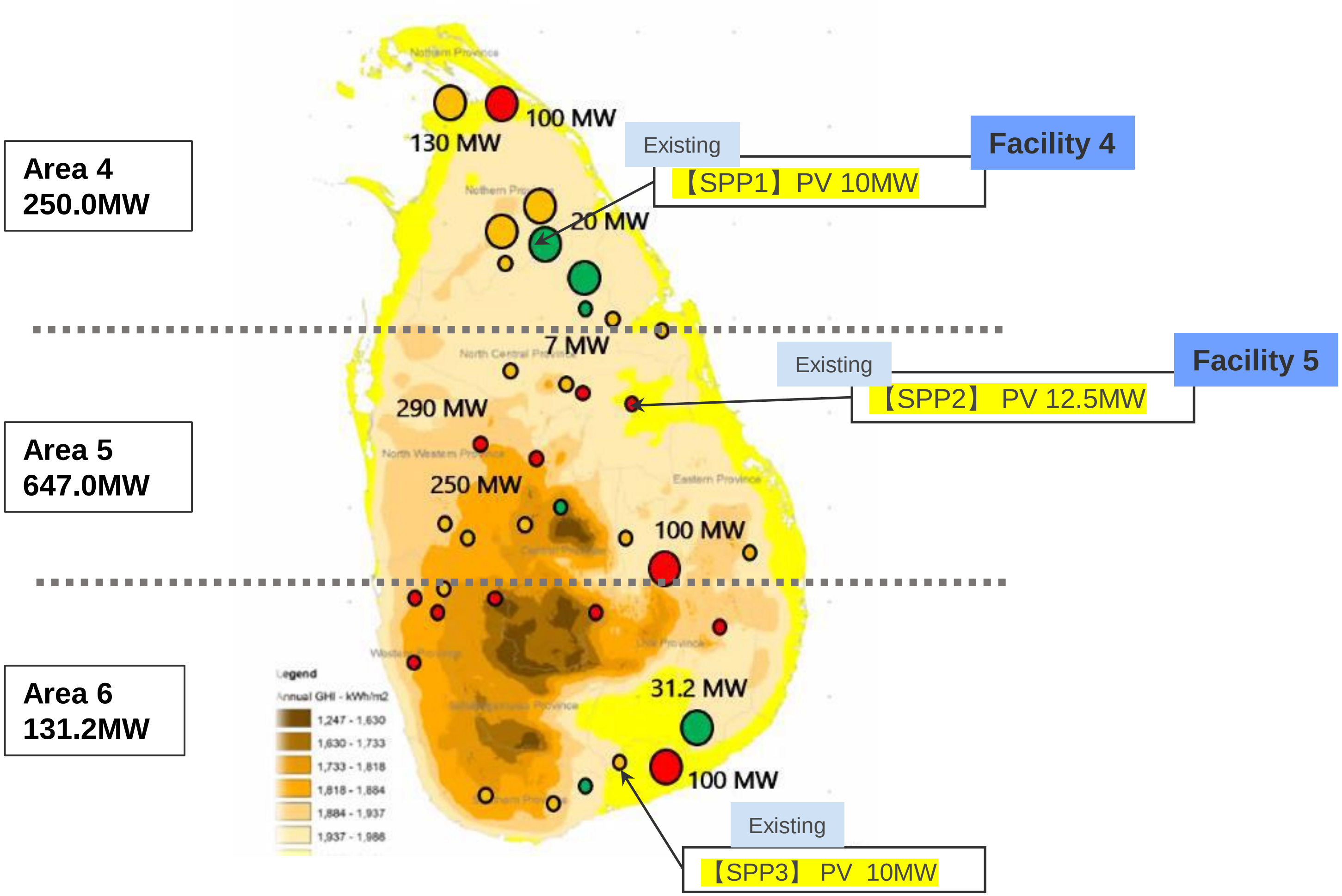
【SPP5】 Roof top PV 90.885kWp

Selected as an alternative Roof top PV

Existing

【SPP3】 PV 10MW — **Saga solar power**

【SPP】


Area 4
250.0MW
Area 5
647.0MW
Area 6
131.2MW
130 MW
100 MW
20 MW
7 MW
290 MW
250 MW
100 MW
31.2 MW
100 MW
Existing
Facility 4
【SPP1】PV 10MW
Existing
Facility 5
【SPP2】 PV 12.5MW
Existing
【SPP3】 PV 10MW
Legend
Annual GHI - kWh/m2
1,247 - 1,630
1,630 - 1,733
1,733 - 1,818
1,818 - 1,884
1,884 - 1,937
1,937 - 1,986

【WPP】

Facility 3

Existing

【WPP1】Wind firm PP 12 MW

Existing in April.2021

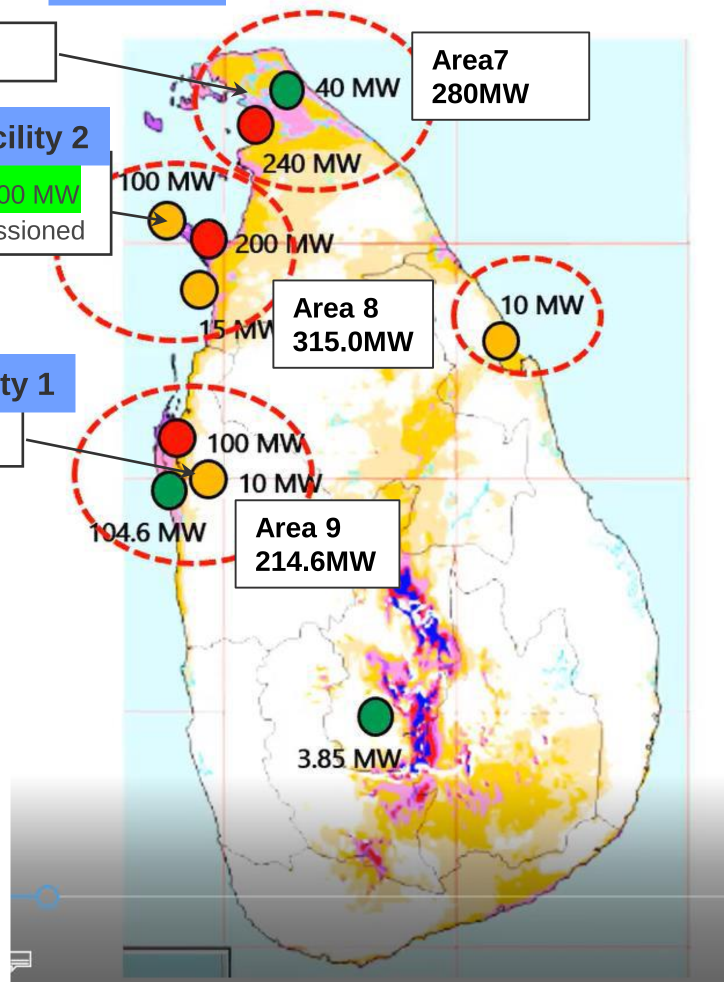
Facility 2

【WPP2】 Wind firm PP 100 MW
※End 2020- Being Commissioned

Existing

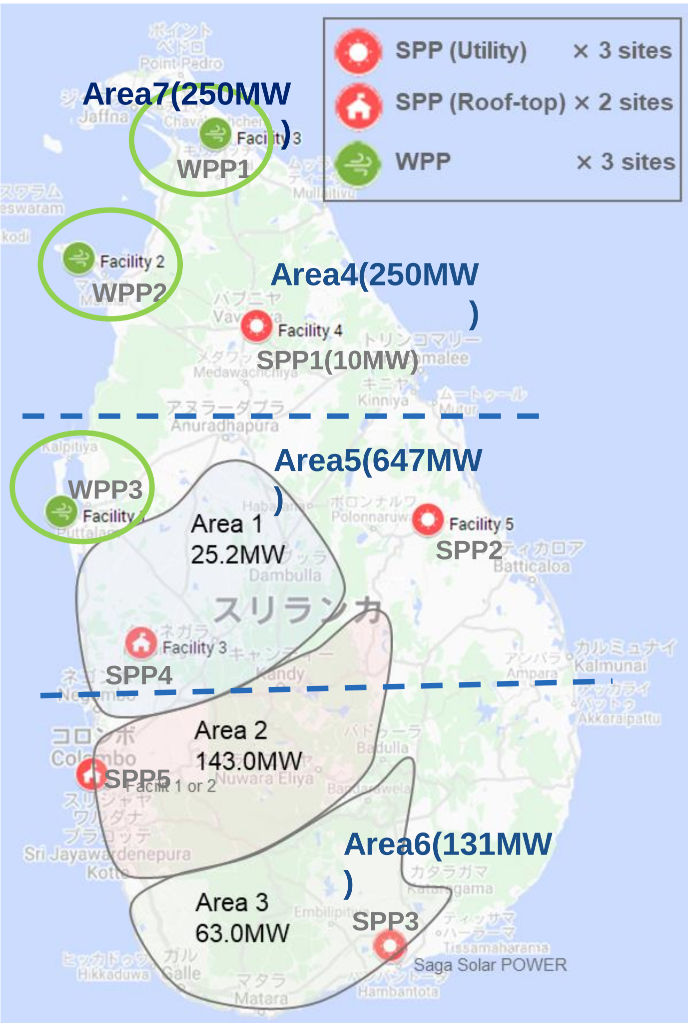
Facility 1

【WPP3】Wind firm PP 10 MW



2. Approach to area VRE forecast

Forecast points



Information on forecast point

Forecast site (Total rated value)	Information on forecast site	Representative area (Total rated value)
WPP1(**12MW**)	Northern Wind Power Plant	Area7(**250MW**)
WPP2(**103.5MW**)	Mannar Wind Power Plant	Area8(**315MW**)
WPP3(**10MW**)	Mampuri Wind Power Plant	Area9(**214.6MW**)
SPP1(**10MW**)	Vydexa solar Power Plant	Area4(**250MW**)
SPP2(**12.5MW**)	Solar One Ceylon Power	Area5(**647MW**)
SPP3(**10MW**)	Saga Solar Power	Area6(**131MW**)
		Area3(**63MW**)
SPP4(**50KW**)	Kuliyapitiya Area	Area1(25.2**MW**)
SPP5(**90.9KW**)	CEB Head office	Area2(143**MW**)

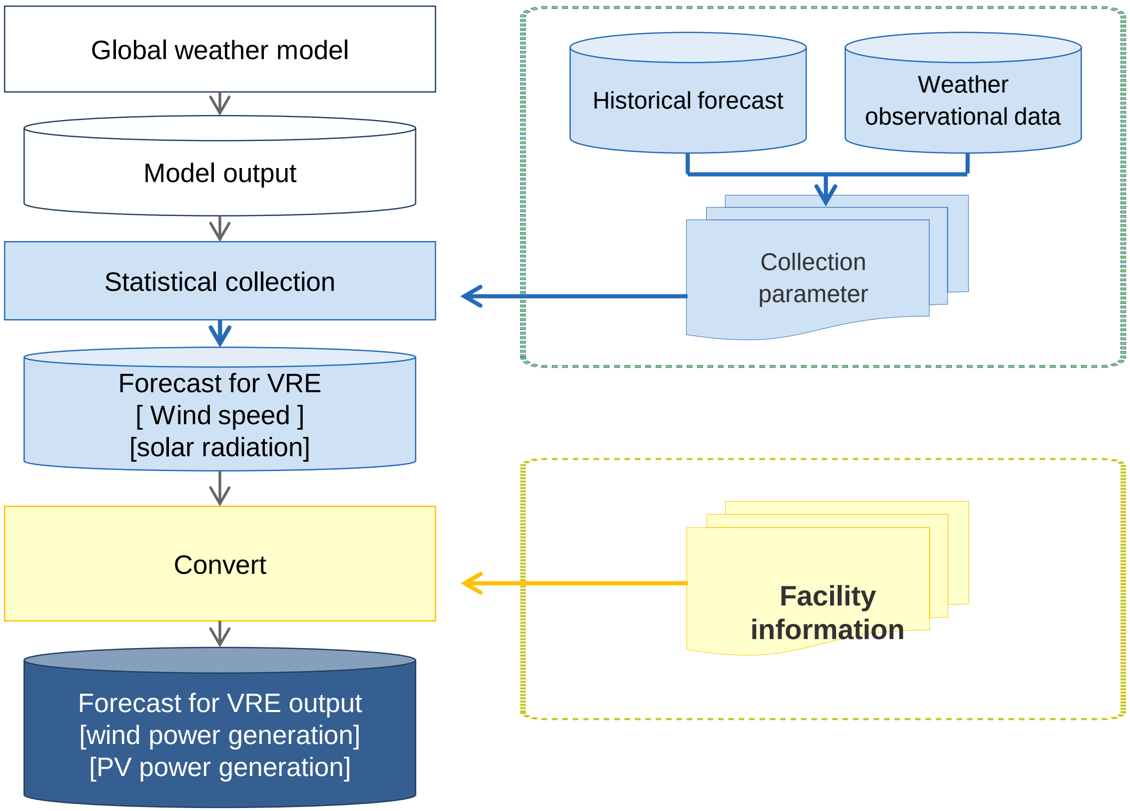
Conversion factor

Forecast area (VRE type)	Conversion factor	Forecast area (VRE type)	Conversion factor
Area1（Roof top PV)	**504**	Area6(Utility PV)	**13.1**
Area2(Roof top PV)	**1,573**	Area7(Wind)	**20.8**
Area3(Roof top PV)	**6.3**	Area8(Wind)	**3.04**
Area4(Utility PV)	**25**	Area9(Wind)	**21.46**
Area5(Utility PV)	**51.76**		

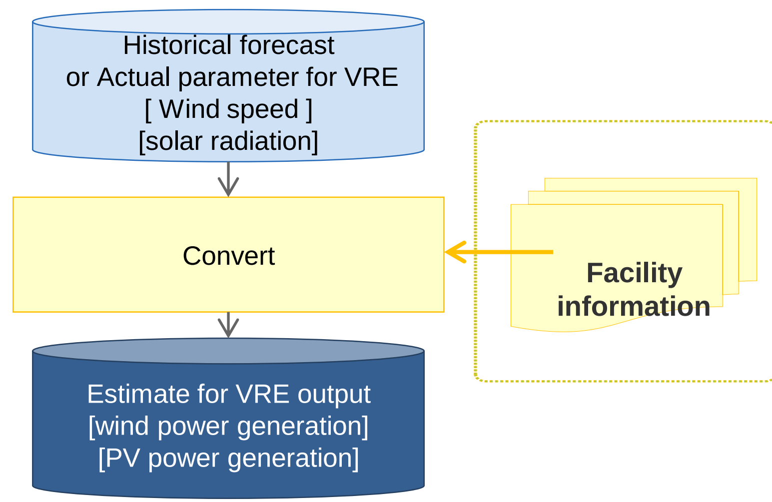
Contents

Difference between VRE forecast system and the tool

◆ VRE forecast system in this project



◆ Conversion tool



1. Overview of the VRE Conversion Tool

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MS Excel is made up of 3 types of below sheets.

. Weather input data for SPP
. Estimated VRE output data
. Facility information for SPP

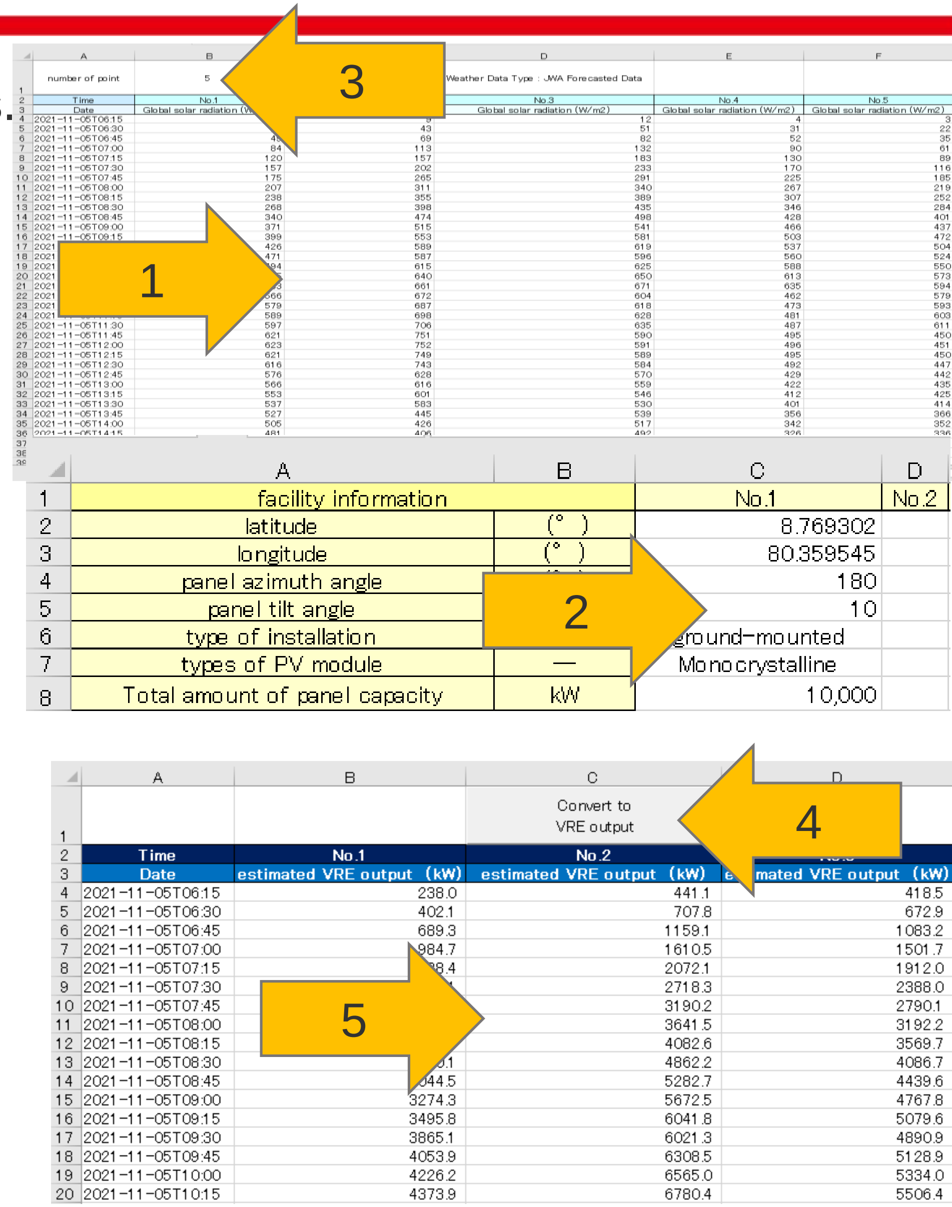
1. Enter the same time series of the conversion source each weather data.

2. Enter the facility information of the entered point.

3. Enter the number of points to be converted.

4. Press the button “Convert to VRE output”.

5. VRE output time series data is output.



2. Example of the VRE Conversion Tool sheet (1/3)

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Weather input data for WPP (e.g. Input sheet)

	A	B	C	D	E
1	number of point	2	Weather Data Type : JWA Forecasted Data		
2	Time	No.1	No.2	No.3	No.4
3	Date	Wind speed (m/s)	Wind speed (m/s)	Wind speed (m/s)	Wind speed (m/s)
4	202209010615	4.6	7.1		
5	202209010630	4.5	7.1		
6	202209010645	4.6	7.2		
7	202209010700	4.8	7.2		
8	202209010715	4.9	7.3		
9	202209010730	5	7.4		
10	202209010745	5.1	7.3		
11	202209010800	5.1	7.2		
12	202209010815	5.3	7.2		
13	202209010830	5.3	7.1		
14	202209010845	5.4	7.1		
15	202209010900	5.5	7.1		
16	202209010915	5.5	7.1		
17	202209010930	5.6	7.1		
18	202209010945	5.6	7.2		
19	202209011000	5.6	7.2		
20	202209011015	5.5	7.2		
21	202209011030	5.5	7.2		
22	202209011045	5.5	7.2		

2. Example of the VRE Conversion Tool sheet (1/3)

Weather input data for SPP　(e.g. Input sheet)

number of point	3		Weather Data Type : JWA Forecasted Data
Time	No.1	No.2	No.3
Date	Global solar radiation (W/m2)	Global solar radiation (W/m2)	Global solar radiation (W/m2)
202209010615			3
202209010630			22
202209010645			42
202209010700			74
202209010715			108
202209010730			143
202209010745			169
202209010800			202
202209010815			233
202209010830			263
202209010845			309
202209010900			339
202209010915			366
202209010930			392
202209010945			443
202209011000			466
202209011015			487
202209011030			506
202209011045			575

2. Example of VRE Conversion Tool sheet (2/3)

Facility information for WPP

Old Version

facility information		No.1	No.2	No.3
number of wind turbines		8	30	8
wind turbine rated capacity per unit	kW	1500	3450	1250
wind turbine hub height	m	85	80	60
Wind speed Classs (m/s)_0~30	kW			
0		0	0	0
0.5		0	0	0
1		0	0	0
1.5		0	0	0
2		0	0	0
2.5		25.9	0	0
3		52.4	34.5	0
3.5		85.8	113.3	0
4		125.7	211.8	11
4.5		175.1	329.9	35
5		240	472.6	64
5.5		342	645	90
6		430	850.7	128
6.5		531	1095	184
7		660	1377	239
7.5		790	1699	321
8		961	2058	403
8.5		1125	2450.7	541
9		1280	2854	679
9.5		1376	3193	825
10		1432.7	3414.6	970
10.5		[illegible]	[illegible]	[illegible]

New Version

facility information		No.1	No.2	No.3
number of wind turbines		8	30	8
wind turbine rated capacity per unit	kW	1500	3450	1250
wind turbine hub height	m	85	80	60
Wind speed Classs (m/s)_0~30	kW			
0		0	0	0
0.5		0	0	0
1		0	0	0
1.5		0.0143	0	0
2		3.33499	0.03586	0
2.5		10.4007	0.3108	0
3		28.0695	7.95574	0
3.5		56.2602	45.0725	0
4		87.2851	115.473	11
4.5		125.373	206.496	35
5		170.913	319.706	64
5.5		225.66	448.975	90
6		299.705	600.189	128
6.5		373.427	775.157	184
7		461.571	981.651	239
7.5		559.789	1217.92	321
8		667.268	1482.95	403
8.5		786.942	1780.18	541
9		916.402	2054.32	679
9.5		1018.99	2339.68	825
10		1147.3	2656	970
10.5		1234.53	[illegible]	1095

✓ **Power curves are adjusted based on the analyses between actual data and forecast data of wind speed and VRE output**

2. Example of VRE Conversion Tool sheet (2/3)

CHUBU Electric Power
NIPPON KOEI

Facility information for SPP

Old Version

facility information		No.1	No.2	No.3	No.4	No.5
latitude	deg	8.769302	7.975383333	6.22	7.469655377	6.930312773
longitude	deg	80.359545	81.23839722	81.085	80.05004525	79.84709214
panel azimuth angle	deg	–	–	180	270	210
panel tilt angle	deg	–	–	10	35	8
type of installation	–	ground–mounted	ground–mounted	ground–mounted	Roof–mounted	Roof–mounted
types of PV module	–	Mono PERC	Monocrystalline	Monocrystalline	Monocrystalline	Polycrystalline
Total amount of panel capacity	kW	10,000	12500	10000	179	90.885

New Version

facility information		No.1	No.2	No.3	No.4	No.5
latitude	deg	8.769302	7.975383333	6.22	7.469655377	6.930312773
longitude	deg	80.359545	81.23839722	81.085	80.05004525	79.84709214
panel azimuth angle	deg	–	–	180	270	210
panel tilt angle	deg	–	–	10	35	8
type of installation	–	ground–mounted	ground–mounted	ground–mounted	Roof–mounted	Roof–mounted
types of PV module	–	Mono PERC	Monocrystalline	Monocrystalline	Monocrystalline	Polycrystalline
Total amount of panel capacity	kW	10,000	12500	10000	179	90.885
※Correction parameter		1	1	0.72304022	0.861968895	0.882200678

✓ **Correction parameters are set based on the analyses between actual data and forecast data of VRE output**

2. Example of the VRE Conversion Tool sheet (3/3)

Estimated VRE output data (e.g. Beta WP, Mannar WP)

Convert to VRE output

Time Date	No.1 estimated VRE output (kW)	No.2 estimated VRE output (kW)	No.3 estimated VRE output (kW)
202209010615	2686.6	71251.2	
202209010630	2526.5	71251.2	
202209010645	2686.6	73805.7	
202209010700	3010.7	73805.7	
202209010715	3202.2	76360.1	
202209010730	3393.6	78914.5	
202209010745	3585.1	76360.1	
202209010800	3585.1	73805.7	
202209010815	3999.5	73805.7	
202209010830	3999.5	71251.2	
202209010845	4212.9	71251.2	
202209010900	4426.2	71251.2	
202209010915	4426.2	71251.2	
202209010930	4654.8	71251.2	
202209010945	4654.8	73805.7	
202209011000	4654.8	73805.7	
202209011015	4426.2	73805.7	
202209011030	4426.2	73805.7	
202209011045	4426.2	73805.7	

2. Example of the VRE Conversion Tool sheet (3/3)

Estimated VRE output data (e.g. Saga SP)

Convert to VRE output

Time Date	No.1 estimated VRE output (kW)	No.2 estimated VRE output (kW)	No.3 estimated VRE output (kW)
202209010615	0.0	0.0	249.7
202209010630	0.0	0.0	476.7
202209010645	0.0	0.0	839.9
202209010700	0.0	0.0	1225.8
202209010715	0.0	0.0	1623.0
202209010730	0.0	0.0	1918.1
202209010745	0.0	0.0	2292.6
202209010800	0.0	0.0	2644.5
202209010815	0.0	0.0	2984.9
202209010830	0.0	0.0	3507.0
202209010845	0.0	0.0	3847.5
202209010900	0.0	0.0	4153.9
202209010915	0.0	0.0	4449.0
202209010930	0.0	0.0	5027.9
202209010945	0.0	0.0	5288.9
202209011000	0.0	0.0	5527.2
202209011015	0.0	0.0	5742.9
202209011030	0.0	0.0	6526.0
202209011045	0.0	0.0	6707.6

3. Evaluation of the accuracy of the VRE conversion tool

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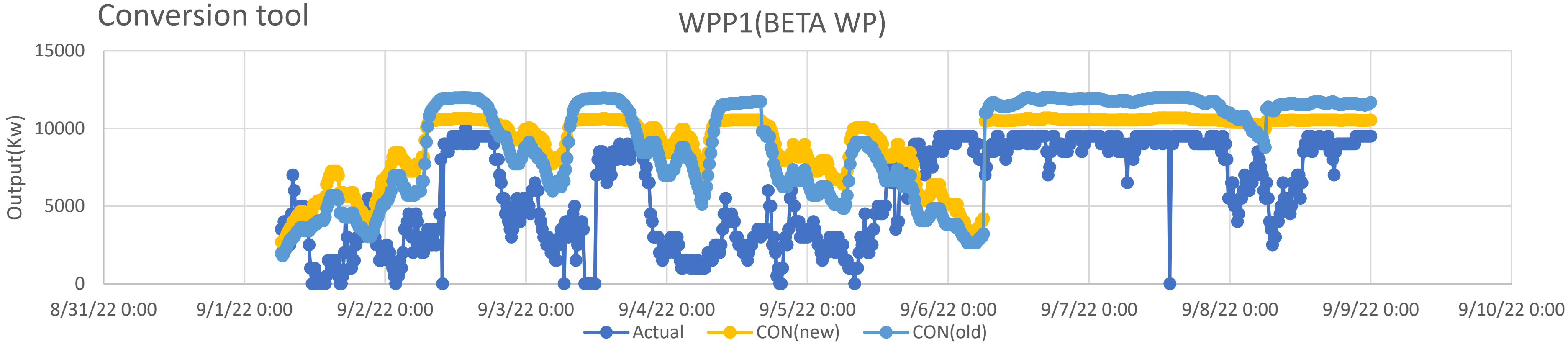
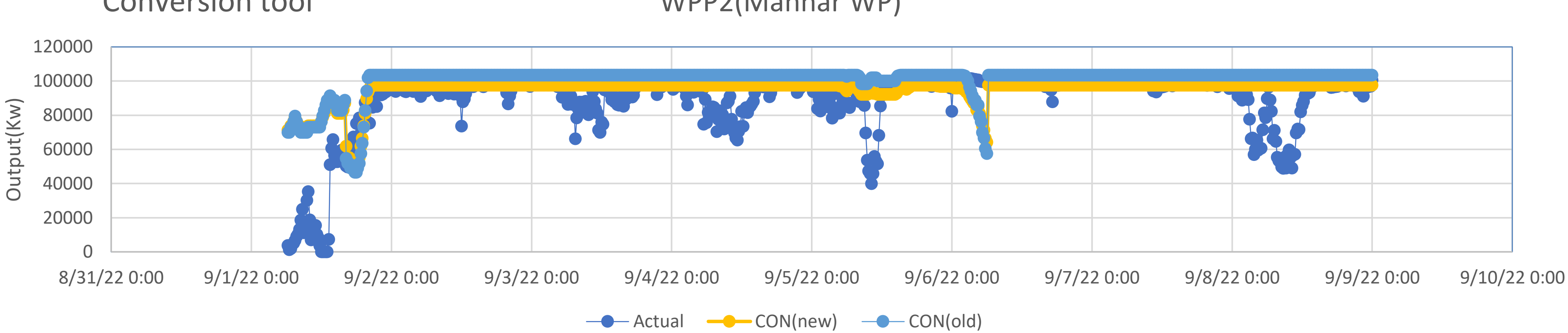
- Evaluation Period： Sep.1 to Sep.9 in 2022
- Evaluation Points: WPP1(Beta WP), WPP2(Mannar WP), and SPP3(Saga SP)
- Input data： Forecast data created by the weather forecast system during the evaluation period
- Output data： VRE output data calculated by the VRE conversion tool and VRE forecast system
- Referring data: VRE output data measured in the evaluation points provided by CEB

3. Evaluation of the accuracy of the VRE conversion tool

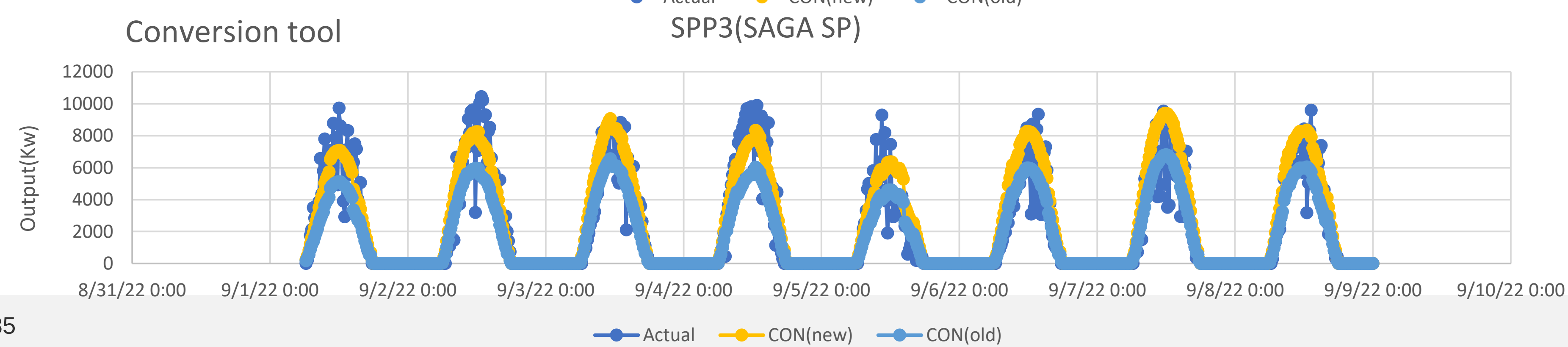
Conversion tool



Conversion tool

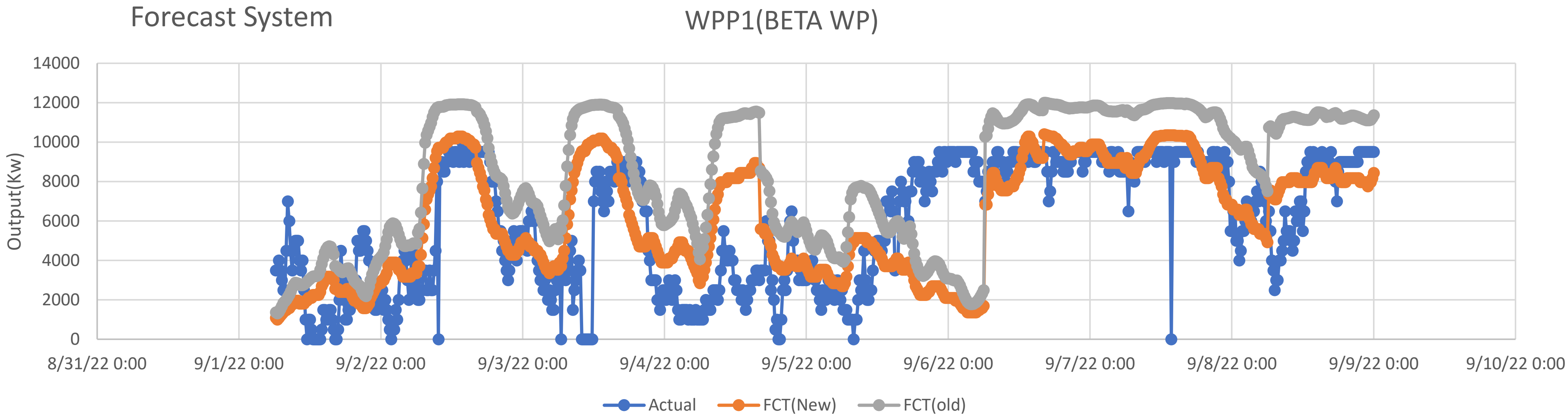


Conversion tool

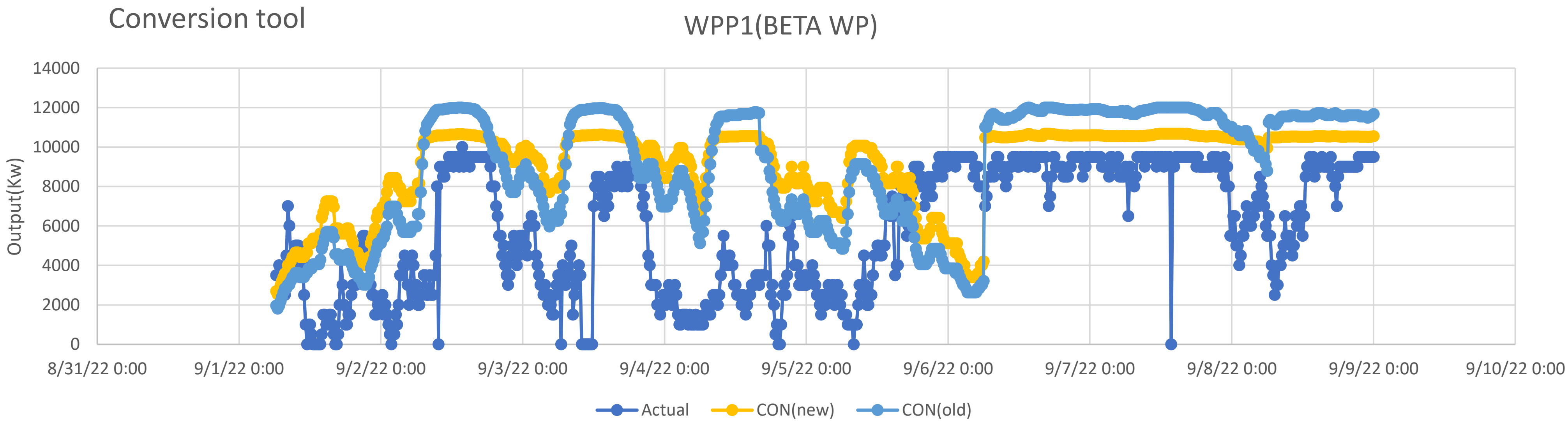


3. Evaluation of the accuracy of the VRE conversion tool

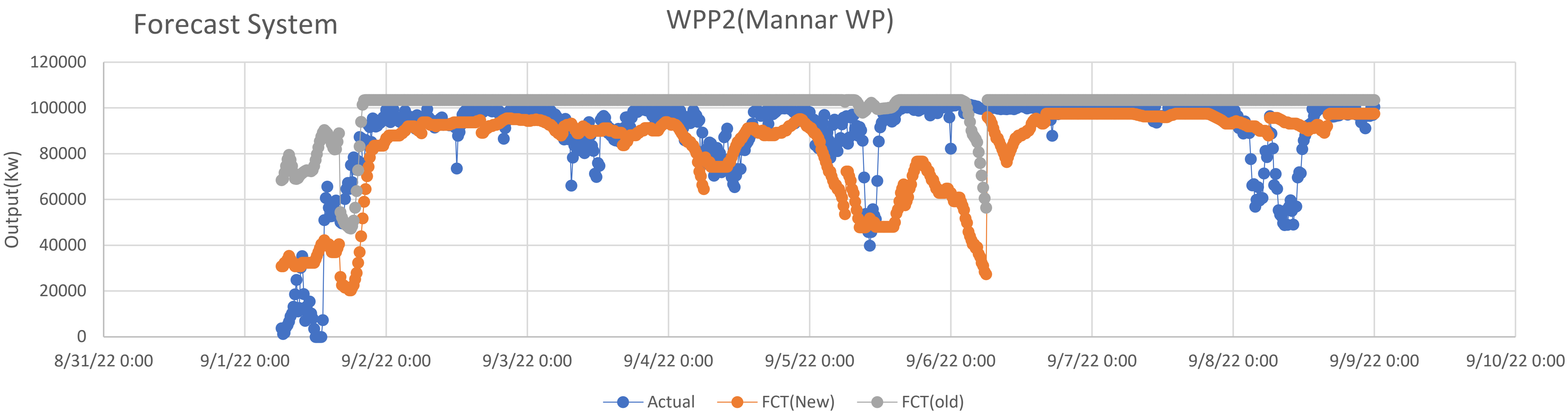
Forecast System

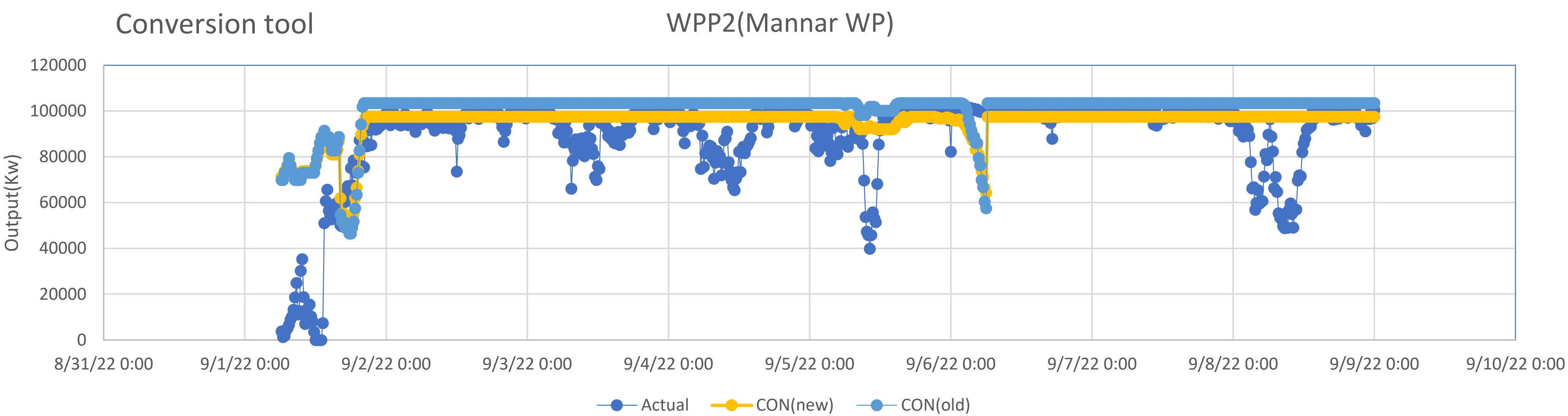


Conversion tool



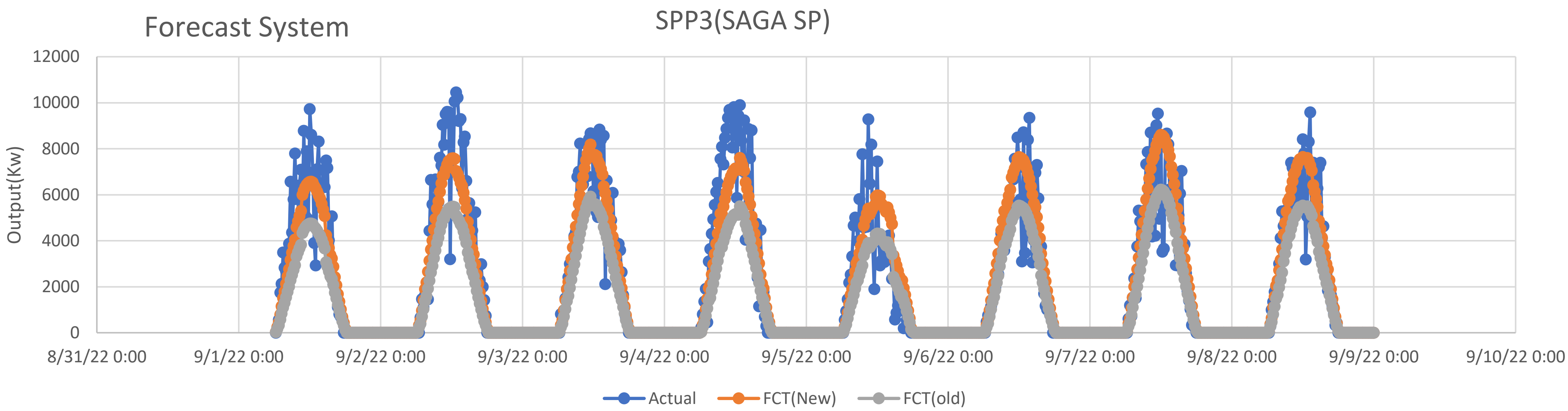
3. Evaluation of the accuracy of the VRE conversion tool



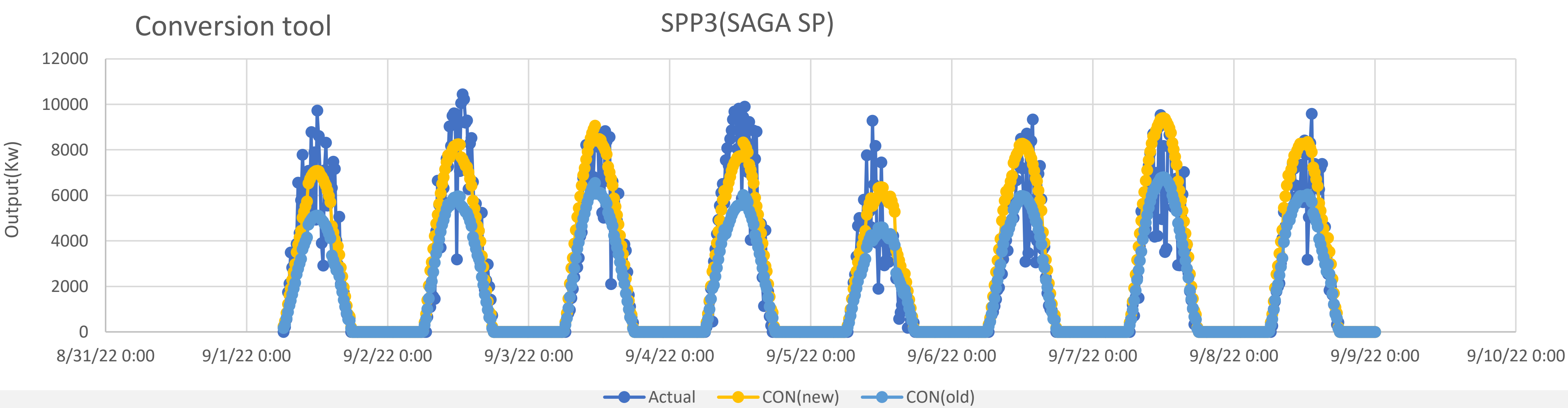


3. Evaluation of the accuracy of the VRE conversion tool

Forecast System

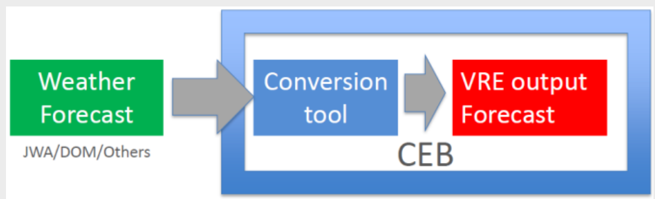


Conversion tool



Contents

1. Sri Lanka entire VRE(SPP) output forecast verification

	Forecast	Actual data
Weather forecast	Weather forecast model based on facility info(longitude, latitude)	Metering value by pyranometer, anemometer 
Individual SPP VRE output	conversion tool based on weather forecast 	Metering value by SM(smart meter) 
Whole Sri Lanka VRE output	Conversion factor × SPP and WPP VRE output forecast based on weather forecast	Assuming that all rooftop PV are not necessarily equipped with SM, need to somehow estimate value.

Verify forecast value by comparing with actual value

How does CEB estimate this value?

2. How to estimate whole Sri Lanka VRE

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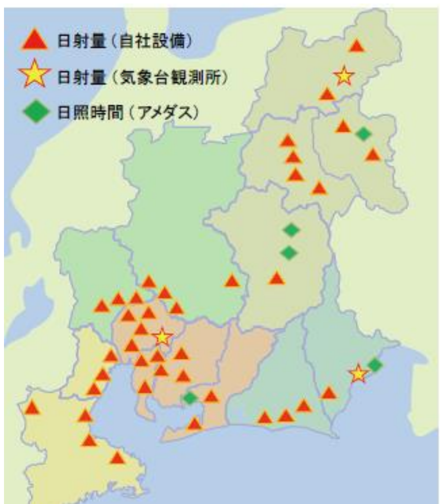
Sri Lanka case

	weather forecast	weather actual	Output forecast	Output actual
IRBGS 132-400kV	Weather forecast model	Pyranometer at the spot		
Embedded Under 33kV		DOM meter		

Japan case(before all of SMs are equipped)

VRE actual value estimate = over 2MW VRE(monitored from CLDC)
+Surplus power contract estimate(deducted by self consumption)
+Total power purchase contract estimate



Metering points by CEPCO : ▲
Metering points by DOM : ★

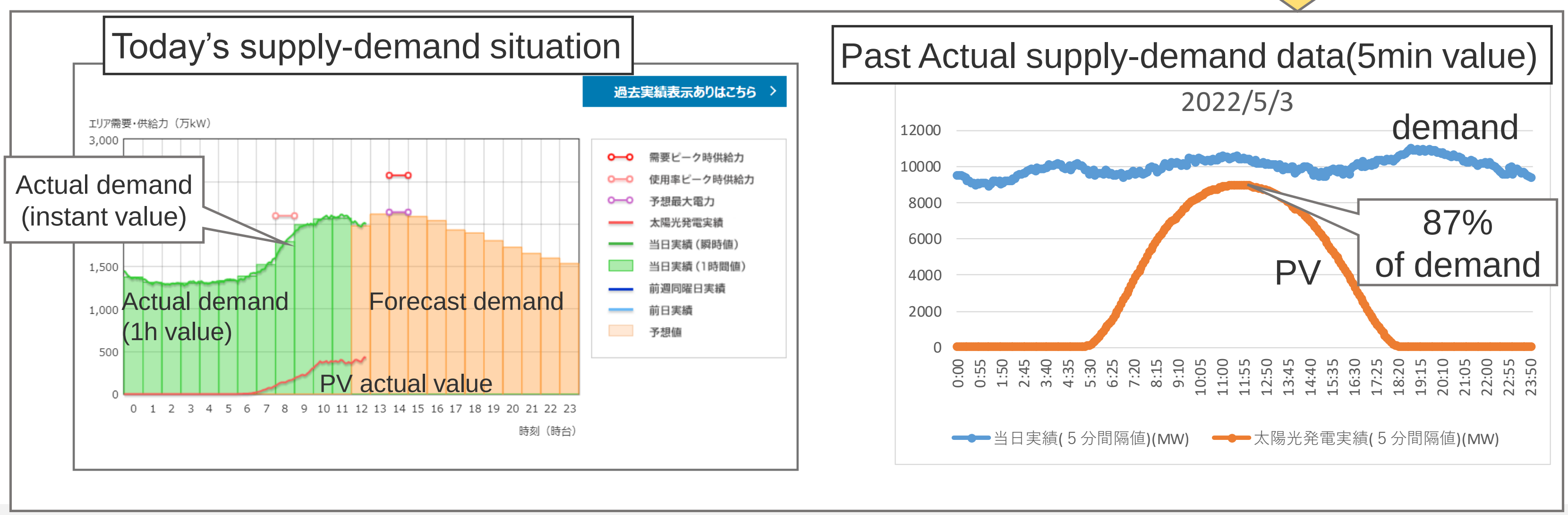
How to verify VRE output actual data in CEPCO

- Even without SM, monthly metering for billing is available to verify the forecast data.

3. (FYI)How to make demand in CEPCO

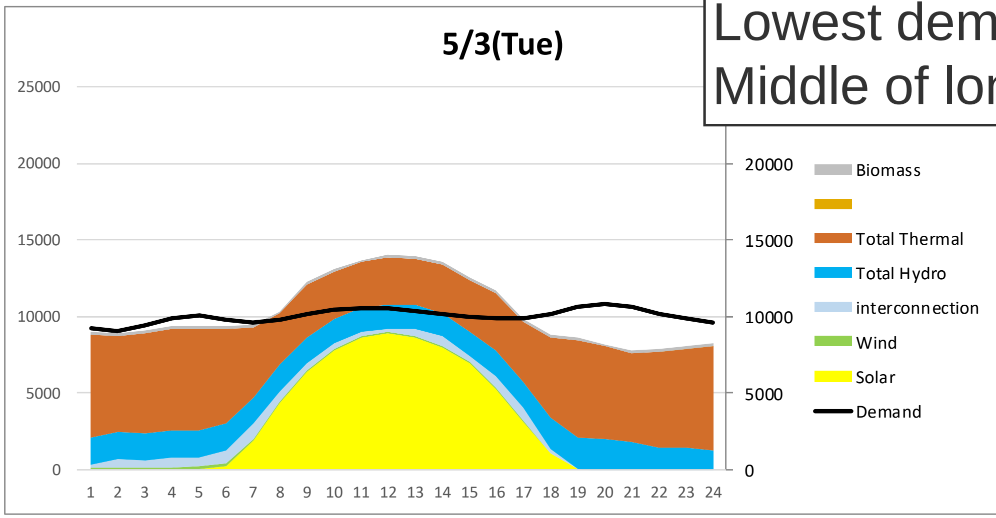
- Whole demand = $\sum generation =$
  $\sum Thermal + \sum Hydro + \sum mini\ Hydro + \sum nuclear + \sum Biomass + \sum WPP + \sum SPP + \sum others$

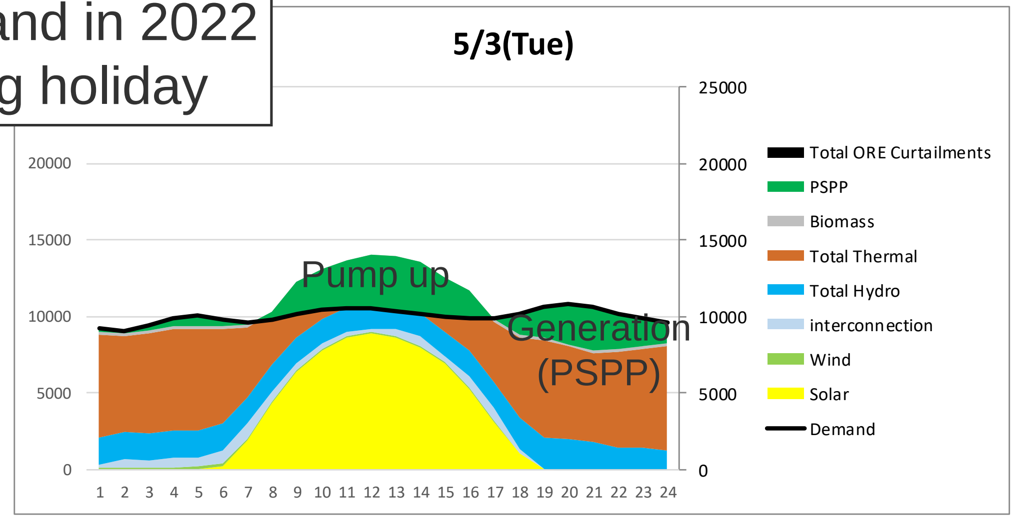
- CEPCO has 4 types of demand;
  - 1 minute instant value : to show on power system board
  - 5 minute instant value : to post on HP for external
  - Preliminary value(30 min value) : fixed every 30 min
  - Confirmed value(30 min value) : fixed one day after target day



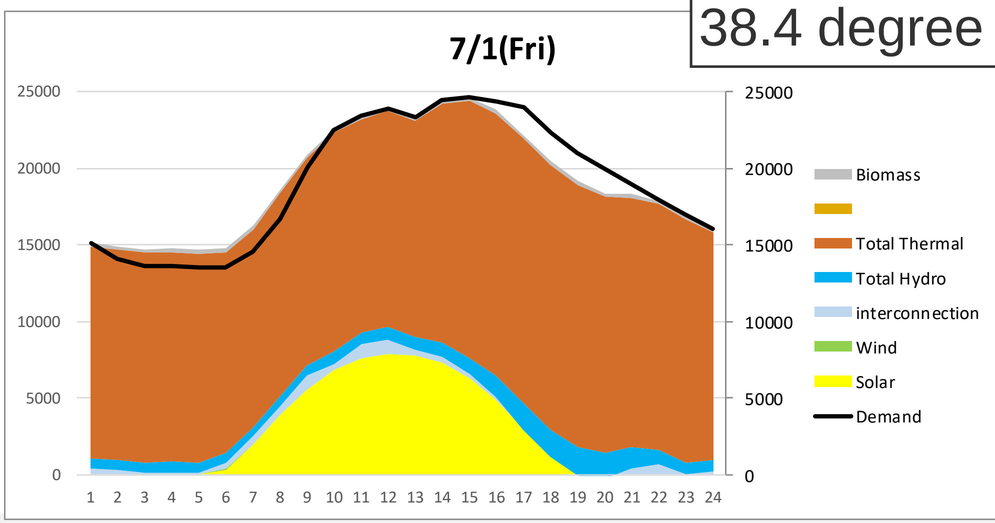
4.(FYI) Supply demand actual value in CEPCO

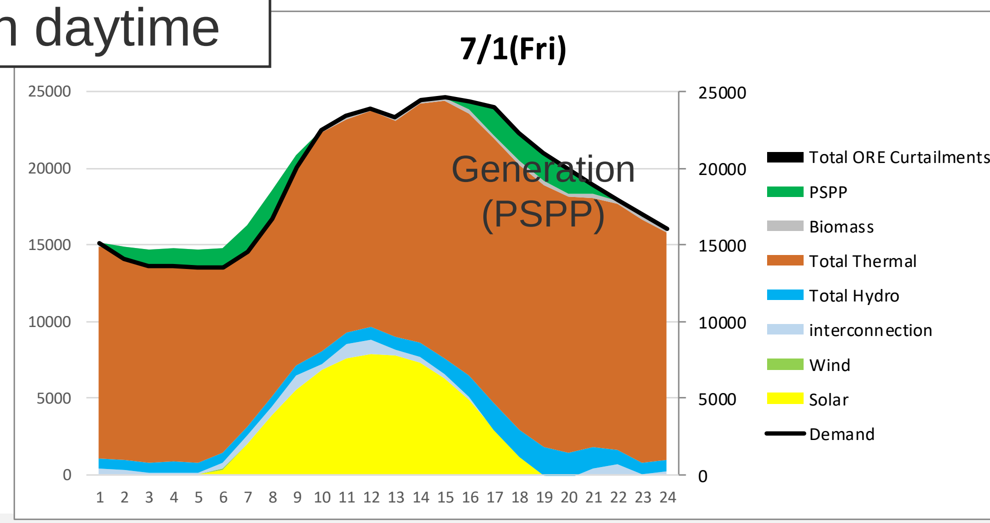
Lowest demand in 2022
Middle of long holiday





Highest demand in 2022
38.4 degree in daytime





Contents

1. The tendency of forecast accuracy by condition
2. The result of the improved VRE forecast model
3. Alternative observation data for SPP and WPP
4. How to improve the VRE forecast model
5. Future plan of the project

1._The tendency of forecast accuracy by condition

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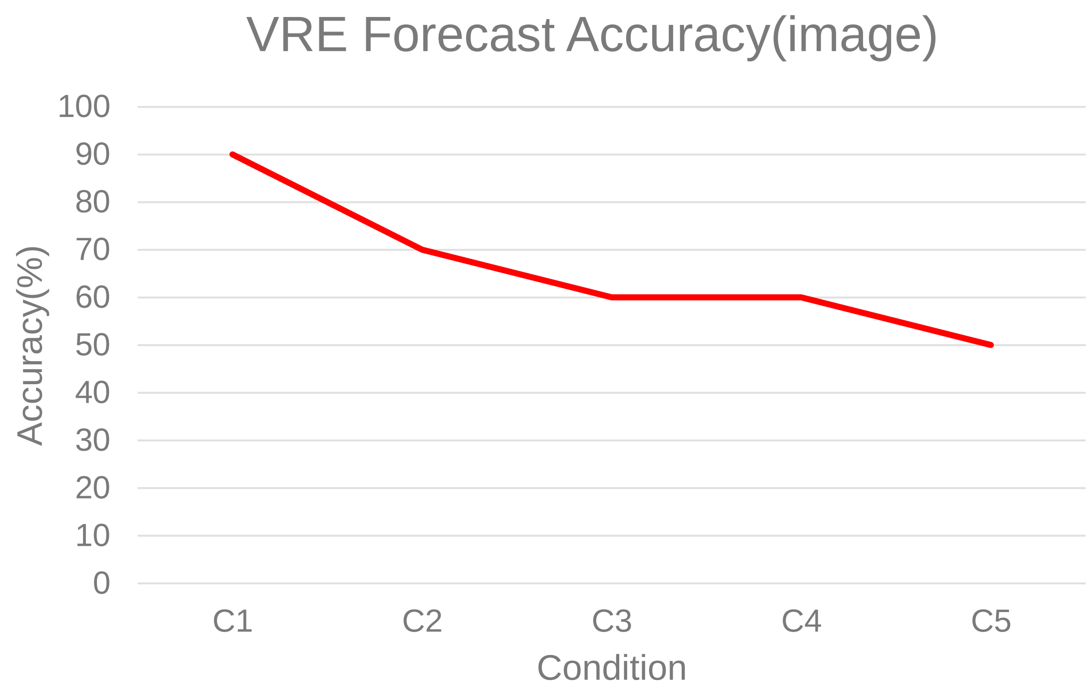
Data acquisition condition

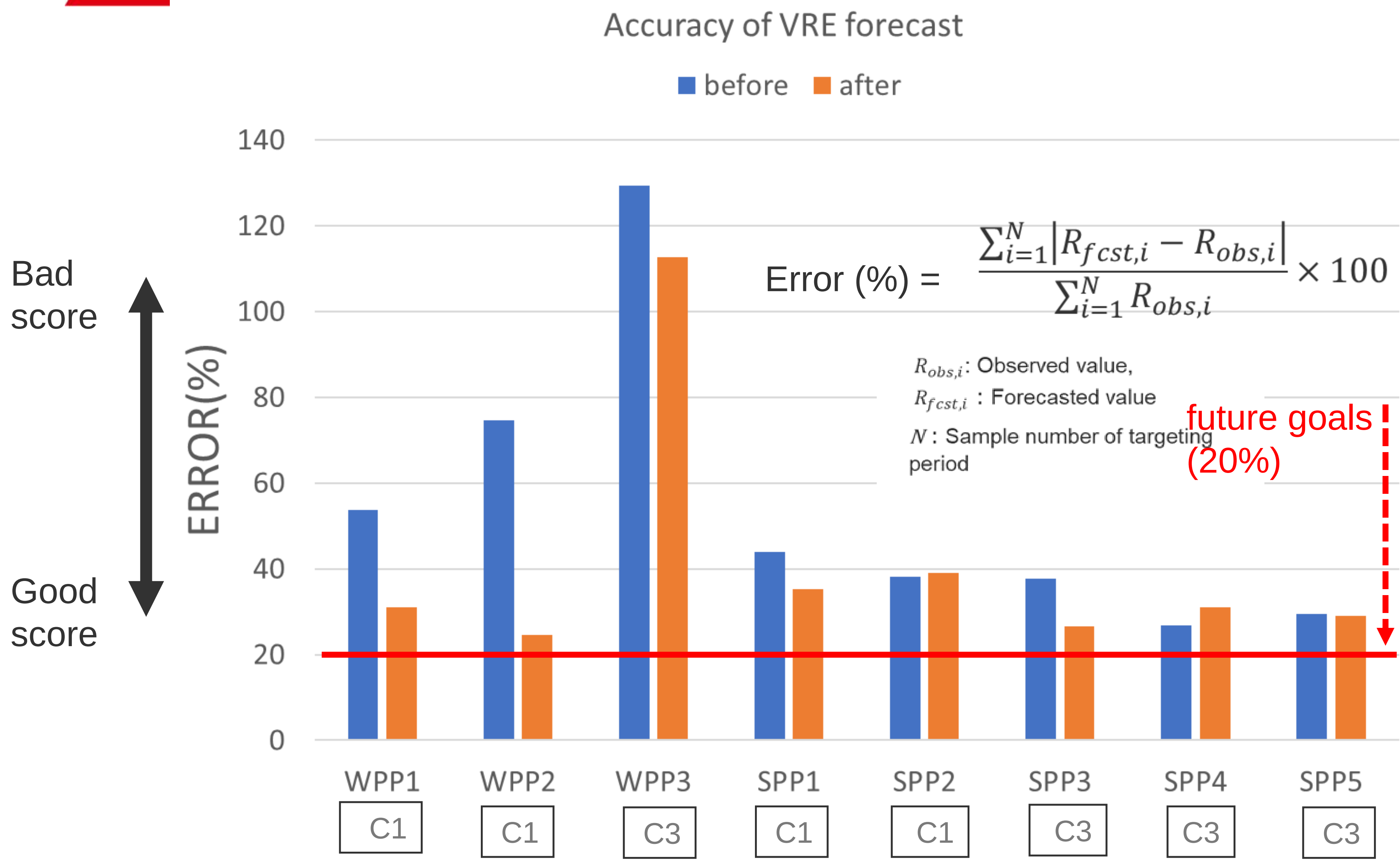
Condition	Weather data (CEB,IPP)	Weather data (DOM)	Output data of VRE	Facility information
C1	〇	×	〇	〇
C2	×	〇	〇	〇
C3	×	×	〇	〇
C4	×	〇	×	〇
C5	×	×	×	〇

〇：Available,×：Not available
DOM：Department of Meteorology, Sri Lanka



The Accuracy of the VRE forecast model depends on the condition of data acquisition

2.The result of the improved VRE forecast model



$$\text{Error (\%)} = \frac{\sum_{i=1}^{N}\left|R_{fcst,i} - R_{obs,i}\right|}{\sum_{i=1}^{N} R_{obs,i}} \times 100$$

$R_{obs,i}$: Observed value,

$R_{fcst,i}$: Forecasted value

N : Sample number of targeting period

3. Alternative observation data for SPP and WPP

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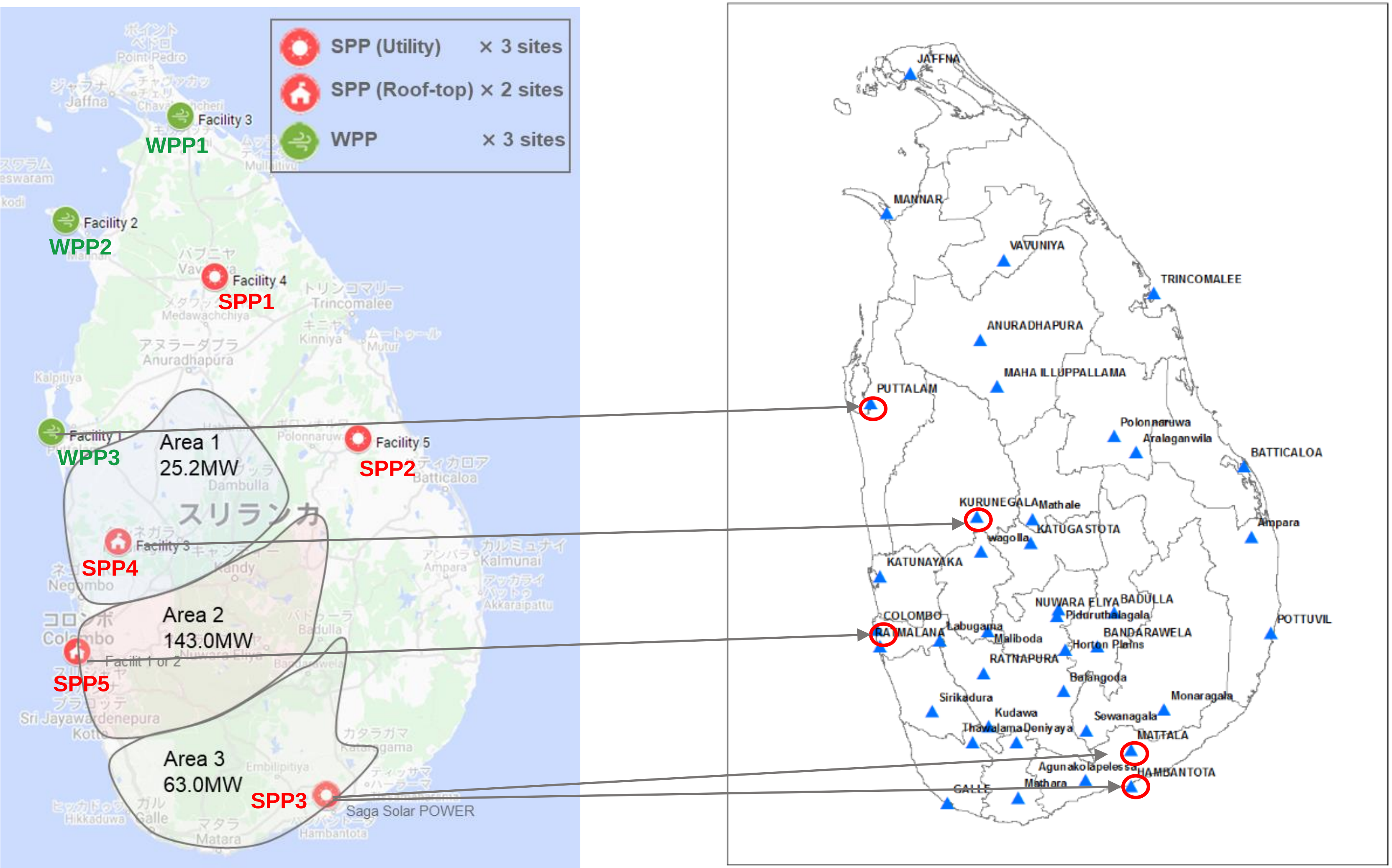
Forecast points

Observation points conducted by DOM



4. How to improve the VRE forecast model

Forecast Point	Improvement Plan
In common	・Check data recording specifications (instantaneous/average values) ・Collect the historical data(CEB, DOM, etc.)
WPP1	Analyze the data hourly/ seasonally
WPP2	Ditto
WPP3	・Adjust the Power Curve by historical data of wind speed ・Analyze the data hourly/ seasonally
SPP1	Analyze the data hourly/ seasonally
SPP2	Ditto
SPP3	Ditto
SPP4	Ditto
SPP5	Ditto

5. Future Plan of the Project

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Within the project(Phase II)

・Collecting historical weather and VRE output data necessary to improve VRE forecast 【1 month】
・Improve the accuracy of the VRE forecast model【3 months】
・Continue to deliver the improved VRE forecast 【2 months】

Collecting historical data
1 month(Sep.2022)

Improvement of VRE forecast
3 months
(Sep.2022 to Dec. 2022)

Delivering improved forecast
2 months
(Jan.2023 to Feb.2023)

5. Future Plan of the Project

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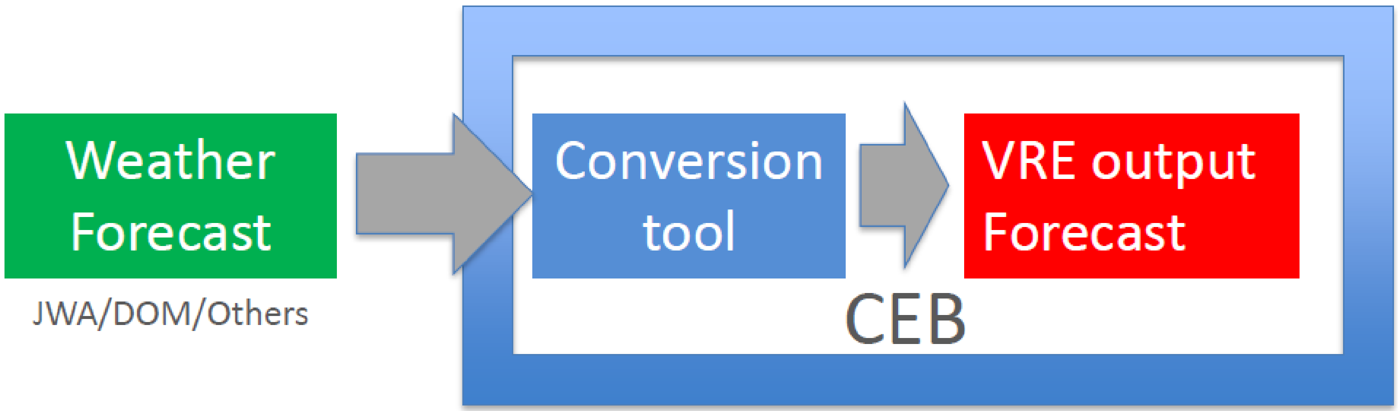
At the end of the project

・Proposal on how to obtain weather forecast data for VRE forecast

・Parchasing the weather forecast data (e.g. Irradiation, wind speed) from Weather bender including JWA

・Follow-up on output forecasts using the conversion tool

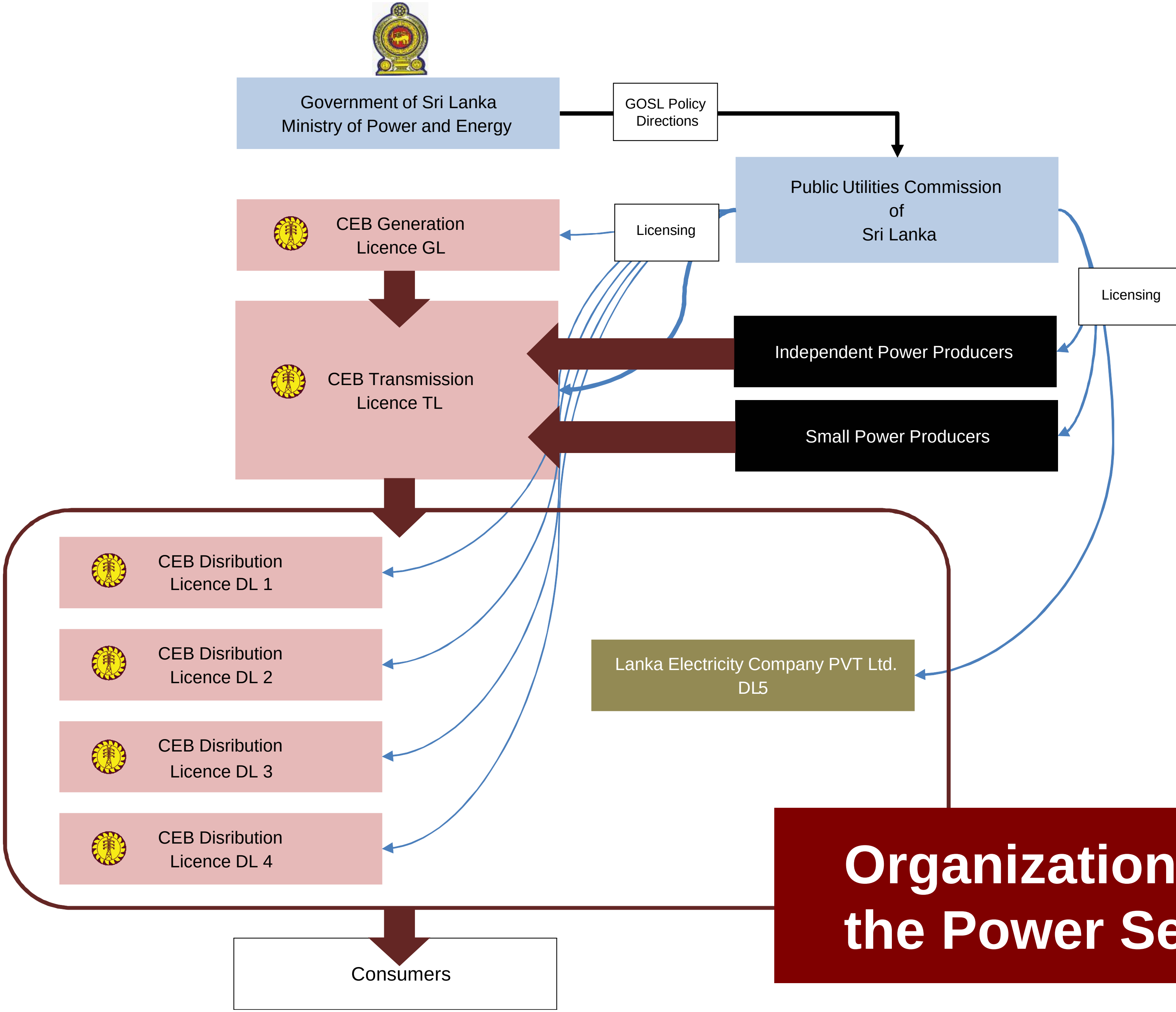


CEYLON ELECTRICITY BOARD

Sri Lanka Power Sector and Recent Developments

Transmission Planning Unit
Transmission Division
May 2020

Organization of the Power Sector



ELECTRICITY DATA FOR 2018

- Installed capacity - 4048 MW
- Peak Demand - 2616 MW
- Net Electricity Generated - 15305 GWh
- Generation Mix
  - Hydro and Other RE 46%
  - Thermal 54 %
- Capacity Mix
  - Hydro & Other RE 49%
  - Thermal 51%
- Tr. And Dist. losses - 7.9 %
- Load Factor - 66.8%
- Access to Electricity - 99%
- Elec. Consumption per Capita - 626 kWh
- Avg. Cost per unit (at selling point 2018) - 19.12 Rs/kWh
- Avg. selling price (2018) - 16.29 Rs/kWh

CEYLON ELECTRICITY BOARD Enrich Life through Power

EXISTING GENERATION SYSTEM

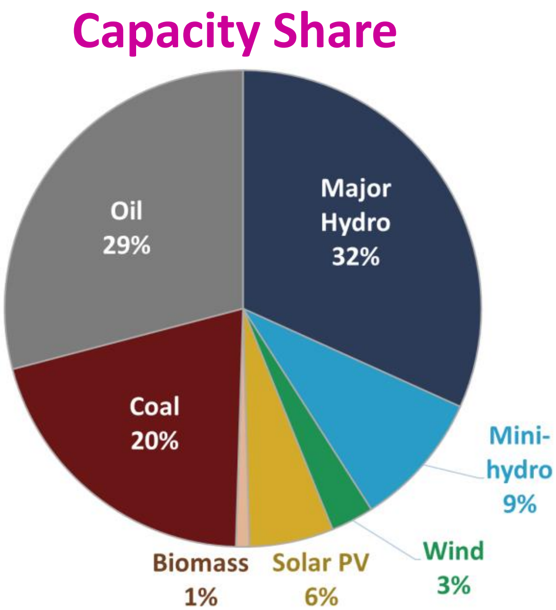
Power Plant	Capacity (MW)	Total Capacity (MW)
Large Hydro		
Laxapana Complex	369.8	1399
Mahaweli Complex	816.8	
Samanala Complex	212.25	
Thermal (CEB)		
Lakvijaya Coal Power Plant	900	1504
Sapugaskanda	160	
Kelanitissa Thermal Complex	360	
Uthuru Janani	24	
Barge Mounted Power Plant	60	
Thermal (IPP)		
West Coast Combined Cycle	270	533
Sojitz Combined Cycle	163	
ACE Power Embilipitiya	100	

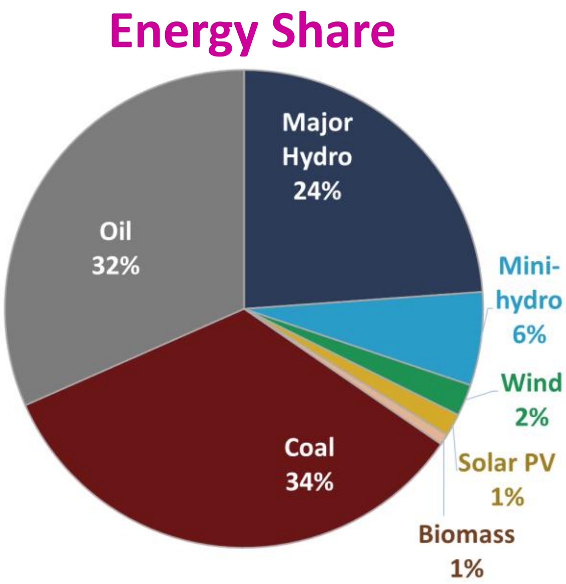
Other Renewable Energy Technology	No of Projects	Capacity (MW)
Mini Hydro Power	210	394
Biomass	12	37
Solar Power- Parks	8	51
Wind Power	15	128
Solar Roof Top (Approx.)		170
Total		**780**

Total Installed Capacity 4216 MW

Updated as per the installed capacity on 31st December 2018

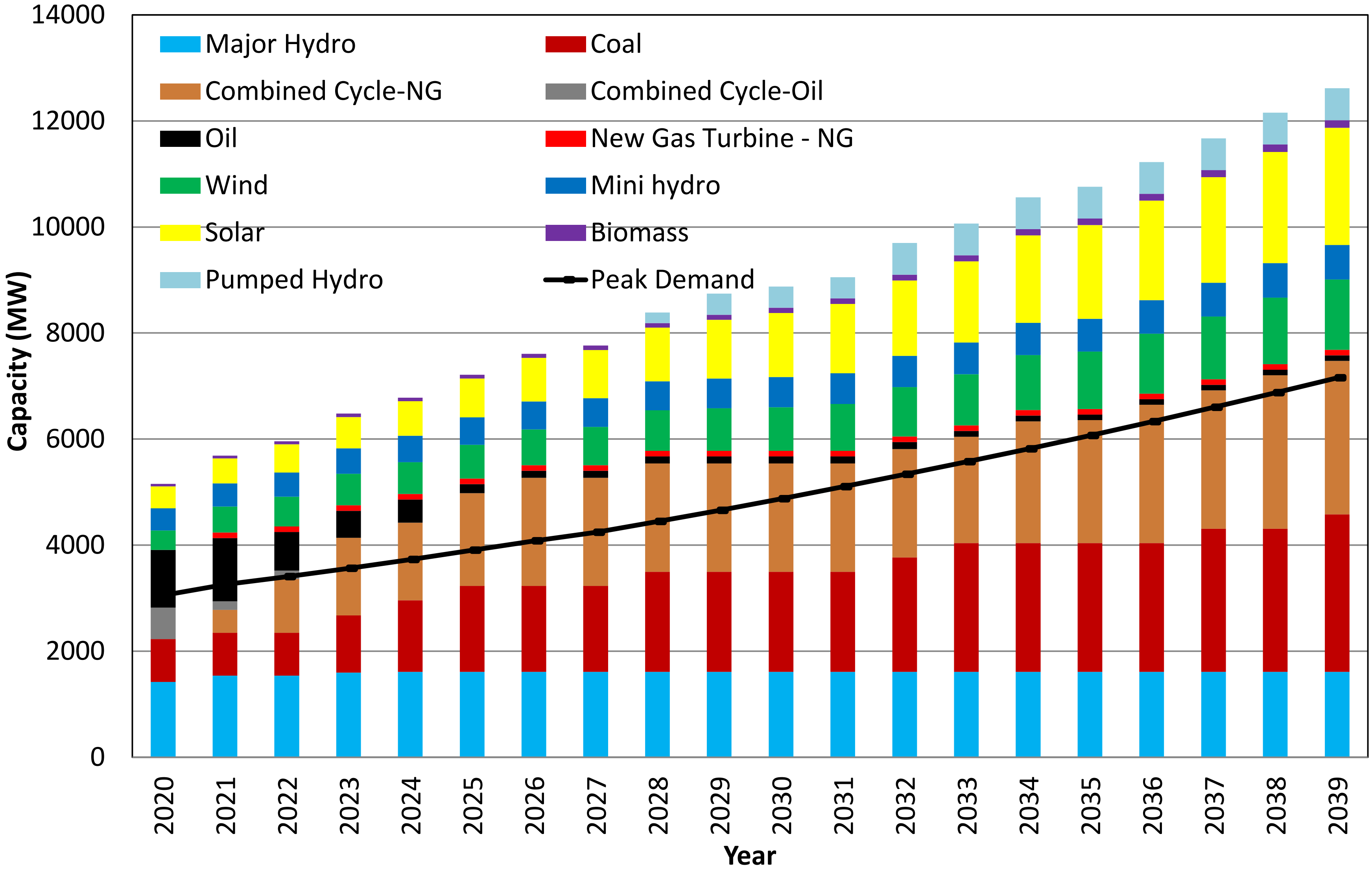
Installed Capacity and Generation as at 31st Dec 2019





	Installed Capacity (MW)	Generation (GWh)
Major Hydro	1399	3785
Mini-hydro	406	1001
Wind	128	340
Solar PV	251	242
Biomass	40	117
Coal	900	5360
Oil	1282	5014
	4406	**15859**

CAPACITY MIX OF THE BASE CASE PLAN FOR NEXT 20 YEARS



Major Renewable Projects in the Pipeline

CEYLON ELECTRICITY BOARD Enrich Life through Power

Project	Present Status	Year of Operation
120MW Uma Oya	Under Construction	2021
35MW Broadlands	Under Construction	2020
31MW Moragolla	Under Construction	2023
15MW Thalpitigala	Feasibility Study Completed	2024
20MW Seethawaka	Prefeasibility Completed	2023
100 MW Mannar Wind Park	Under Construction	2020
37X1 MW Solar Parks	Under Construction	2021
90x1MW Solar Parks	Awarded/under Construction	2021
150 MW Dist. Solar	Bidding stage	2022
100 MW Solar Parks	Prefeasibility is being done	2020
100 MW Mannar Wind Ph 2	Procurement process yet to start	2023

Solar Power Development in the Pipeline

CEYLON ELECTRICITY BOARD Enrich Life through Power

LTGEP 2020 -2039 has identified cumulative capacity of 730 MW Solar power by 2025 which includes

- Rooftop Solar Power program
- 37x 1 MW Solar Parks
- 90 x 1 MW Solar Parks
- 2x10 MW Solar Parks
- 150 MW Dist. Solar Parks
- Utility Scale Solar Parks
- *Pooneryn & Siymbalanduwa Land Based Locations Identified*
- *Floating Type / Highway Solar ..etc Concepts also envisioned*

Wind Power Development in the Pipeline

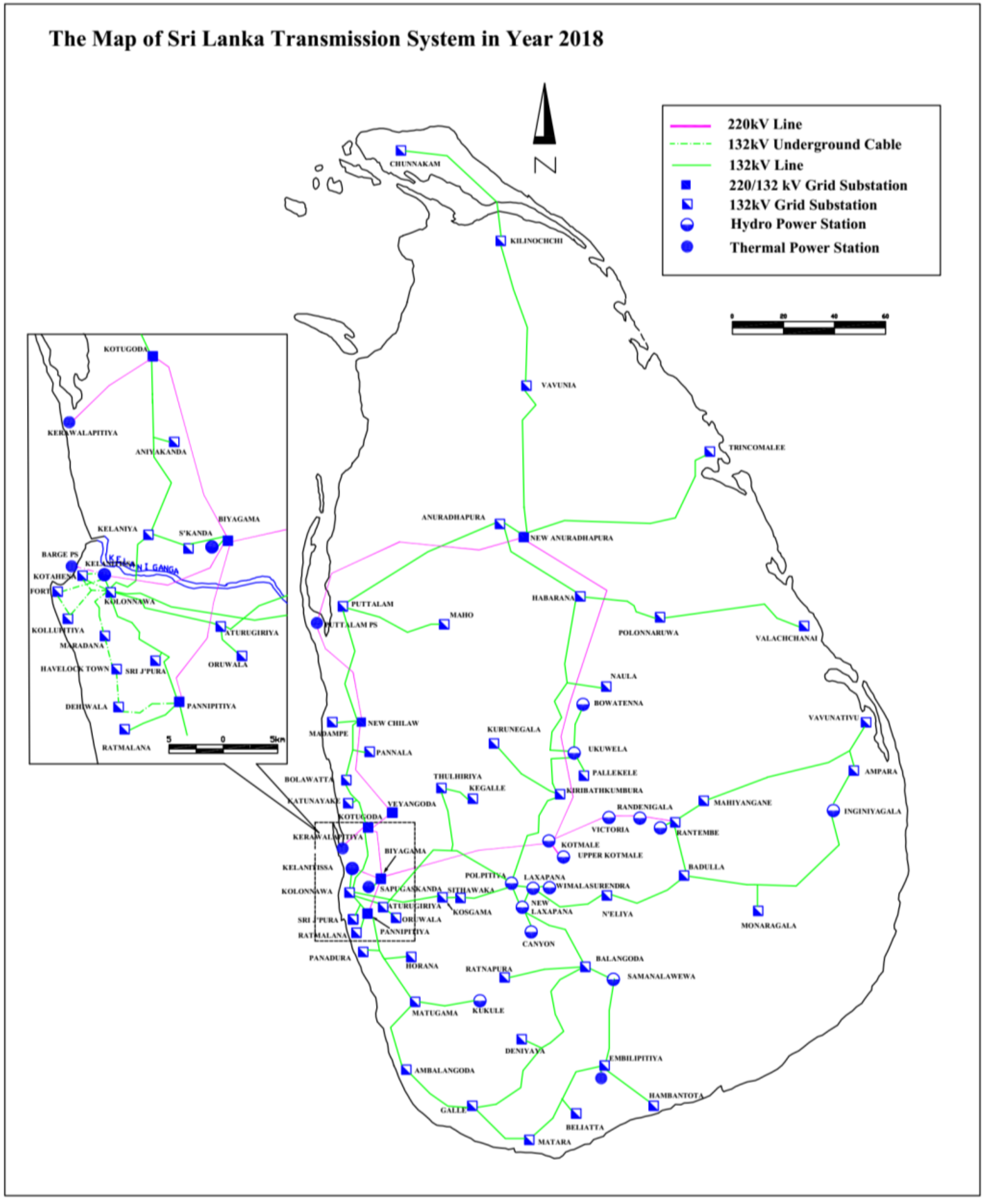
CEYLON ELECTRICITY BOARD Enrich Life through Power

- LTGEP 2020 -2039 has identified cumulative capacity of 638 MW wind power by 2025 which includes

  - Mannar WPP Phase I
  - Mannar WPP Phase II and Phase III
  - 240 MW WPP at Pooneryn

2018 Sri Lankan Transmission System

CEYLON ELECTRICITY BOARD Enrich Life through Power



Present Transmission Network

CEYLON ELECTRICITY BOARD Enrich Life through Power

Description	Number of GSS	Total Capacity (MVA)
Grid Substations		
132/33 kV	56	4474
220/132/33 kV	4	1600/380
220/33 kV	1	75
132/11 kV	5	369
220/132kV	4	1510

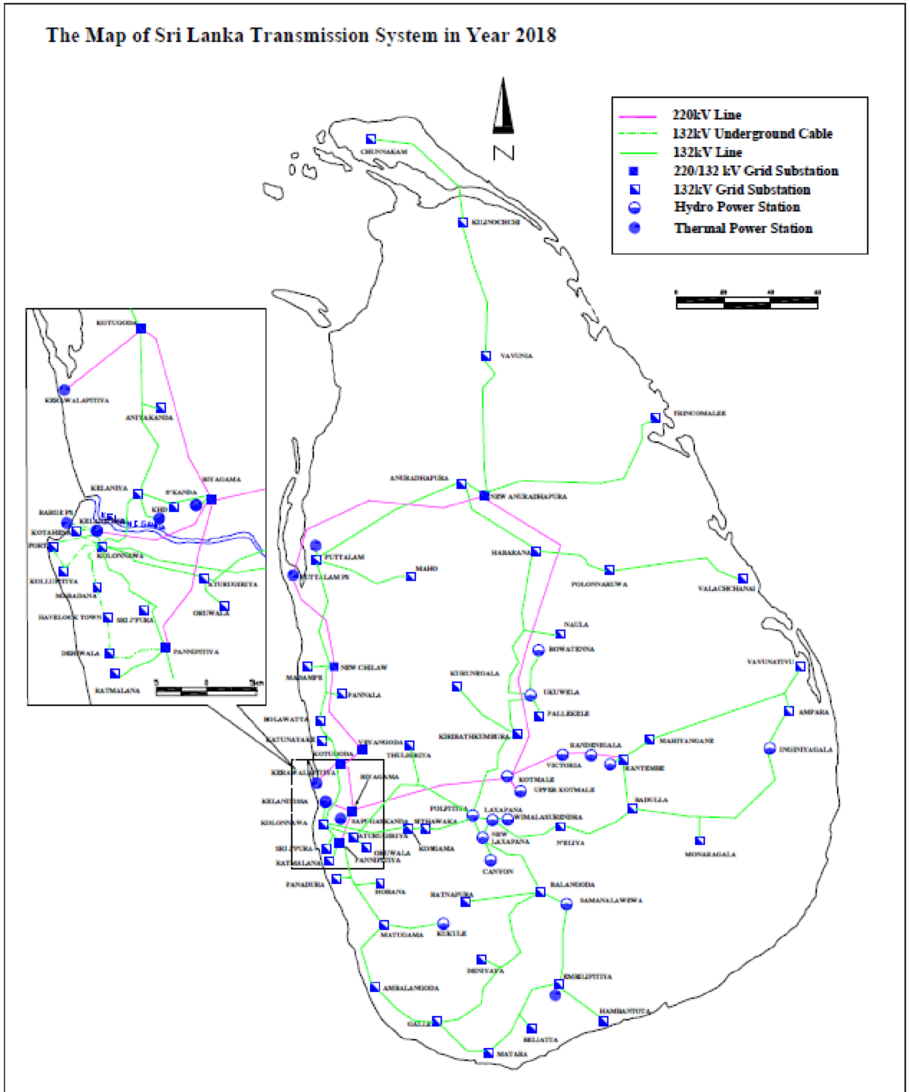
Transmission Lines	Length (km)
220 kV, Double circuit	582
220 kV, Single Circuit	20
132 kV, Four Circuit	4
132 kV, Double Circuit	1867
132 kV, Single Circuit	415
132 kV UG cable	51.5

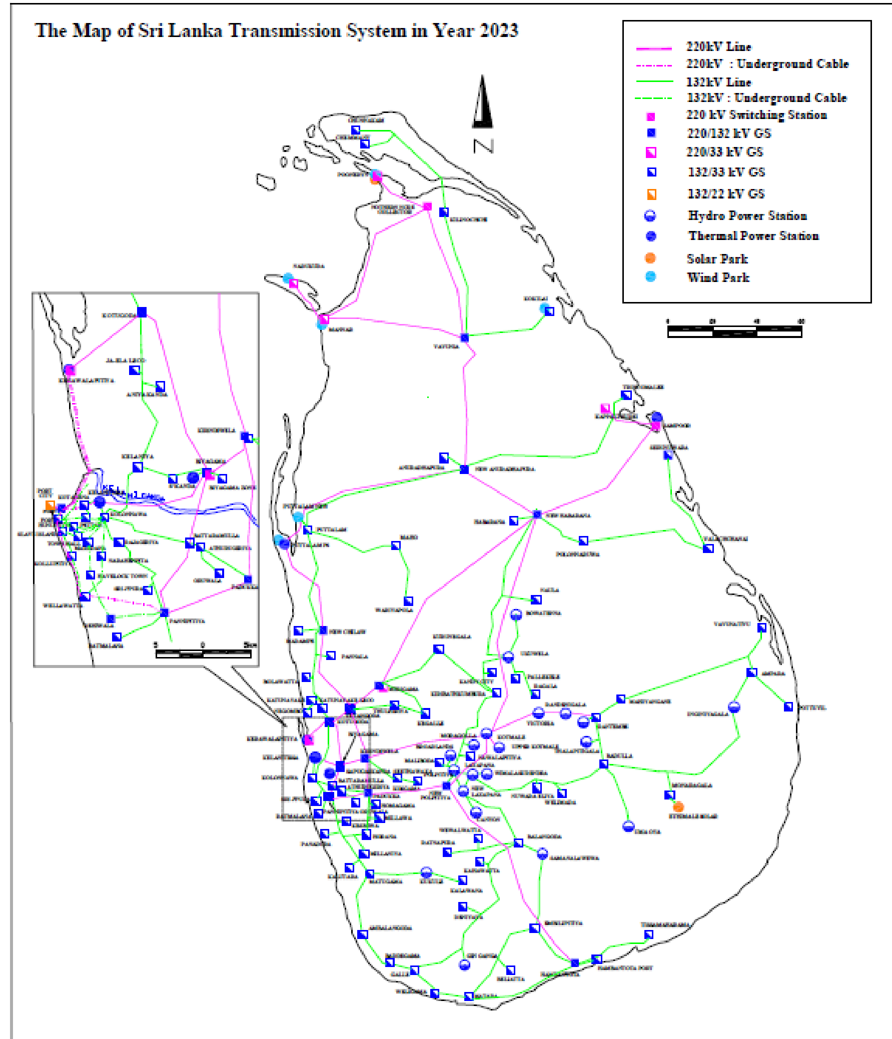
Reactive Power Sources	Capacity
Capacitors (BSC)	485 Mvar

Transmission Network Improvement

CEYLON ELECTRICITY BOARD Enrich Life through Power

2018 → 2023

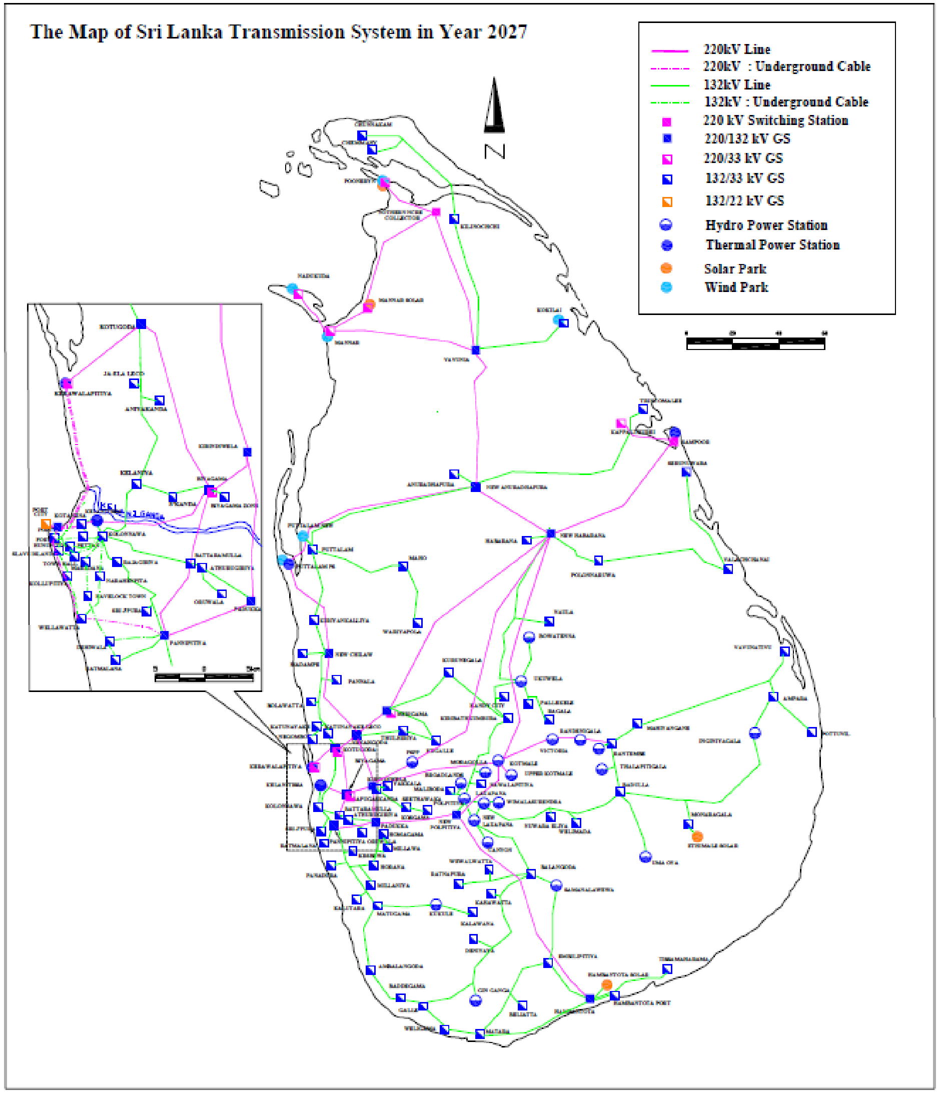


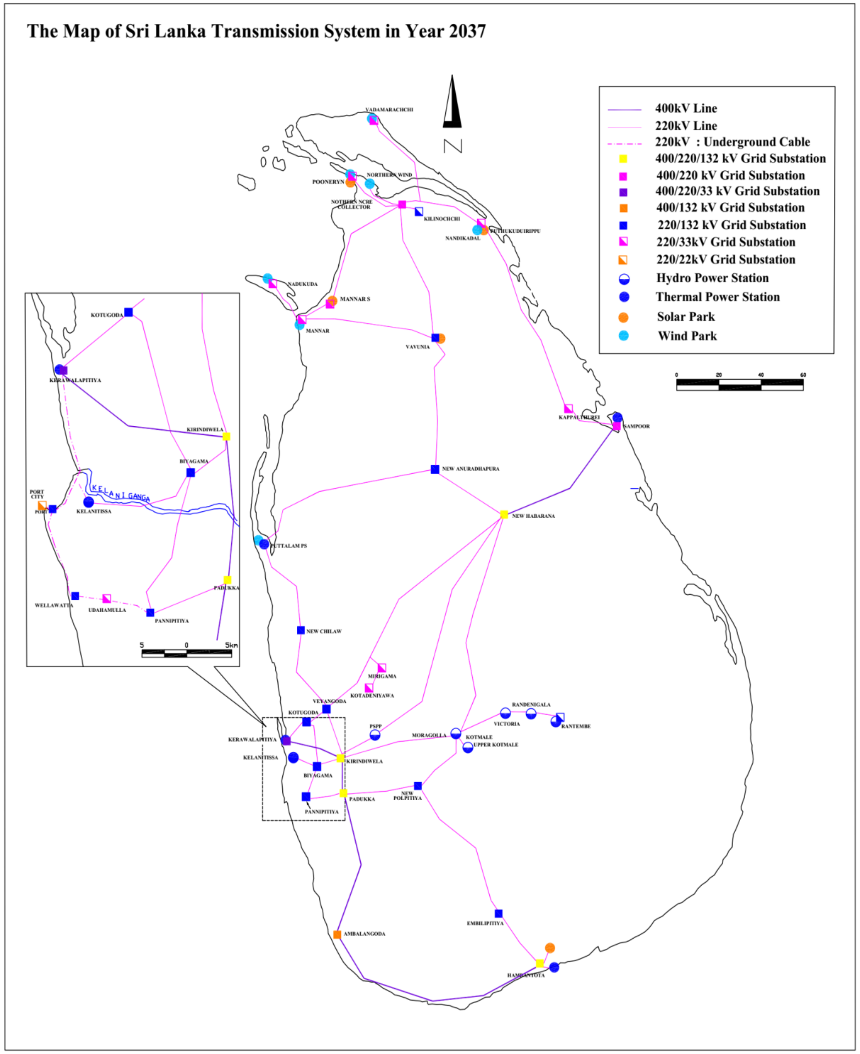


Transmission Network Improvement

CEYLON ELECTRICITY BOARD Enrich Life through Power

2027 → 2037

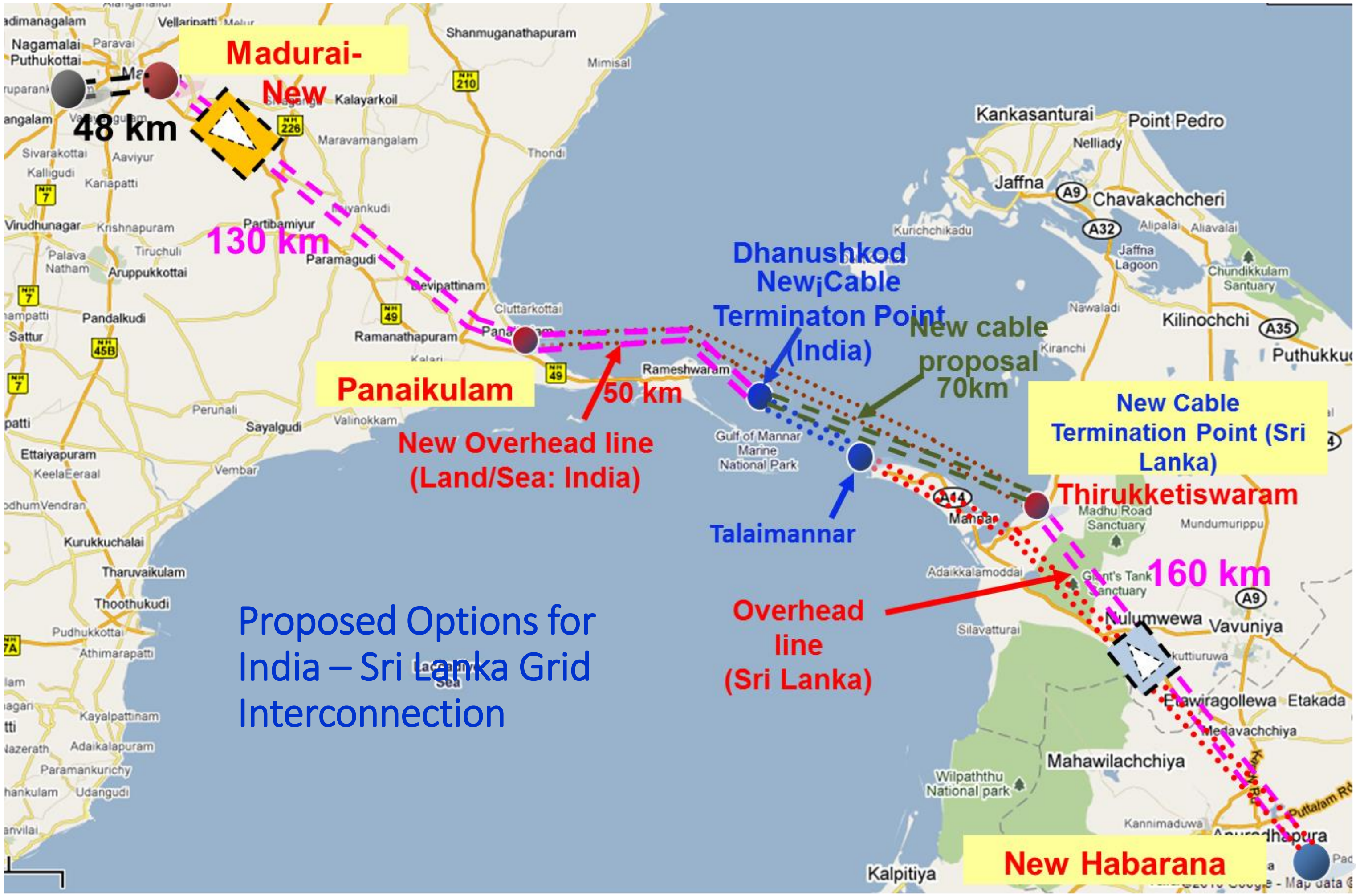




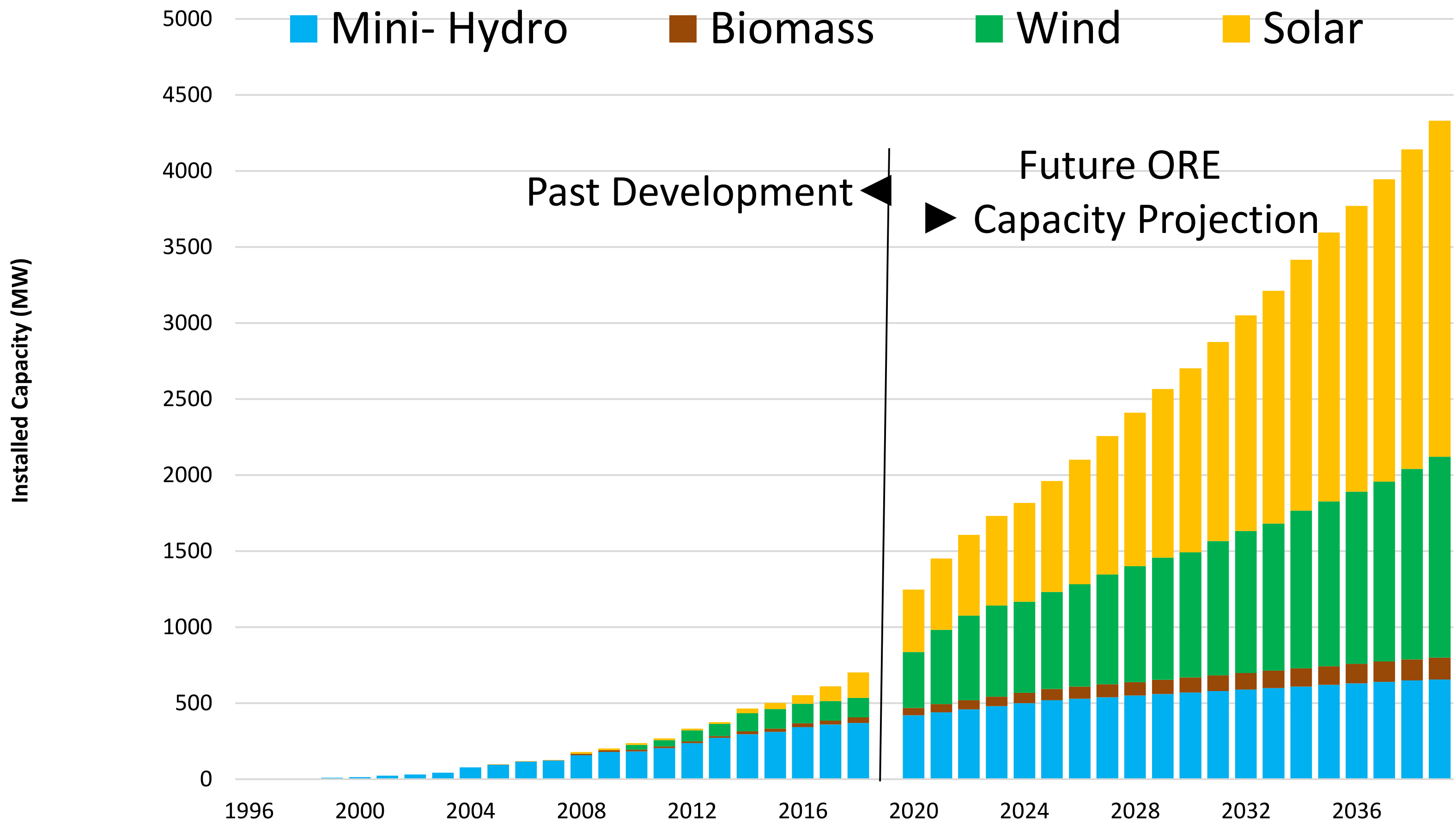
Future Options-conventional Generation

HVDC Link Between Sri Lanka and India

- Technical and Economical feasibility studies are carried out between CEB and Power Grid India to interconnect two Networks by DC link.
- Project to be expedite as soon as the completion of the Feasibility Studies.



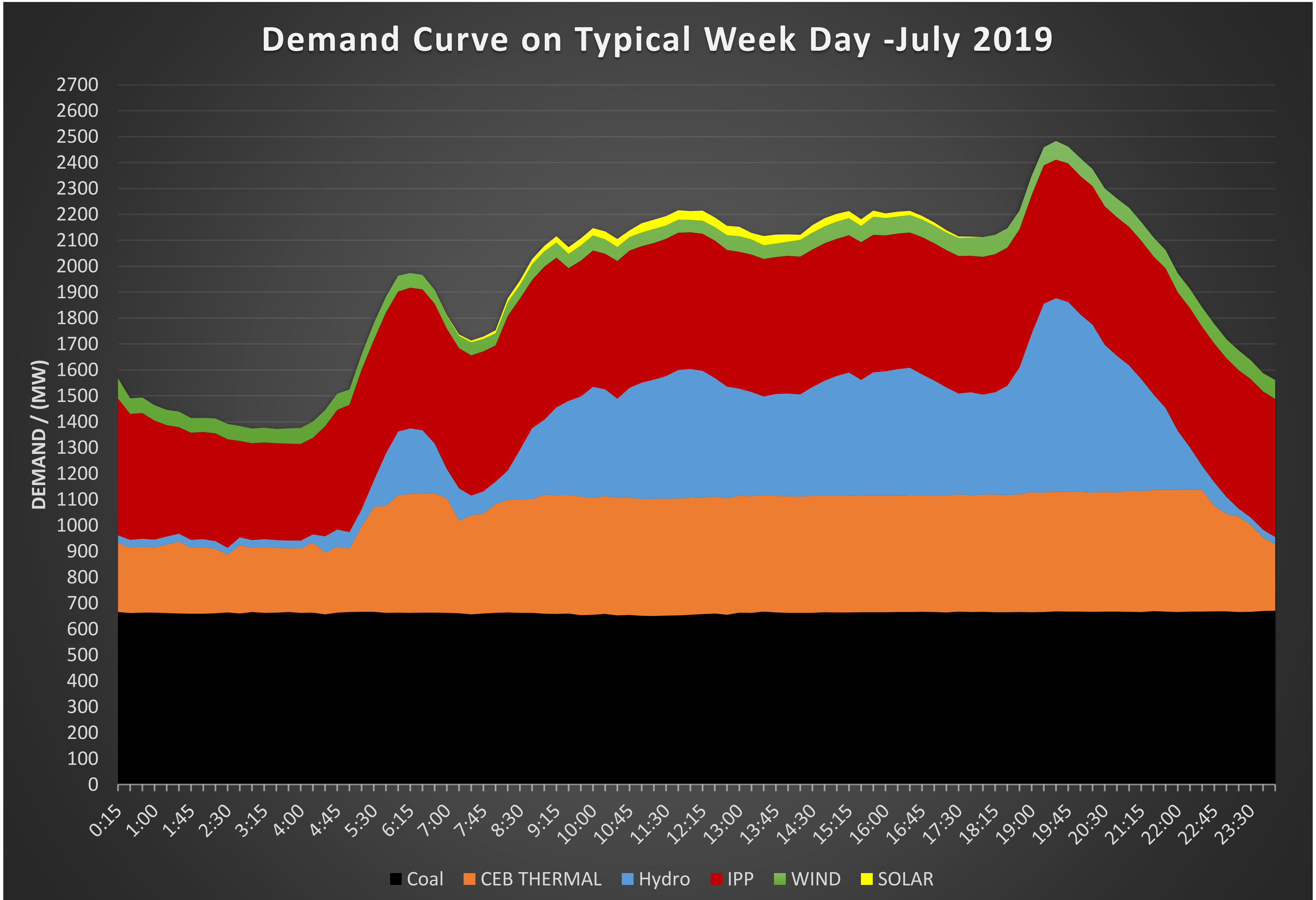
ORE CAPACITY ADDITIONS



Thank You …

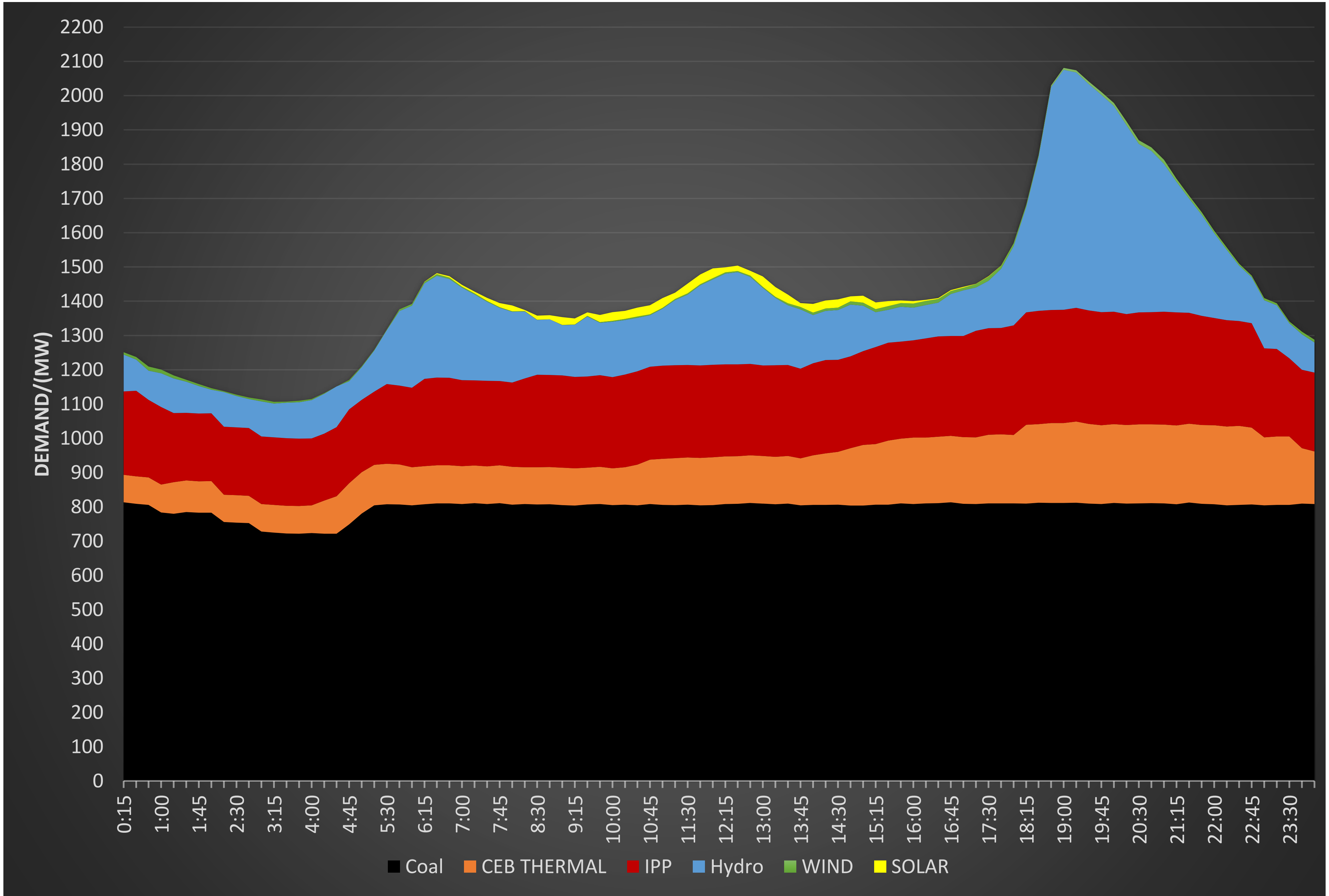
Technical issues and measures for supply and demand operation of Sri Lankan power system with increasing VRE.

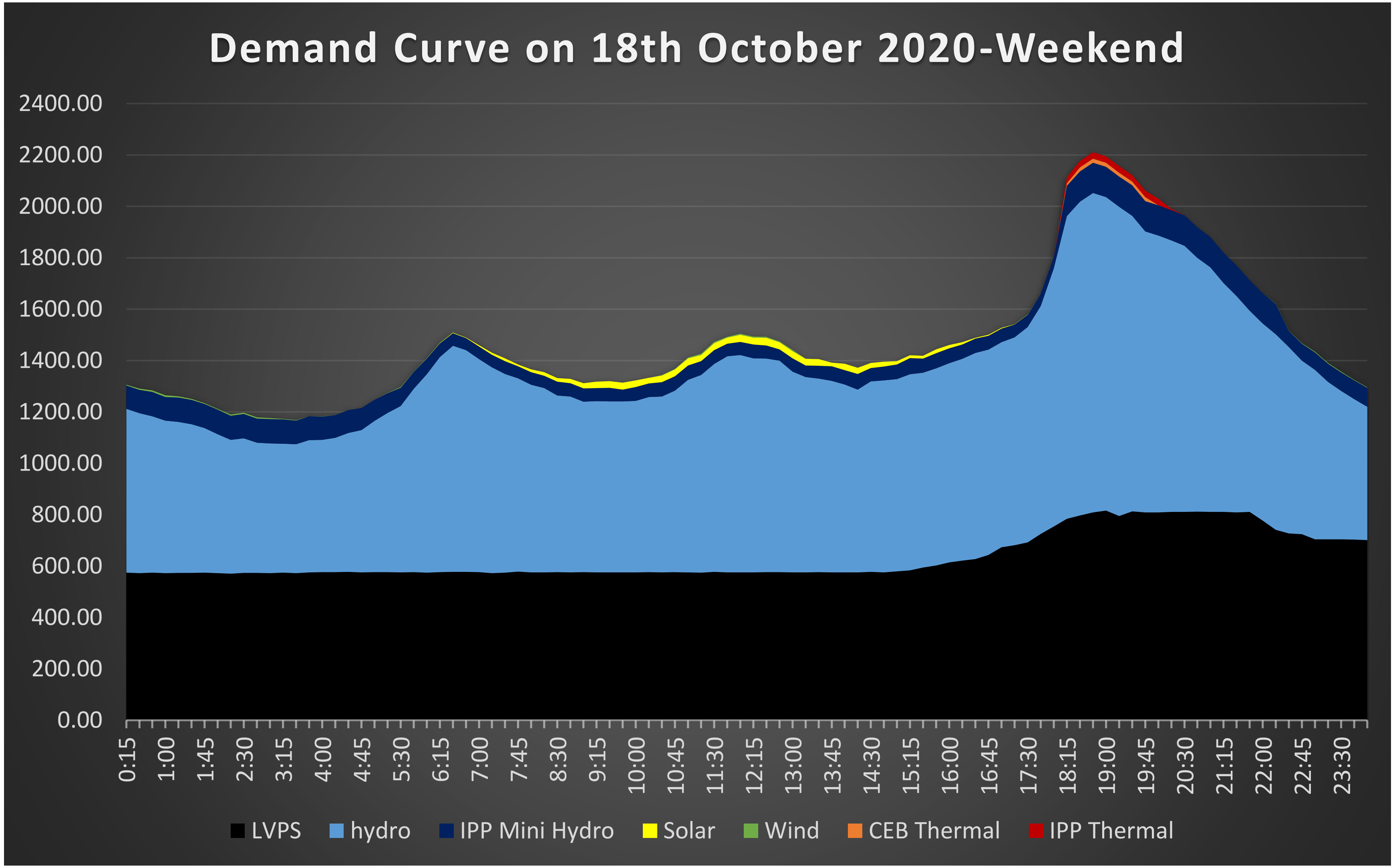
Understanding the Daily Load Profile



Demand Curve on Typical Week Day -July 2019
DEMAND / (MW)
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0:15
1:00
1:45
2:30
3:15
4:00
4:45
5:30
6:15
7:00
7:45
8:30
9:15
10:00
10:45
11:30
12:15
13:00
13:45
14:30
15:15
16:00
16:45
17:30
18:15
19:00
19:45
20:30
21:15
22:00
22:45
23:30
Coal
CEB THERMAL
Hydro
IPP
WIND
SOLAR

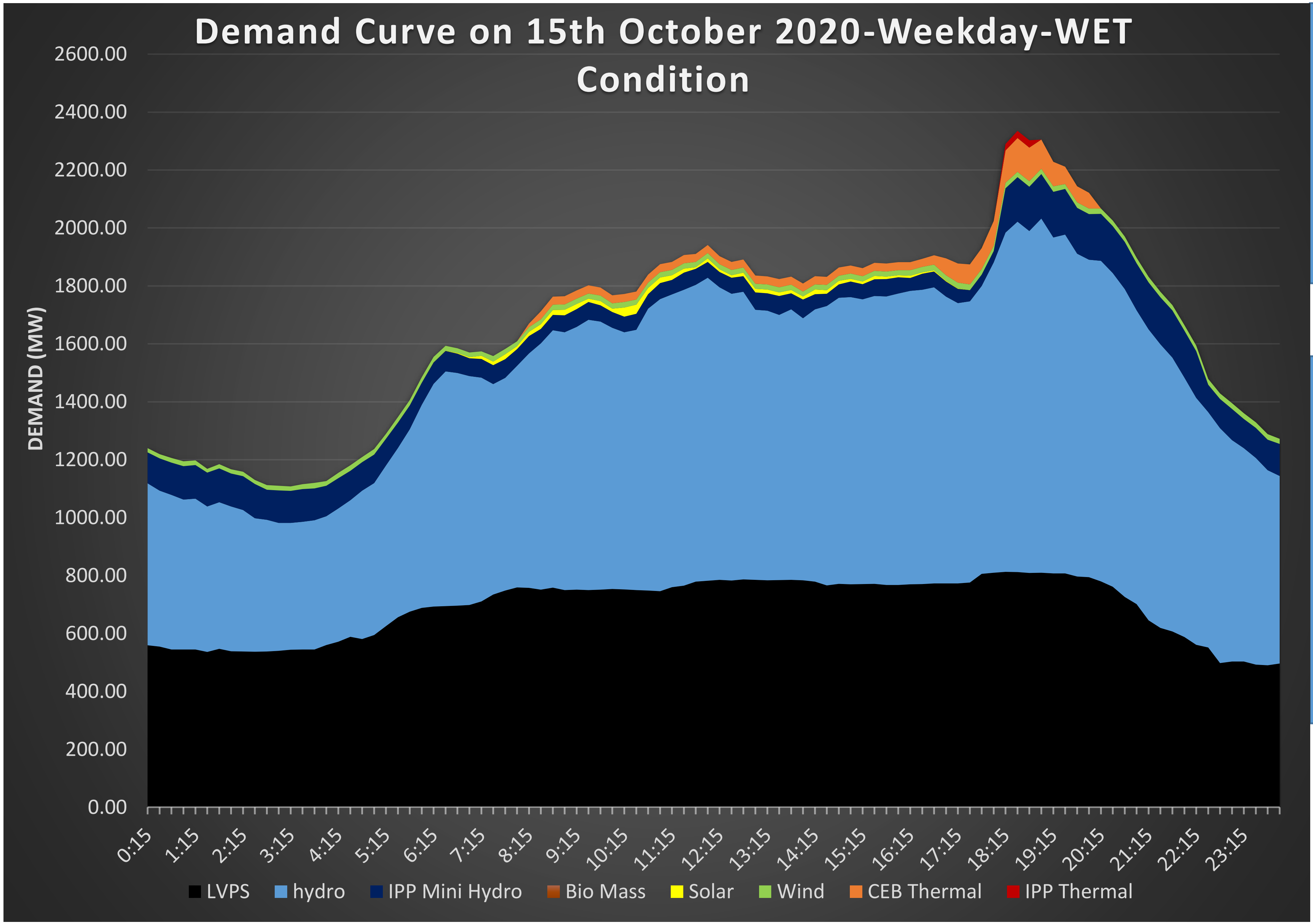
Typical Demand Curve of Sunday





- Coal 3 units are at minimum Load except for night peak

- Almost all Hydro plants during off peak are R/R and ponds to avoid the spilling
- Cyclic operation of Coal Plants is not possible
- No provision for further NCRE specially during off peak under present demand condition.

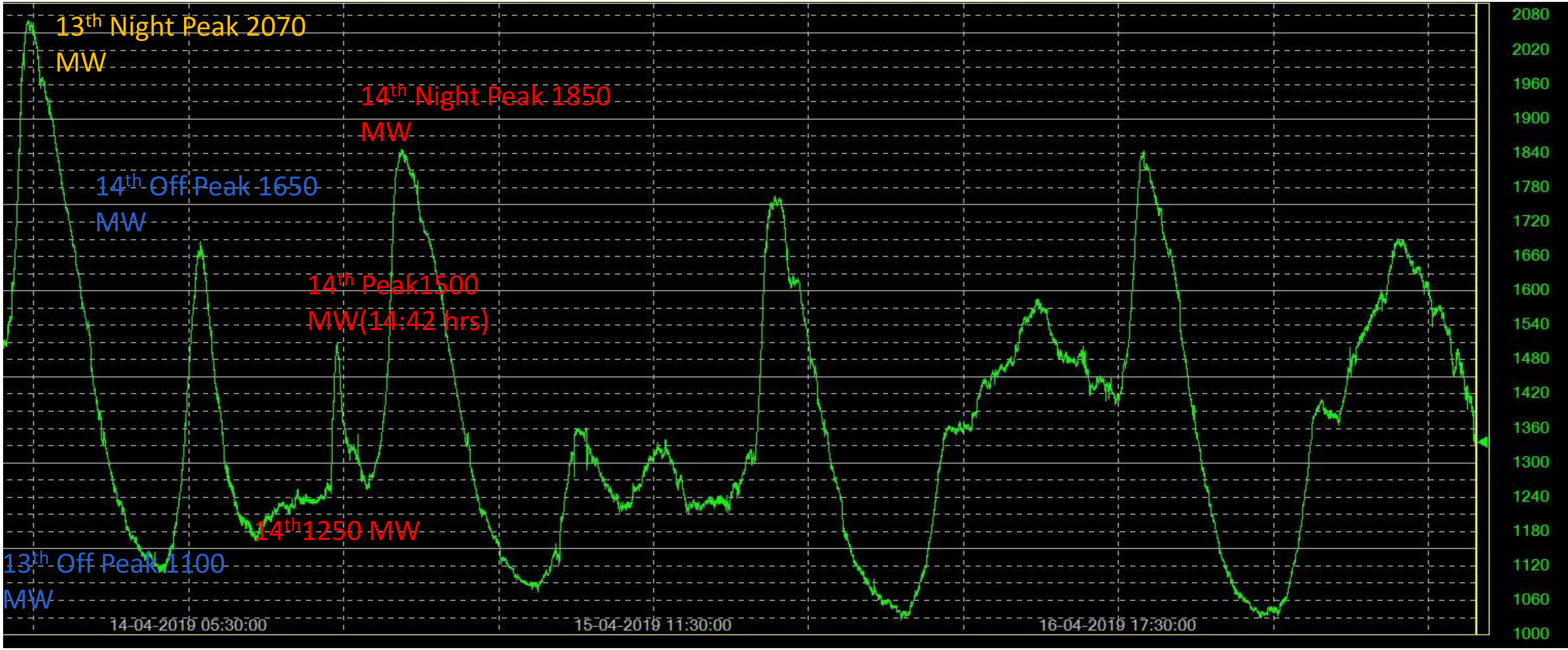


During off Peak

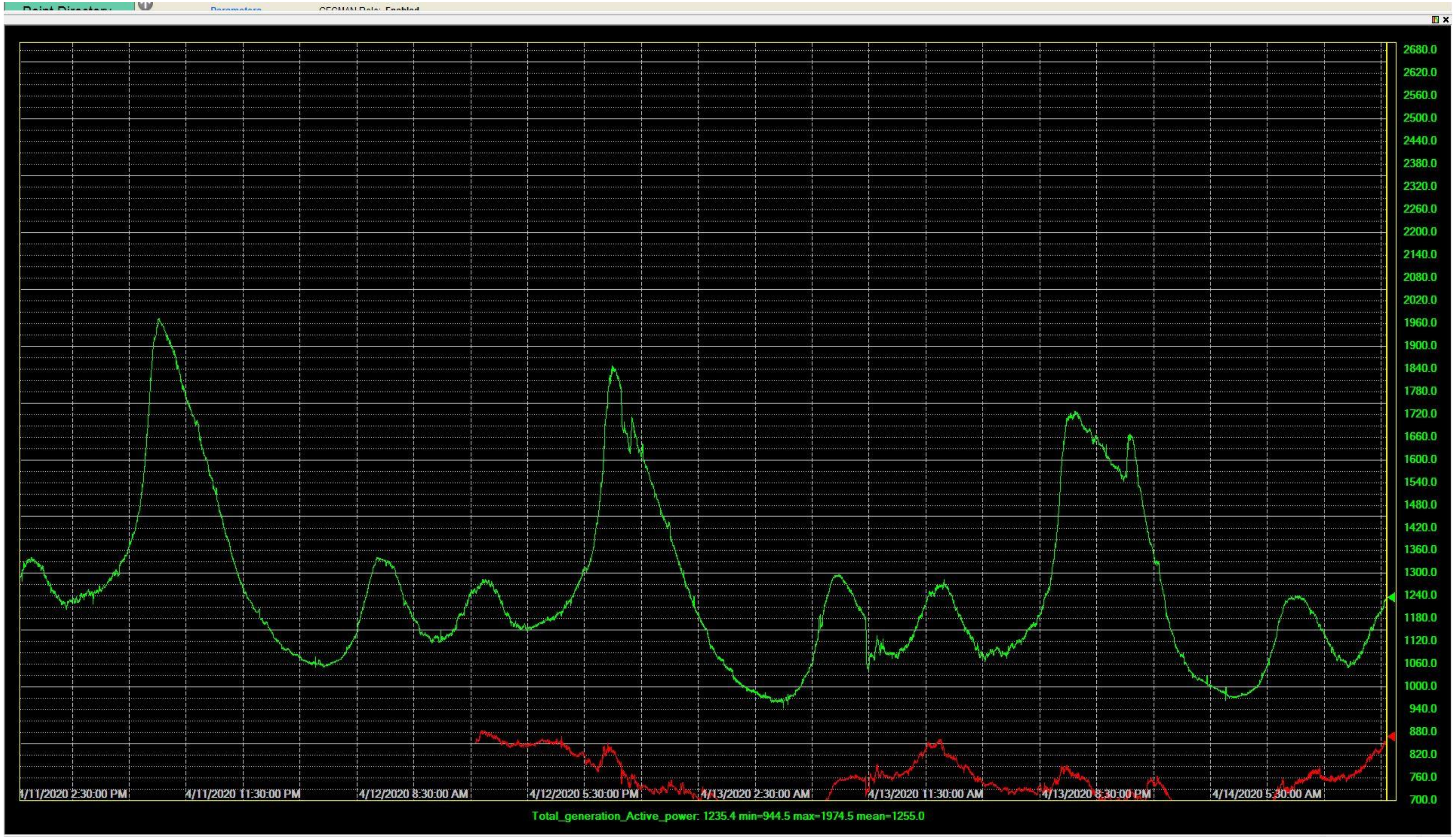
- Coal 3 units are at minimum Load
- No Thermal
- Hydro and available Wind

- Almost all Hydro plants during off peak are R/R and ponds to avoid the spilling
- Cyclic operation of Coal Plants is not possible
- No provision for further NCRE specially during off peak under present demand condition.

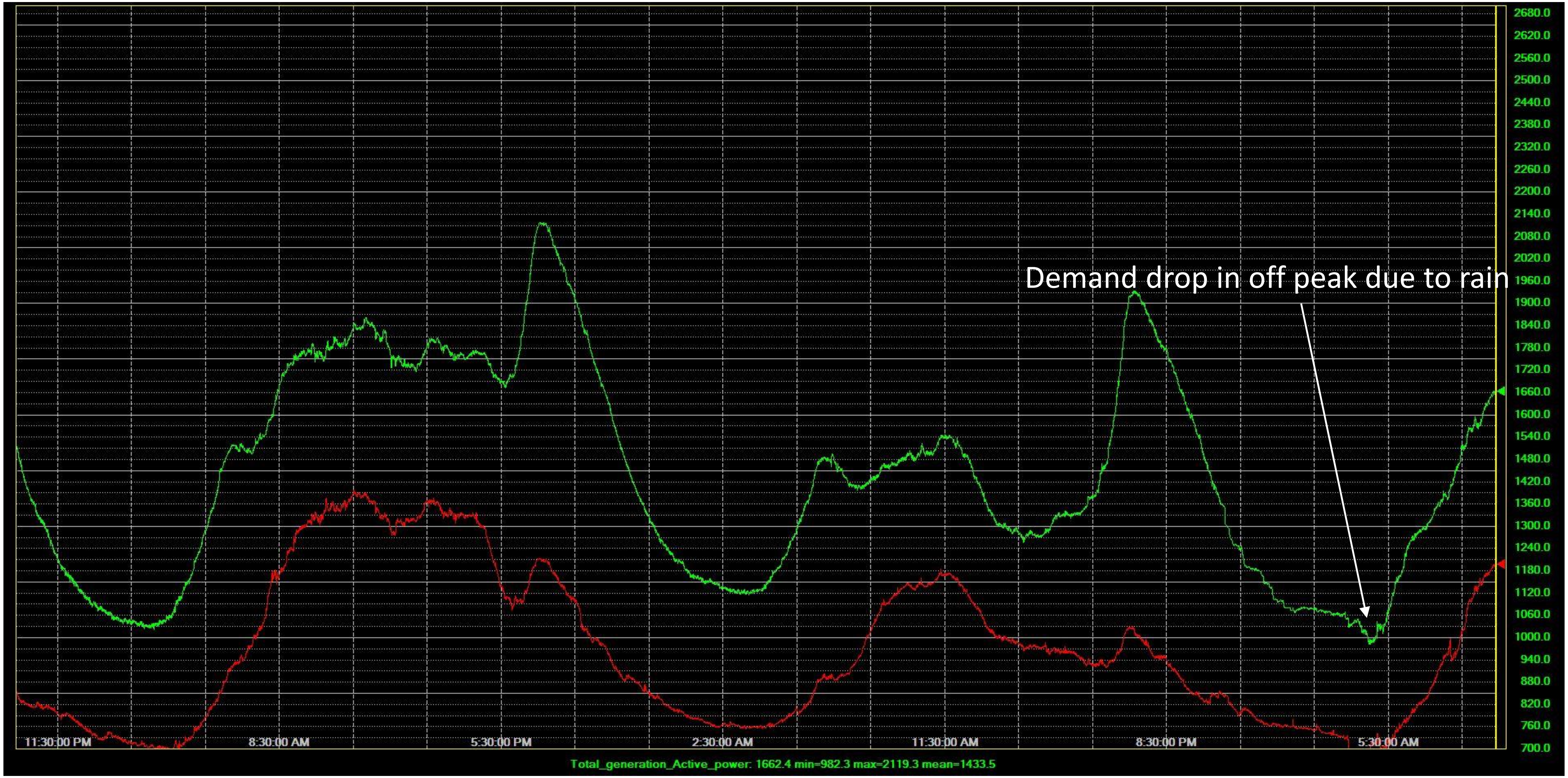
New Year 2019



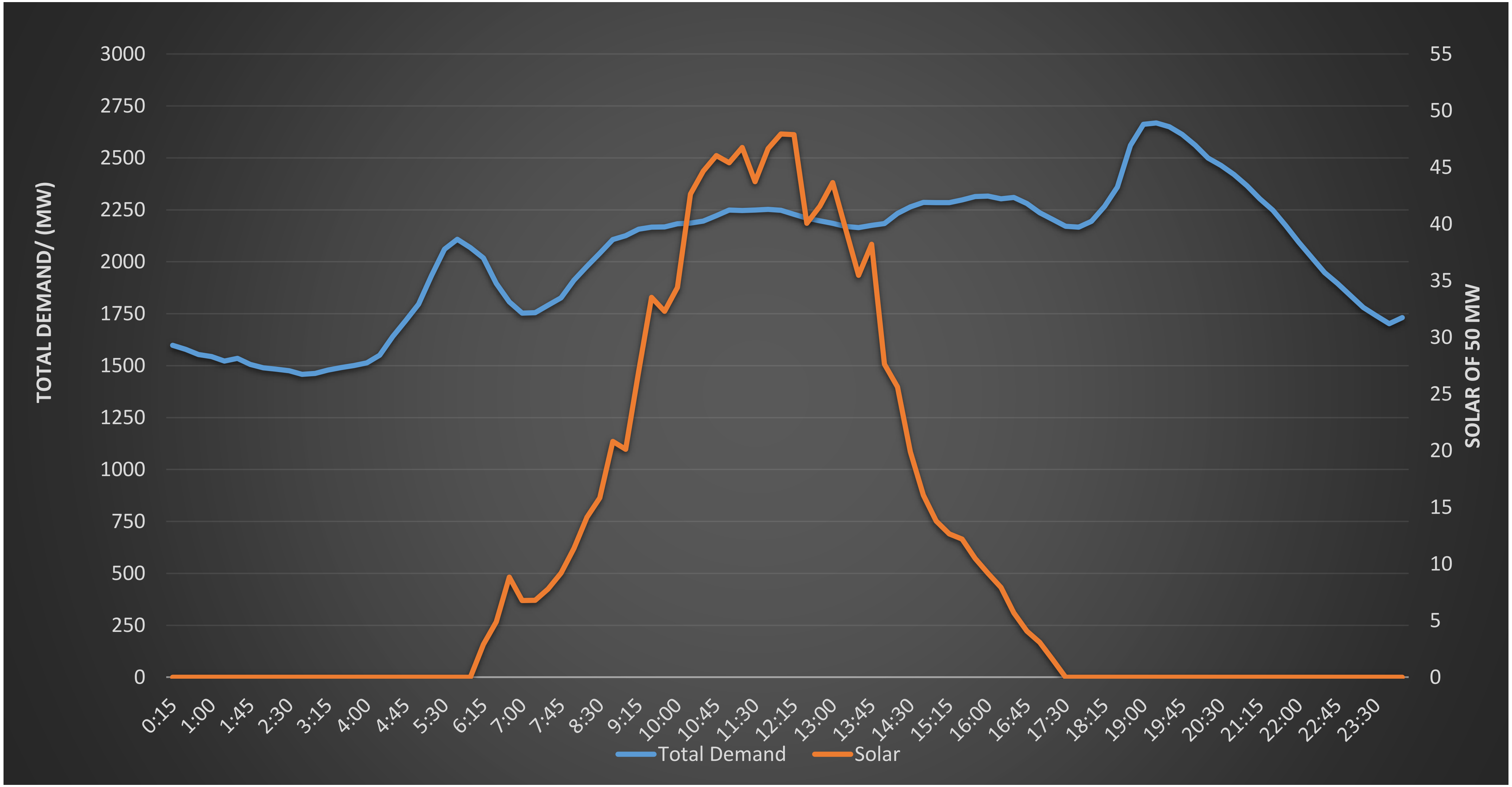
New Year 2020



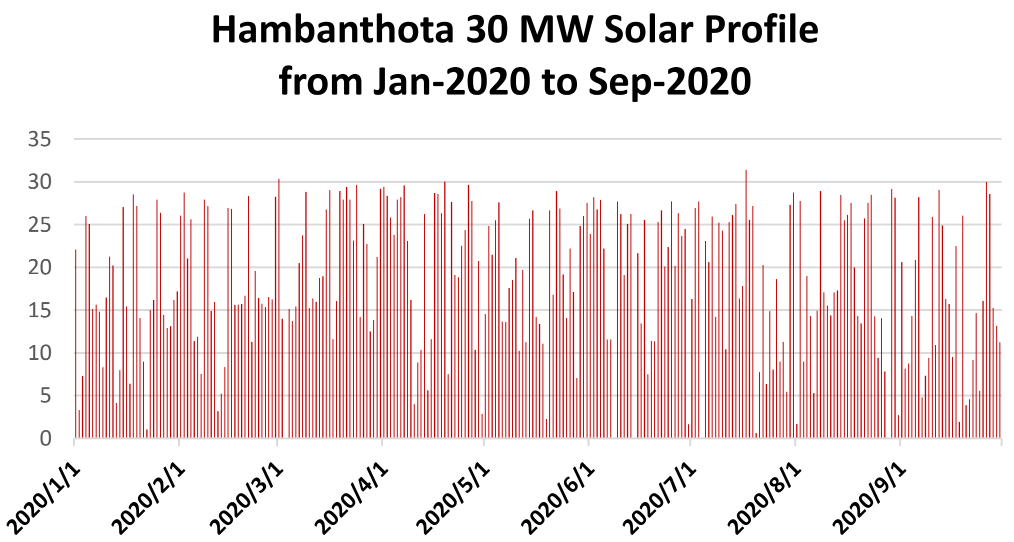
Sudden Demand Variation due to Rain

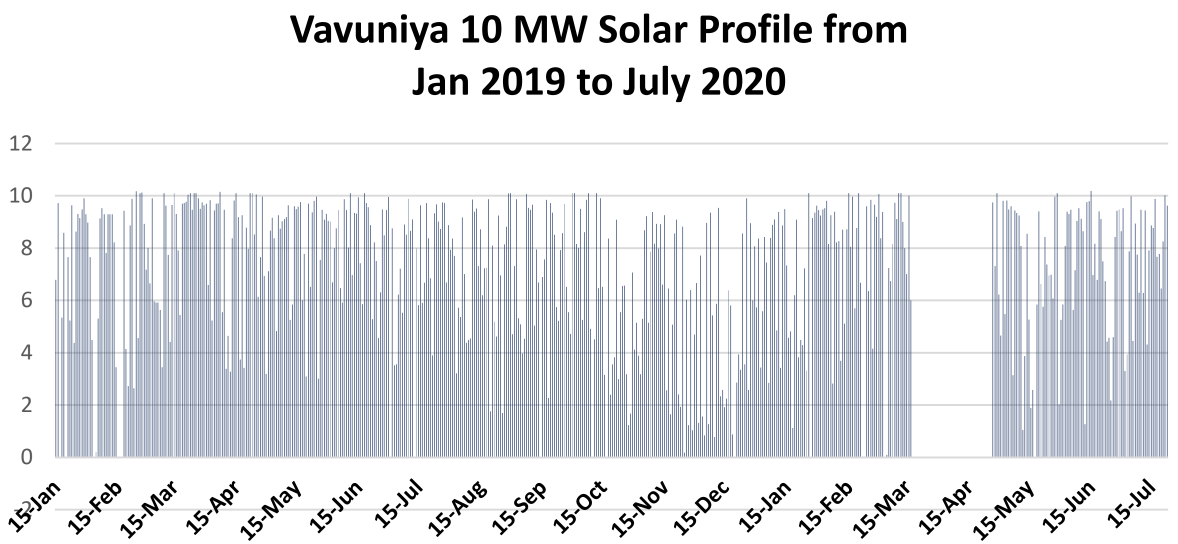


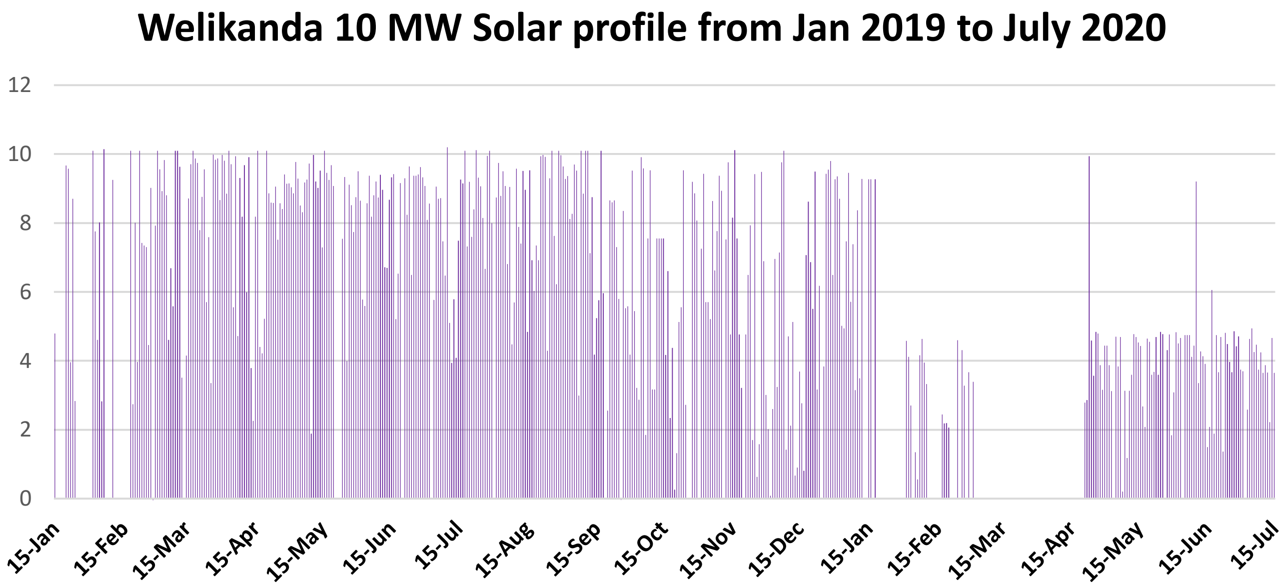
Solar Power Output Variation with Daily Total Generation Requirement



Variation of Solar Power at 11.00 hrs daily

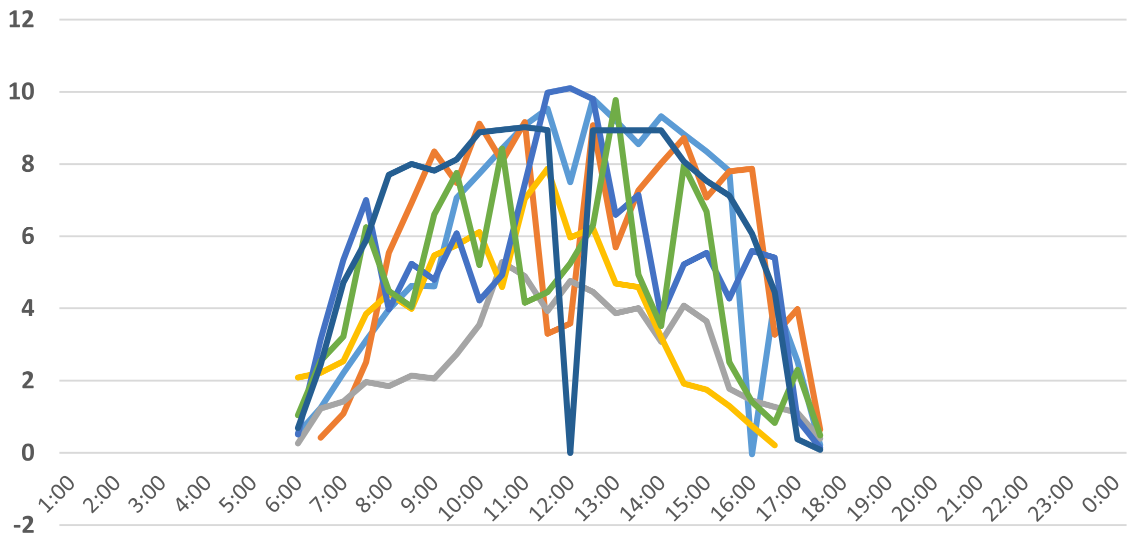




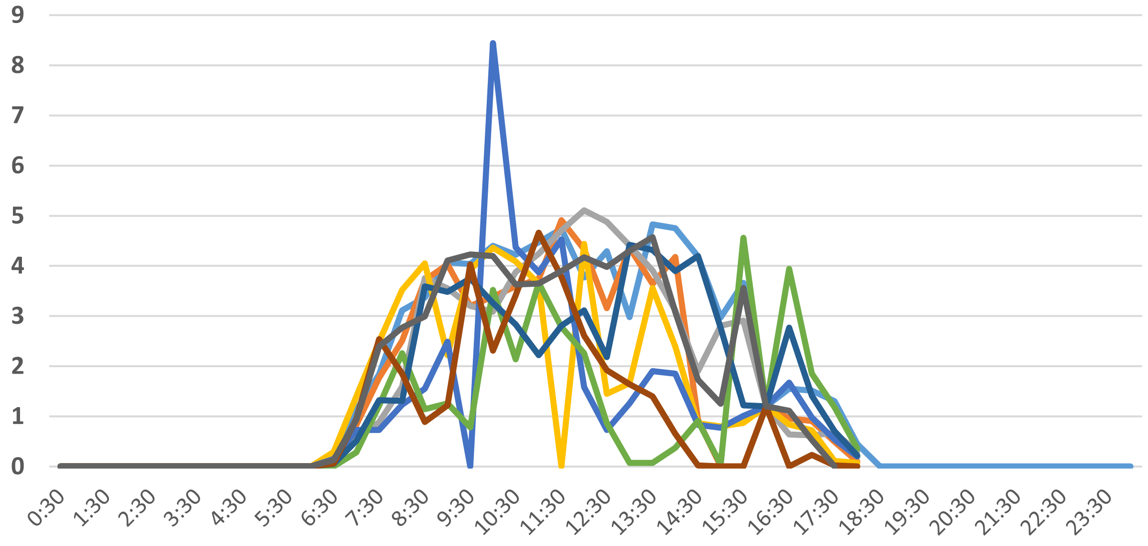


high NCRE penetration

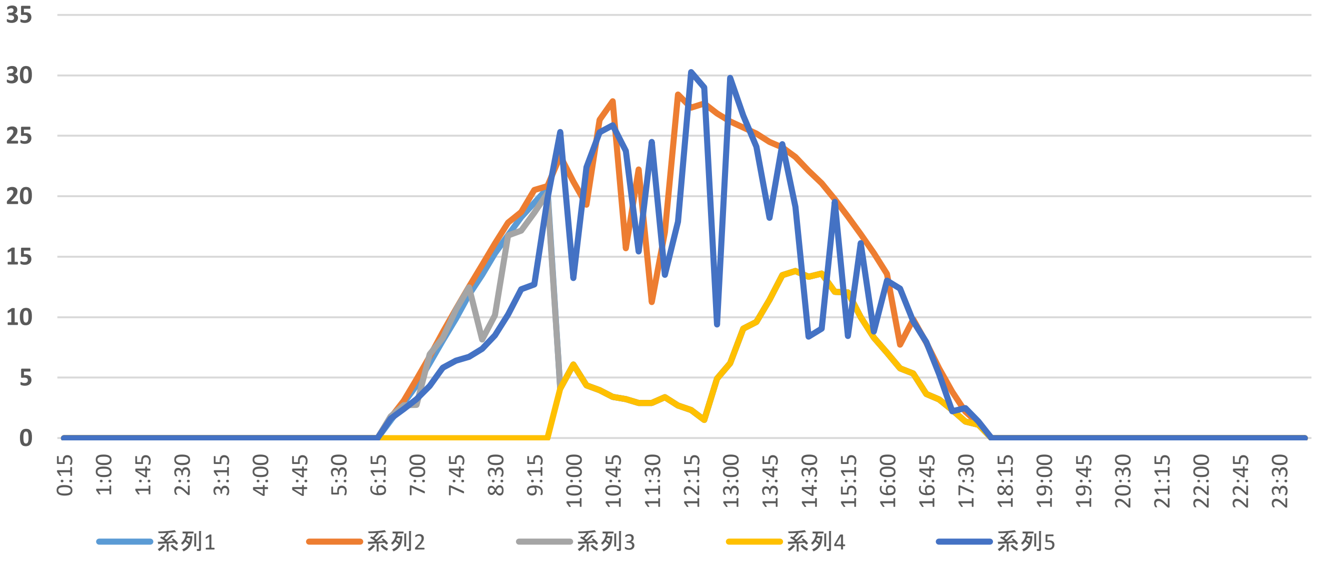
10 MW Vavuniya-Solar Variation during a Day



Welikanda 10 MW Solar Variation

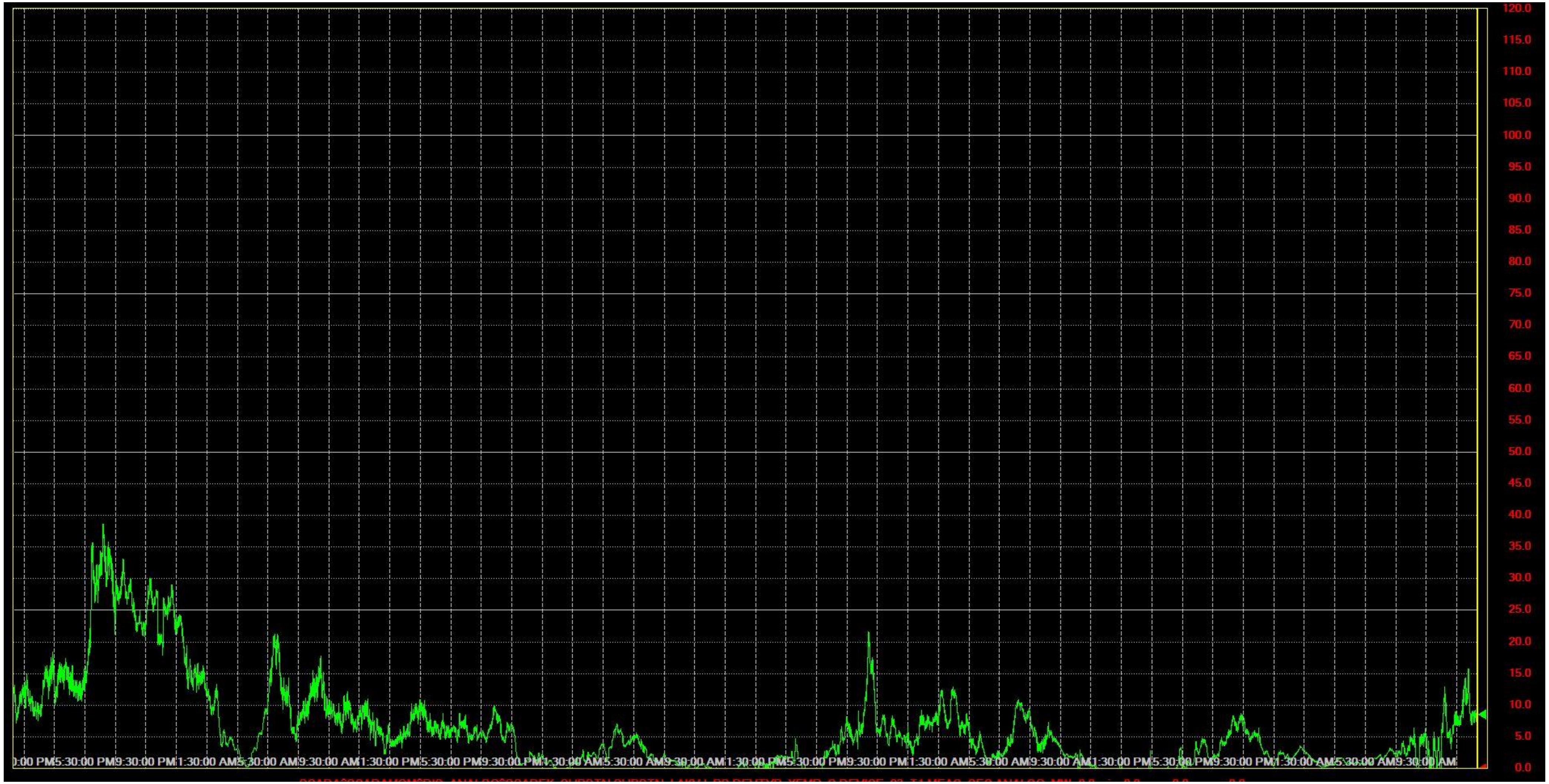


Hambanthota 30 MW Sloar Variation

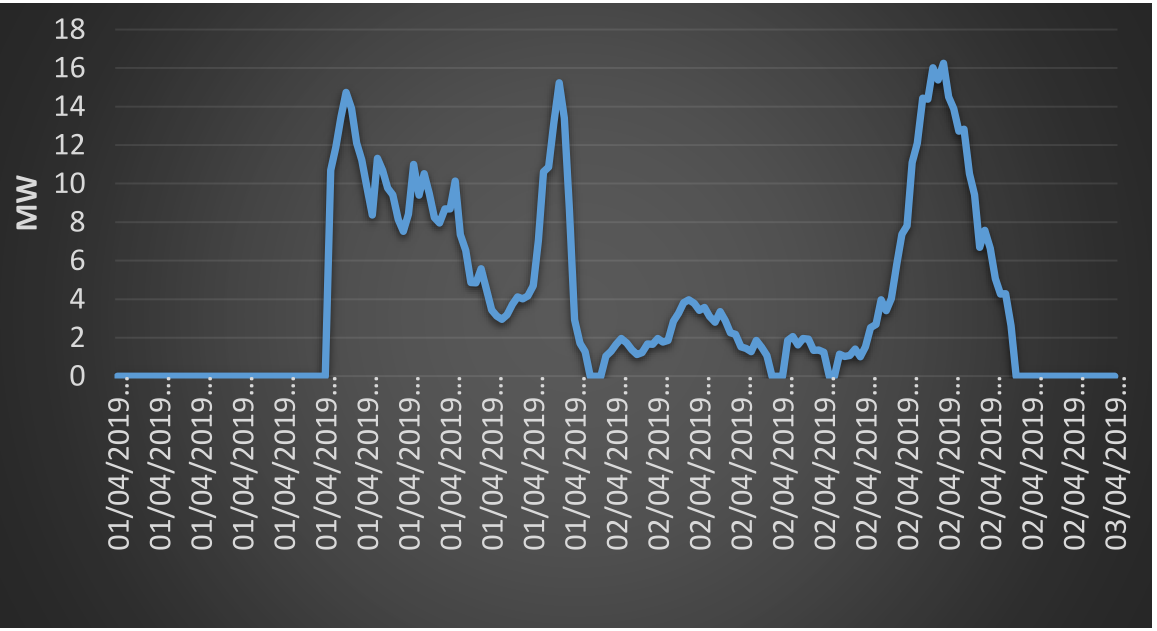


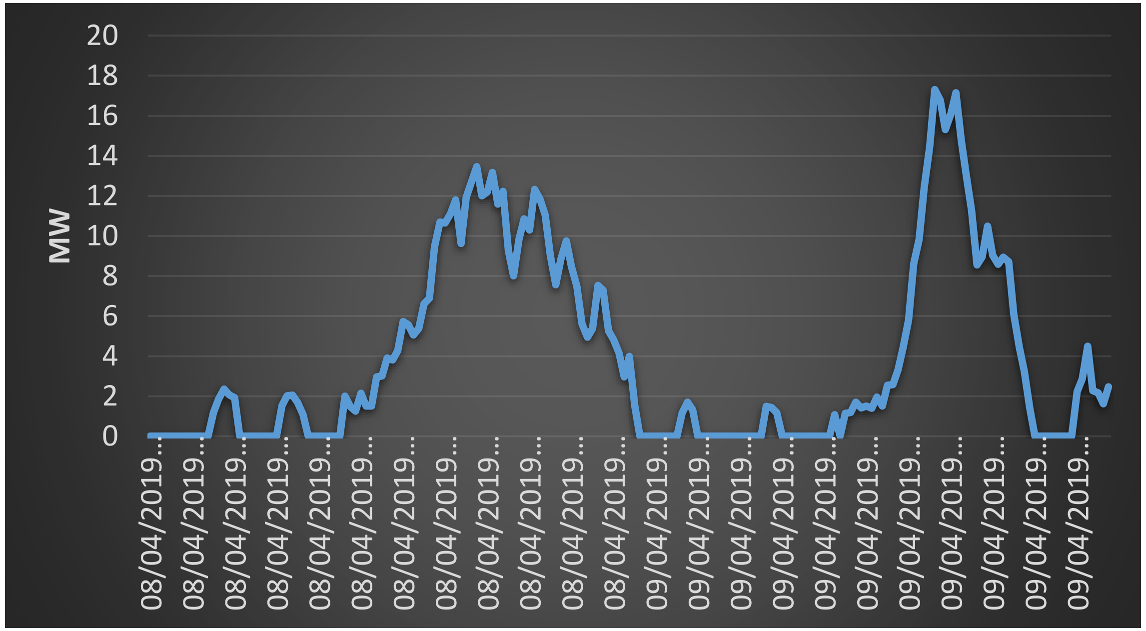
Levelized Average varies between 40-50% of rated Capacity

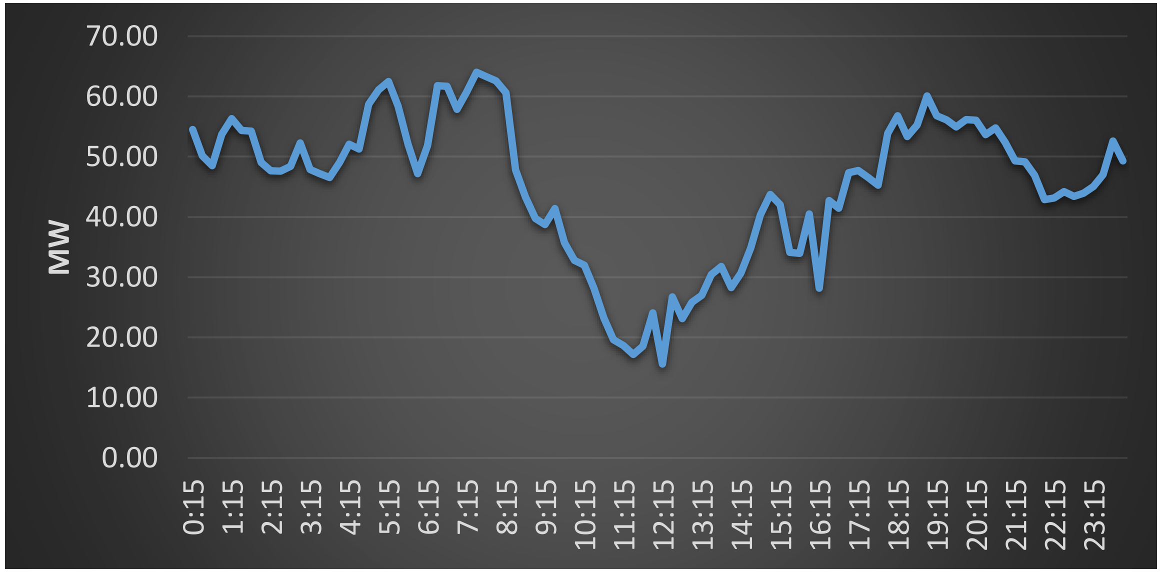
Wind Power Profile for last 4 days (Low wind period)



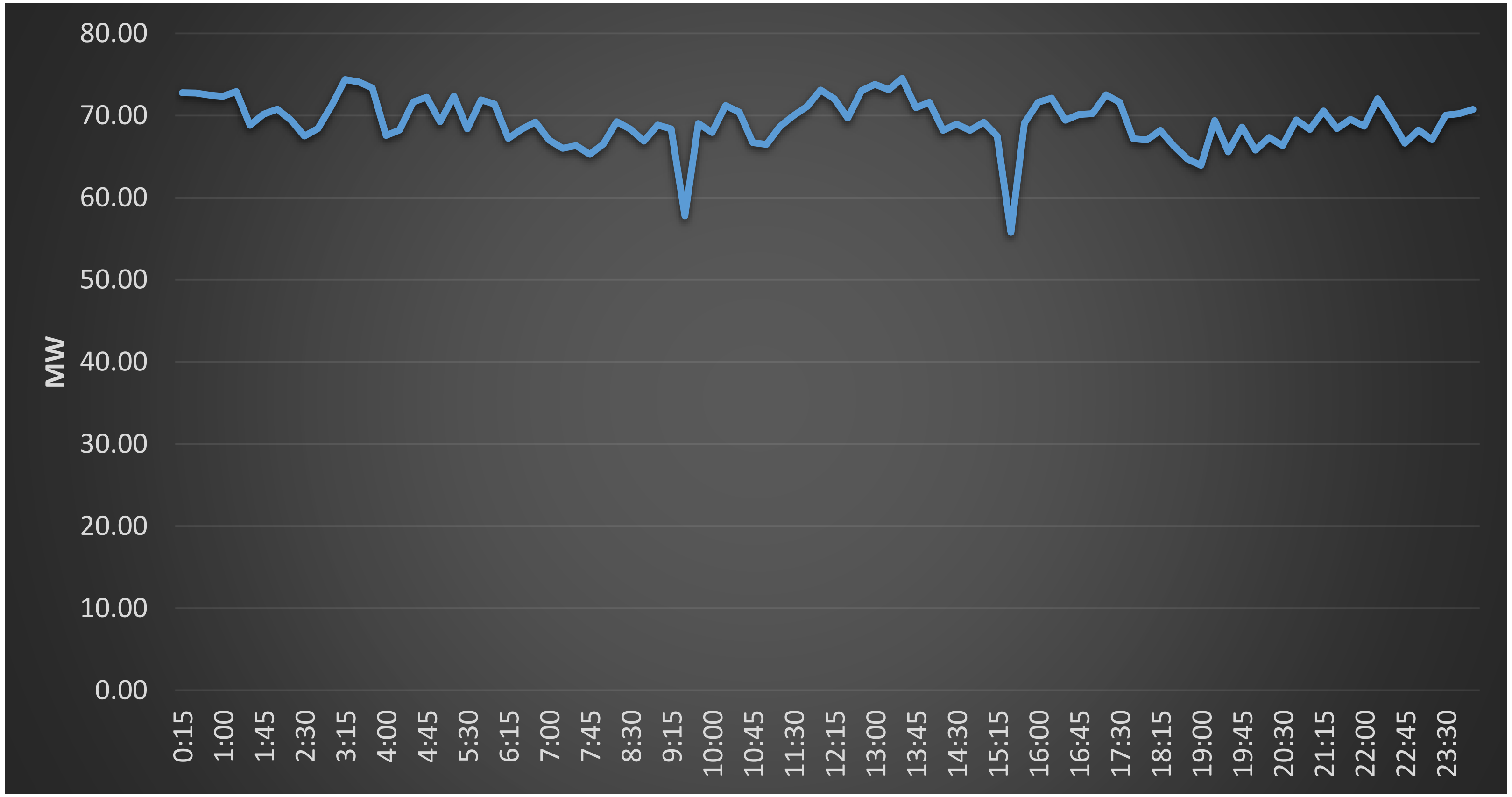
Norechchole 65 MW Wind Profile on April 2019







Wind Profile in high wind season



Day with very less fluctuations

Constraints in present power system operations with high VRE Penetration

- Maintain the balance between supply and demand with high VRE penetration specially in during low demand hours (during rainy day with high wind profiles, etc.).
- Cyclic operations of Coal plants are not possible.
- Even some of combined cycle plants also reluctant to do the cyclic operations due to frequent maintenance and high start up costs.
- Supply demand imbalance with Intermittent nature of the Solar and Wind with high VRE penetration.
- Non availability of real time monitoring facility of VRE

Possible measures to minimize the operational issues with high VRE Penetration

- New VRE projects shall be developed with provision for proper curtailment policy.
- Precise VRE forecasting system shall be implemented.
- Real time monitoring of VRE shall be facilitated at National System Control Centre. Further, remote controlling facility for switching ON/OFF of the grouped VRE installations when there are small scale VRE installations.
- Installation of Pump storage plants to cater the more VRE.
- Having a proper Reserve margin for catering the intermittency and costing the same.
- Declaration of Plant availability may be hourly (depending on the installed capacity)

Other Technical Issues

- Replacing conventional generators with VRE leads to lower the system inertia and significant affect the system frequency stability
- Replacing conventional generators with VRE leads to lower the capability of primary frequency regulation.
- Tripping of VRE s (specially Mini Hydro Plants) for system disturbances leading to intensify the frequency instability of the system.

Possible measures minimize the other technical issues with high VRE Penetration

- Emerging technologies for improving the system inertia shall be incorporated for future plans.
- Batteries can be used as fast acting reserves for primary frequency regulation with proper evaluation on cost vs requirement.
- VRE plants should be able to operate continuously during the system disturbances such as sudden frequency / voltage fluctuation. CEB VRE interconnection code must be satisfied.
- Maximum limit of VRE penetration shall be evaluated by considering the operational and other stability constraints in the system.

Thank You

Long Term Generation Expansion Plan

2023-2042

Generation Planning Unit
Transmission & Generation Planning Branch
Ceylon Electricity Board

Background

2021 July

Conditionally approved !!!

2021 July-September

Key Highlights of Sri Lanka's Nationally Determined Contributions and Vision for a Low Carbon Future

Sri Lanka is highly vulnerable to the adverse impacts of climate change. The country focuses on building the resilience of **Agriculture, Fisheries, Livestock, Health, Water, Biodiversity, Coastal and Marine, Tourism, Urban Planning and Human Settlement** sectors

Sri Lanka's per capita greenhouse gas emission in 2010 was **1.02** tons and its global cumulative contribution in 2019 was **0.03%.**

Despite this low carbon footprint and highly vulnerable status, Sri Lanka commits to increase **32%** forest cover by 2030 and reduce greenhouse gas emissions by **14.5%** for the period of 2021-2030 from **Power (electricity generation), Transport, Industry, Waste, Forestry, and Agriculture**

In order to realize this ambitious target, Sri Lanka further commits;

- To achieve **70%** renewable energy **in electricity generation** by 2030
- To achieve **Carbon Neutrality** by 2050 in electricity generation
- **No** capacity addition of **Coal** power plants

Sri Lanka has already launched following major initiatives;

- Adopting 'Colombo Declaration on Sustainable Nitrogen Management' with an ambition to halve nitrogen waste by 2030
- Banning agro-chemicals and chemical fertilizer
- Promoting organic fertilizer and farming
- Banning single-use plastics
- Promoting E-mobility
- Promoting circular economy

Sri Lanka expects to achieve its **Carbon Neutrality** by 2050

2021 October

ශ්‍රී ලංකා මහජන උපයෝගිතා කොමිෂන් සභාව
இலங்கைப் பொதுப் பயன்பாடுகள் ஆணைக்குழு
PUBLIC UTILITIES COMMISSION OF SRI LANKA

ඔබේ අංකය / உமது இல. / Your No. }

මගේ අංකය / எமது இல. / Our No. } PUC/LIC/AP21/01

දිනය / திகதி / Date } 5th October 2021

- To achieve 70% renewable energy in electricity generation by 2030
- To achieve Carbon Neutrality by 2050 in electricity generation
- No capacity addition of Coal power plants

The Commission requires you to submit the Least Cost Long Term Generation Expansion Plan prepared in compliance with the government policy on or before 30th June 2022.

Thank you,
Yours Sincerely,

Public Utilities Commission of Sri Lanka

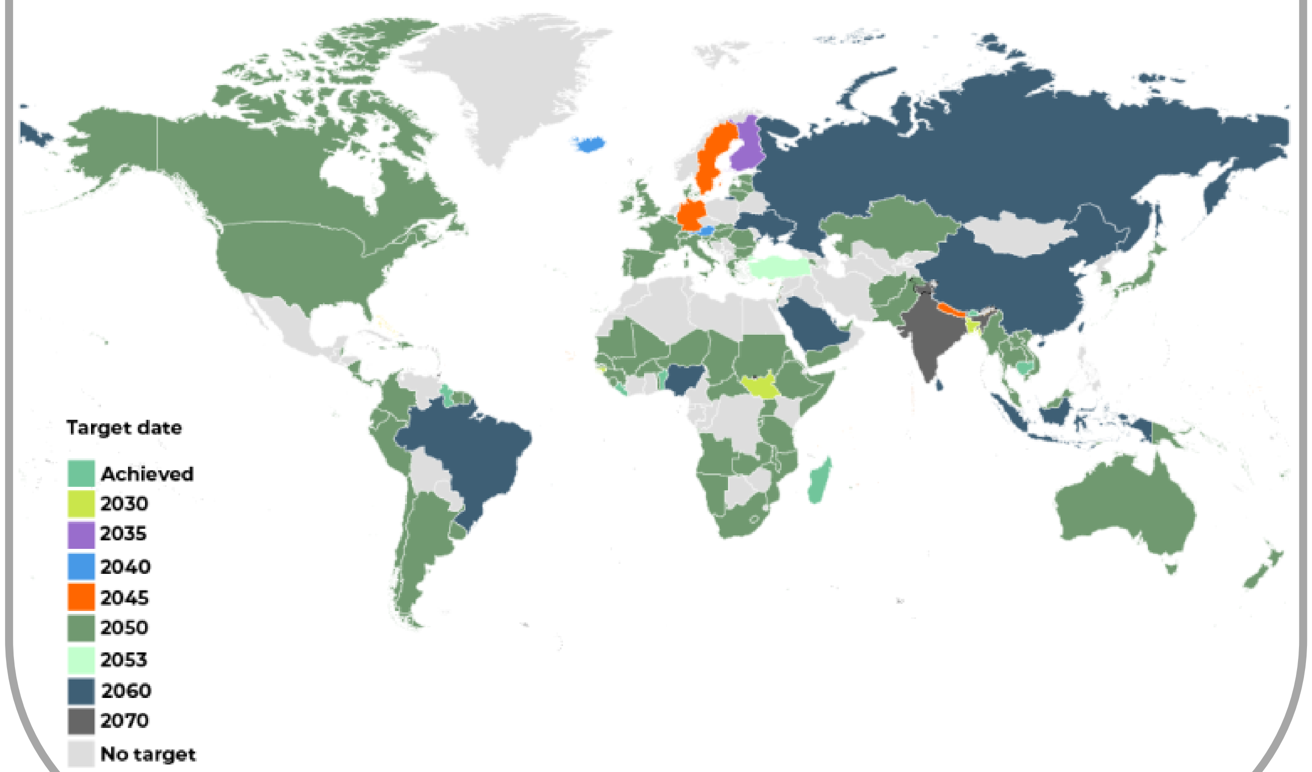
Janaka Ratnayake
Chairman

Global International Commitments

CLIMATE CRISIS

Net zero pledges

More than **137 countries have committed to net zero**. India and Nigeria were the latest nations to make the pledge at COP26, with India expecting to reach the target by 2070.



CLIMATE

Pledge to quit coal

At COP26, more than 40 countries have pledged to shift away from coal

Afghanistan
Albania
Algeria
Andorra
Angola
Antigua & Barbuda
Argentina
Armenia
Australia
Austria
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benin
Bhutan
Bolivia
Bosnia & Herzegovina
Botswana
Brazil
Brunei
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon
Canada
Cape Verde
CAR
Chad
Chile
China
Colombia
Comoros
DRC
Congo
Cook Islands
Costa Rica
Côte d'Ivoire
Croatia
Cuba
Cyprus
Czech Republic
Denmark
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Estonia
Ethiopia
European Union
Fiji
Finland
France
Gabon
Gambia
Georgia
Germany
Ghana
Greece
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
Hungary
Iceland
India
Indonesia
Iran
Iraq
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kazakhstan
Kenya
Kiribati
North Korea
South Korea
Kuwait
Kyrgyzstan
Laos
Latvia
Lebanon
Lesotho
Liberia
Libya
Liechtenstein
Lithuania
Luxembourg
North Macedonia
Madagascar
Malawi
Malaysia
Maldives
Mali
Malta
Marshall Islands
Mauritania
Mauritius
Mexico
Micronesia
Moldova
Monaco
Mongolia
Montenegro
Morocco
Mozambique
Myanmar
Namibia
Nauru
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Niue
Norway
Oman
Pakistan
Palau
Palestine
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Romania
Russia
Rwanda
St. Kitts & Nevis
St. Lucia
St. Vincent & Grenadines
Samoa
San Marino
São Tomé & Príncipe
Saudi Arabia
Senegal
Serbia
Seychelles
Sierra Leone
Singapore
Slovakia
Slovenia
Solomon Islands
Somalia
South Africa
South Sudan
Spain
Sri Lanka
Sudan
Suriname
Eswatini
Sweden
Switzerland
Syria
Tajikistan
Tanzania
Thailand
Timor-Leste
Togo
Tonga
Trinidad & Tobago
Tunisia
Turkey
Turkmenistan
Tuvalu
Uganda
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Uzbekistan
Vanuatu
Venezuela
Vietnam
Yemen
Zambia
Zimbabwe

Policy Directives

Ministry of Power

GENERAL POLICY GUIDELINES FOR THE ELECTRICITY INDUSTRY

General Policy Guidelines formulated in terms of Section 5(1) of the Sri Lanka Electricity Act No. 20 of 2009 was approved by the Cabinet of Ministers as required by Section 5(3) of the Said Act at its meeting held on 01.11.2021.

9. The GOSL has set the targets of achieving 70% of electricity generation in the country using renewable energy sources by 2030 and carbon neutrality in power generation by 2050, and has decided to cease building of new coal-fired power plants. The Cabinet of Ministers has approved these two policy elements that shall form the basis of Sri Lanka's future electricity capacity expansion planning.[1]. Further, new addition of firm capacity will be from clean energy sources such as regasified liquefied natural gas (RLNG).

Repelling of clauses from 2019 General Policy Guideline that reflect.

Removal of firm capacity requirement of 2/3rd of demand of power.

+

Removal of firm capacity mix ratios defined from coal, Natural gas, locally refined oil and Hydro

+

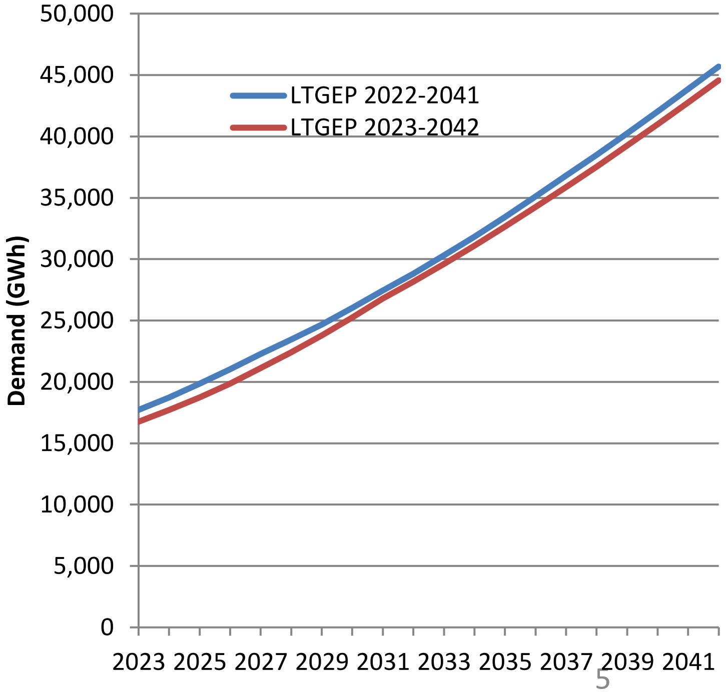
Removal of 1/3rd of demand of power from NCRE sources.

Demand Forecast 2023-2047

Year	Demand	System Loss	Generation	Peak
	GWh	%	GWh	MW
2023	16,741	7.95	**18,186**	**3,021**
2024	17,705	7.89	**19,222**	**3,149**
2025	18,725	7.83	**20,317**	**3,283**
2026	19,854	7.77	**21,526**	**3,432**
2027	21,124	7.70	**22,886**	**3,651**
2028	22,419	7.63	**24,272**	**3,890**
2029	23,794	7.57	**25,741**	**4,127**
2030	25,253	7.50	**27,300**	**4,378**
2031	26,801	7.45	**28,958**	**4,645**
2032	28,165	7.40	**30,415**	**4,880**
2033	29,601	7.35	**31,949**	**5,127**
2034	31,099	7.30	**33,548**	**5,385**
2035	32,646	7.25	**35,198**	**5,652**
2036	34,241	7.25	**36,917**	**5,929**
2037	35,879	7.25	**38,684**	**6,214**
2038	37,547	7.25	**40,482**	**6,504**
2039	39,253	7.25	**42,321**	**6,801**
2040	41,002	7.25	**44,207**	**7,106**
2041	42,777	7.25	**46,120**	**7,415**
2042	44,584	7.25	**48,070**	**7,730**
2043	46,431	7.25	**50,061**	**8,051**
2044	48,321	7.25	**52,098**	**8,380**
2045	50,259	7.25	**54,188**	**8,718**
2046	52,248	7.25	**56,332**	**9,064**
2047	54,315	7.25	**58,560**	**9,426**

Night Peak (2023–2025)

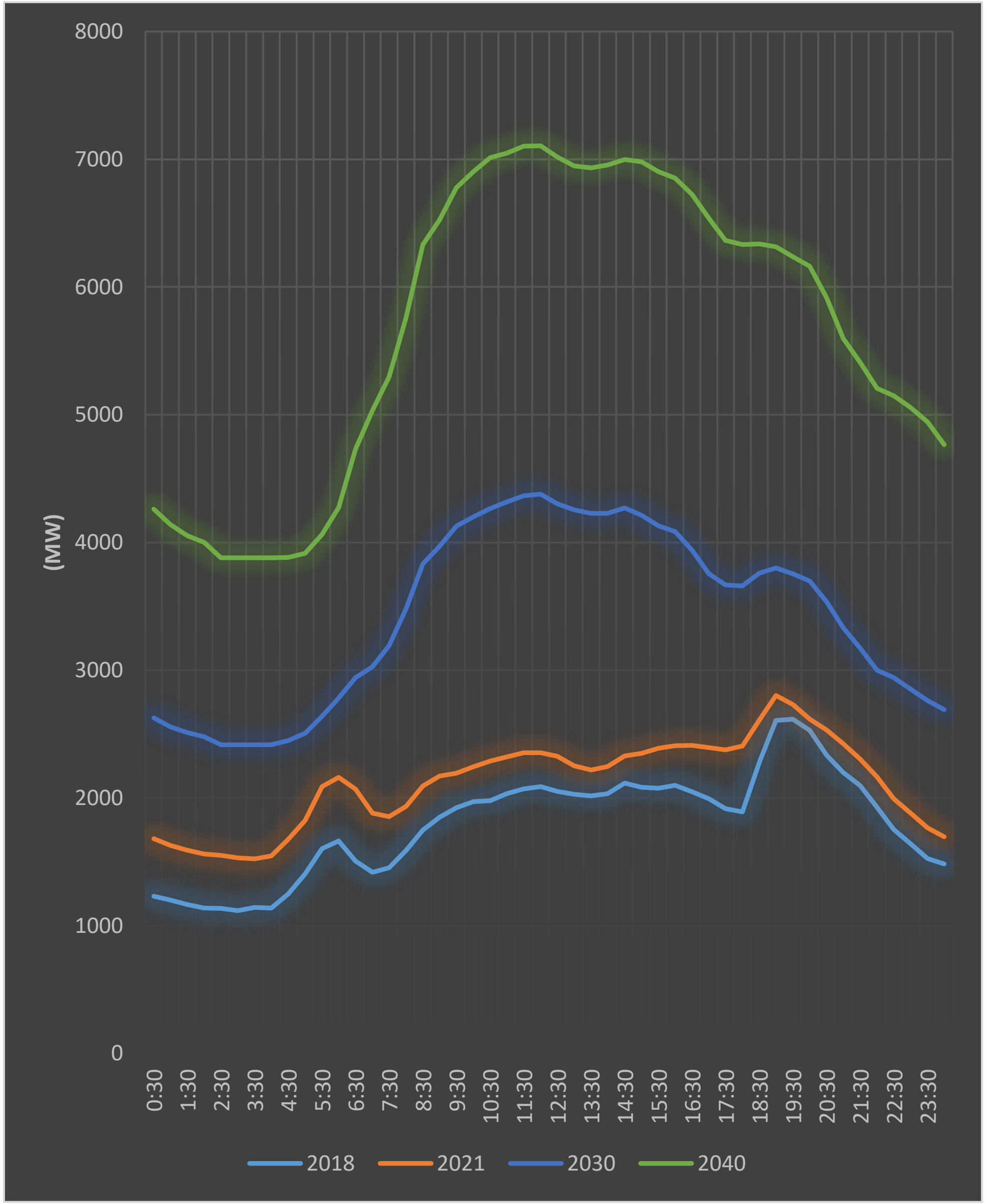
Day Peak (2026–2047)



Typical Day Load Curve Pattern

- Day Peak Growth Faster than Night Peak Growth.

- Day peak would surpass the Night peak in year 2026



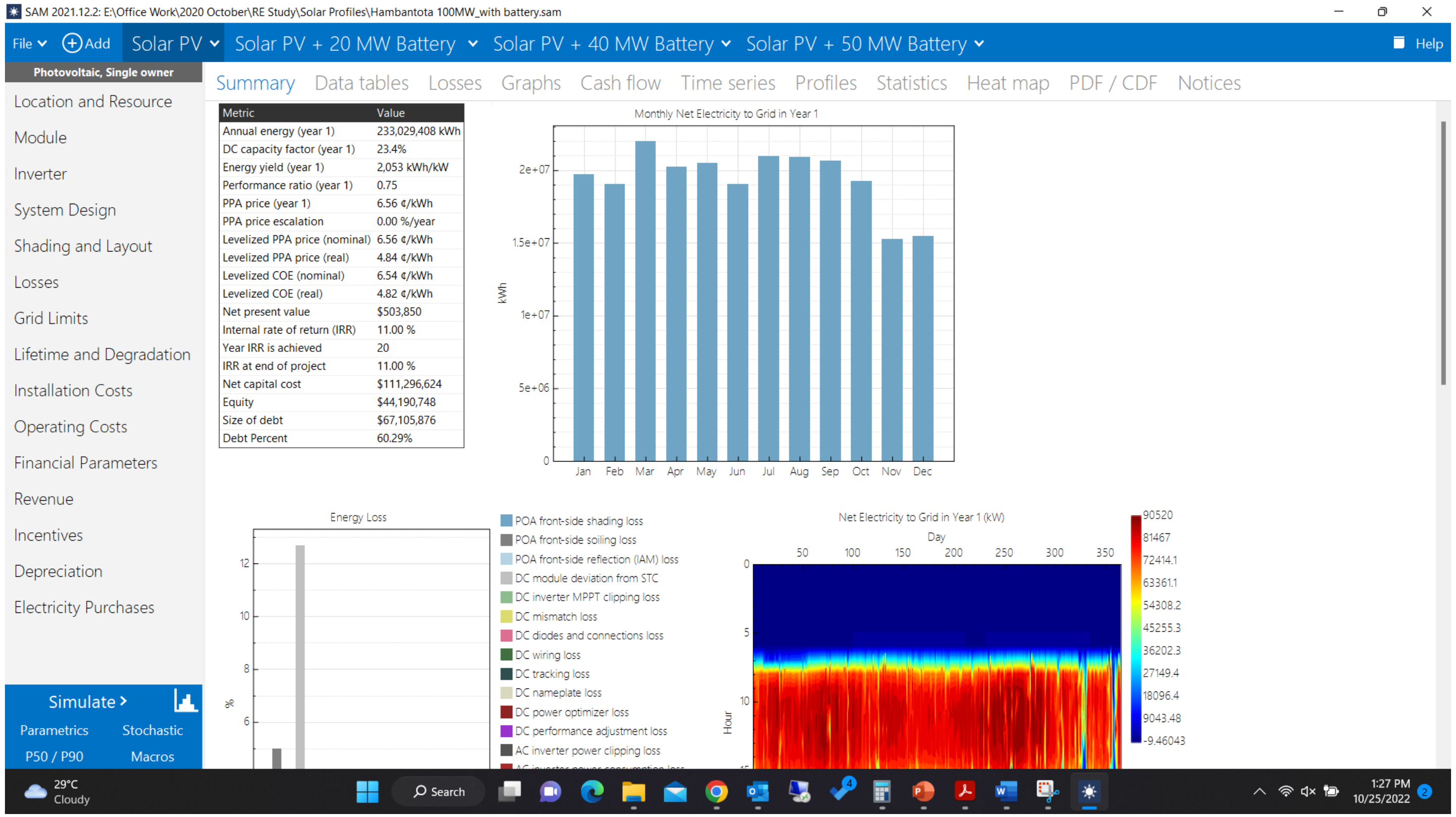
Consideration in Different timeframes

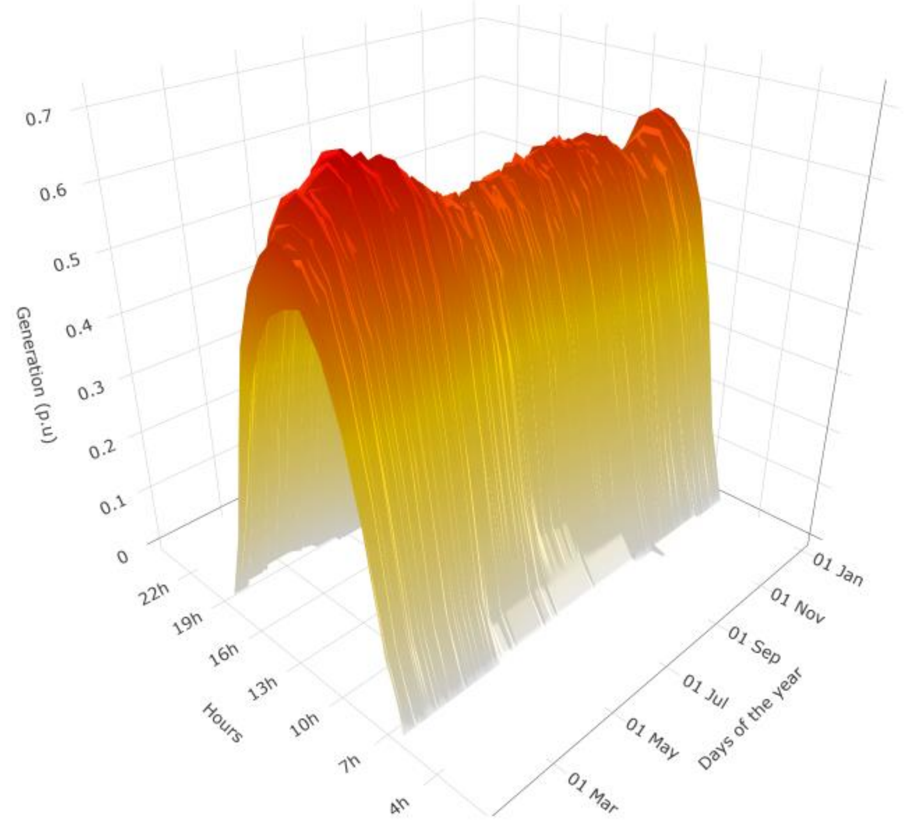
Ultra Short Term	Very Short Term	Short Term	Medium Term	Long Term	Very Long Term
Sub second to second	Second to Minutes	Minutes to Hours	Hours to Days	Days to Months	Months to years
Dynamic Stability (Inertia, Grid Strength)	Primary and Secondary Frequency Control (AGC)	Automatic Generation Control, Economic Dispatch, regulating reserves	Hourly Dispatch, Unit commitment for day ahead	Unit Commitment, Scheduling, Monthly Capacity Adequacy	Hydro Thermal Coordination, Capacity adequacy, System Reliability

Resource Modelling - Solar Parks

NREL NATIONAL RENEWABLE ENERGY LABORATORY **System Advisor Model (SAM)**

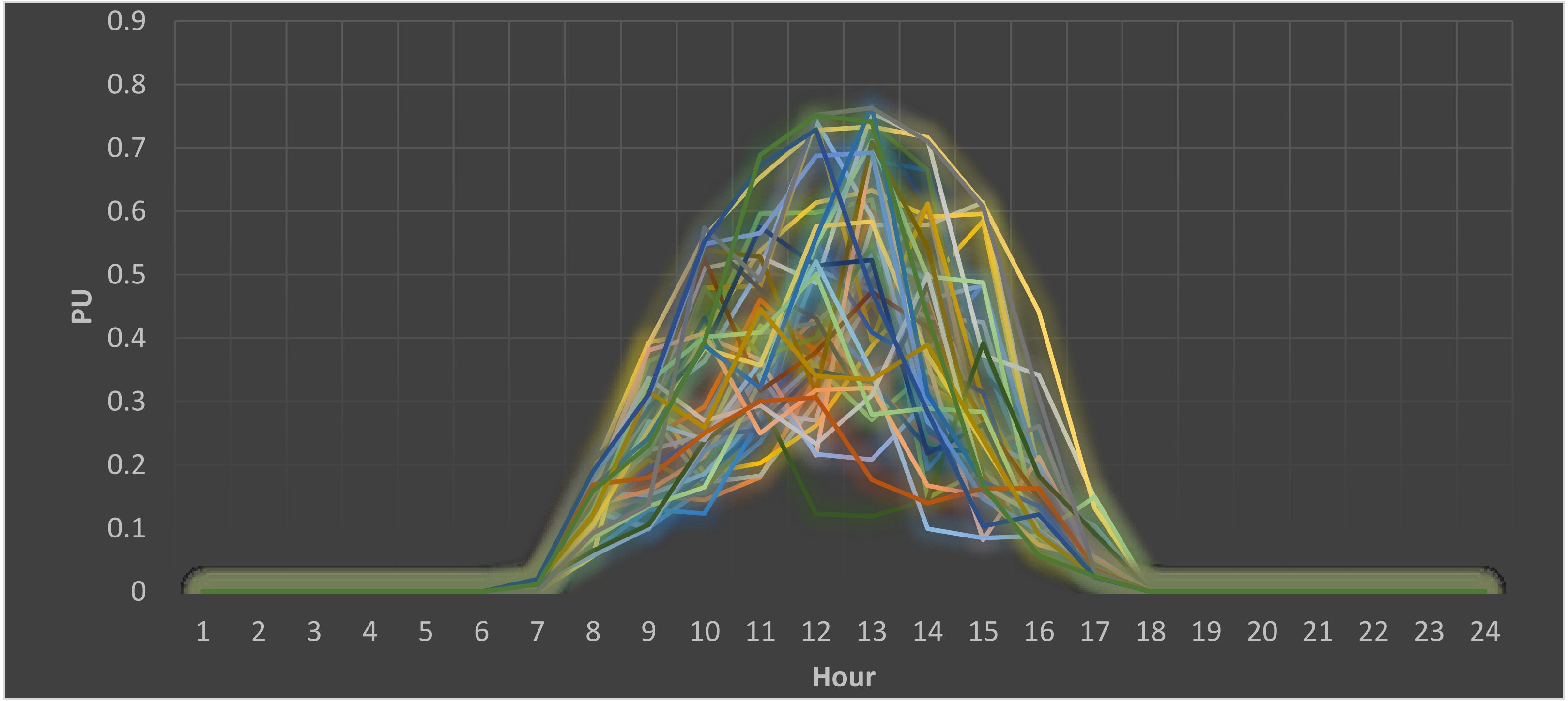
- Ground Mounted (Single Axis Tracking) / Floating Solar
- Hybrid Parks with Storage
- Dispatchable with Curtailment Policies

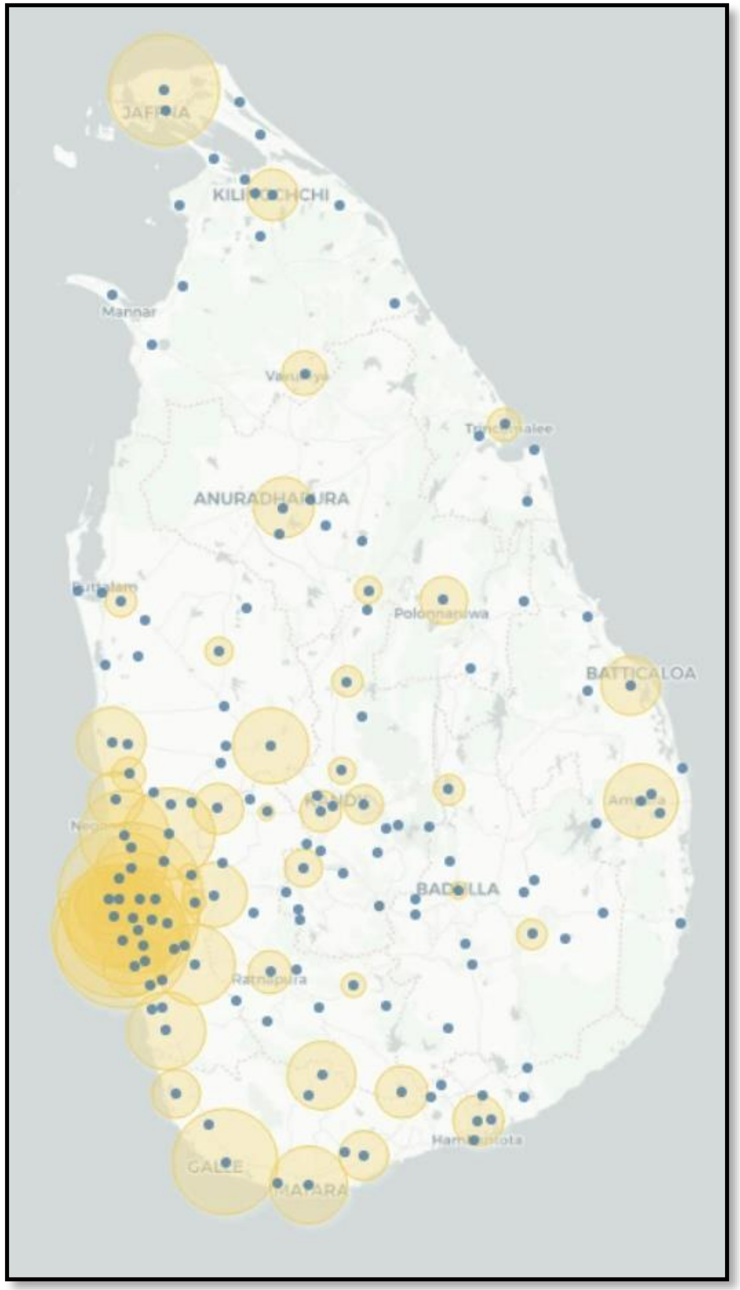




Resource Modelling - Distributed Solar

Location	Annual PF	Location	Annual PF	Location	Annual PF	Location	Annual PF
Dehiwala	17.80%	Horana	16.98%	Kurunegala	17.48%	Balangoda	17.36%
Colombo	17.74%	Veyangoda	16.90%	Anuradhapura	17.86%	Nuwaraeliya	15.46%
Katunayaka	17.91%	Pannala	18.03%	Vavuniya	17.72%	Habarana	17.58%
Bolawatta	17.97%	Chunnakam	18.50%	Kilinochchi	17.79%	Embilipitiya	17.80%
Madampe	18.08%	Mathugama	17.19%	Matara	18.49%	Mahiyanganaya	16.75%
Puttalam	18.07%	Kirindiwela	17.35%	Deniyaya	16.46%	Badulla	16.50%
Panadura	17.49%	Galle	18.23%	Nawalapitiya	15.87%	Polonnaruwa	17.60%
Pannipitiya	17.44%	Seethawaka	16.98%	Kiribathkumbura	16.87%	Hambanthota	18.95%
Biyagama	17.39%	Thulhiriya	17.33%	Pallekele	16.89%	Trincomalee	17.93%
Aniyakanda	17.49%	Maho	17.72%	Ukuwela	16.52%	Monaragala	17.38%
Ambalangoda	18.01%	Ratnapura	16.43%	Naula	17.22%	Ampara	17.69%
Kosgoda	17.82%	Kegalle	17.21%	Beliatta	18.24%	Vavunathivu	17.90%

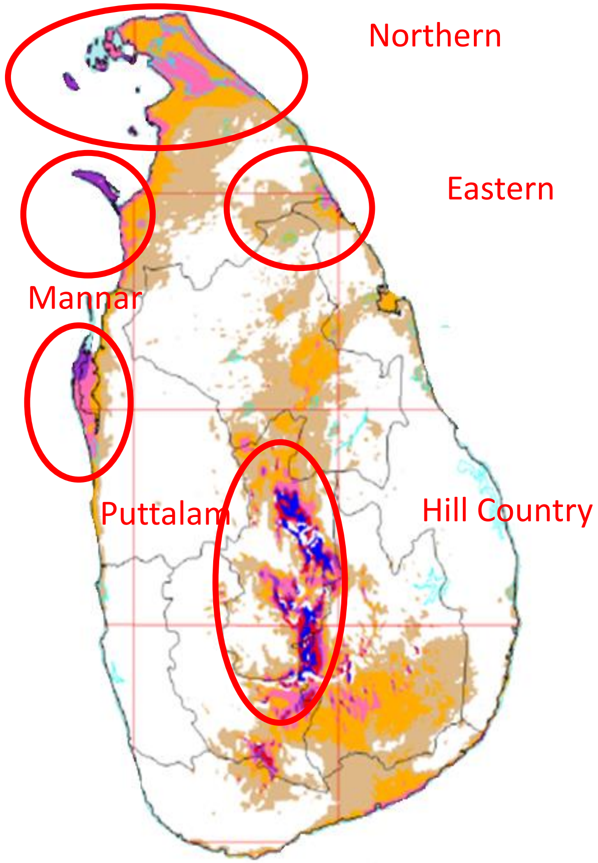




Resource Modelling - Wind

Five wind regimes were identified and wind plants were modelled based on actual site measurements for wind Production estimation

Wind Regime	Annual Plant Factor
Mannar	40.7%
Puttalam	31.4%
Hill country	19.1%
Northern	34.1%
Eastern	27.3%



Highlights of the Base Case Plan

Increased Level of VRE Integration

~ 500 MW Annual Solar PV Capacity Additions

~ 150 MW Annual Wind Capacity Additions

Large Scale Energy Storage Deployment

- **1,400** MW Pumped Storage development by 2032
- **1,125 MW** Battery Energy Storage development by 2030 / **4,670 MW** Battery Energy Storage development by 2042

70% RE TARGET

More Flexible Thermal Generation

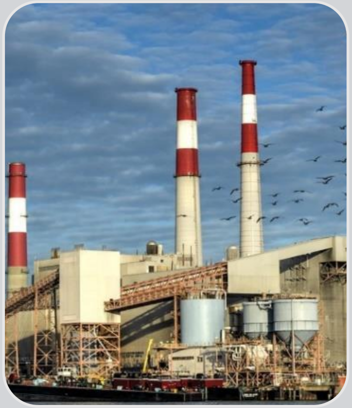
- 1,130 MW Gas Turbine Power Plants
- 850 MW IC Engine Power Plants

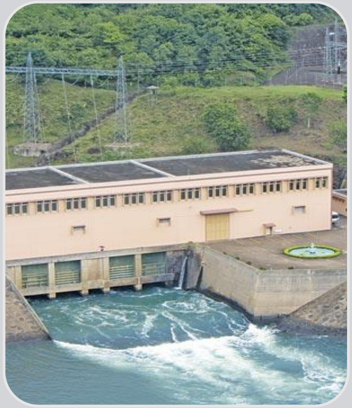
High Initial Investment

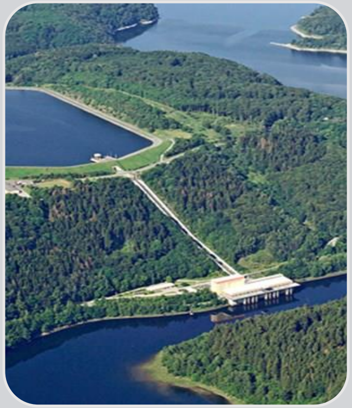
- Average annual generation and storage capacity investment of 1.25 USD Billion up to 2030
- Average annual generation and storage capacity investment of 1.43 USD Billion up to 2042

**This investment requirement contains only the investments needed on generation capacity and storage additions.*

Future Capacity Mix at Key Years





	Baseload , Intermediate Thermal	Flexible Thermal Power	Major Hydro	Other Renewable Energy	Grid Scale Battery Storage	Pumped Hydro Storage
	Coal Steam NG Combined Cycle Oil Combined Cycle Other Thermal	Gas Turbine Gas Engine		Solar Wind Mini Hydro Biomass		
2023	1,430 + 731	-	1,541	2,029	-	-
2025	2,104 + 24	330	1,571	3,302	120	-
2030	2,104 + 24	430	1,571	7,212	1,125	700

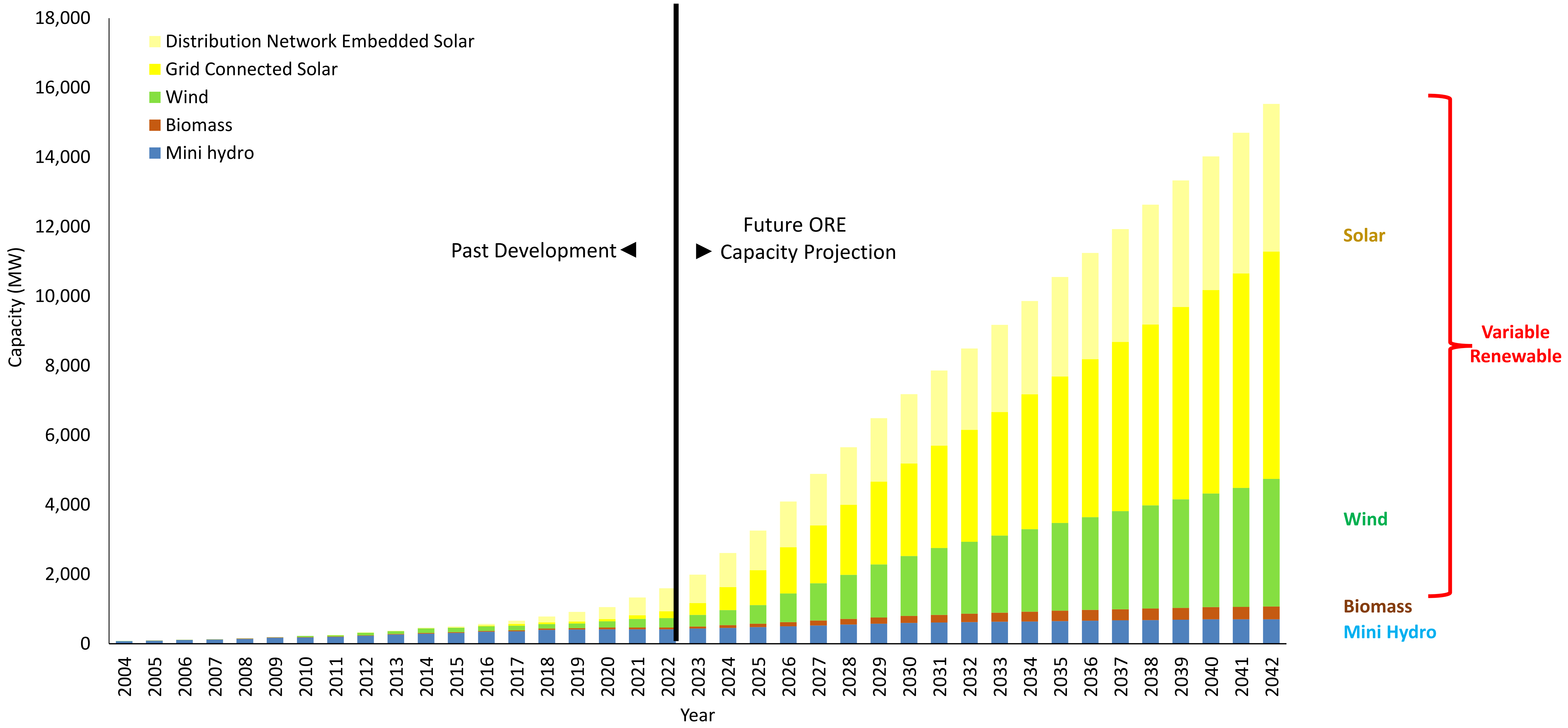
Base Case Plan Additions & Retirements

Year	Gross Capacity Addition (MW)										
	Gas Turbines	IC Engines	Coal	Combined Cycle	Major Hydro	Battery Storage	Pumped Hydro	Short Term	ORE	Existing Plant Retirements	Battery Storage Retirements
2022					155				309		
2023				240 (GT)				320	407		
2024	130			350 (ST+GT)	31	20		(200)	623	(130)	
2025				110 (ST)		100			650	(255)	
2026		200				180		(120)	835		
2027	100					200			795		
2028						350			775	(10)	
2029						150	350		835		
2030						125	350		711	(31)	
2031						125	350		692	(12)	
2032						125	350		660	(385)	
2033						150			694	(14)	
2034	100					200			737	(347)	(20)
2035	100	250				245			705	(25)	(100)
2036	200					380			730	(40)	(180)
2037	200					400			775	(85)	(200)
2038		200				550			785	(85)	(250)
2039	200					350			820	(120)	(150)
2040		200				340			793	(413)	(125)
2041	100			400		340			958	(278)	(125)
2042						340			958	(264)	(125)
Total	**1,130**	**850**	**0**	**1,100**	**31**	**4,670**	**1,400**	**0**	**14,938**	**(2,494)**	**(1,150)**

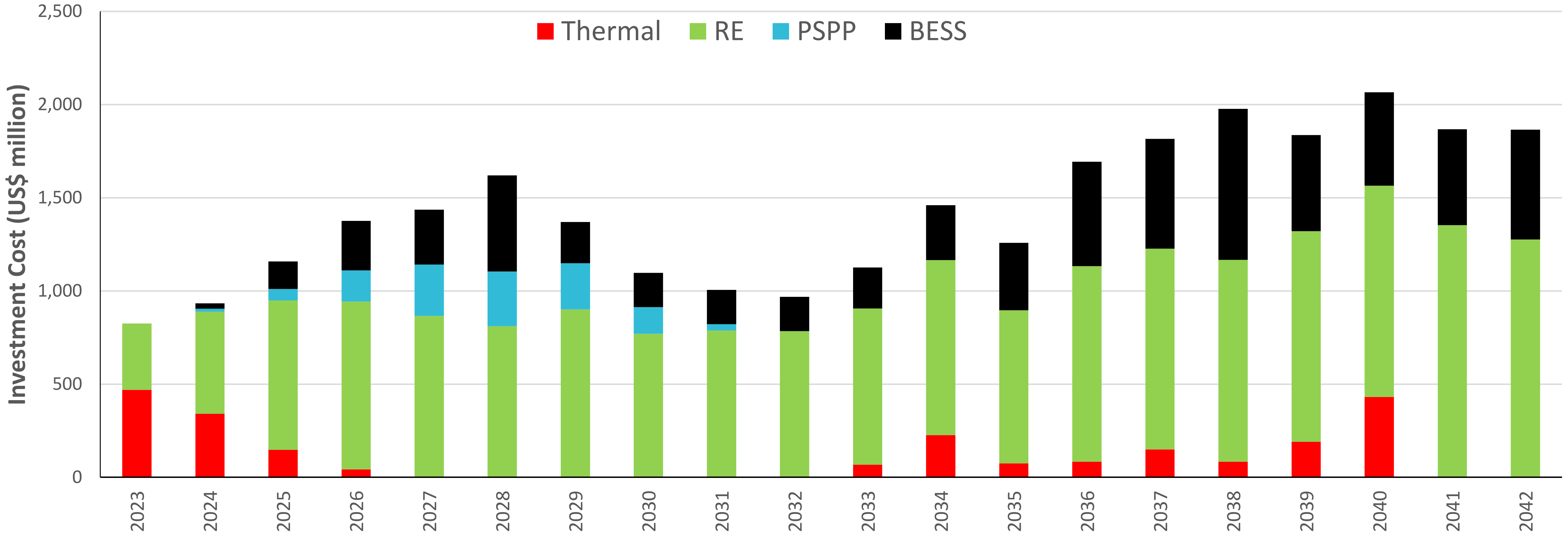
Renewable Energy Development Annual Additions (in MW)

Type	Major Hydro	Mini Hydro	Biomass	Wind	Distribution Network Embedded Solar	Grid Connected Partially Facilitated Solar	Grid Connected Fully Facilitated Solar (park)	Total Solar
Present Cumulative Capacity (2021)	1383	415	50	248	515	100	-	615
2022	155	20	10	-	160	94	-	254
2023	-	20	20	25	160	147	-	307
2024	31	20	20	60	160	223	100	483
2025	-	25	20	200	165	80	260	505
2026	-	25	20	290	170	70	260	500
2027	-	25	20	250	170	50	280	500
2028	-	25	20	200	170	40	310	520
2029	-	25	20	250	170	20	350	540
2030	-	10	20	200	170	30	250	450
2031	-	10	20	200	170	30	250	450
2032	-	10	20	150	170	30	250	450
2033	-	10	20	150	170	30	300	500
2034	-	10	20	150	180	30	300	510
2035	-	10	10	150	180	30	300	510
2036	-	10	10	150	190	30	300	520
2037	-	10	10	150	190	30	300	520
2038	-	10	10	150	200	30	300	530
2039	-	10	10	150	200	30	300	530
2040	-	-	10	150	200	20	300	520
2041	-	-	10	150	200	20	300	520
2042	-	-	10	150	200	20	300	520

Renewable Energy Development – Past & Future (Excluding Major Hydro)

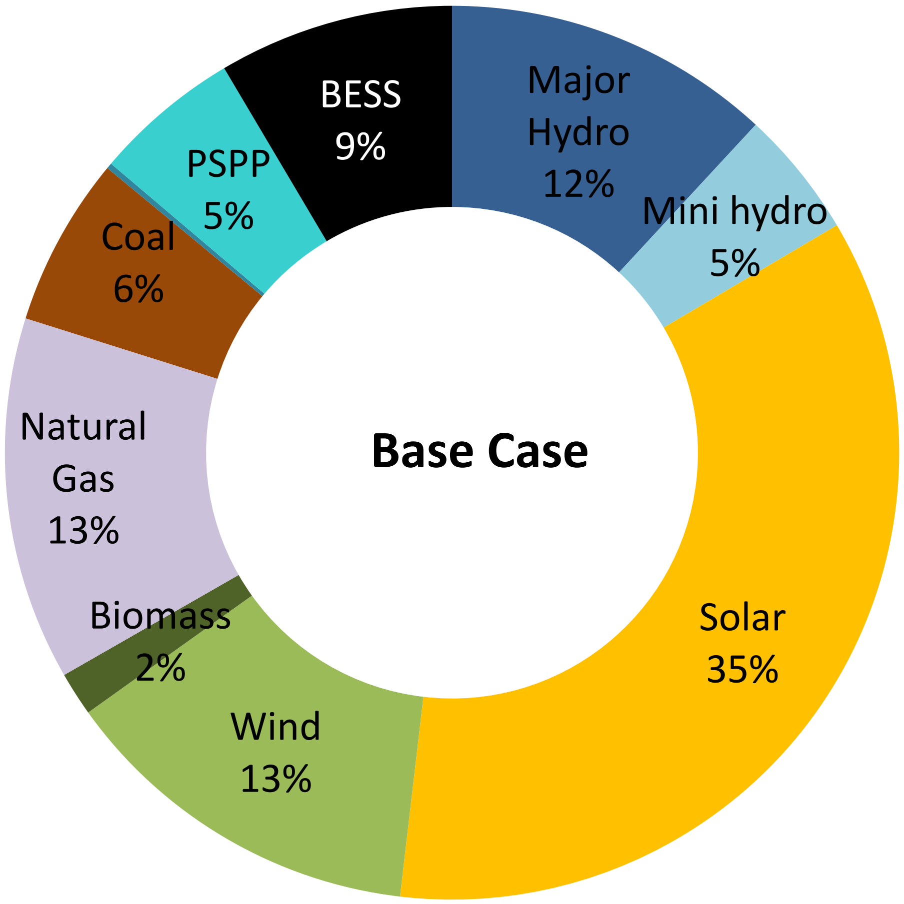


Base Case Plan – Annual Investment Requirement

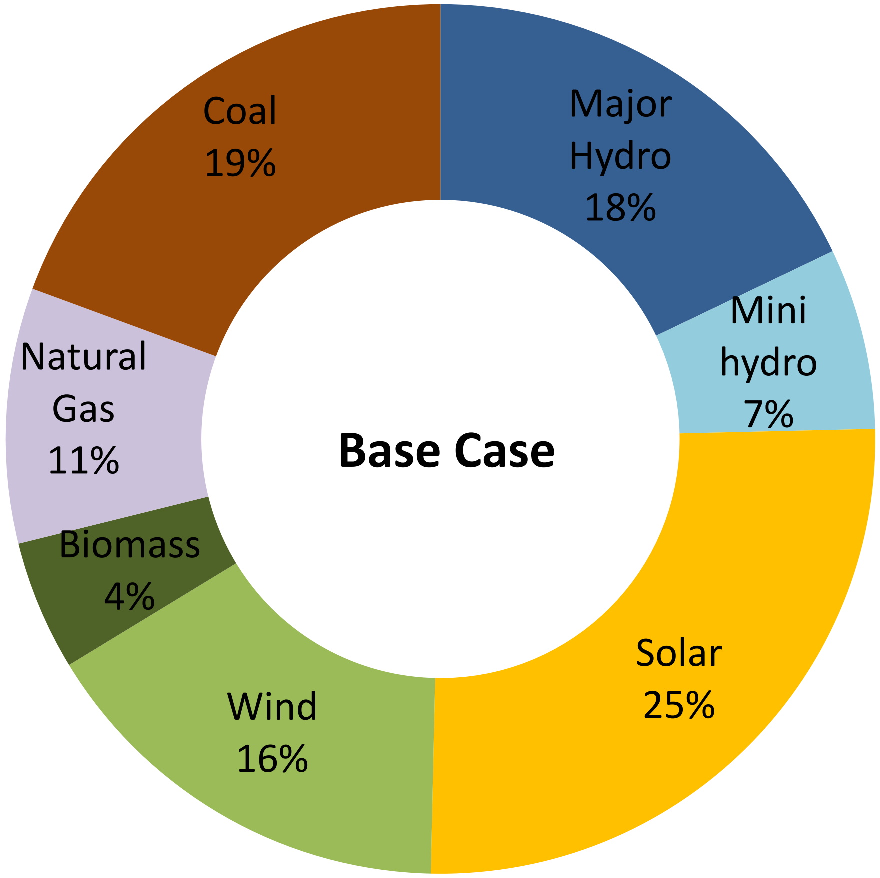


	Thermal	Renewables	Storage	Total
Average annual investment requirement for 2023-2030	**USD 125 million**	**USD 744 million**	**USD 358 million**	**USD 1,226 million**
Average annual investment requirement for 2031-2042	**USD 109 million**	**USD 1,022 million**	**USD 446 million**	**USD 1,578 million**
Average annual investment requirement for total horizon	**USD 116 million**	**USD 911 million**	**USD 411 million**	**USD 1,438 million**

Capacity Mix and Energy Mix (2030)

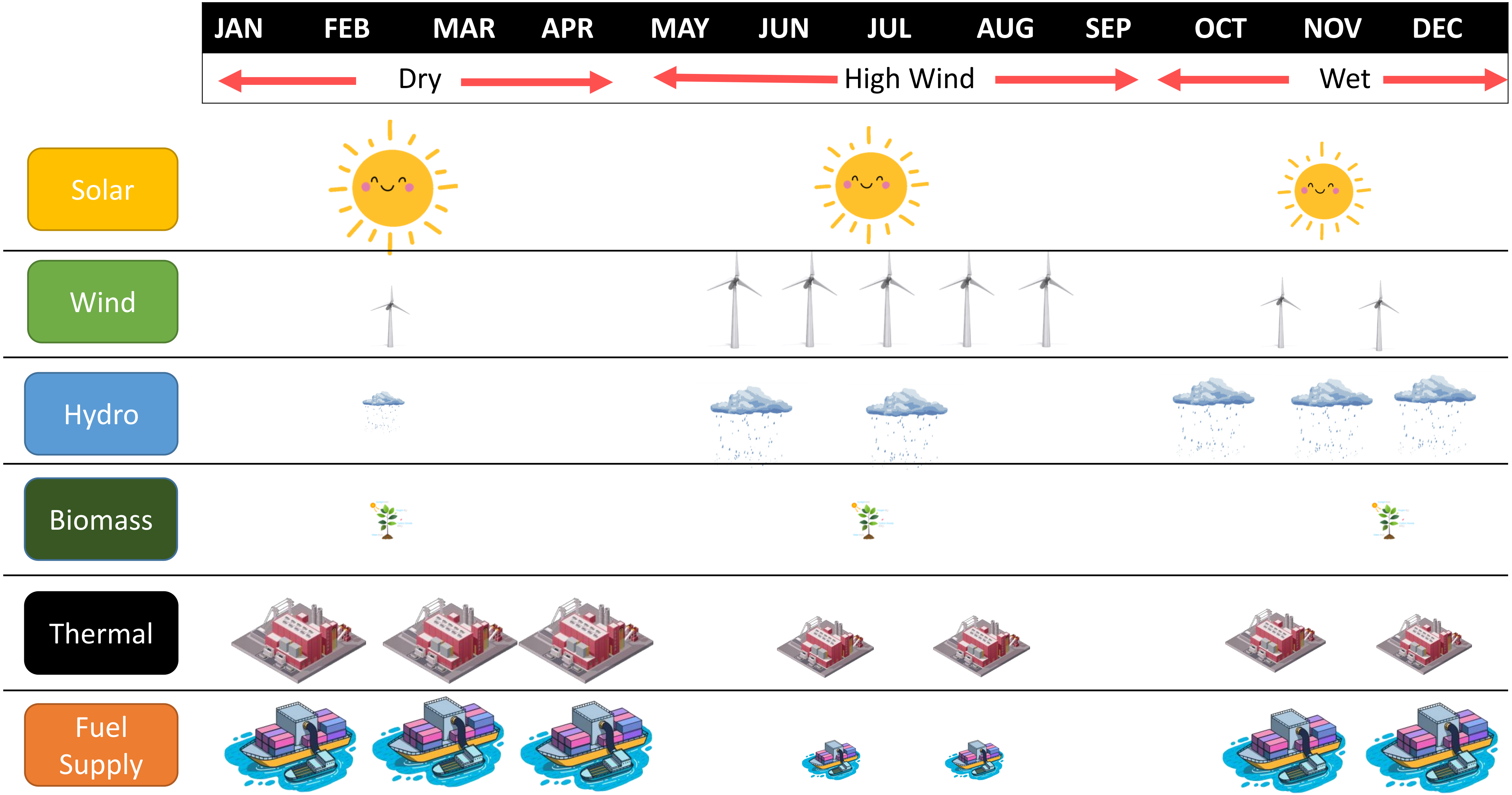


Capacity Mix

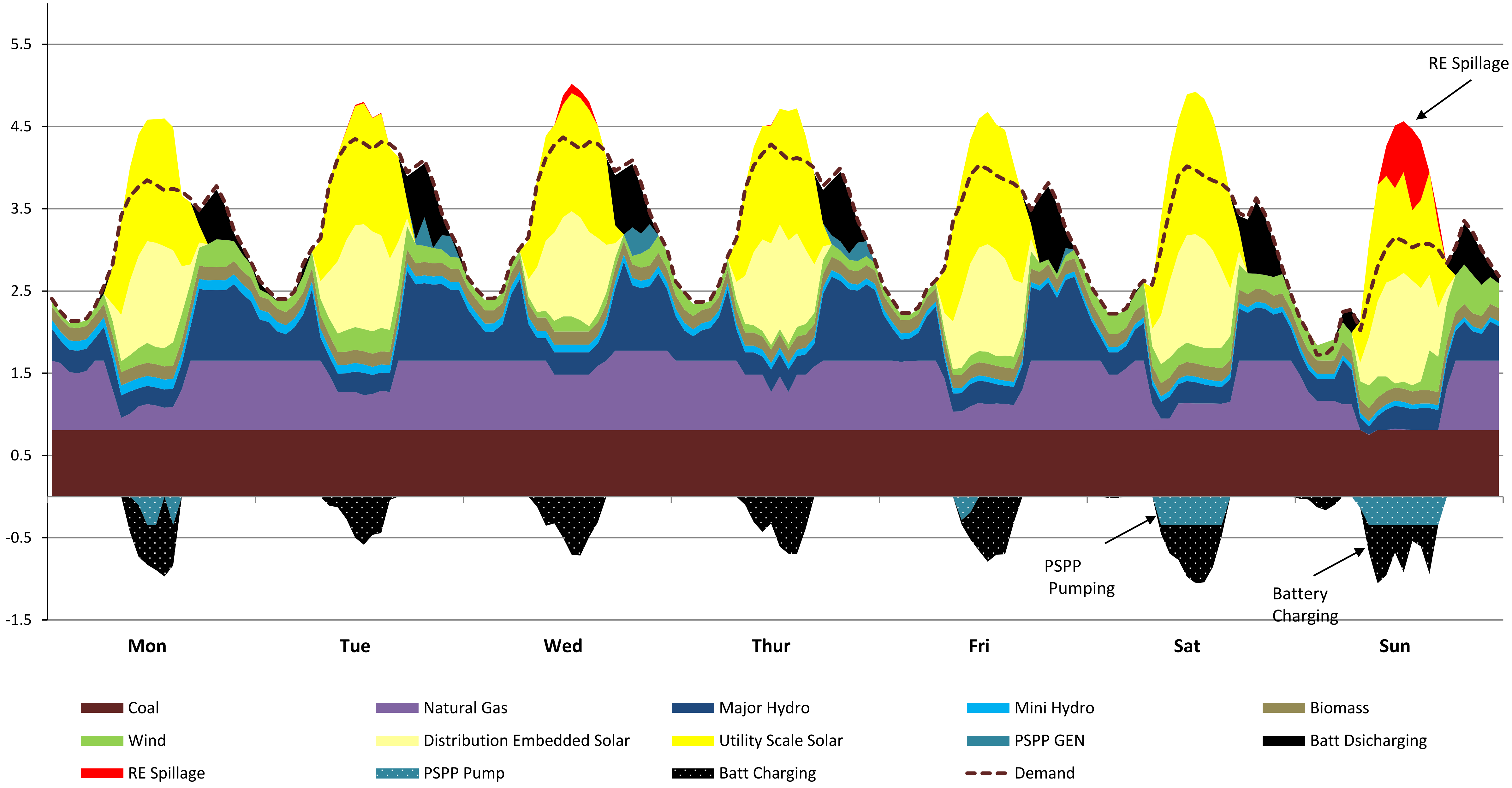


Energy Mix

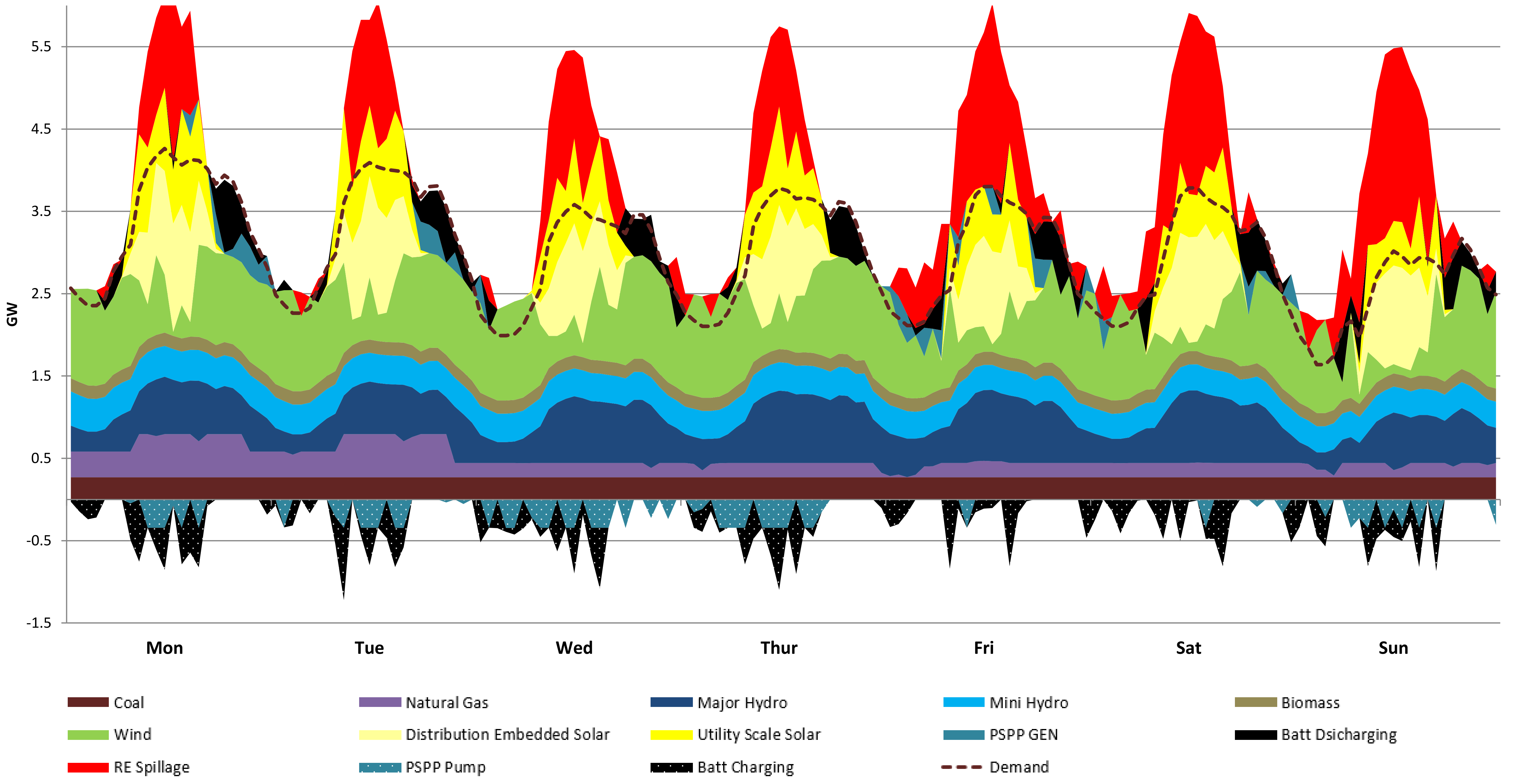
Seasonality with Source of Generation



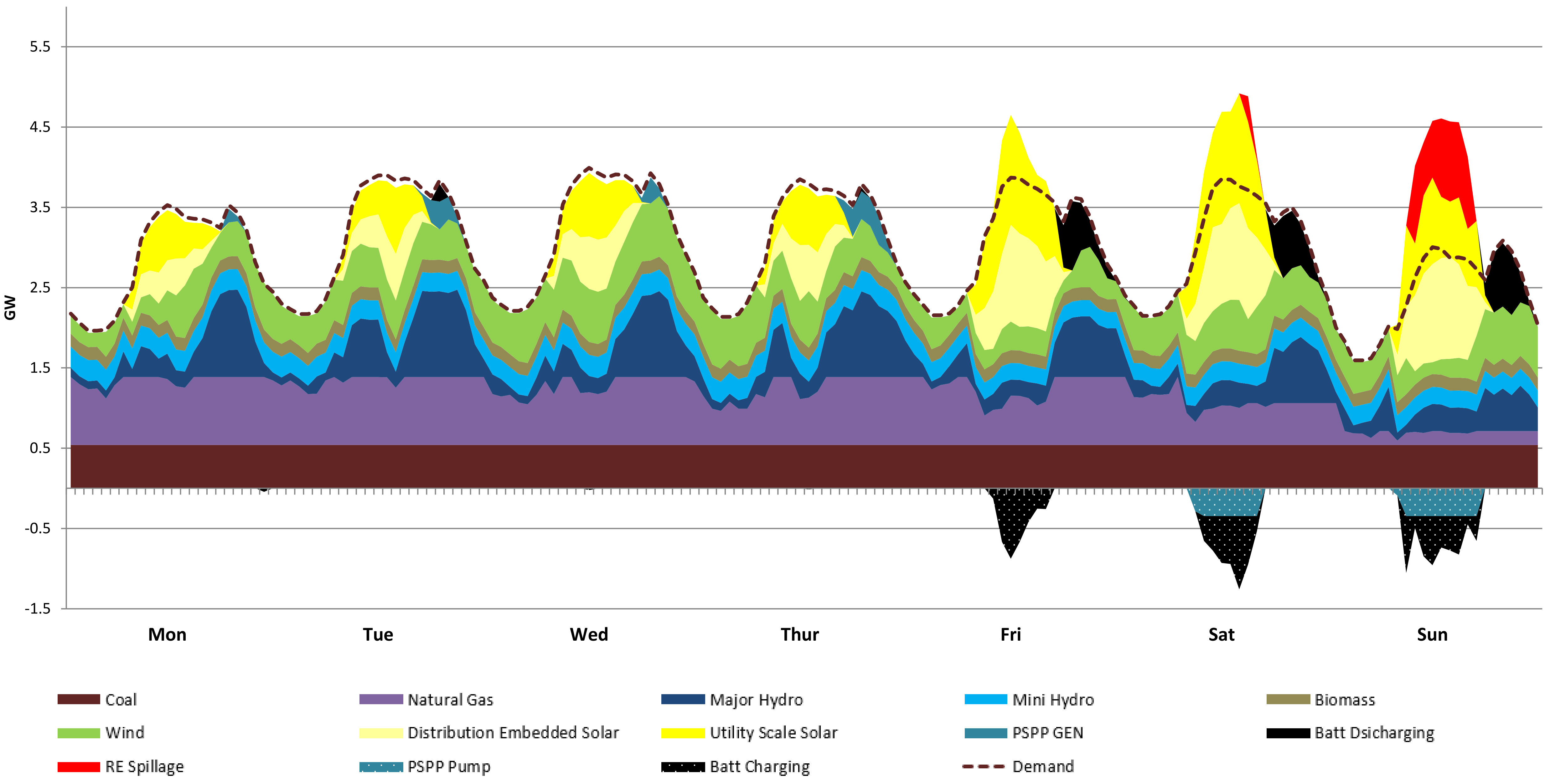
Typical Weekly Load Curve (Mon-Sun) - Dry Season 2030



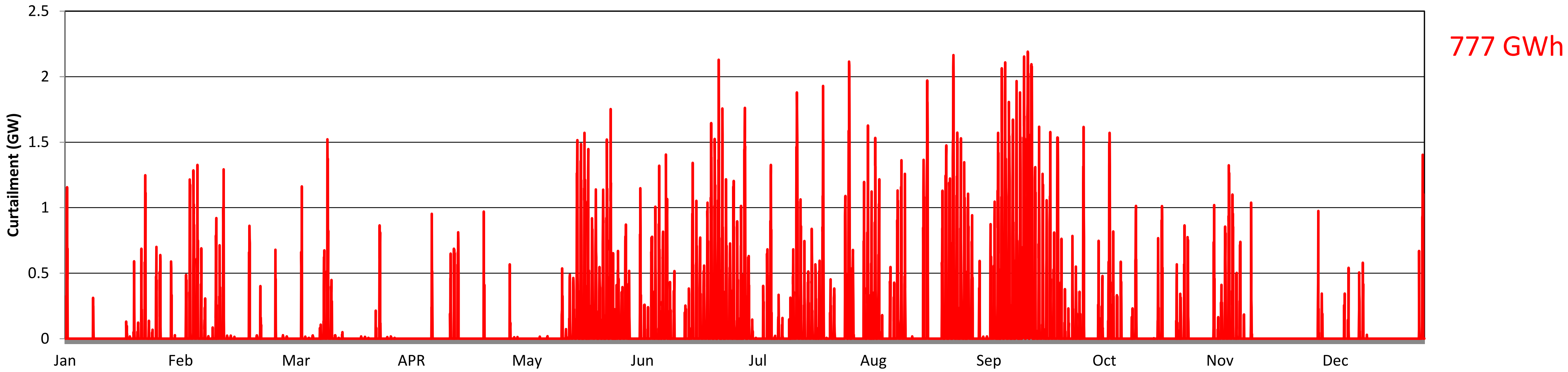
Typical Weekly Load Curve (Mon-Sun) - High Wind Season 2030



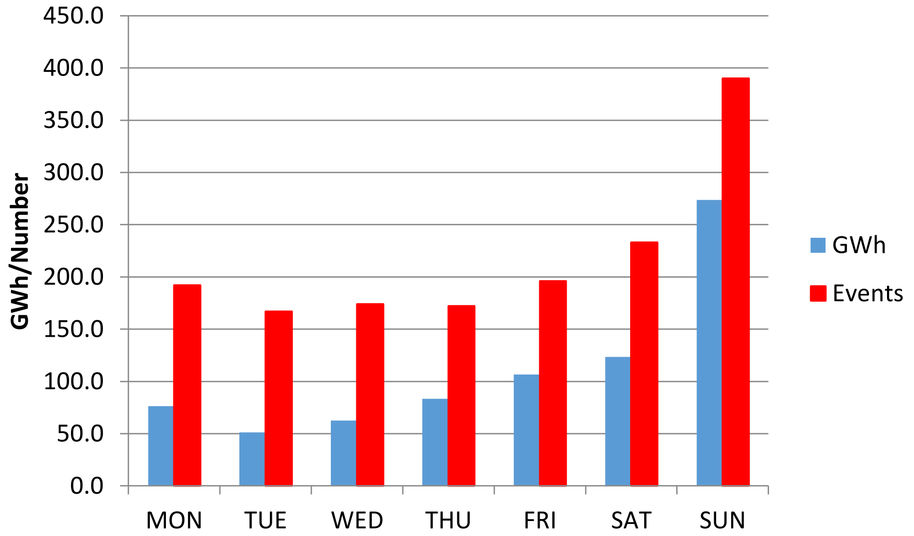
Typical Weekly Load Curve (Mon-Sun) - Wet Season 2030



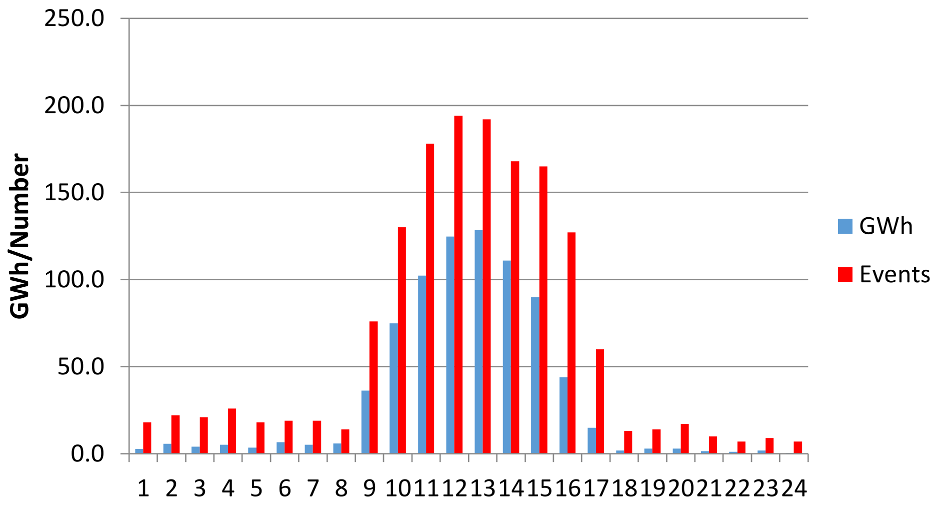
Renewable Curtailment for Year 2030



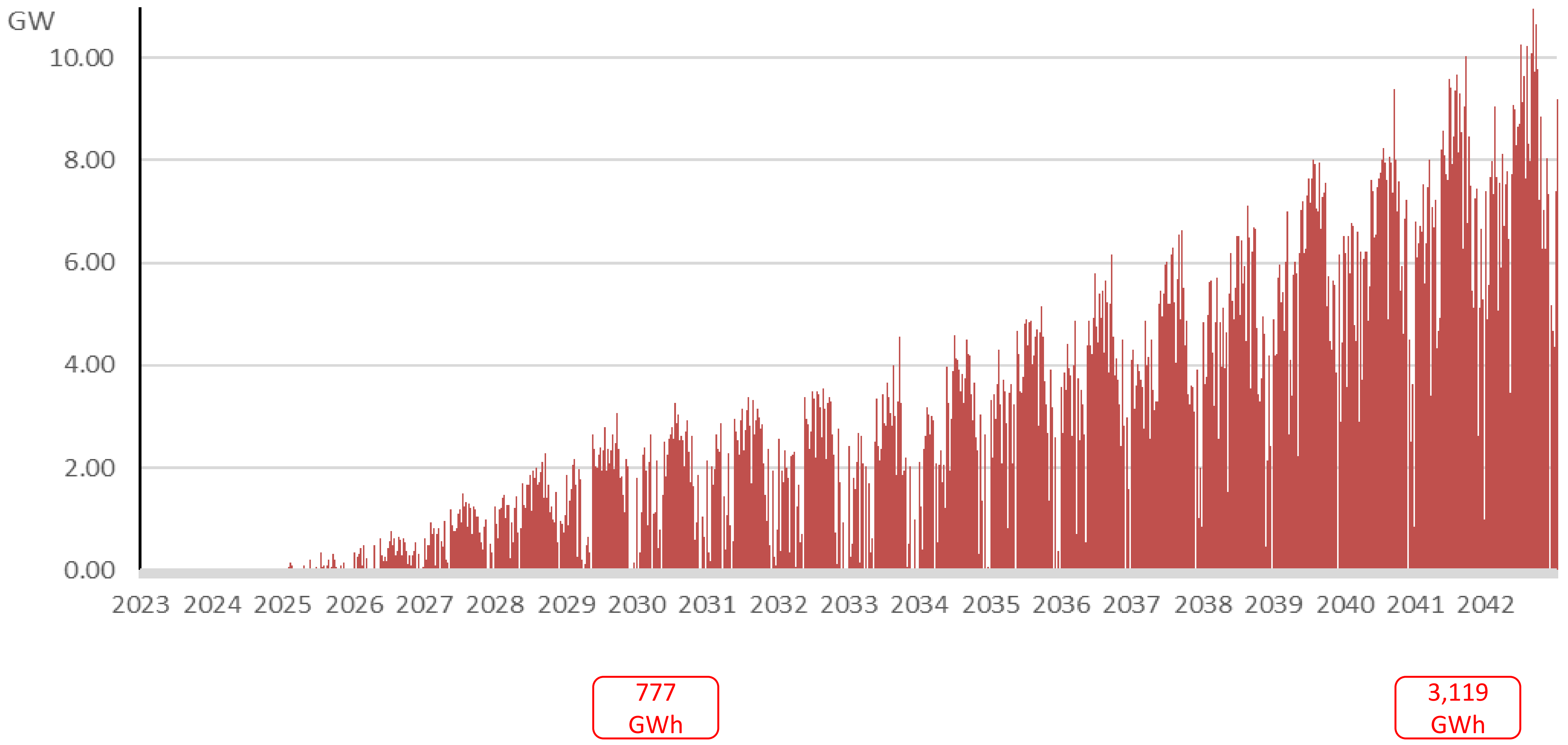
Distribution of RE Curtailments among days of the week



Distribution of RE Curtailments among hours of the day



Renewable Energy Curtailments (2023-2042)

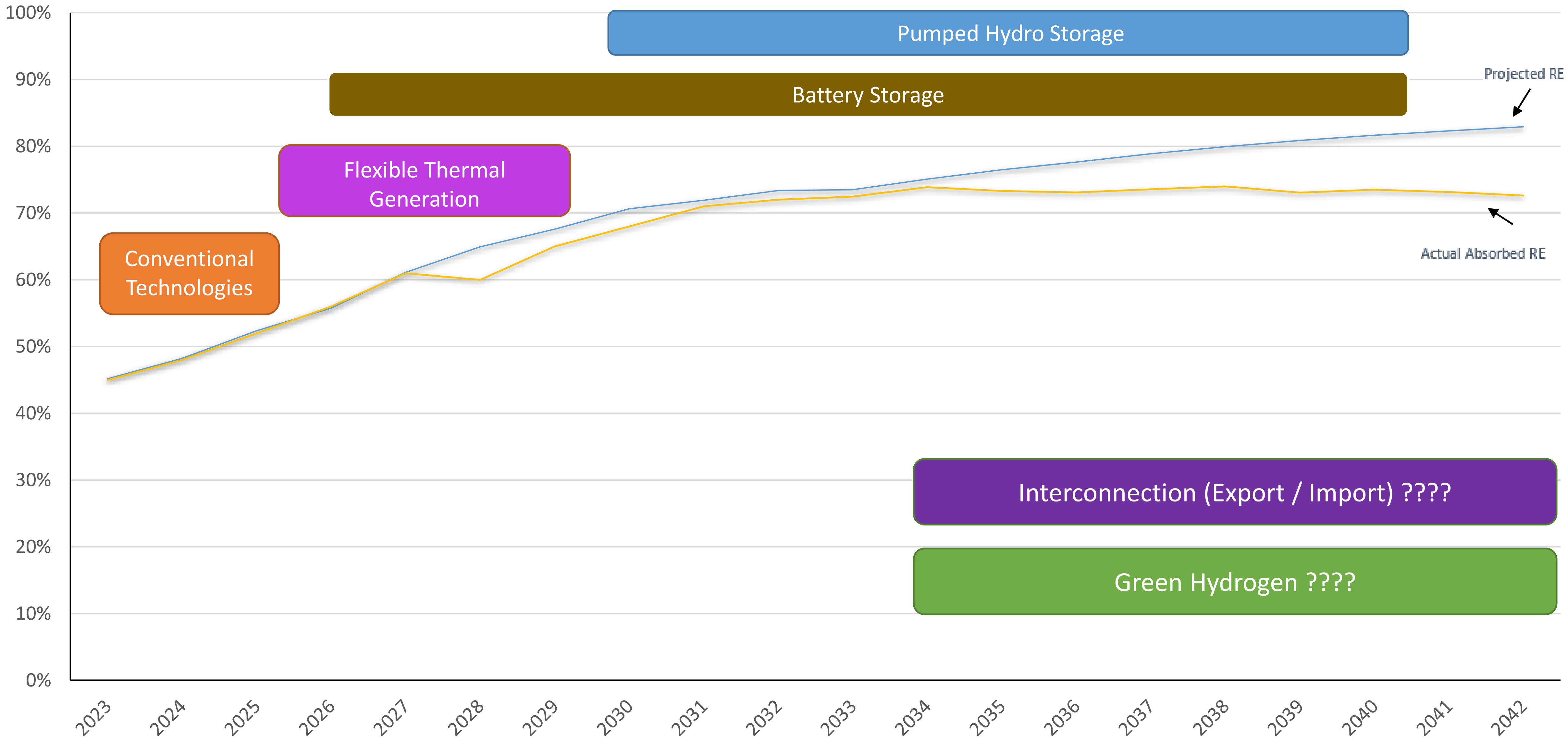


Key Scenarios - Results

		Policy Constrained Scenarios				Policy Unconstrained Scenarios		
		1. 70% RE by 2030 + No Coal (New Policy)	2. 70% RE by 2030 Increasing RE Share beyond 2030 + No Coal	3. 70% RE by 2030 HVDC Interconnection + No Coal	4. 70% RE by 2030 Nuclear 2040 + No Coal	5. 50% RE by 2030 With Coal Option Open Until 2030	6. 60% RE by 2030 With Coal Option Open Until 2030	7. 60% RE by 2030 + No Coal
Plant Additions 2023-2042 (MW)	Major Hydro	31	Need Additional Interventions	31	31	31	31	31
	ORE	13,795		13,795	13,795	10,097	11,608	11,065
	NG CCY	1,100		1,100	1,100	1,110	1,100	1,100
	NG GT/ ICE	1,930		1,580	1,880	4,030	3,820	4,130
	Coal	-		-	-	540	270	-
	Nuclear	-		-	600	-	-	-
	HVDC	-		500	-	-	-	-
	Battery	3,365		3,365	3,365	350	400	400
	PSPP	1,400		1,400	1,400	700	1,050	1,050
Present Value US$ Million	Investment	10,119	↑	10,400	10,220	7,589	7,946	7,498
	Operational	8,753	↓	8,483	8,766	10,203	9,561	10,357
	Total	18,872	↑	18,883	18,986	17,792	17,507	17,855

*Scenarios were developed considering fuel costs used for planning studies and imposing limits on instantaneous asynchronous penetration.

Renewable Share Growth and Interventions to achieve Carbon Neutrality



THANK YOU !!!

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1st Technical Seminar

Supply-demand Balancing Operation Considering VRE Output Forecast

15th December, 2020

Chubu Electric Power Co., Inc.
Nippon Koei Co., Ltd.

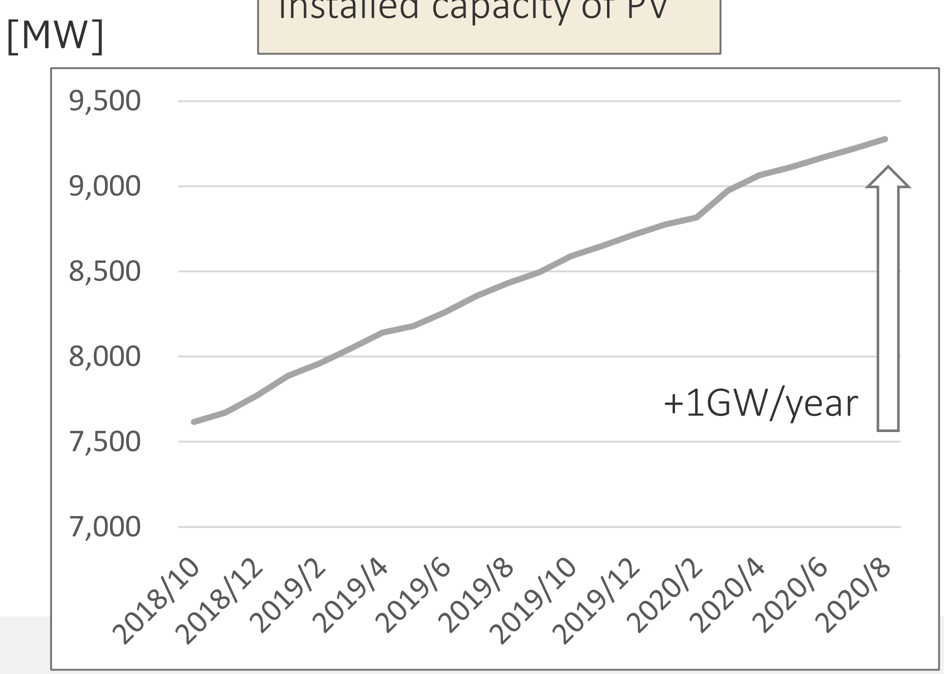
Introduction &
Operation Overview

- Supply-demand balancing operation is being more difficult due to a large amount of PV installation in Chubu area.

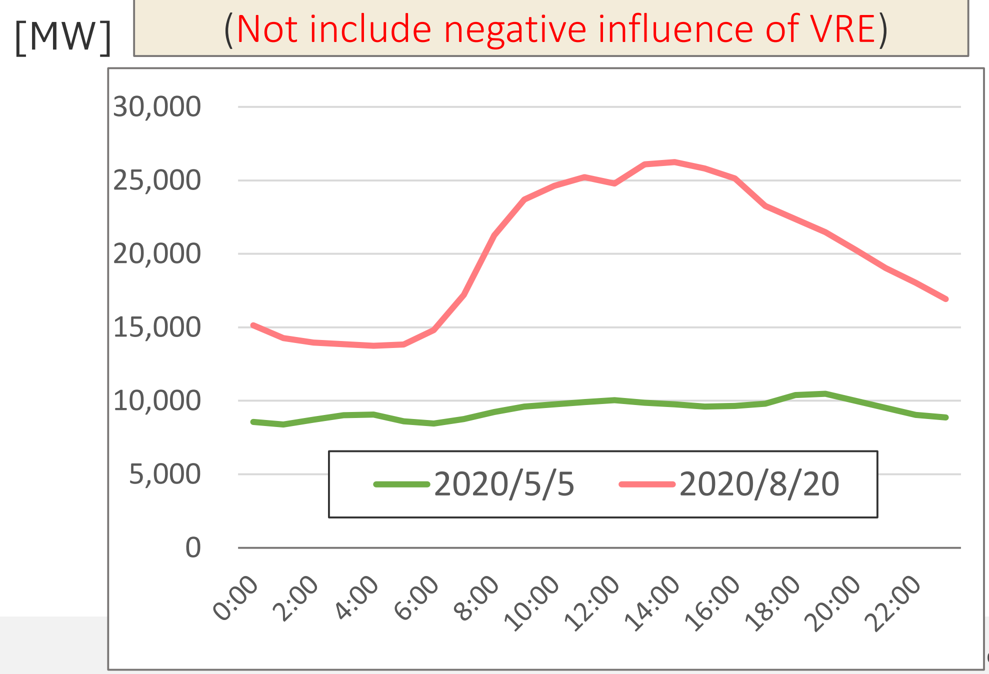
- In such a situation, **VRE output forecast is being more important and flexibility of PSPP or battery, too**.

- In this material, we focus on the day ahead operation in Chubu area, because CEB is planning to receive day ahead forecast data of VRE output from JWA in this project.

Installed capacity of PV



"Real" Demand Curve in Chubu Area
(Not include negative influence of VRE)



Timeline of day ahead operation

- Central Load Dispatching Center(CLDC) of CEPCO receives updated weather forecast data per 3 hours. (▽ in the table below)
- <u>The highlighted contents are the key operations for supply-demand balancing.</u>

	D-1 11:00 ▽	D-1 14:00 ▽	D-1 17:00 ▽
• Area demand prediction • VRE output forecast	• Area demand prediction • VRE output forecast • Plan submission of non–dispatchable (IPP units etc) power plant from generation entities	• Area demand prediction • VRE output forecast	• Area demand prediction • VRE output forecast
		• Considering forecast error of VRE output	• Same as on the left Content No.1
		• PSPP scheduling and reserve margin (for generation) considering reservoir level	• Same as on the left Content No.2
		• Unit scheduling of thermal power plant(TPP) • Instruction to TPP	• Change instruction Content No.3

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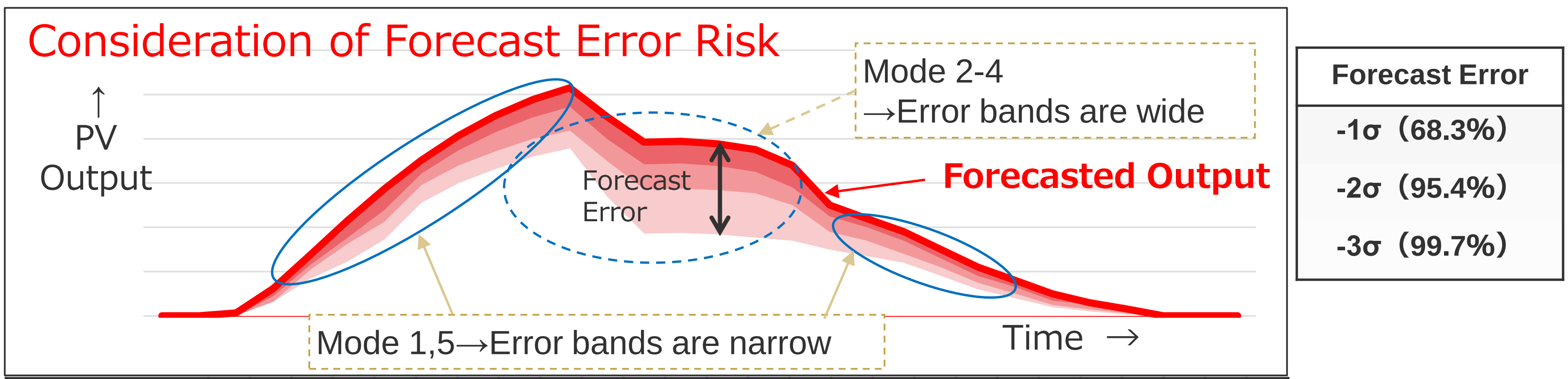
02 Operation for VRE output reduction

No.1 Considering forecast error of VRE output

- Solar forecast error is considered in day ahead operation in CLDC.
- The **"modes"** are classified by the "clearness index" " based on weather forecast.
- In the case of Mode 1 and 5, the downside forecast error is relatively small, meanwhile greater in the case of Mode 2-4.

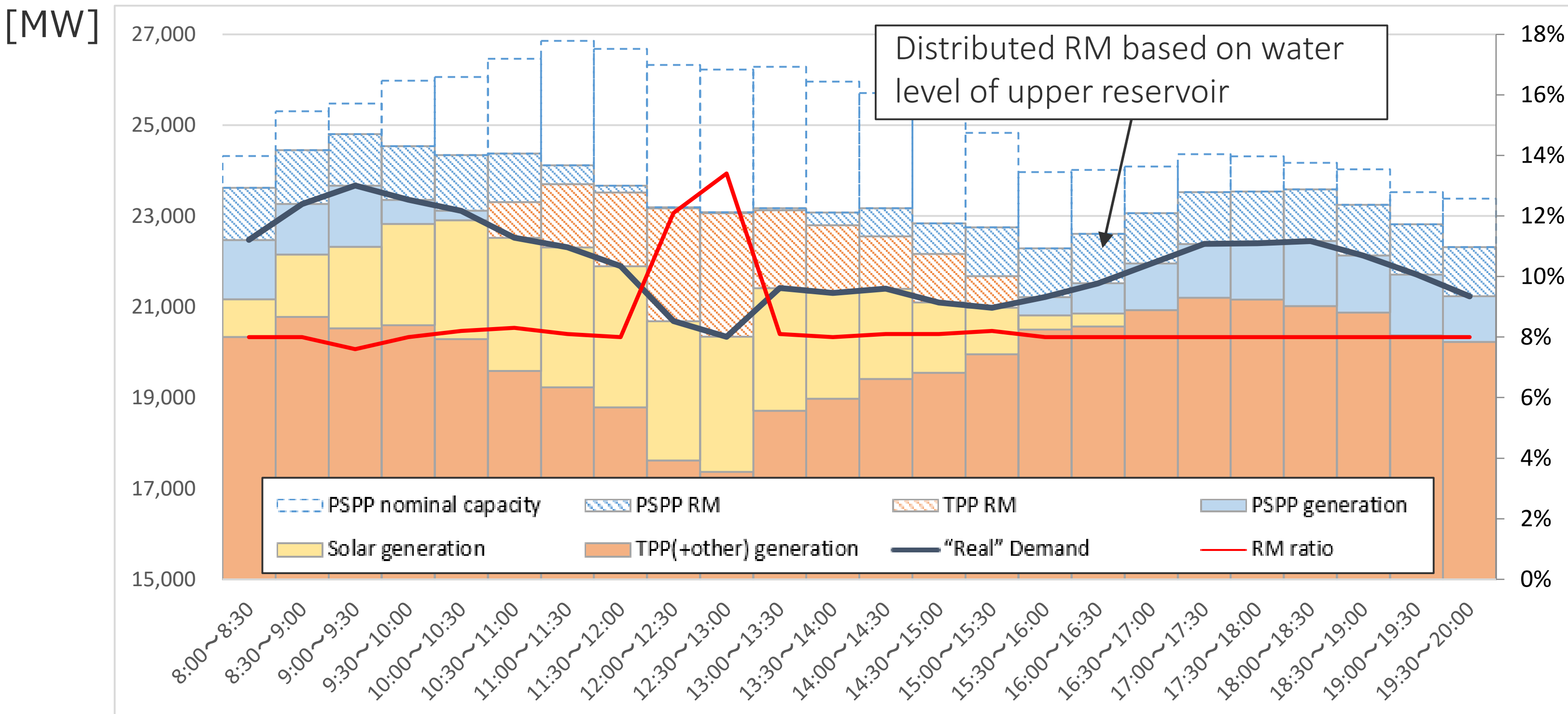
Mode	1	2	3	4	5
Clearness Index	1～0.71	0.71～0.62	0.62～0.43	0.43～0.21	0.21～0
Weather	Clear Sunny	Sunny	Little cloudy	Cloudy	Rainy



Mode	5	4	1	1	1	1	1	1	2	3	3	3	3	3	4	5	5	5	5	5	5	5	5	5	5	-

No.2 PSPP RM distributed based on reservoir level

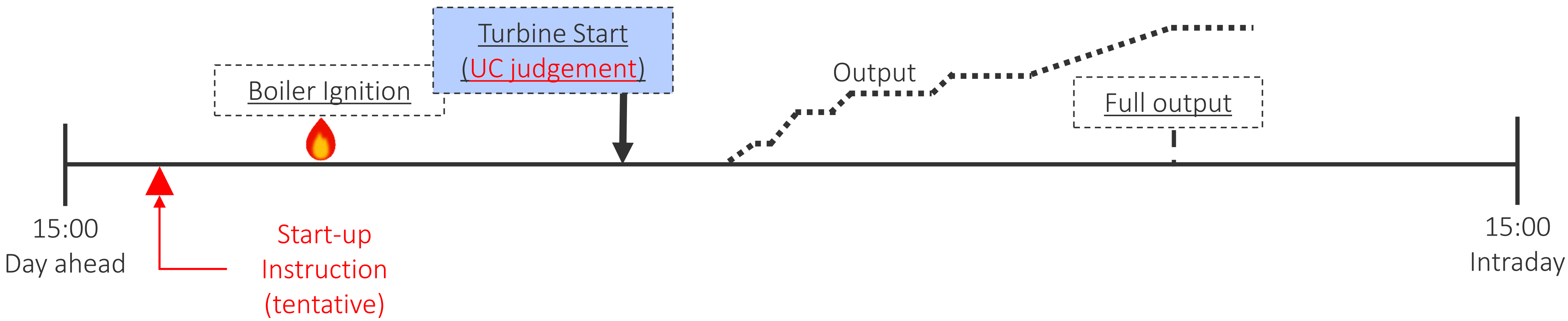
- There is kWh constraint of upper reservoir of PSPPs, therefore they do not keep their nominal capacity all time.
- CLDC evaluates **their RM for generation** by distributing kWh based on upper reservoir water level <u>to equalize the ratio of “RM / predicted demand” each time</u>.



No.3 Tentative Instruction to TPP

To deal with the forecast error, **CLDC uses "tentative start-up instruction" to TPPs that enables CLDC to extend the final judgement of unit commitment** until their turbine start.

Schedule of TPPs Start-up (Cold Start-up)

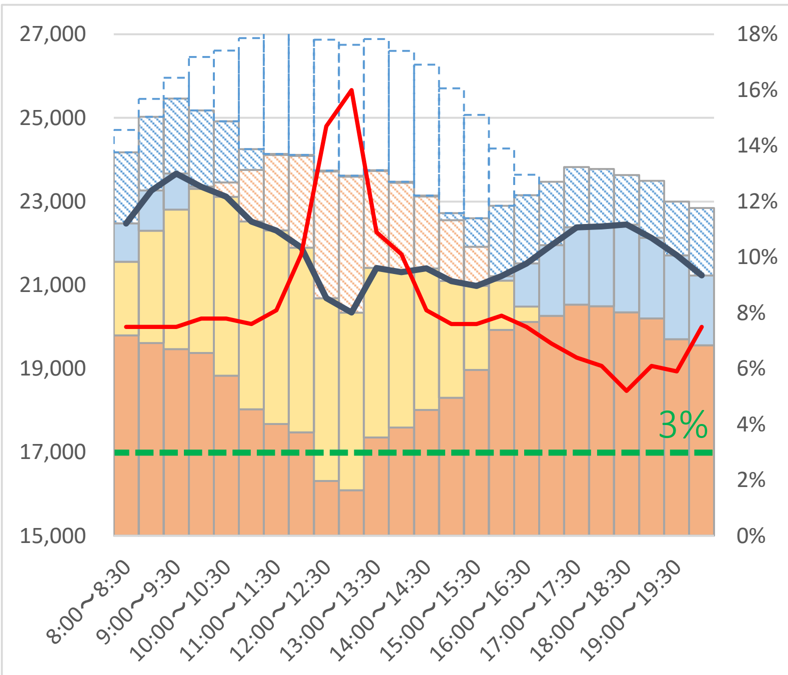


Case study (Considering PV forecast error)

- 3% indicated with green lines is the criterion of the least RM ratio of CEPCO.
- RM goes down below 3% when the -3σ forecast error occurs.

D-1 17:00 (PV forecast: normal)
Original TPP scheduling

[MW]

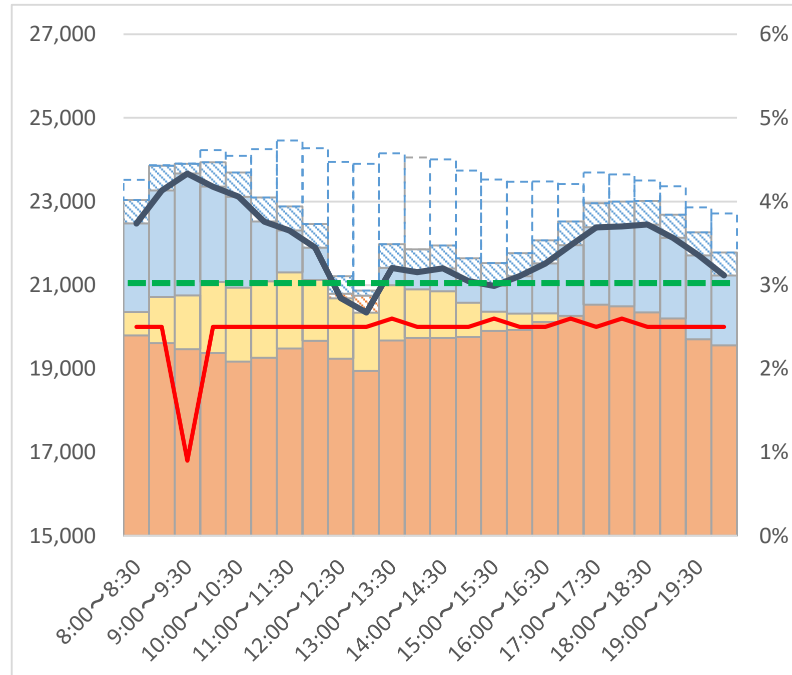


(No.1)
Considering forecast error

(No.2)
PSPP RM re-distribution

D-1 17:00 (PV forecast : -3σ)
Original TPP scheduling

[MW]



PSPP nominal capacity | PSPP RM | TPP RM | PSPP generation
Solar generation | TPP(+other) generation | "Real" Demand | RM ratio

Case study (Tentative start-up instruction on TPP)

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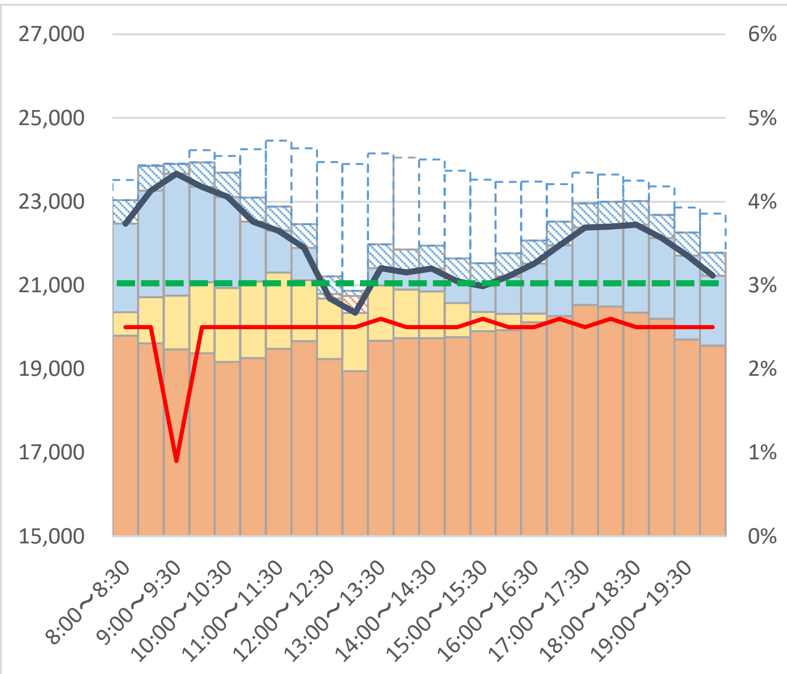
CLDC gives the tentative start-up instruction to an additional 700MW TPP and RM ratio recovers over 3%.

D-1 17:00 (PV forecast : -3σ)
Original TPP scheduling

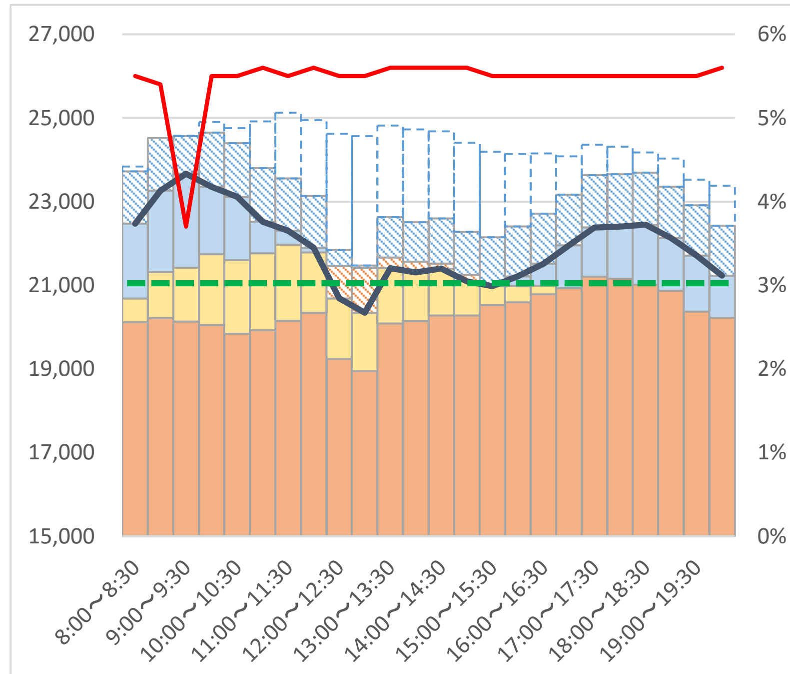
[MW]



(No.3)
Tentative TPP start-up

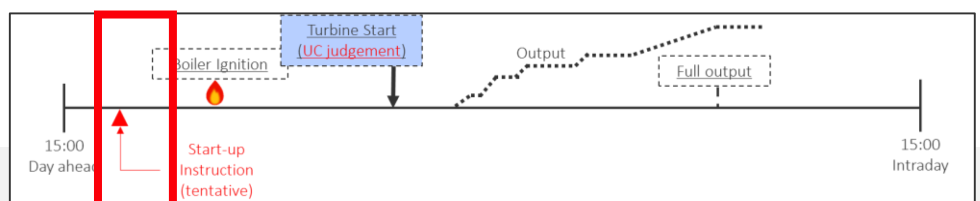
D-1 17:00 (PV forecast : -3σ)
Additional 700MW TPP start-up (tentative)

[MW]



<Schedule of TPPs tentative Start-up>

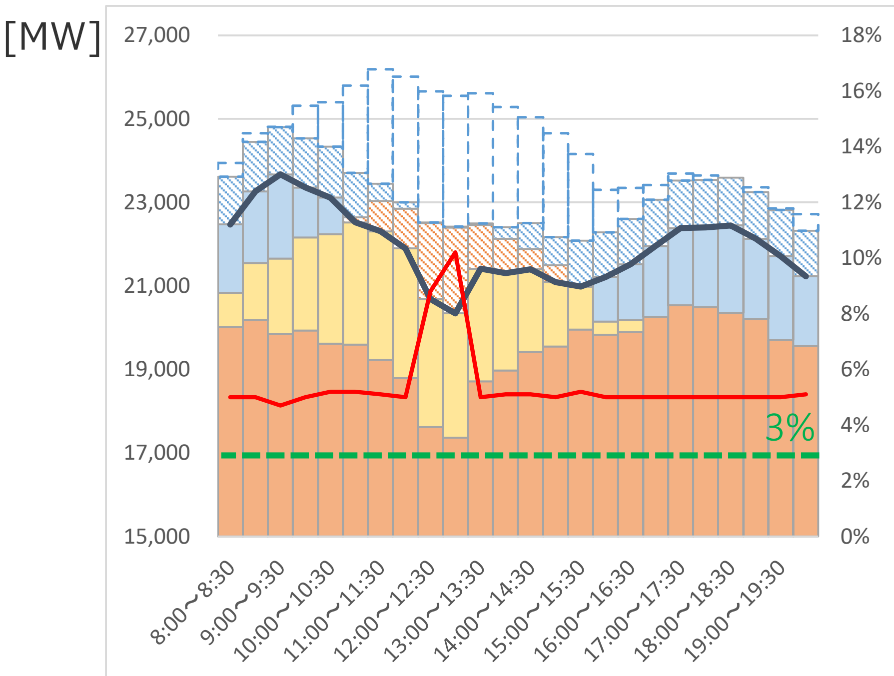
PSPP nominal capacity | PSPP RM | TPP RM | PSPP generation
Solar generation | TPP(+other) generation | "Real" Demand | RM ratio



Case study (Judgment of TPP start-up)

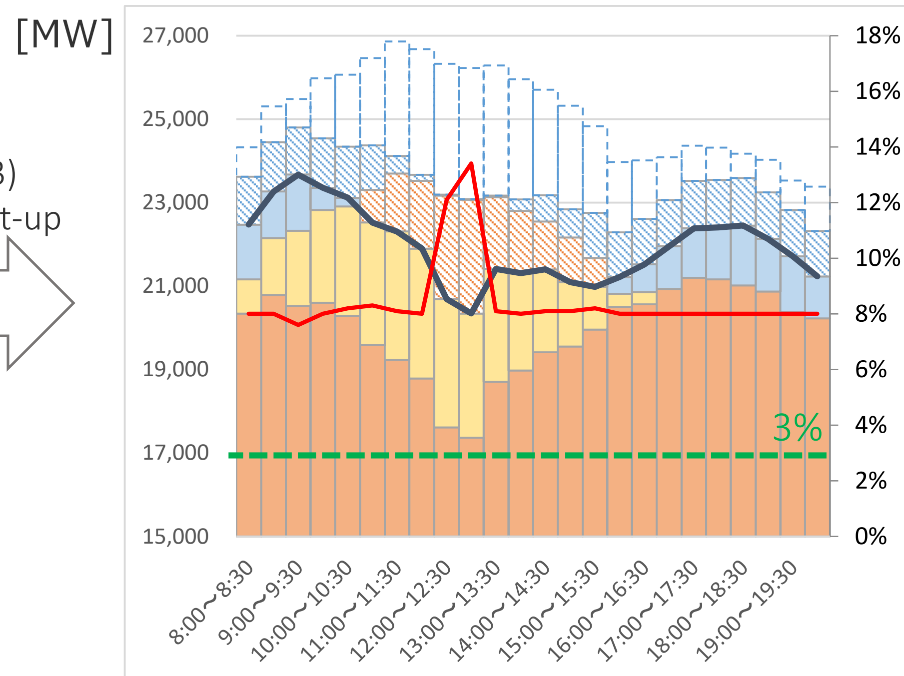
At D-1 23:00, the forecasted PV output reduction from D-1 17:00 is observed and RM becomes close to 3%, then CLDC determines an additional 700MW TPP start-up.

D-1 23:00 (PV forecast : normal)
Original TPP scheduling

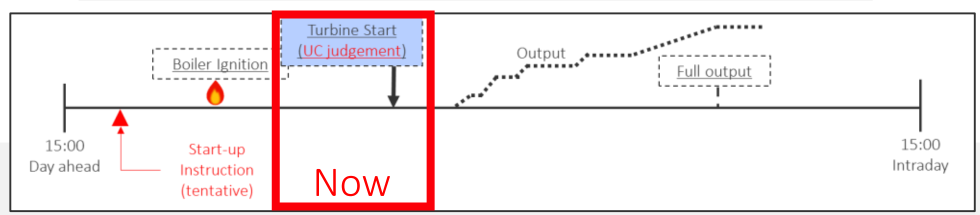


(No.3)
TPP start-up

D-1 23:00 (PV forecast : normal)
Additional 700MW TPP start-up (determined)



<Schedule of TPPs tentative Start-up>



PSPP nominal capacity | PSPP RM | TPP RM | PSPP generation
Solar generation | TPP(+other) generation | "Real" Demand | RM ratio

03 Operation for VRE surplus

How to consider VRE surplus in CEPCO

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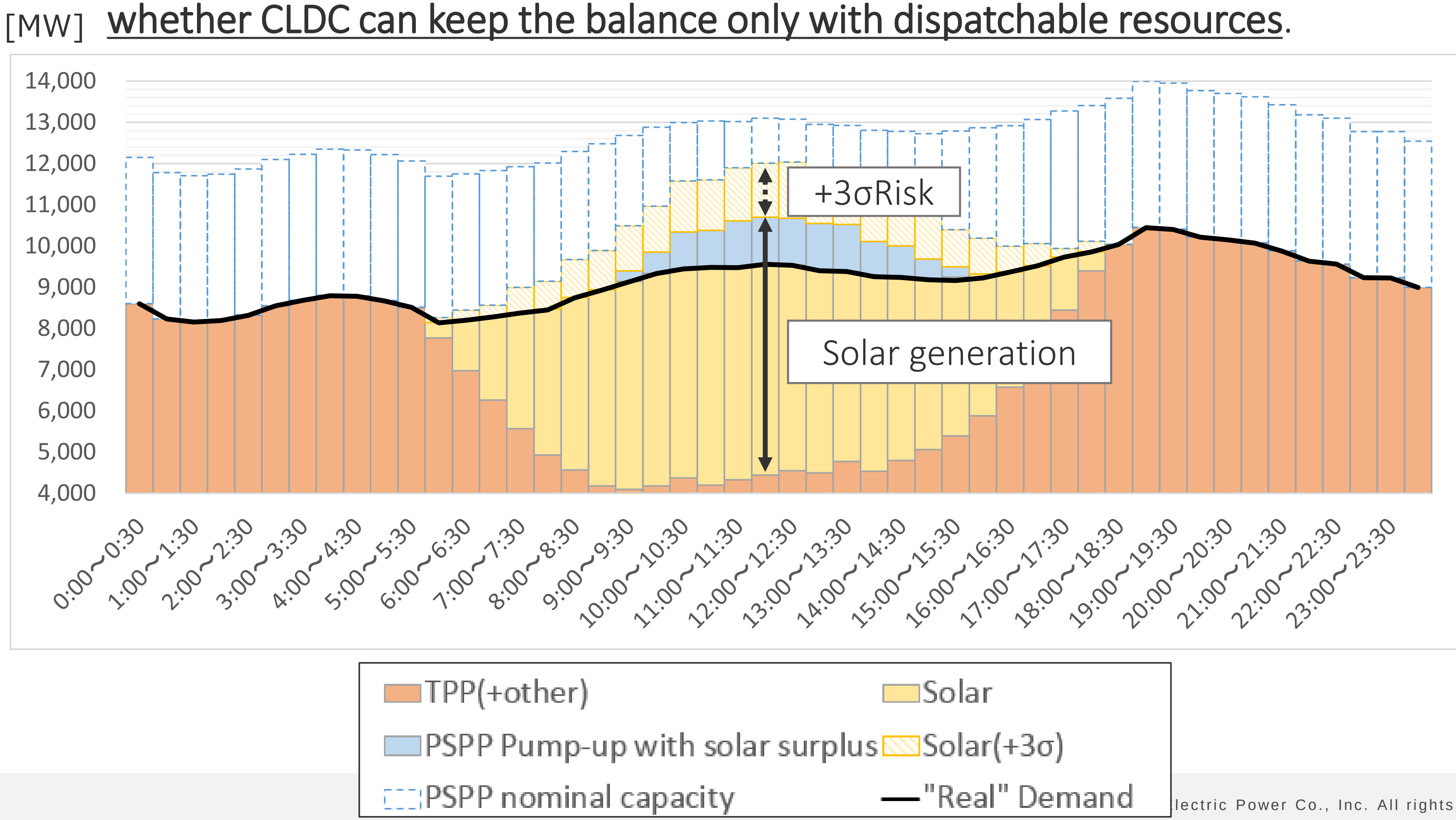
- CLDC pumps lower reservoir water up to keep the supply-demand balance in day time during spring and autumn.
- In the day ahead operation, <u>**CLDC considers +3σ PV forecast error to confirm whether CLDC can keep the balance only with dispatchable resources**</u>.



Operation based on the Rule of "Priority Dispatch"

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- When CLDC can't keep the balance only with dispatchable resources, <u>**CLDC controls non-dispatchable ones etc. based on "Priority Dispatch"**</u>.
- The order of control of the output is determined by the cost of power generation and technical characteristics of the generating system.

The order in which the output is suppressed

① Output control of thermal power and water pumping operations (dispatchable)

② Ditto(Non-dispatchable except for biomass and VRE, day ahead instruction)

③ Export to other regions using interconnected lines(day ahead instruction)

④ Biomass output control(day ahead instruction)

⑤ Solar and wind power control(day ahead instruction)

⑥ Output control of long-term fixed power sources (hydro, nuclear, geothermal)

Source: Agency for Natural Resources and Energy

04 PSPP Utilization Purposes

PSPP Utilization Purposes

Today's content (marked with dashed red boxes: Reserve Margin; Downward Balancing Reserve / VRE Curtailment Reduction)

	Purpose	Note
Generation	**Reserve Margin**	kWh distribution of Reservoir
Generation	**Upward Balancing Reserve**	
Generation	→ Load Frequency Control	Time Range < 5 min (From Stop Mode)
Generation	→ Governor Free Capability	• Time Range < 10 sec (During Running) • Chubu Criterion = 3% × Area Demand
Pump up	→ Keep Frequency in N-1 Contingency by Shedding PSPP	• Time Range ≒ instant (During Running) • Chubu Criterion = Keeping 59.5Hz in N-1 Contingency
Pump up	**Downward Balancing Reserve**	
Pump up	VRE Curtailment Reduction	Time Range > 15 min(From Stop Mode)
Pump up ↓ Generation	**Economical Operation**	Marginal Cost for Pumping up Divided by 70% vs Substituted Marginal Cost by PSPP Generation after Pumping up
Other	**Voltage Control**	Operation of Voltage Control Mode
Other	**Black Start**	—

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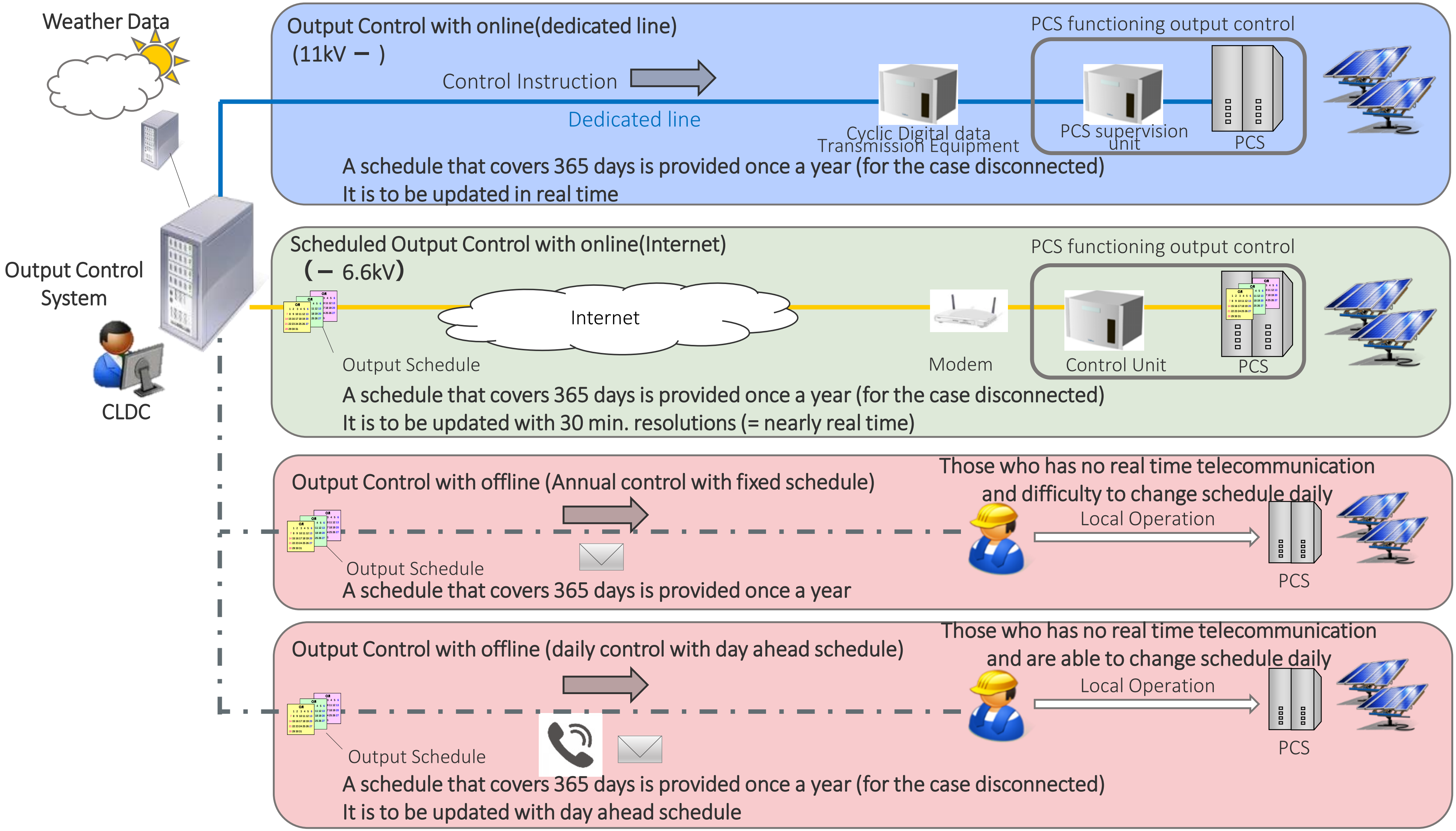
Specification of VRE Control System

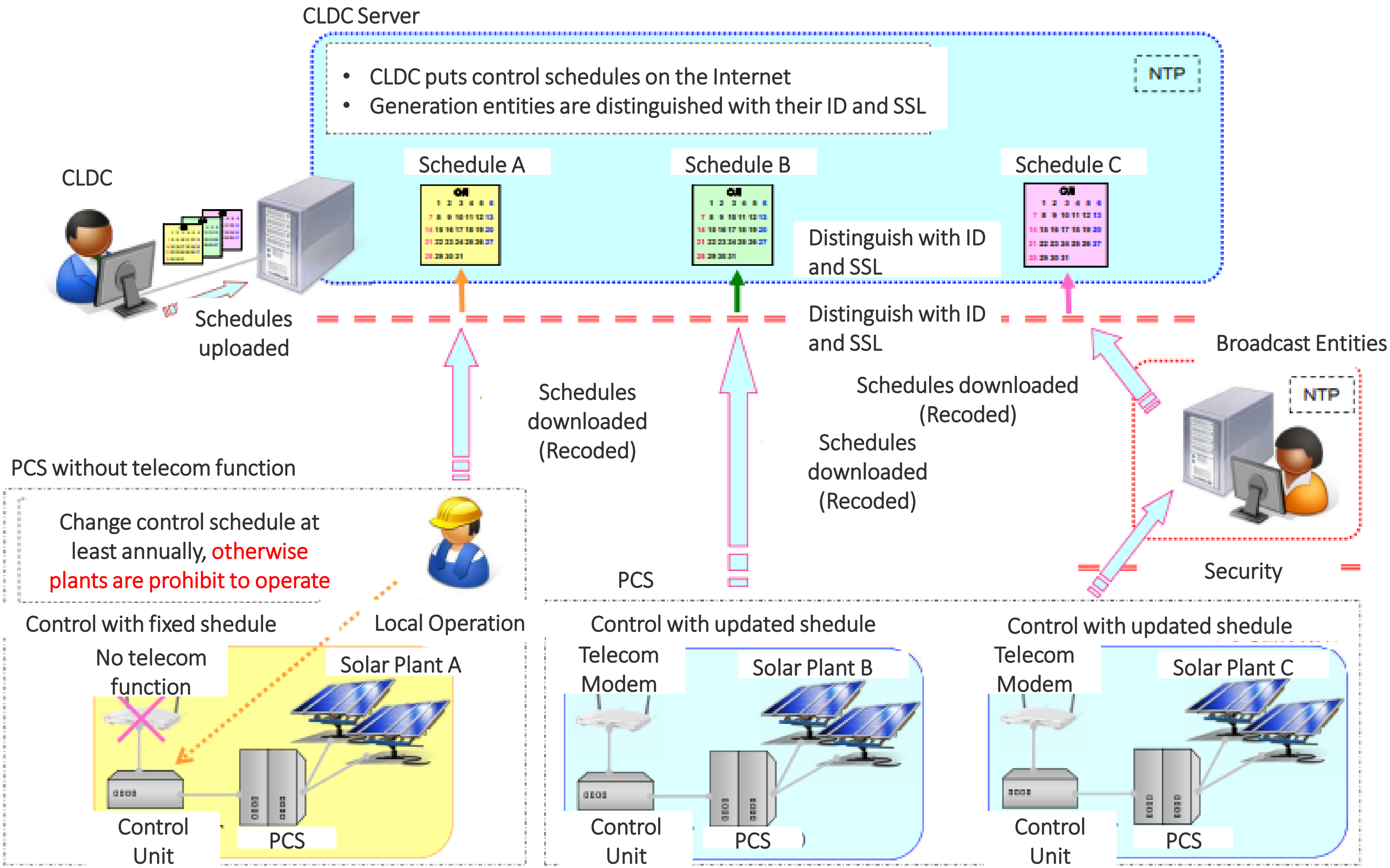
December 24th, 2021

Chubu Electric Power Co., Inc.
Nippon Koei Co., Ltd.

Specification of VRE Control System



Specification of VRE Control System



How to operate with 30 min. resolutions schedule

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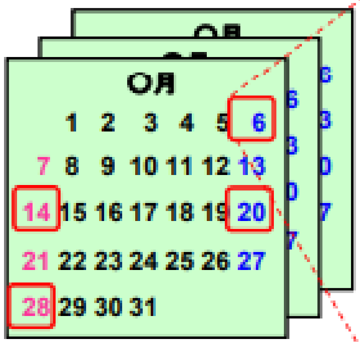
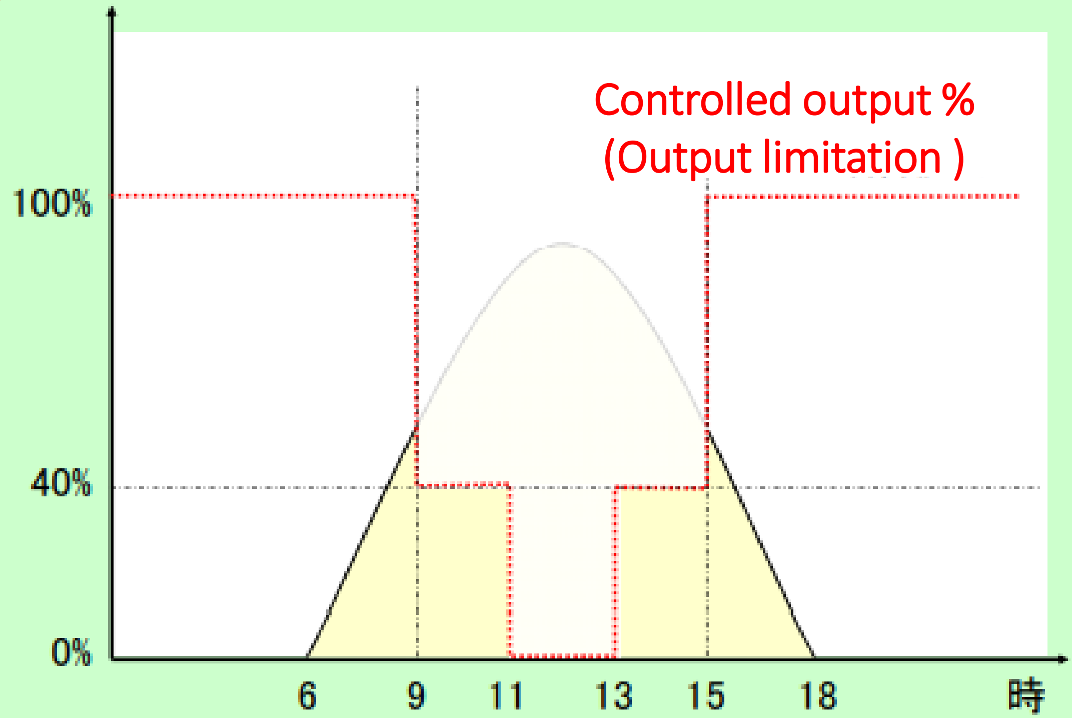
Daily Control Schedule

Control Schedule



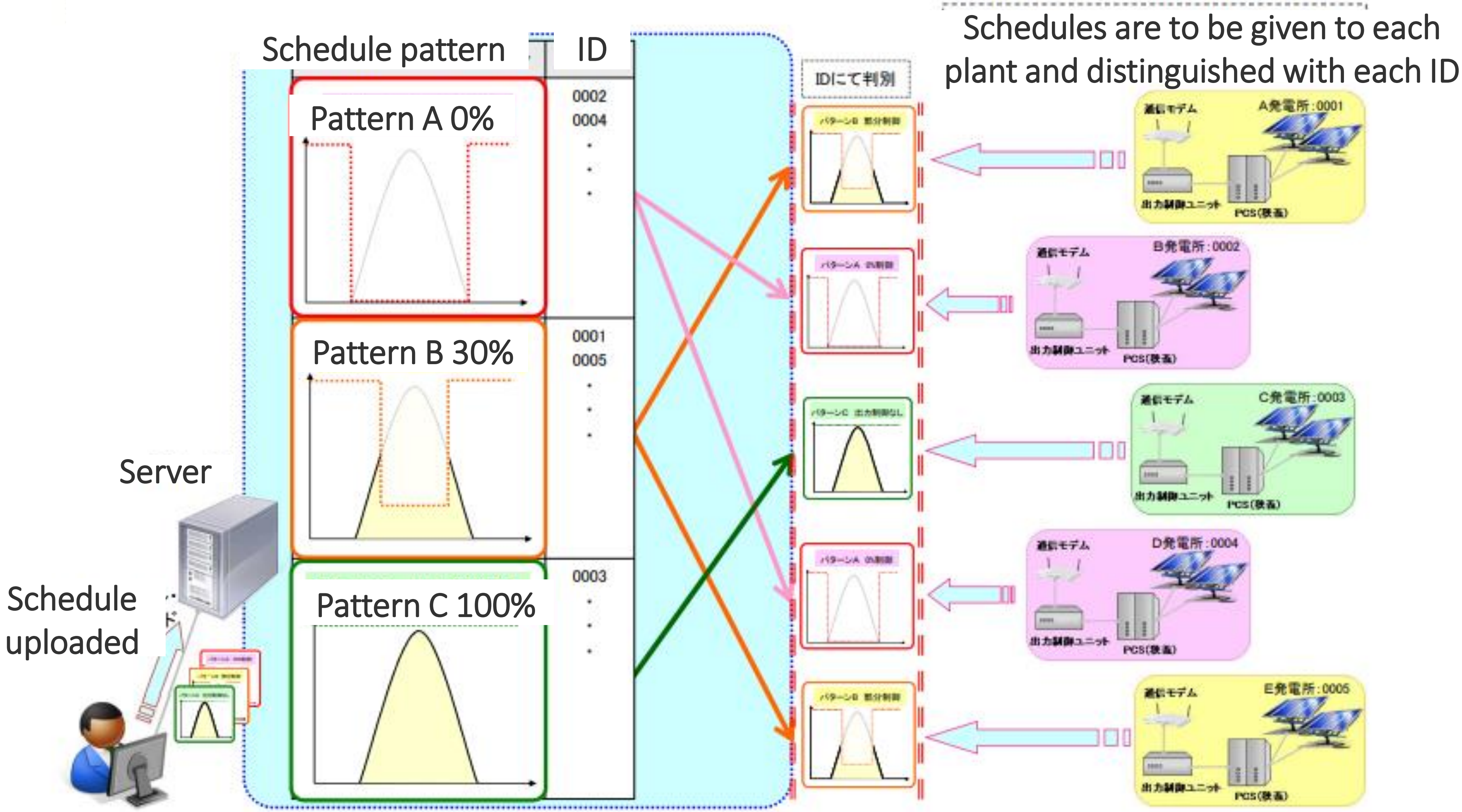
Fixed schedule can be uploaded 400 days forward



Time	0～9	9～11	11～13	13～15	15～24
Output limitation	100%	40%	0%	40%	100%

Control Schedule can be set with 30 min. time resolution and 1% output resolution

How to operate with 30 min. resolutions schedule



Technical Specification Details of PCS 1

1	Partial output control	Output change	• 100%→0%(0%→100%) change of PCS nominal capacity is possible in the range of 5-10 min. • This time should be adjustable with 1 min. resolution in the range above • Error should be within 5% • Change rate should be constant as 100%/ 5-10min in case of linear change. • Step change is also possible, in this case, single control step should be within 10%
		Control resolution	1% of nominal capacity (Error should be within 5%)
		Conversion function from % to output	Converting provided % to appropriate output considering inputted panel capacity and PCS capacity (Input process should be secured with passwords)
2	Reverse flow protection	Protection accuracy	• Detection criteria regarding flow level and time are greater of 5% of nominal capacity and 150W, and within 5 min. (i.e. for those who intends all self-consumption) • In 0% control cases, 1. For surplus purchase plants (such as there are some self consumption), no reverse flow at interconnection point or no generation output 2. For generation purchase plants, no generation output
3	Internal fault of "PCS functioning output control"	telecom fault (Internal one such as between control unit and PCS)	• Generation stop within 5 min. after detecting internal telecom fault • When telecom functions are recovered, generation can restart automatically or manually

Technical Specification Details of PCS 2

4	Online control	Telecom frequency	• Schedules can be updated with 30 min. resolution • Updating frequency (server-access timing) can be designated by CLDC servers
5	Schedule	Controllable period	• 400 days × 48(one day divided by 30 min.) resolution and forward Schedules of certain period (i.e.only 1 day) can be updated
6	External fault of “PCS functioning output control”	Clock	• With telecom function Keeping synchronization with CLDC severs • Without telecom function 1. Clock setting is to be conducted by synchronization with GPS or vender servicemen 2. Manual adjustment of clock after operation should be within 10 min. a day 3. In case of outage, clock should not be stop If clock time record disappeared, it is required to stop operation until clock setting conducted by synchronization with GPS or vender servicemen 4. Clock error should be within 60 sec. a month 5. Clock setting should be conducted when annually updating fixed schedules in order to keep the accuracy above
		External telecom fault	Control with the latest schedule served before telecom fault

Renewable Energy Desk

Sep, 2022

Chubu Electric Power Co., Inc.
Nippon Koei Co., Ltd.

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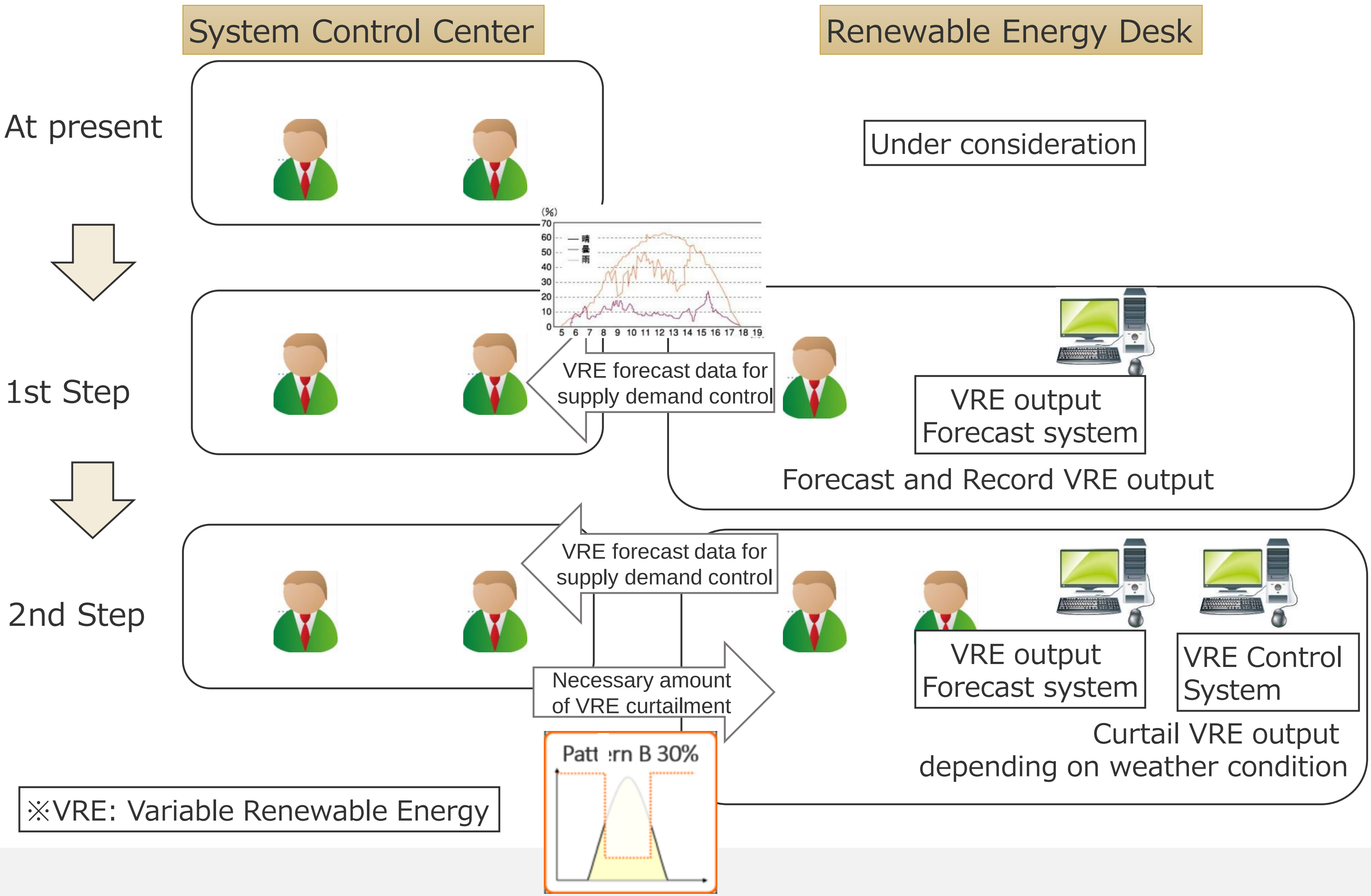
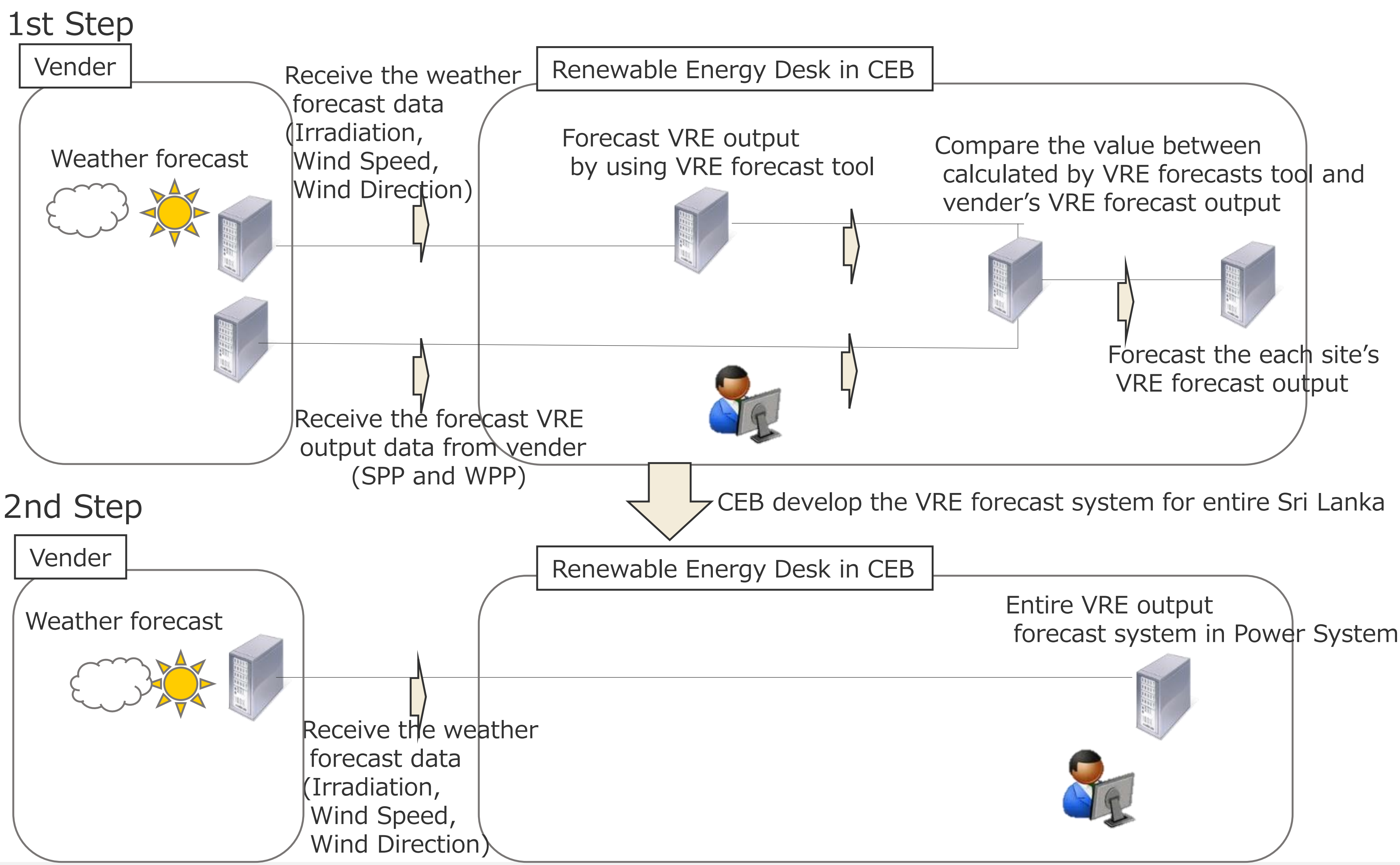
Organization of Renewable Energy Desk and Renewable Energy Desk's personnel



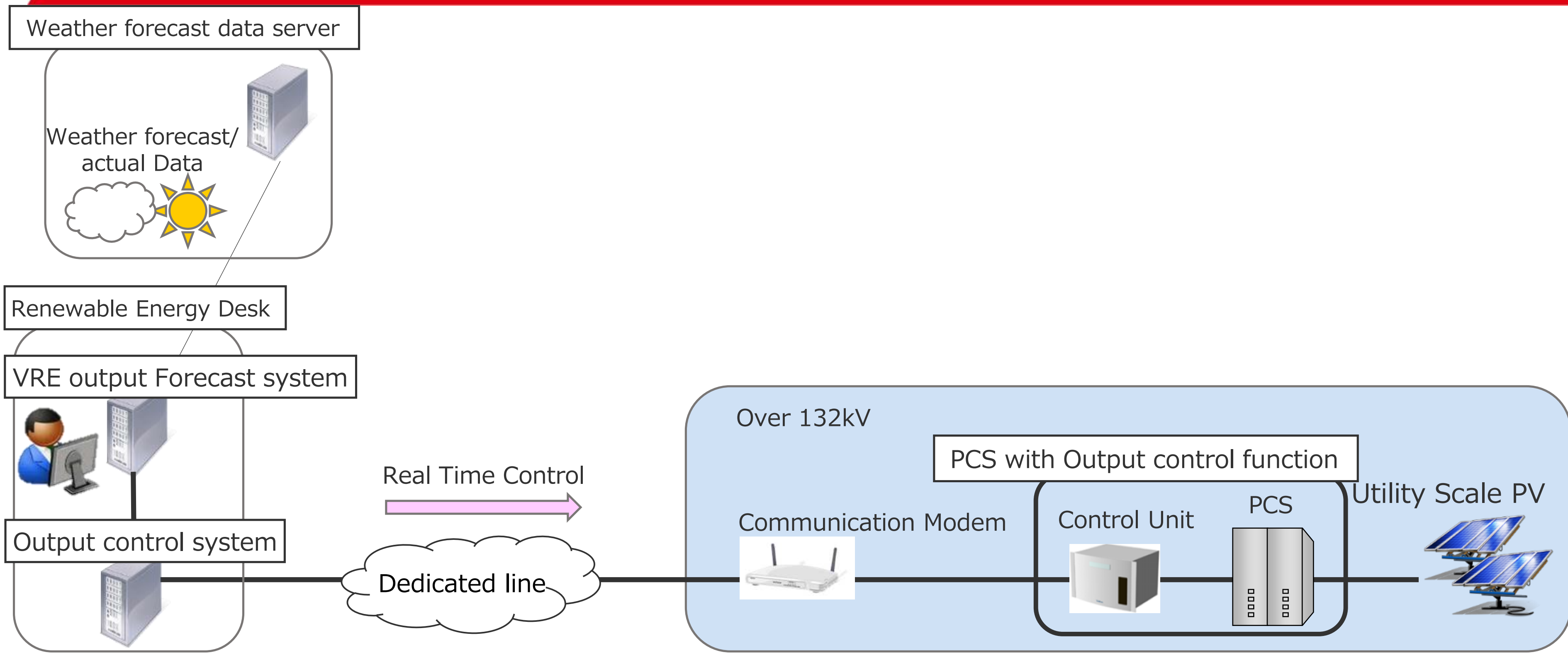
※VRE: Variable Renewable Energy

VRE output Forecast system



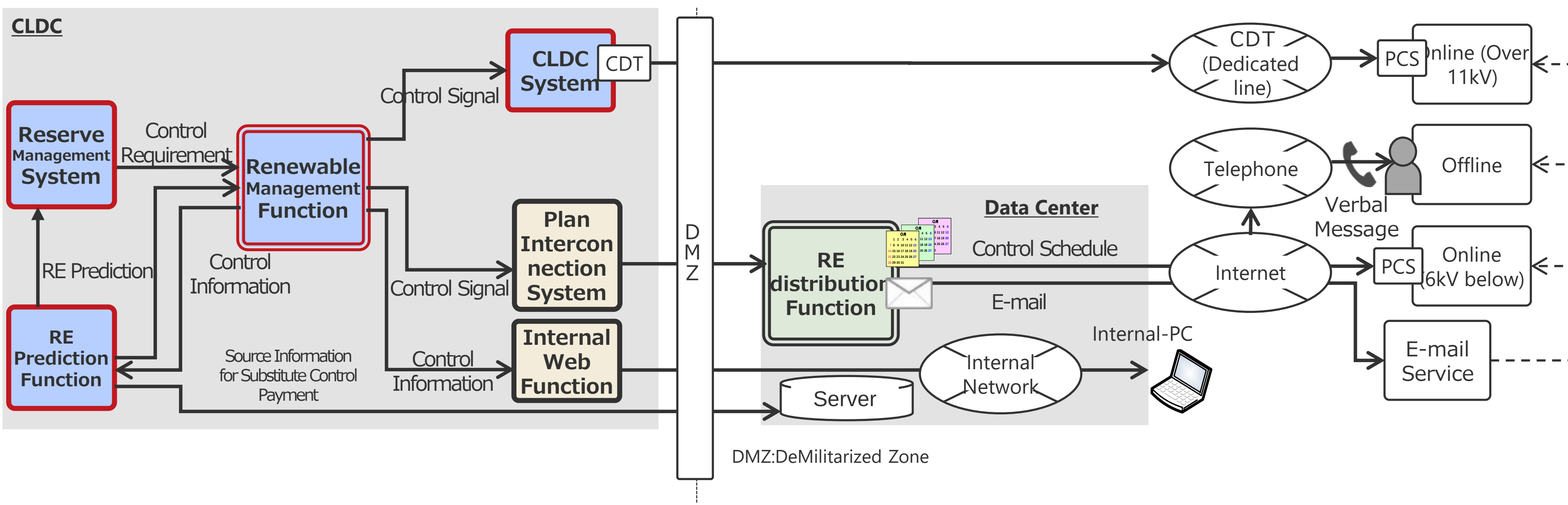
03 VRE Control System

Structure of VRE Output Control System



No	Communication environment	output control schedule	operation		merit	demerit
			previous day	on the day		
1	Dedicated line			real time control	high security	expensive
2	internet	flexible	RED send schedule to PCS	update schedule on server PCS control output automatically	low-cost low burden of generation company	low security
3	none	fixed	Generation company update schedule on site once a year based on power company's schedule		no communication cost	long control time

Chubu System Overview



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Democratic Socialist Republic of Sri Lanka

The Project for Capacity Development on the Power Sector Master Plan Implementation Program

Standard asset responsibility and cost burden

Oct 2022

Chubu Electric Power Co., Inc.
Nippon Koei Co., Ltd.

Standard asset responsibility and cost burden in case of connecting Independent Power Producer

CHUBU Electric Power
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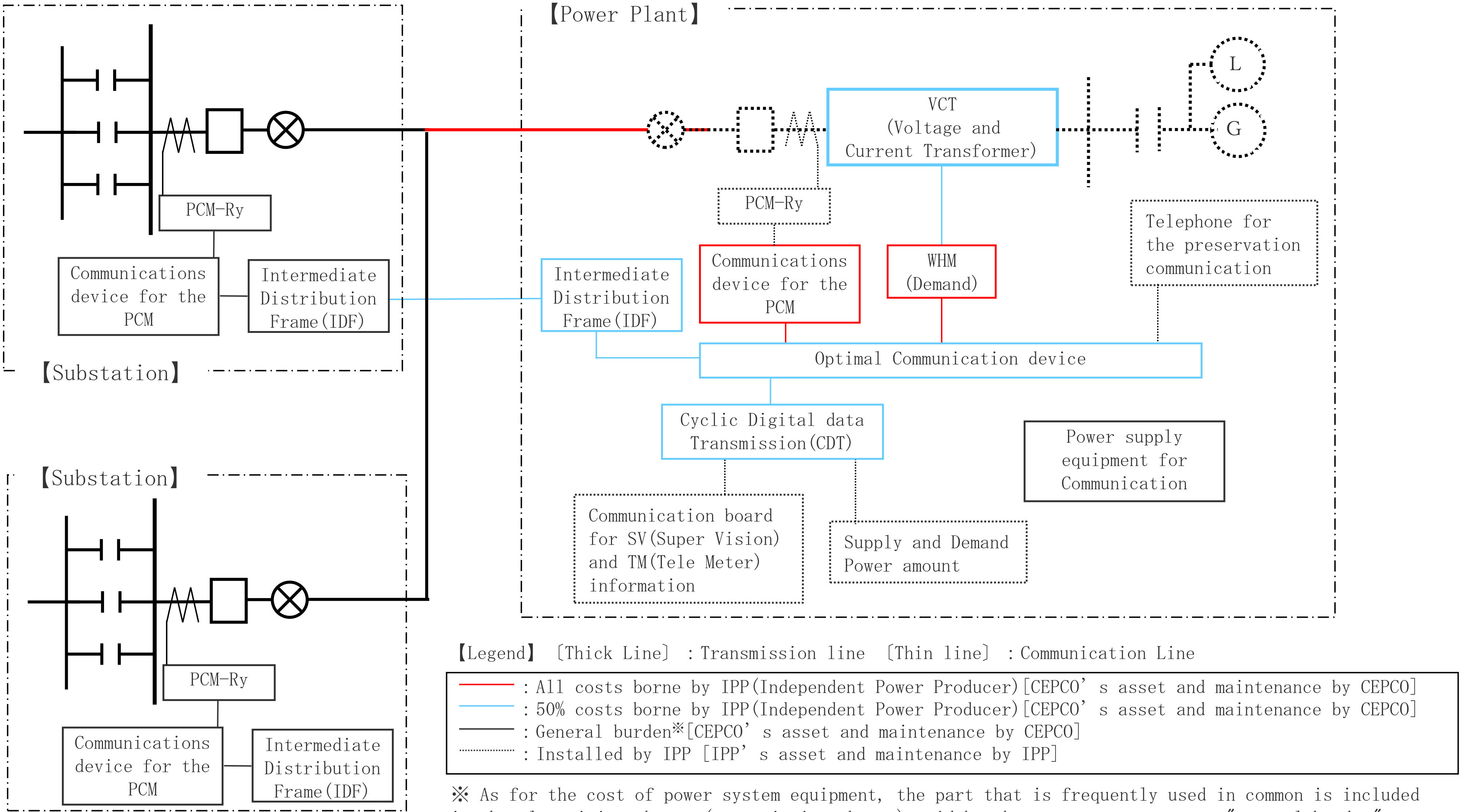

※ As for the cost of power system equipment, the part that is frequently used in common is included in the electricity charge (transmission charge) paid by the power consumer as a "general burden".

Standard asset responsibility and cost burden in case of connecting extra high voltage consumer

CHUBU Electric Power
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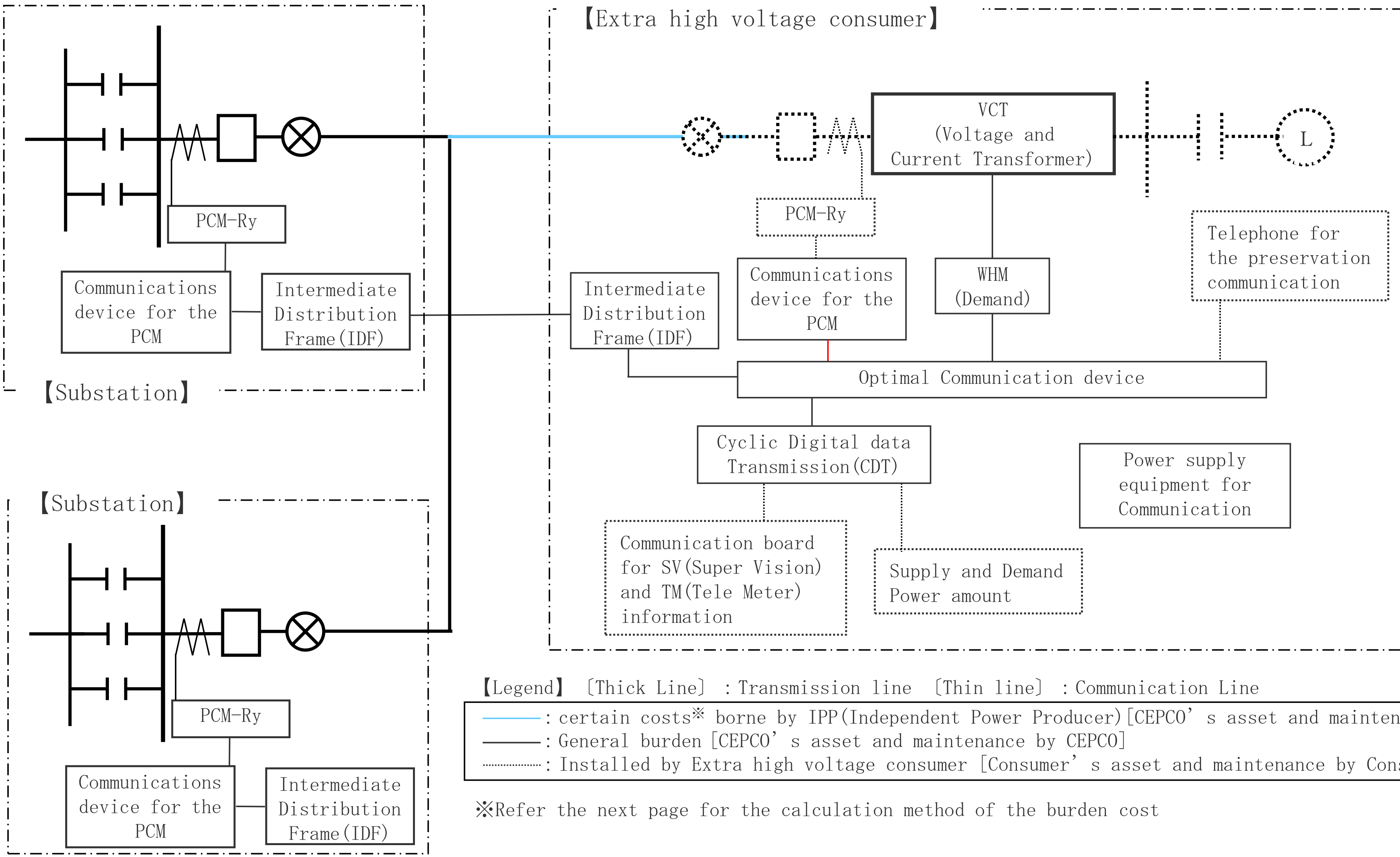

【Legend】 〔Thick Line〕 : Transmission line 〔Thin line〕 : Communication Line

(blue line) : certain costs※ borne by IPP(Independent Power Producer)[CEPCO's asset and maintenance by CEPCO]
(black line) : General burden [CEPCO's asset and maintenance by CEPCO]
(dotted line) : Installed by Extra high voltage consumer [Consumer's asset and maintenance by Consumer]

※Refer the next page for the calculation method of the burden cost

Calculation method of burden cost

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【The burden cost of Construction】

Transmission line form	Voltage	Burden Cost for 1cct Per construction length of 100m	Burden cost by CEPCO as general facility expenses
Overhead line	22kV or 33kV	¥363/kW	¥5,500/kW
	77kV	¥165/kW	
	154kV	¥88/kW	
Underground line	22kV or 33kV	¥638/kW	
	77kV	¥451/kW	
	154kV	¥242/kW	

If consumer need backup line(2cct), they need to pay additional 1/5 of the burden cost of construction

【A example of burden cost of Construction】

・contract power is 3000kW , Transmission line is constructed by overhead line (300m×2cct) , voltage is 77kV

The burden cost(main line) : 165＊3000*3 = 1,485,000
Burden cost by CEPCO : 5,500×3,000 = 16,500,000(this value is larger above one , so consumer don't need to pay for main line)

The burden cost(backup line) : 165*3000*3*0.2 = 297,000
The concept of general facility expenses is not applied to the backup line

Total burden cost by consumer:¥297,000

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Evaluation of VRE & hydro supply capability in long term planning

Sep, 2022

Chubu Electric Power Co., Inc.
Nippon Koei Co., Ltd.

Background

CHUBU Electric Power
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- CEB evaluates VRE supply capability in long term planning study as solar : 0%, wind : 2-3%, hydro : 5% - 50% of their nominal capacity.
- Japanese utility and OCCTO evaluate them greater compared to CEB and supply capability increase is expected to contribute to CEB efficient long term planning, therefore, we'd like to introduce how to evaluate in Japan.

<De-rating factor of hydro in Sri Lanka>
Source : CEB grid code

Table 2.1.2.B: Probabilities of Hydro Conditions

Hydro Condition	Probability
Very Wet	10%
Wet	20%
Medium	50%
Dry	15%
Very dry	5%

<De-rating factor % of solar & wind in Chubu>

Solar

FY	4月	5月	6月	7月	8月	9月	10月	11月	12月	1月	2月	3月	(参考)年間
2022	7.2	14.7	18.8	23.8	24.2	16.7	12.0	0.4	7.1	7.8	2.5	2.6	
2023	7.0	14.6	18.7	23.8	23.5	16.6	12.2	0.3	6.4	7.3	2.7	2.4	
2024					13.5					13.5			13.5
2025					13.4					13.4			13.4
2026					13.2					13.2			13.2
2027					13.0					13.0			13.0
2028					12.6					12.6			12.6
2029					12.5					12.5			12.5
2030					12.5					12.5			12.5
2031					12.5					12.5			12.5

Wind

FY	4月	5月	6月	7月	8月	9月	10月	11月	12月	1月	2月	3月	(参考)年間
2022	31.2	11.2	12.5	14.5	12.1	12.1	12.2	30.5	24.8	32.8	41.4	44.4	
2023	30.8	11.2	12.6	14.3	11.8	11.9	13.2	30.7	26.3	31.4	40.6	44.3	
2024					27.2					27.2			27.2
2025					27.4					27.4			27.4
2026					27.5					27.5			27.5
2027					27.9					27.9			27.9
2028					27.5					27.5			27.5
2029					28.0					28.0			28.0
2030					28.3					28.3			28.3
2031					28.3					28.3			28.3

<De-rating factor % of hydro in Chubu>

Run of river and resevoir hydro

FY	4月	5月	6月	7月	8月	9月	10月	11月	12月	1月	2月	3月	(参考)年間
2022	51.3	51.4	48.1	49.5	43.2	44.0	36.0	30.6	29.9	25.7	26.6	37.0	
2023	51.4	51.4	47.8	49.9	42.9	43.7	36.2	30.7	29.3	25.5	26.7	37.0	
2024					47.1					47.1			47.1
2025					47.0					47.0			47.0
2026					47.1					47.1			47.1
2027					47.1					47.1			47.1
2028					47.5					47.5			47.5
2029					47.5					47.5			47.5
2030					47.5					47.5			47.5
2031					47.5					47.5			47.5

PSPP

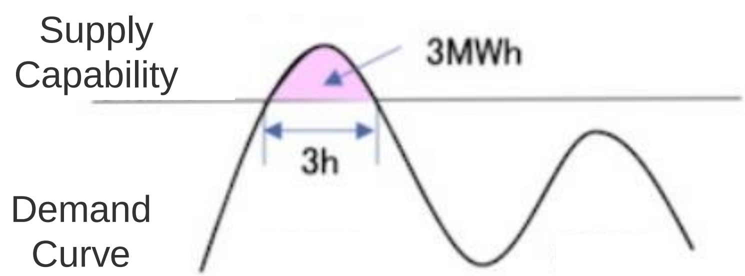
2022: FY

Duration	4月	5月	6月	7月	8月	9月	10月	11月	12月	1月	2月	3月	(参考)年間
20h	87.5	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	98.8	100.0	95.6	
19h	87.5	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	98.8	100.0	95.6	
18h	87.5	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	98.8	100.0	95.6	
17h	87.5	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	98.8	100.0	95.6	
16h	87.5	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	98.8	100.0	95.6	
15h	87.5	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	98.8	100.0	95.6	
14h	87.5	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	98.8	100.0	95.6	
13h	87.5	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	98.8	100.0	95.6	
12h	87.5	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	98.6	100.0	95.6	
11h	87.3	89.4	97.2	100.0	100.0	100.0	97.6	96.5	99.5	97.6	99.7	95.6	
10h	86.5	89.4	97.2	100.0	100.0	100.0	97.6	96.4	99.0	95.7	98.7	95.1	
9h	85.3	88.8	96.2	100.0	100.0	100.0	97.0	95.5	97.5	93.0	97.0	93.9	
8h	83.6	87.4	94.1	100.0	100.0	99.3	95.5	93.9	95.0	89.3	94.6	92.0	
7h	81.5	85.4	90.8	99.5	97.6	96.3	93.3	91.4	91.5	84.8	91.6	89.5	
6h	78.9	82.6	86.4	96.3	93.0	92.1	90.4	88.2	87.0	79.5	87.8	86.3	
5h	75.9	79.0	80.8	92.0	86.9	86.7	86.7	84.2	81.5	73.2	83.4	82.4	
4h	72.4	74.7	74.1	86.5	79.3	80.1	82.2	79.4	75.0	66.1	78.2	77.9	
3h	68.4	69.7	66.3	79.9	70.3	72.3	76.9	73.9	67.5	58.1	72.4	72.7	

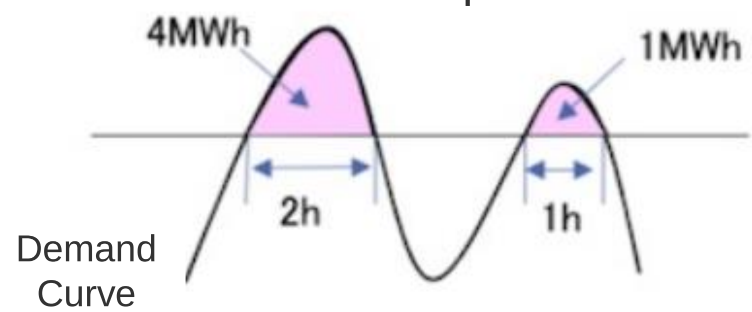
Evaluation Indicators

- Japanese utility and OCCTO uses EUE(Expected Unserved Energy) instead of LOLP.
- EUE is expressed as k(M)Wh or k(M)Wh/kWd * year (kWd means electricity demand).
- EUE can be calculated by averaging each result of 10,000 times Monte Carlo yearly simulation in Japan.

<Example 1>



<Example 2>

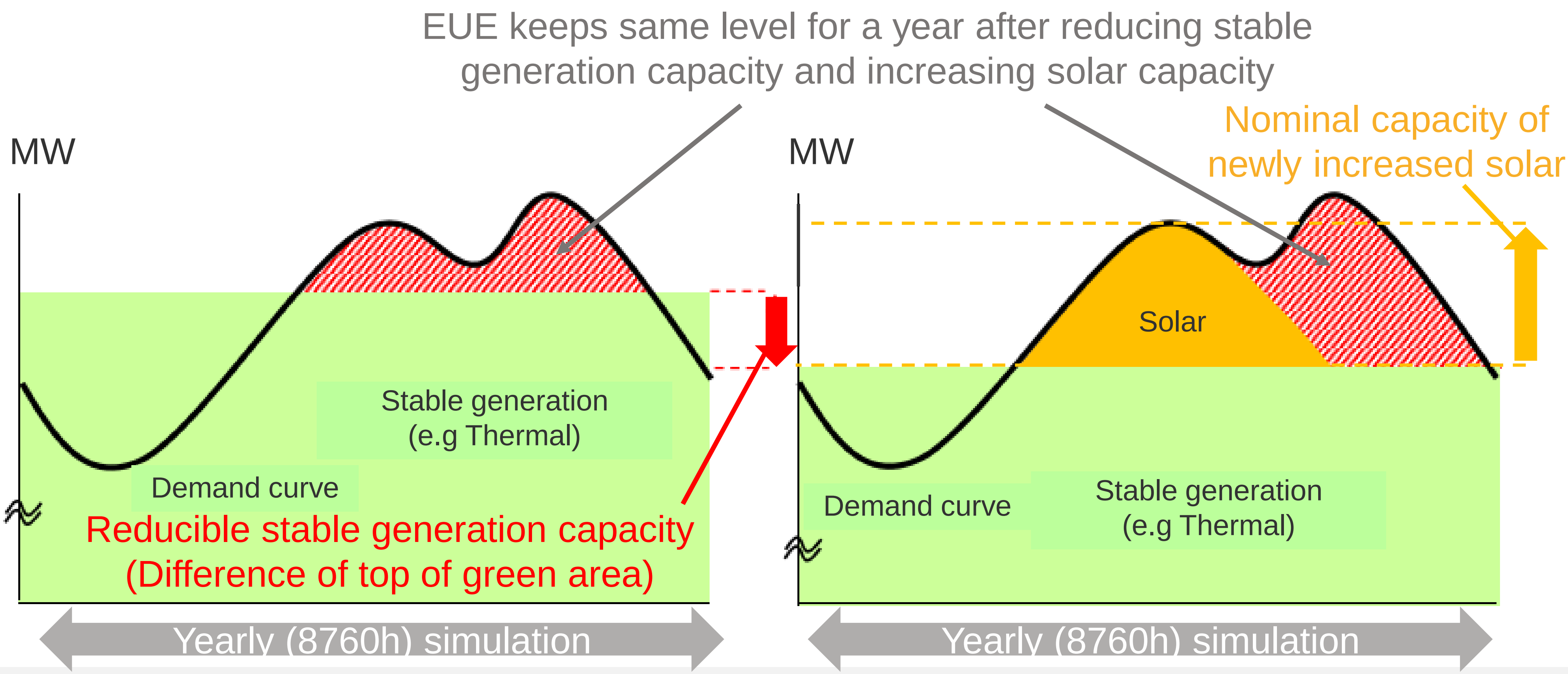


	Example 1	Example 2	Use case
LOLP	Once/year	Twice / year	Former Japan
LOLE	3 hours/year	3 hours/year	UK
EUE	3MWh/year	5MWh/year	Japan

Evaluation Procedure (Definition & Solar)

- De-rating factor can be calculated in the following equation.

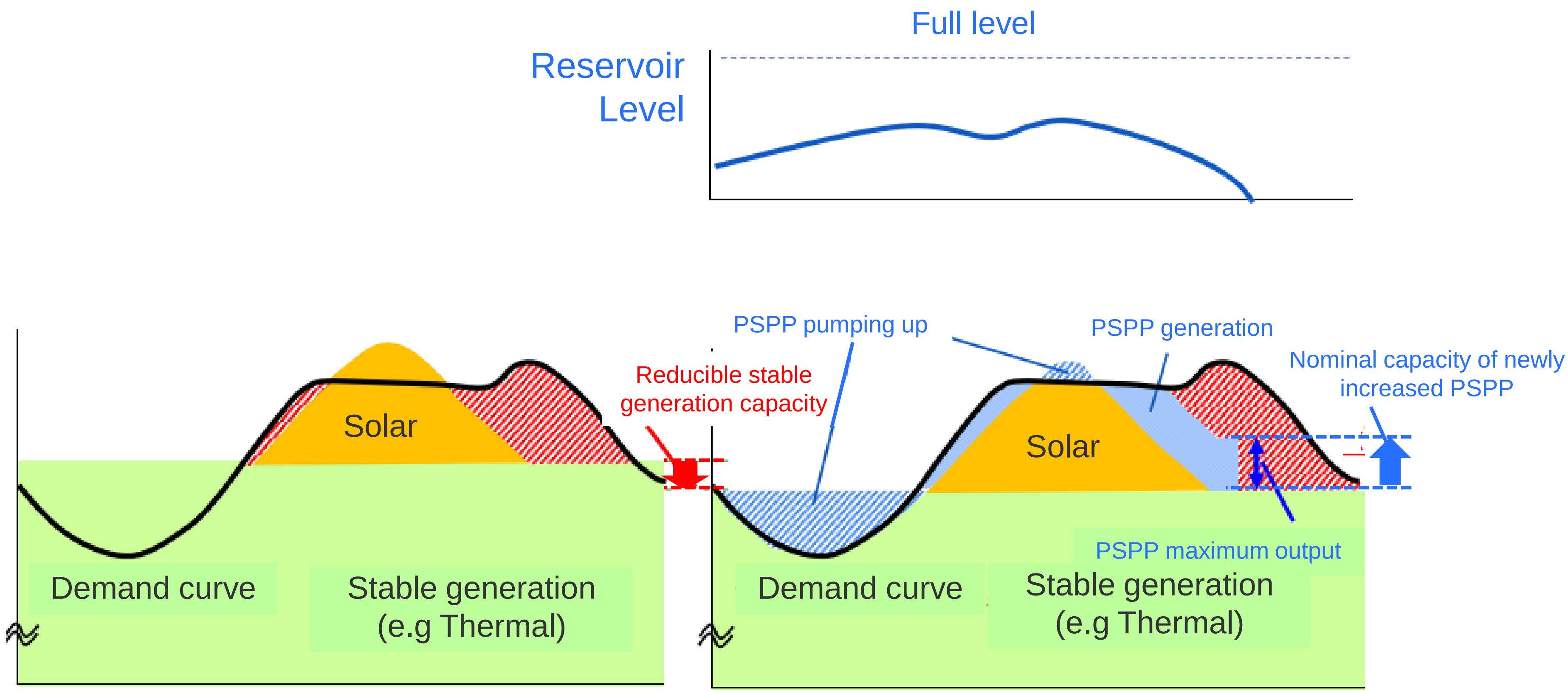
$$\text{De-rating factor} = \frac{\text{Reducible stable generation capacity keeping the same EUE}}{\text{Nominal Capacity of newly increased VRE or hydro}}$$



*For wind, the same evaluation applicable

Evaluation Procedure (PSPP)

- For PSPP, it is necessary to simulate pumping up & generation when calculating EUE.
- Basically, pumping up as much as possible is operational policy for evaluating EUE.



PSS/E renewable Dynamic Simulation

June 07, 2022

Chubu Electric Power Co., Inc.
Nippon Koei Co., Ltd.

Table Contents

01 Renewable Energy model

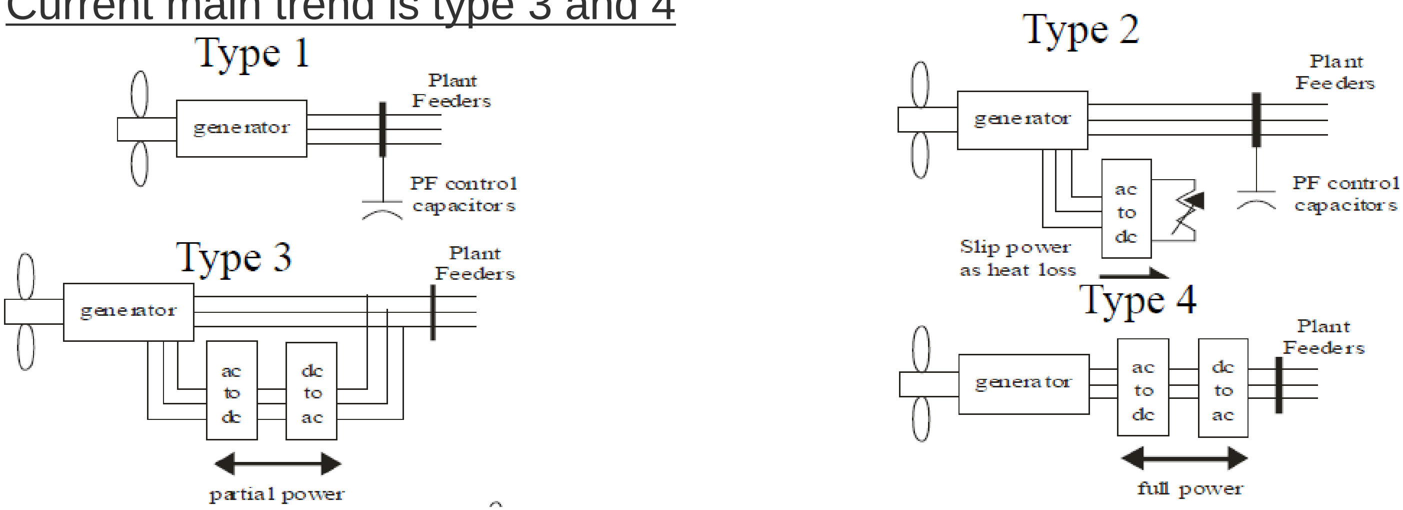
PSS/E Renewable Energy Model

Model	Wind				PV	BESS (Battery Energy Storage System)		DER (Distributed Energy Resource)
	W1	W2	W3	W4		2nd Generation	1st Generation	
Generator /Converter	WT1G1	WT2G1	WT3G1, WT3G2	WT4G1, WT4G2	PVGU1		CBEST	DERAU1
			REGCA1 (Current source model) REGCB (New model : Voltage source model) REGCC (Grid Forming Inverter)					
Electrical Control		WT2E1	WT3E1	WT4E1, WT4E2	PVEU1	REECC1		
			REECA1 (Wind, PV)		REECB1 (Simplified Model)			
			REECDU1 (New model: Recommended for Wind, large scale PV, BEES. Momentary Cessation in large scale PV.)					
Mechanical (Drive Train)	WT12T1		WT3T1 WTDTA1	WTDTA1* WTDTB*	PANELU1 (Panel's output curve)			
Pitch Control			WT3P1 WTPTA1 WTPTB		IRRADU1 (Solar irradiance profile)			
Aero Dynamic	WT12A1 (Unapproved by Task Force) WT12A1U_B		WTARA1					
Gust								
Plant Control (Auxiliary Control)			REPCTA1					
			REPCA1 REPCC (Providing added flexibility in the specification of limits of the pitch controller)					
			PLNTBU1 with REAX3BU1 (Multi-Unit)	PLNTBU1 with REAUX4BU1 (Multi-Unit)				
Torque Control			WTTQA1					
Weak Grid				WTGWGOA* (Reduce Pref for post-fault recovery)				
IBFFR (Inertia Based Fast Frequency Response Mode)			WTGIBFFRA (Synthetic Inertia)					

・Blue : Currently under development and/or being tested, Green : Testing not yet started.. * : optional

Wind Type

- Current main trend is type 3 and 4

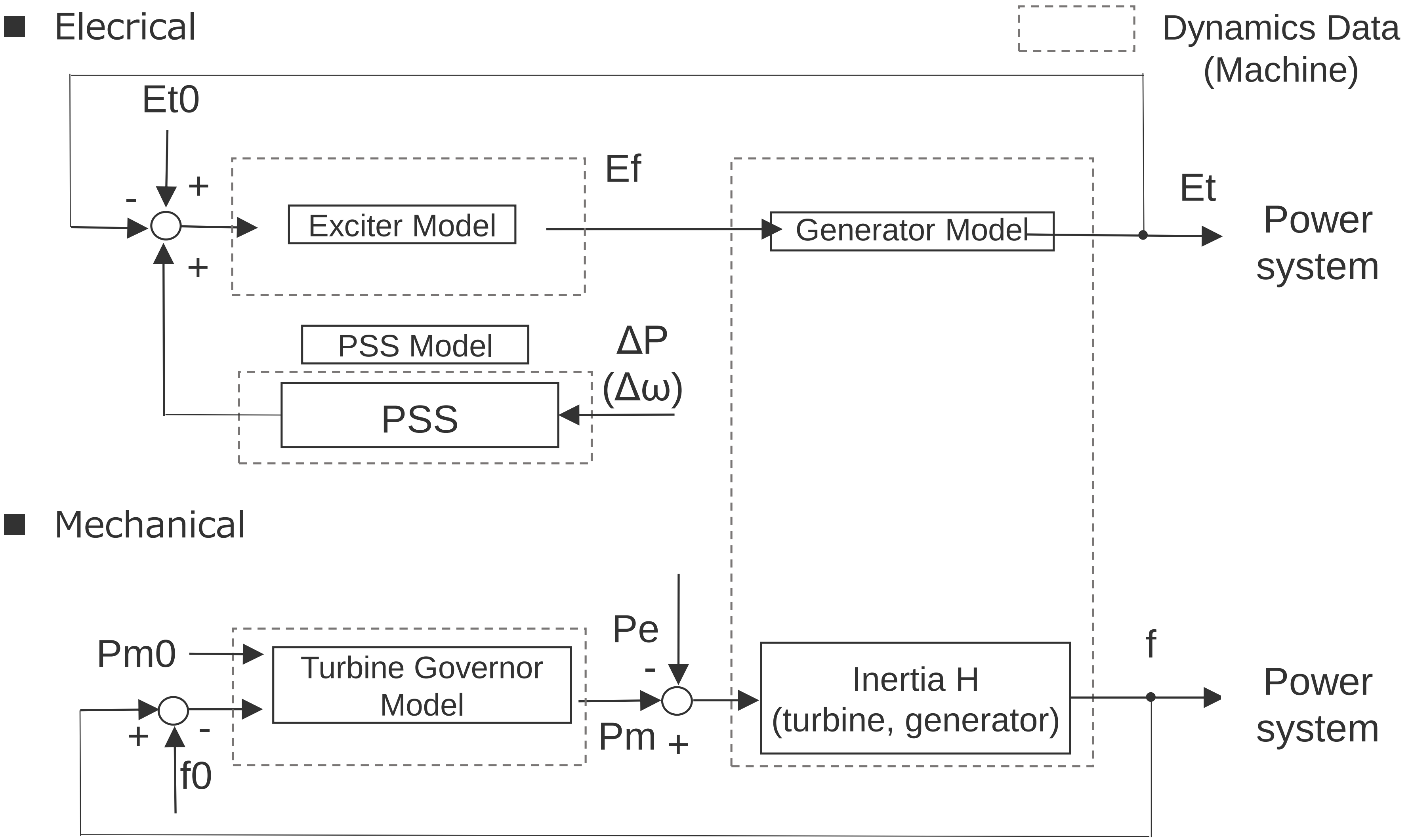


Type	Name	Merit	Demerit	share
1	conventional directly connected induction generator	Low cost, simple Sturdy	Flicker voltage Voltage not adjustable	4.9%
2	wound rotor induction generator with variable rotor resistance	optimum output control	Expensive under 1MW	5.9%
3	doubly-fed induction generator	optimum output control Compact convertor	Limited speed range	63.3%
4	full converter interface	High efficiency	Full converter is necessary expensive	22.2%

Source : User Group Meeting PSS@E Session 2 P35 (13 January 2022, SEMENS)

Source : BTM Consult

Machine Model (Conventional model : hydro, thermal, nuclear)



Renewable Machine Model (Wind power model Type 3)

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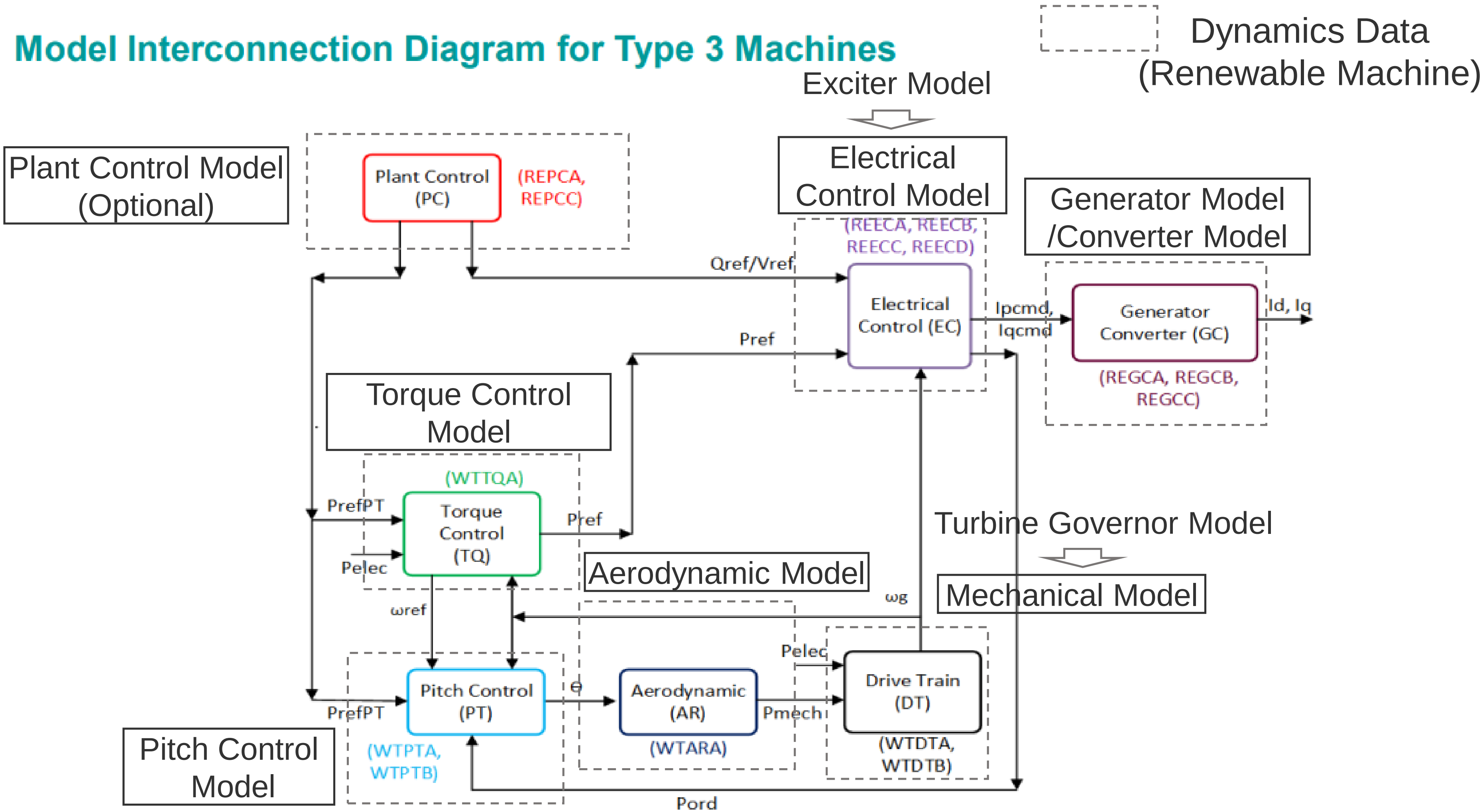
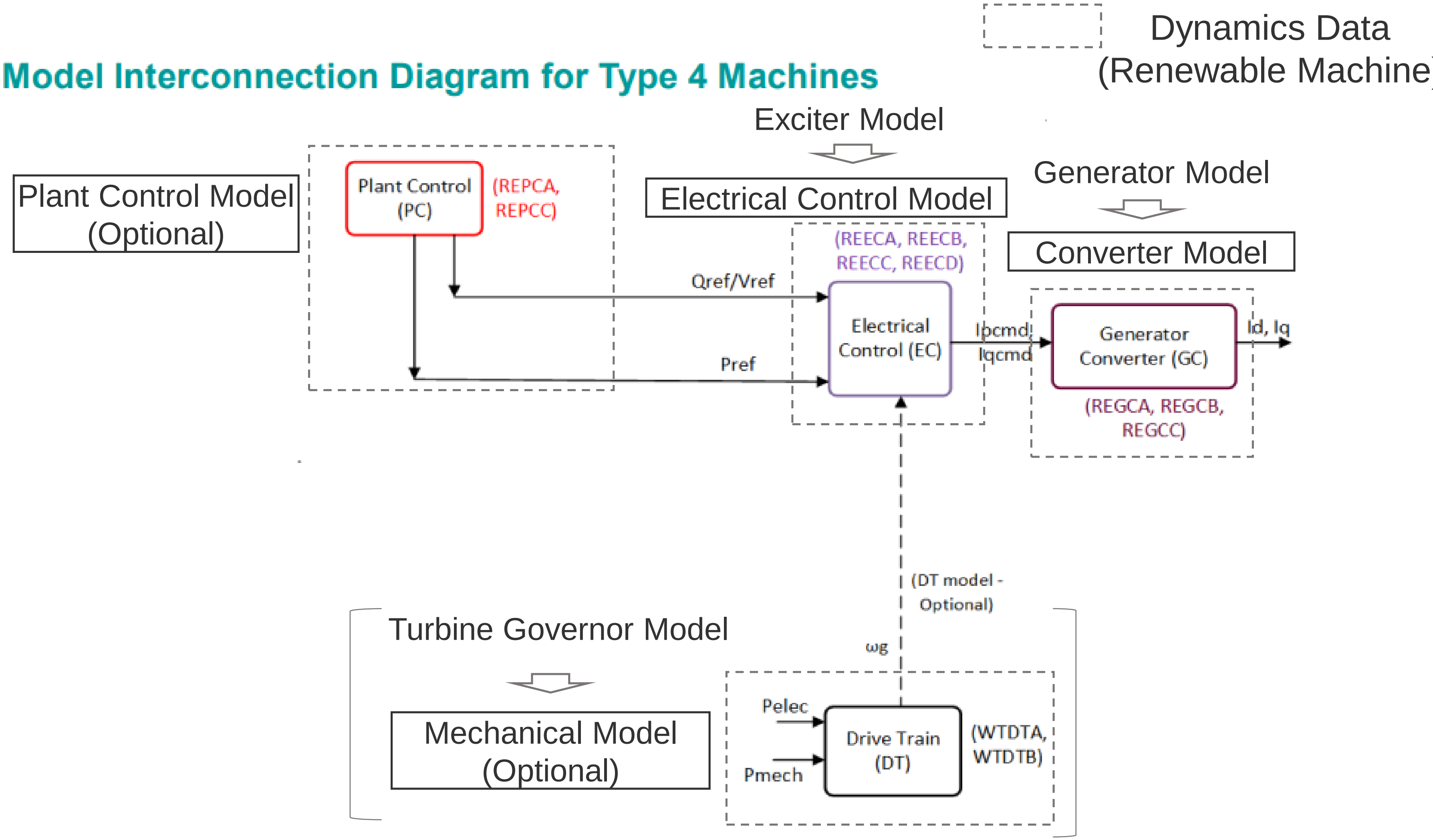


Source : User Group Meeting PSS@E Session 2 P38 (13 January 2022, SIEMENS)

Model Interconnection Diagram for Type 4 Machines



Source : User Group Meeting PSS@E Session 2 P39 (13 January 2022, SIEMENS)

PSS®E 1st, 2nd Generation Type 3 & 4 Wind Machine Models

1st Generation

Model Type	Wind Type 3 (version 32 and above)	Wind Type 4 (version 32 and above)
Generator/Converter model	WT3G1, WT3G2	WT4G1, WT4G2
Electrical Control Model	WT3E1	WT4E1, WT4E2
Drive Train model	WT3T1	
Pitch Control Model	WT3P1	

2nd Generation

Model Description	Model Name in V33.4 and above	Model Name in V34
Generator/Converter model	REGCAU1	REGCA1
Electrical Control Model	REECAU1	REECA1
Drive Train model	WTDTAU1	WTDTA1
Aerodynamic Model	WTARAU1	WTARA1
Pitch Control Model	WTPTAU1	WTPTA1
Torque Control Model	WTTQAU1	WTTQA1
Auxiliary Control Model	REPCAU1	REPCA1

The WECC and NERC Renewable Energy Modeling Working Group (REMWG) have unapproved the use of these 1st generation models. The suggestion is to use the 2nd generation models (REGCA or REGCB for modeling the Renewable Generator, and the REECD for modeling the EC model)

PV model (Output fluctuation model due to solar radiation fluctuation)

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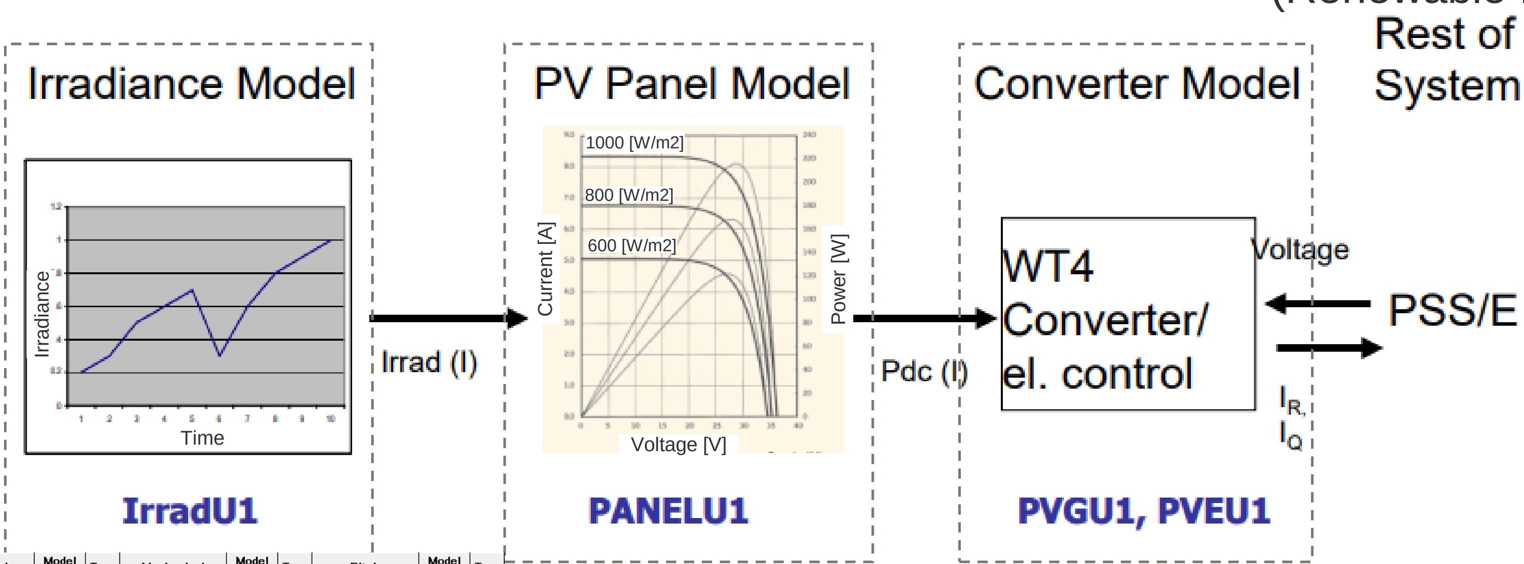
Dynamics Data (Renewable Machine)



Type	Electrical	Model Status	Type	Mechanical	Model Status	Type	Pitch	Model Status	Type
Wrtn	PVEU1	☑	Wrtn	PANELU1	☑	Wrtn	IRRADU1	☑	Wrtn

Edit Model Parameters

Model IRRADU1 Model 154 '1 '

Model CONS | Model ICONS | Model VARS

Solar irradiance setting time by time

	Con Value	Con Description
1	5.0000	T1, Time of the first data point, second
2	1000.0000	I1, Irradiance at first data point, W/m2
3	10.0000	T2, Time of the second data point, second
4	900.0000	I2, Irradiance at second data point, W/m2
5	15.0000	T3, Time of the third data point, second
6	850.0000	I3, Irradiance at third data point, W/m2
7	20.0000	T4, Time of the fourth data point, second
8	800.0000	I4, Irradiance at fourth data point, W/m2
9	25.0000	T5, Time of the fifth data point, second
10	700.0000	I5, Irradiance at fifth data point, W/m2
11	30.0000	T6, Time of the sixth data point, second
12	600.0000	I6, Irradiance at sixth data point, W/m2
13	35.0000	T7, Time of the seventh data point, second
14	700.0000	I7, Irradiance at seventh data point, W/m2
15	0.0000	T8, Time of the eigth data point, second
16	0.0000	I8, Irradiance at eigth data point, W/m2
17	0.0000	T9, Time of the ninth data point, second
18	0.0000	I9, Irradiance at ninth data point, W/m2
19	0.0000	T10, Time of the tenth data point, second
20	0.0000	I10, Irradiance at tenth data point, W/m2

OK Cancel

Source : PSS@E Wind and Solar Models P50 (July 5-6, 2011 SIEMENS)

PSS®E 1st, 2nd Generation Large Scale PV Model

CHUBU Electric Power
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1st Generation

Model Description	Model Name in V33.5 and above
Generator/Converter model	PVGU1
Electrical Control Model	PVEU1
Irradiance Model (Pitch Control)	IRRADU1
Panel Model (Mechanical System)	PANELU1

2nd Generation

Model Description	Model Name in V33.5 and above	Model Name in V34
Generator/Converter model	REGCAU1	REGCA1
Electrical Control Model	REECBU1	REECB1
Plant Control Model	REPCAU1	REPCA1

The WECC and NERC Renewable Energy Modeling Working Group (REMWG) have unapproved the use of these 1st generation models. The suggestion is to use the 2nd generation models (REGCA or REGCB for modeling the Renewable Generator, and the REECD for modeling the EC model)

BESS (Battery Energy Storage System) Model

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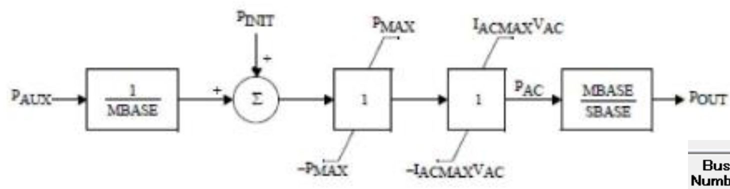
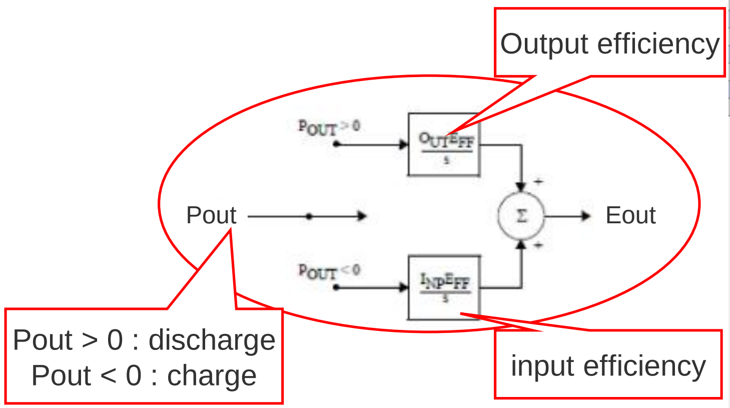
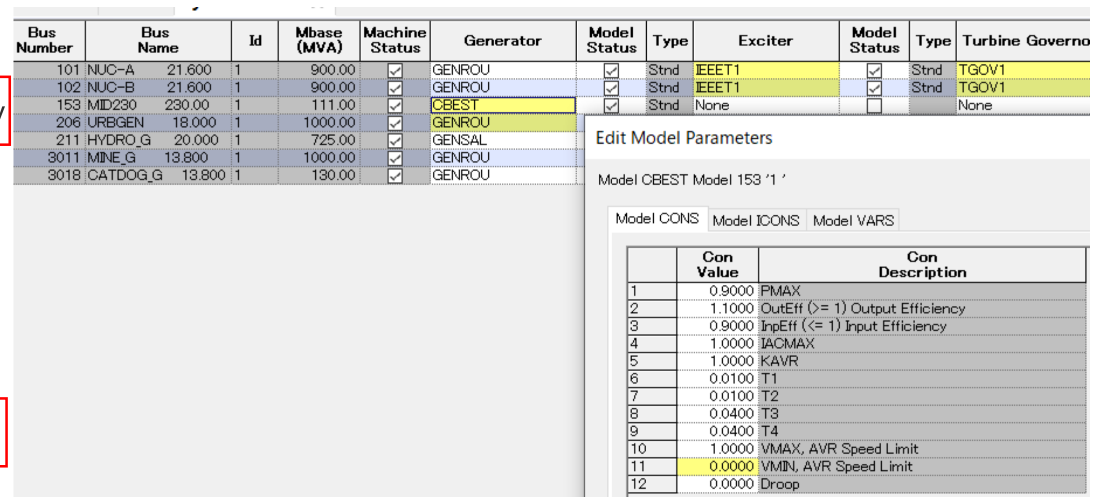
■ CBEST







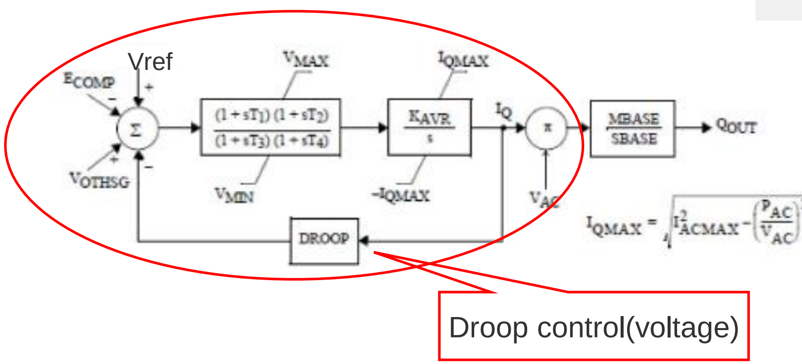
Bus Number	Bus Name	Id	Mbase (MVA)	Machine Status	Generator	Model Status	Type	Exciter	Model Status	Type	Turbine Governo
101	NUC-A 21.600	1	900.00	☑	GENROU	☑	Stnd	IEEET1	☑	Stnd	TGOV1
102	NUC-B 21.600	1	900.00	☑	GENROU	☑	Stnd	IEEET1	☑	Stnd	TGOV1
153	MID230 230.00	1	111.00	☑	CBEST	☑	Stnd	None	☐		None
206	URBGEN 18.000	1	1000.00	☑	GENROU						
211	HYDRO_G 20.000	1	725.00	☑	GENSAL						
3011	MINE_G 13.800	1	1000.00	☑	GENROU						
3018	CATDOG_G 13.800	1	130.00	☑	GENROU						

Edit Model Parameters

Model CBEST Model 153 '1 '

Model CONS | Model ICONS | Model VARS

	Con Value	Con Description
1	0.9000	PMAX
2	1.1000	OutEff (>= 1) Output Efficiency
3	0.9000	InpEff (<= 1) Input Efficiency
4	1.0000	IACMAX
5	1.0000	KAVR
6	0.0100	T1
7	0.0100	T2
8	0.0400	T3
9	0.0400	T4
10	1.0000	VMAX, AVR Speed Limit
11	0.0000	VMIN, AVR Speed Limit
12	0.0000	Droop



$$I_{QMAX} = \sqrt{I_{ACMAX}^2 - \left(\frac{P_{AC}}{V_{AC}}\right)^2}$$

Assuming an 80% turnaround efficiency, retrieval (OutEff) and storage (InpEff) efficiencies would typically be set to 1.1 and 0.9, respectively."

PSS®E 1st, 2nd Generation Battery Model

1st Generation

Model Description	1st Generation Dynamic Model
Generator/Converter model	CBEST

2nd Generation

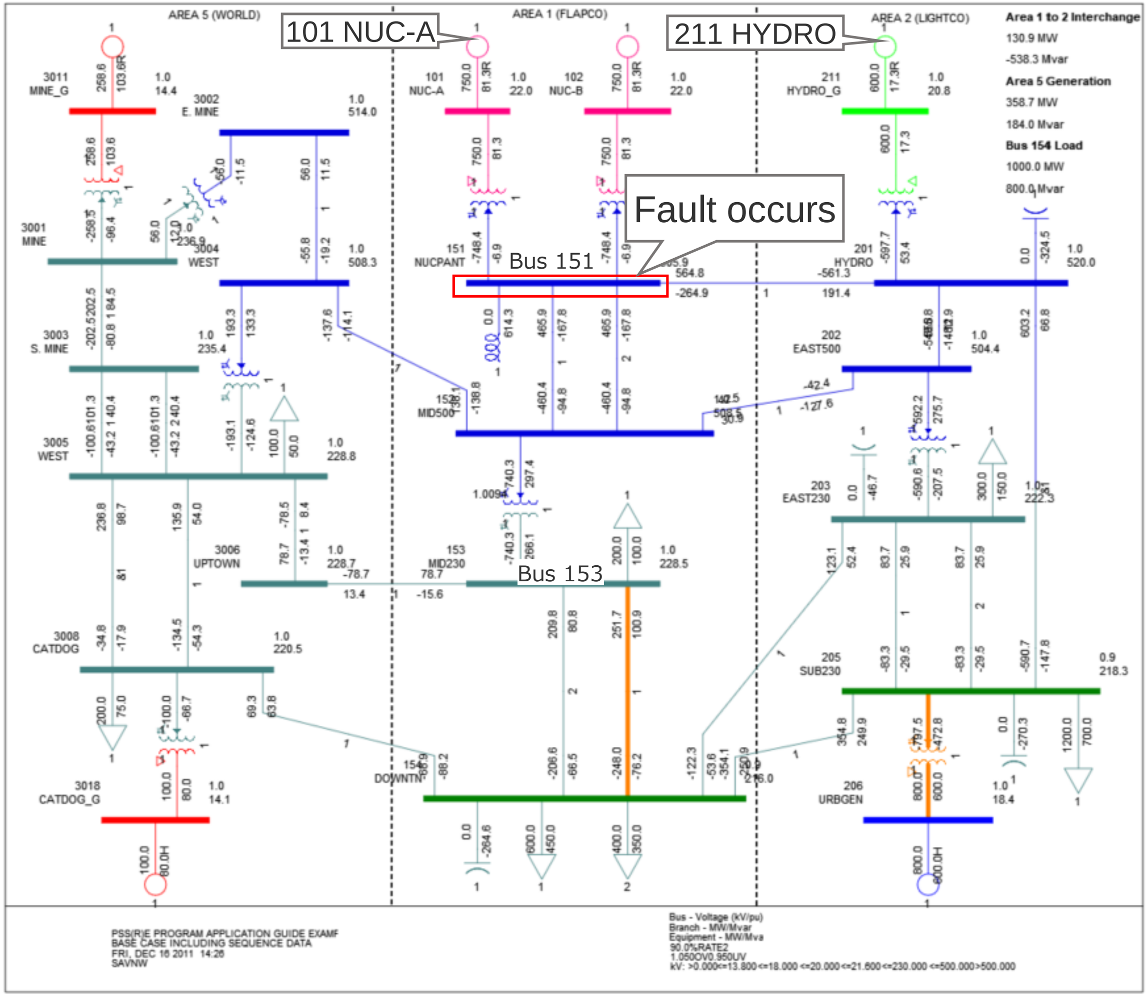
Model Description	Model Name in V33.5 and above	Model Name in V34
Generator/Converter model	REGCAU1	REGCA1
Electrical Control Model	REECCU1	REECCU1
Plant Control Model	REPCAU1	REPCA1

The WECC and NERC Renewable Energy Modeling Working Group (REMWG) have unapproved the use of these 1st generation models. The suggestion is to use the 2nd generation models (REGCA or REGCB for modeling the Renewable Generator, and the REECD for modeling the EC model)

02 Dynamic Simulation

Base case Assumption

- Base case is Siemens sample model
- Fault at No.151 Bus



Analysis procedure of Dynamic Simulation (Ver. 34)

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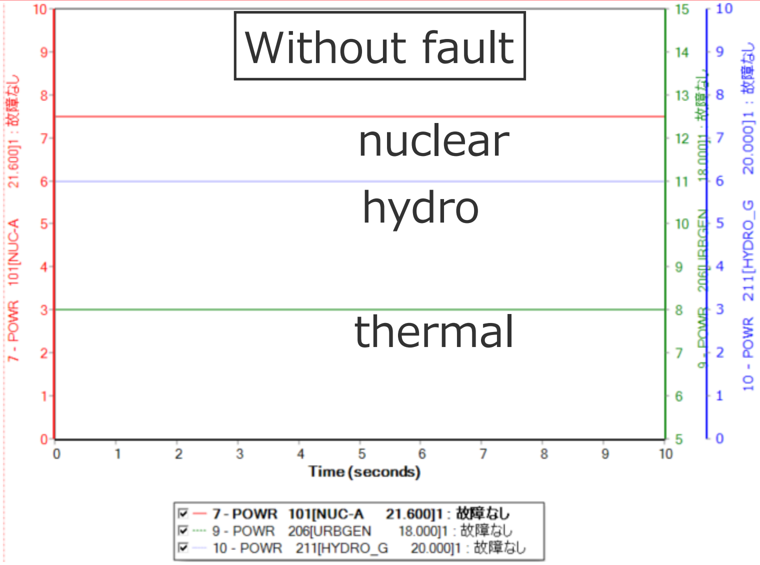
(1) File → Open → File (Ctrl + O)
Open savnw.sav and savnw.sld in HPLC
(2) Power Flow → Solution → Solve
Click → Solve
Click → Close
(3) File → Open → File (Ctrl + O)
Open savnw.dyr in HPLC
(4) Dynamics → Channel Setup wizard
Click → Go
Click → Close
(5) Dynamics → Perform simulation (STRT / RUN)
Perform Dynamic Simulation
Initialization options → Enter the output file name
(example: test.out)
Click → Initialize
(6) Perform Dynamic Simulation
Simulation options
Enter 1 (second) to "Run to" and 120 for "Print" , and click → Run (steady state for 1 second).
Click → Close
(7) Dynamics → Disturbances → Bus fault
Apply a Bus Fault
Apply fault at bus → Enter 151 (151: 500kV Bus)
Click → OK

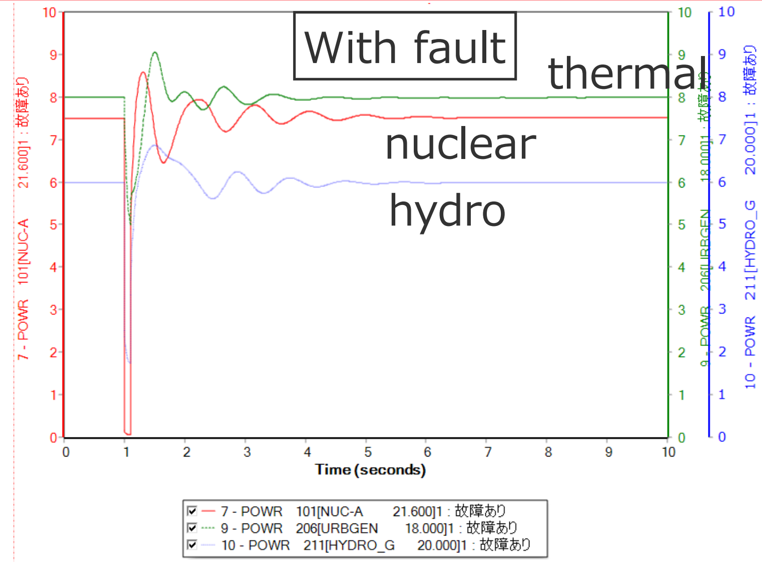
(8) Dynamics → Perform simulation (STRT / RUN)
Perform Dynamic Simulation
Simulation options
Enter 1.1 (seconds) to "Run to" and click → Run (three - phase short circuit for 0.1 seconds (1.0 to 1.1 seconds))
Click → Close
(9) Dynamics → Disturbances → Clear fault
Click → OK
(10) Dynamics → Perform simulation (STRT / RUN)
Perform Dynamic Simulation
Simulation options
Enter 10 (seconds) in Run to and click → Run (analysis after clear fault for about 10 seconds (1.1 to 10 seconds))
Click → Close

(11) File → Open → File (Ctrl + O)
Open test.out in EXAMPLE
Click → OK
(12) View → To the right of Plot Tree ✓
(13) View: Plot Tree
Plot Data → Channel Files → test
Move the contents to the plot area by drag and drop
(Output of 211 HYDRO-G and voltage of 153 MID 230 (230kV))

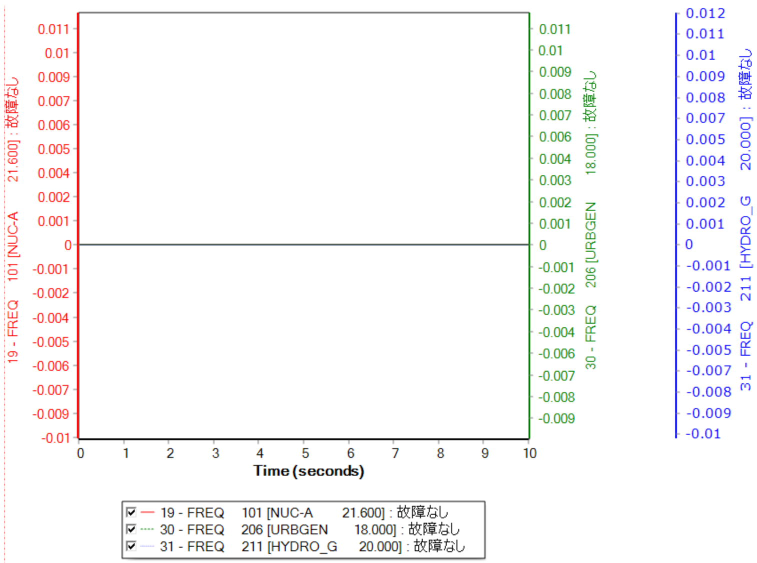
Comparison between with and without fault

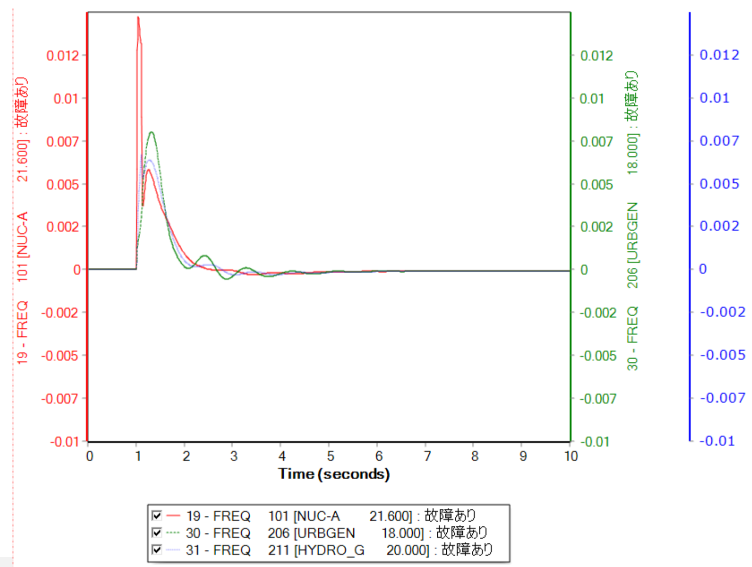
Generator output





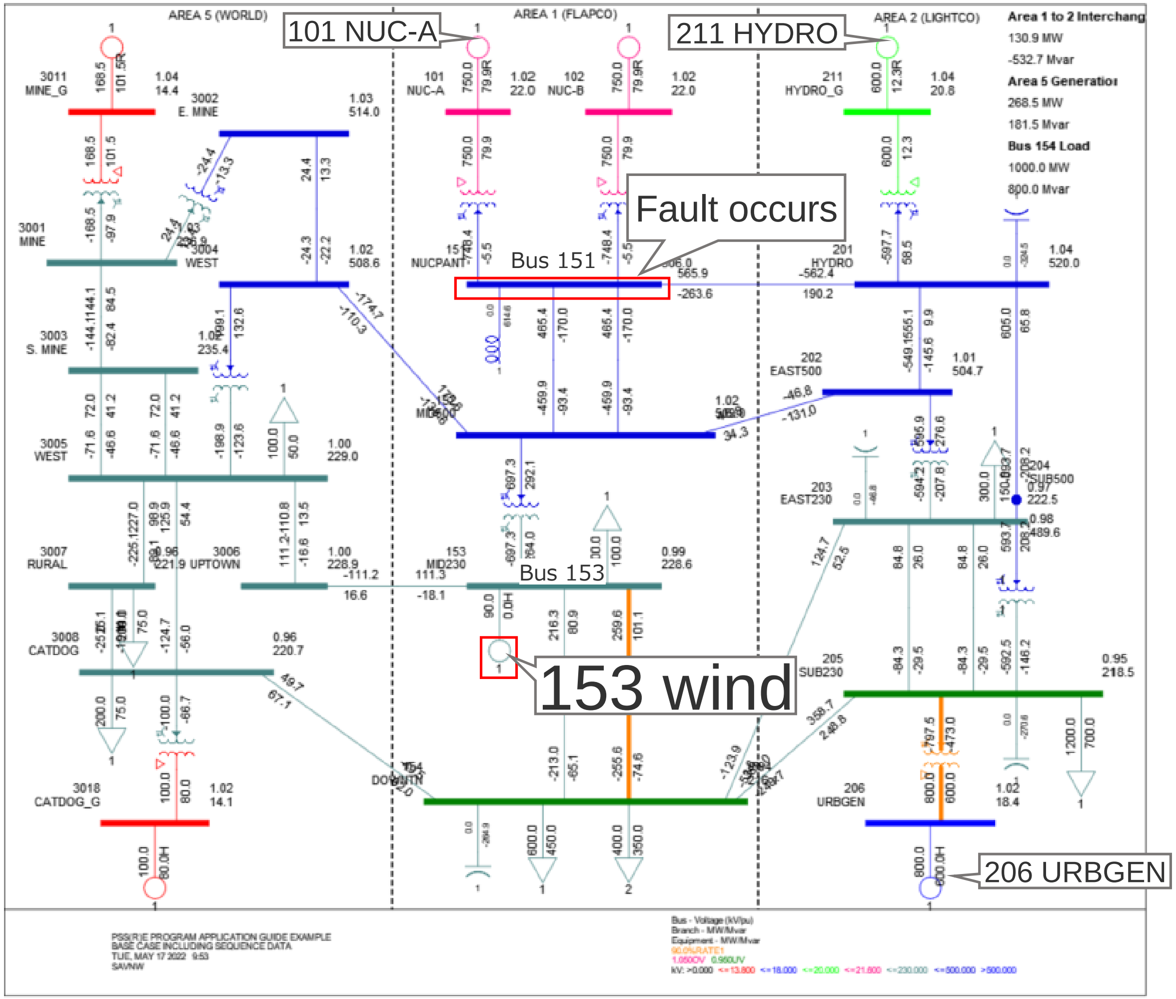
frequency





Wind model Assumption

- Base case is Siemens sample model
- Fault at No.151 Bus

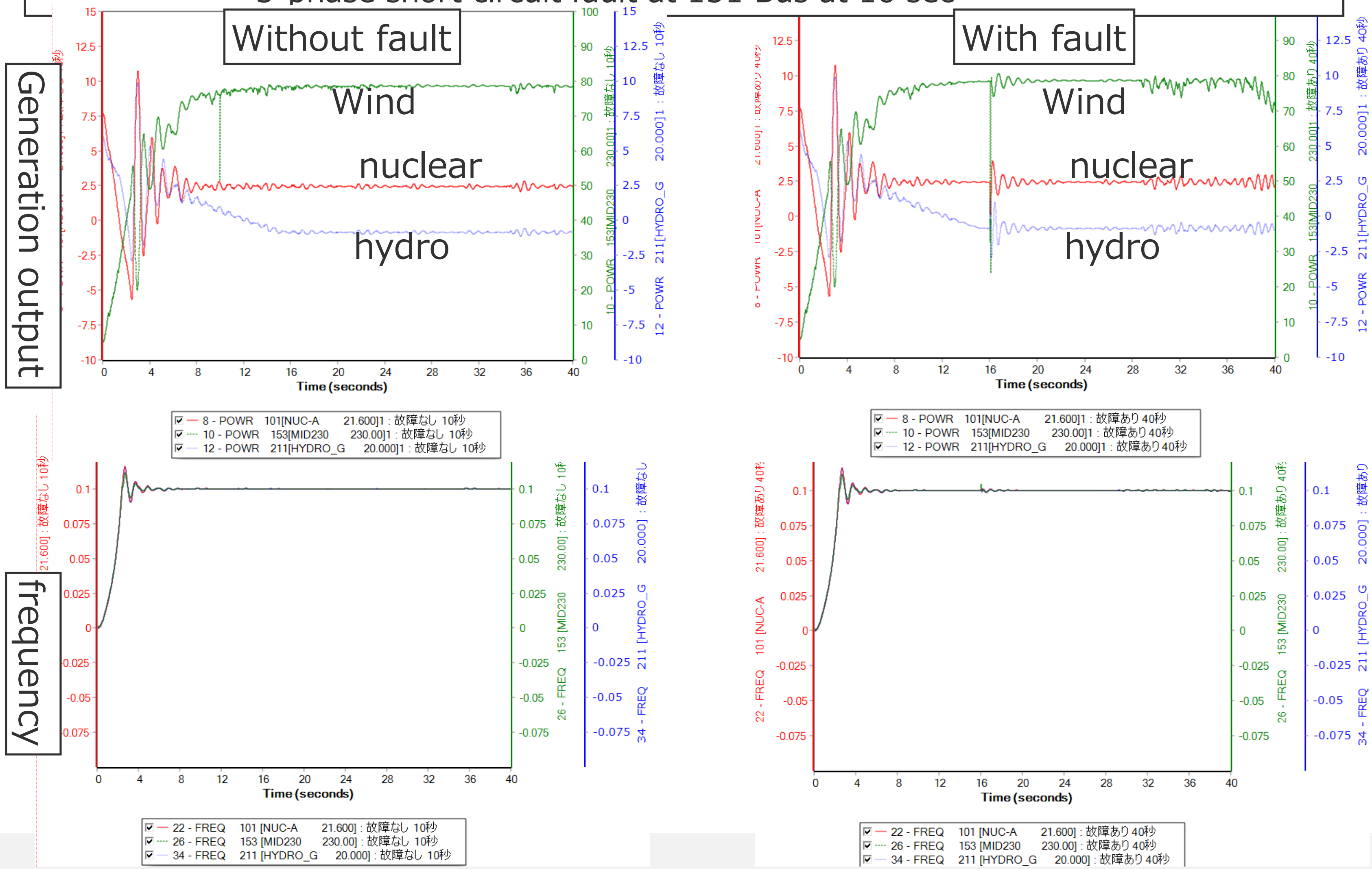


Wind model

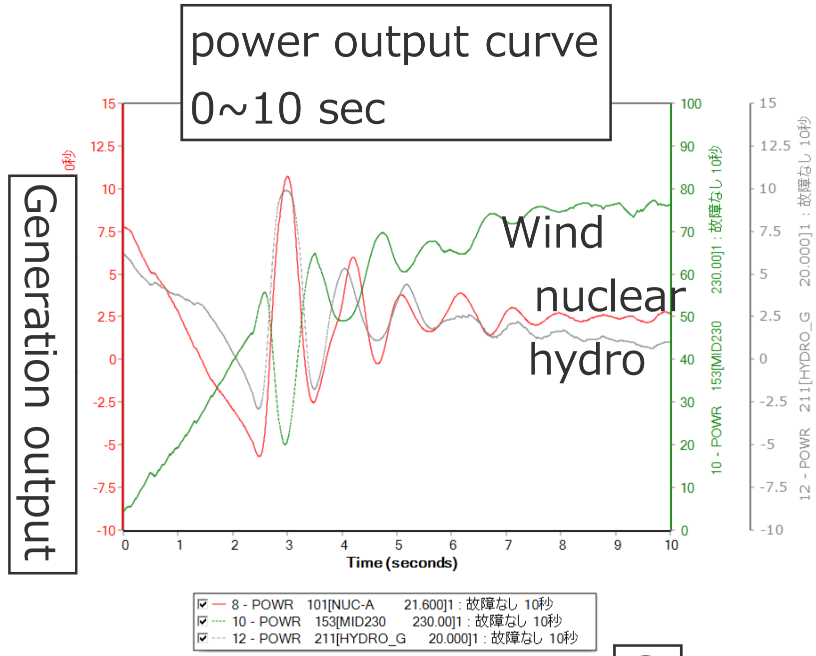
Model : Generator model : WT3G1, Electrical Control Model : WT3E1

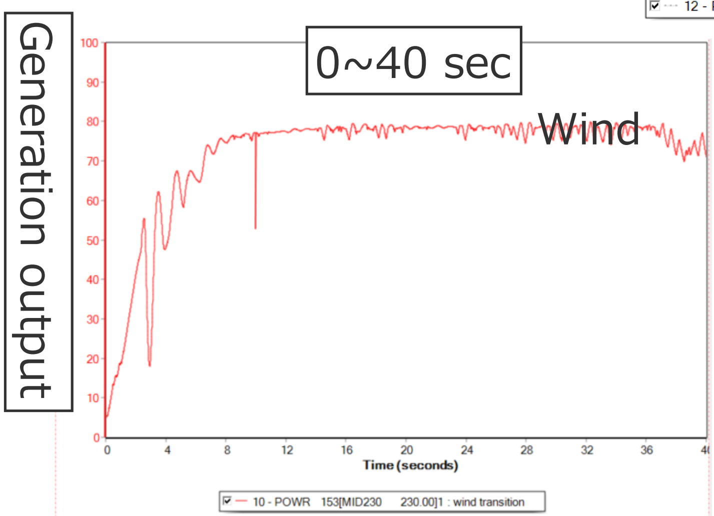
(1) Exercise -90 MW wind power connection to MID230 Bus (230kV)

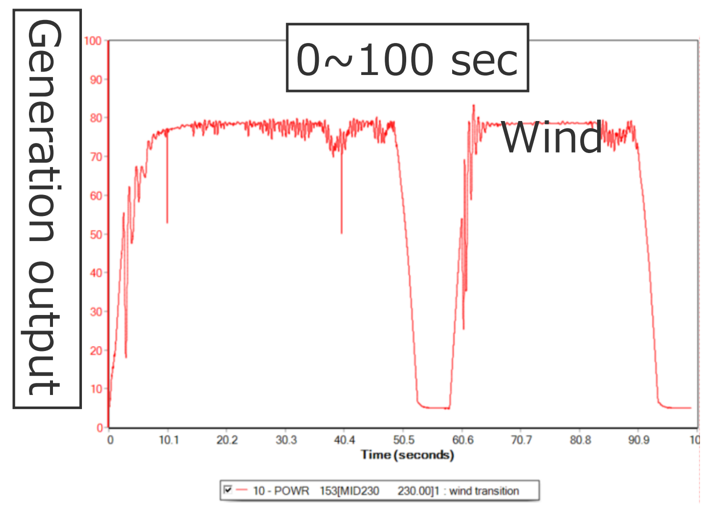
-3-phase short circuit fault at 151 Bus at 16 sec



For reference







PV model (Output fluctuation model due to solar radiation fluctuation)

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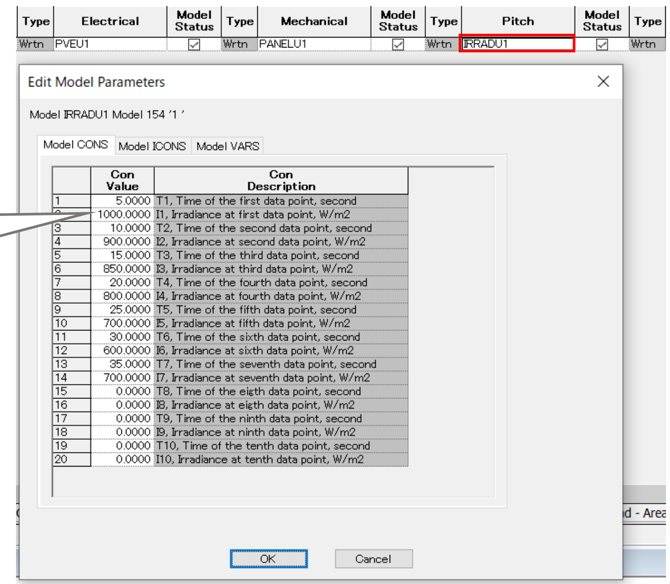
■ Dynamics Simulation

1. File > Open > File
   Select “savnw_PV_battery.sav”
   Select “savnw_PV_battery.sld”
   Select “savnw_PV_battery.dyr”
   Click “OK”
2. Power Flow > Solution > Solve
   Click “Solve”
   Click “Close”
3. Dynamics > Channel Setup Wizard
   Click “Go”
   Click “Close”
4. Dynamics > Simulation
   > Perform simulation (STRT/RUN)
   Click “OK”
   Input “pv1” for Channel output file
   Click “Initialize”
   Input “40.0” for Run to
   Click “Run”
5. File > Open > File
   Select “pv1.out”

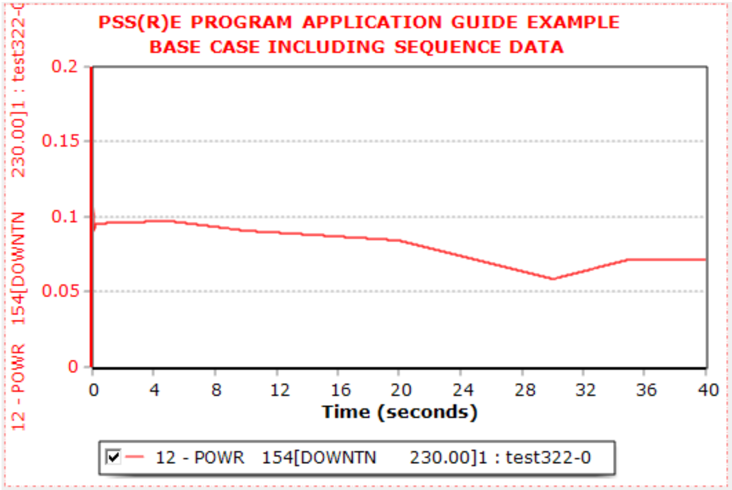
■ Irradiance model

Solar irradiance setting time by time



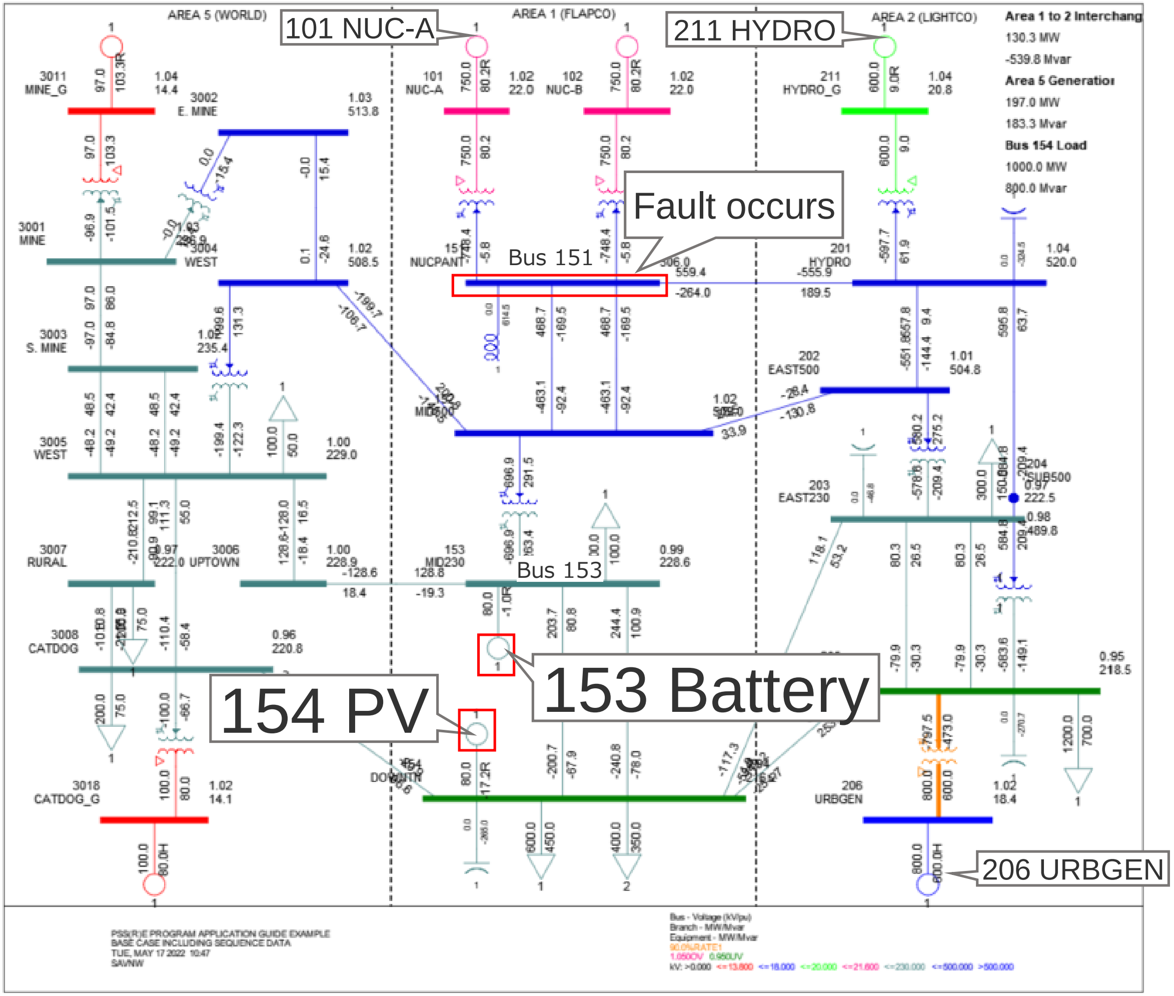
	Con Value	Con Description
1	5.0000	T1, Time of the first data point, second
2	1000.0000	I1, Irradiance at first data point, W/m2
3	10.0000	T2, Time of the second data point, second
4	900.0000	I2, Irradiance at second data point, W/m2
5	15.0000	T3, Time of the third data point, second
6	850.0000	I3, Irradiance at third data point, W/m2
7	20.0000	T4, Time of the fourth data point, second
8	800.0000	I4, Irradiance at fourth data point, W/m2
9	25.0000	T5, Time of the fifth data point, second
10	700.0000	I5, Irradiance at fifth data point, W/m2
11	30.0000	T6, Time of the sixth data point, second
12	600.0000	I6, Irradiance at sixth data point, W/m2
13	35.0000	T7, Time of the seventh data point, second
14	700.0000	I7, Irradiance at seventh data point, W/m2
15	0.0000	T8, Time of the eigth data point, second
16	0.0000	I8, Irradiance at eigth data point, W/m2
17	0.0000	T9, Time of the ninth data point, second
18	0.0000	I9, Irradiance at ninth data point, W/m2
19	0.0000	T10, Time of the tenth data point, second
20	0.0000	I10, Irradiance at tenth data point, W/m2

■ Result (pv1.out)



PV+Battery model Assumption

- Base case is Siemens sample model
- Fault at No.151 Bus



PV + Battery model

(1) Model

-PV : PVGU1, PVEU1, PANELU1, IRRADU1

-Battery : CBEST

(2) Exercise

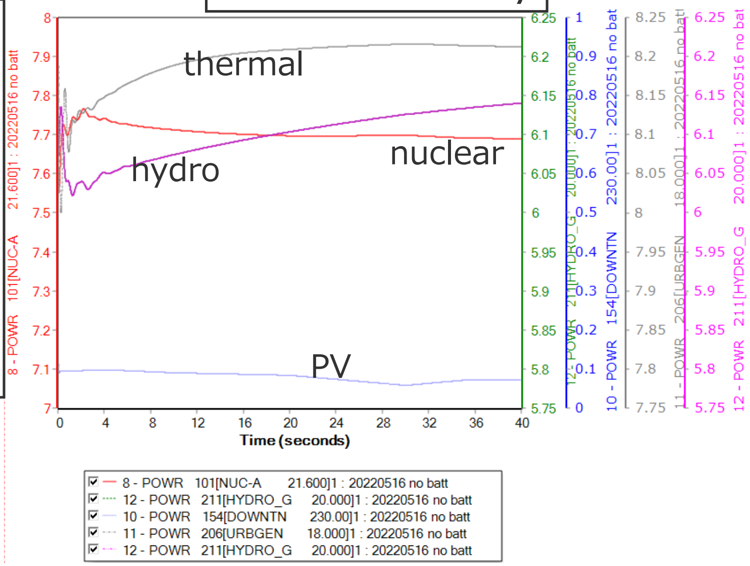
-80 MW PV connection to MID230 Bus (230kV)

-80 MW Battery connection to DOWNTN (154kV)

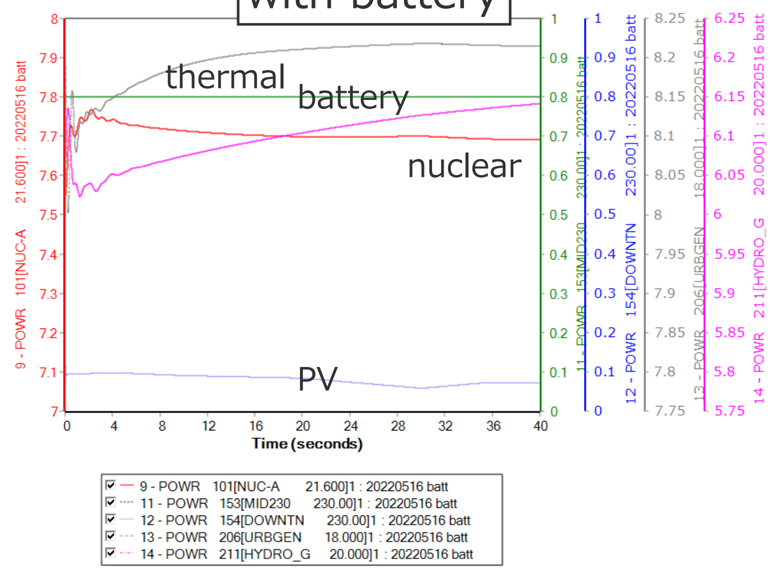
-The same procedure as previous one. 3-phase short circuit fault at 151 Bus.

Generation output

without battery



with battery



03 Short Circuit calculation (how to protect power system even though mass introduction of RE)

Short Circuit Calculation Procedure(on SLD screen)

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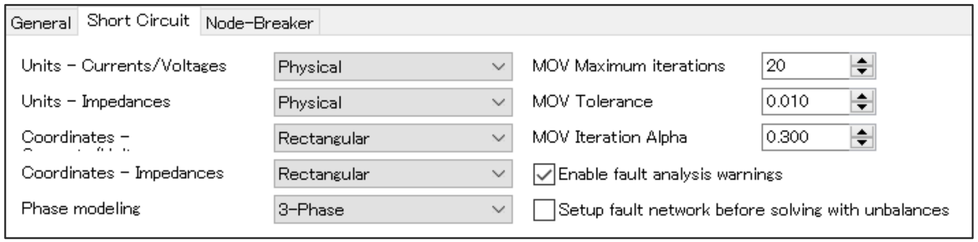
1. Calculate power flow

2. Input 0s for zero sequence data and negative sequence data

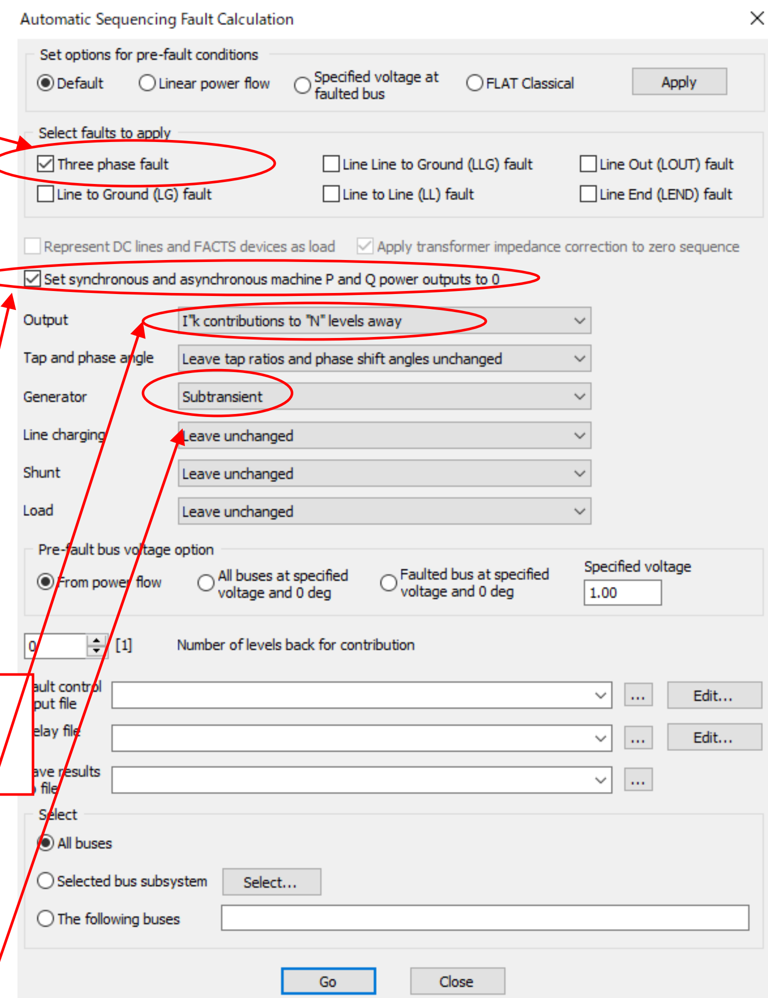
Three phase fault

3. Misc > OPTN



Select "Physical" for short circuit output
Select "Polar" for short circuit coordinated
Select "3-phase" for short circuit phase modeling

4. Fault > Automatic Sequencing Fault Calculation (ASCC)



- Normally, "Polar" to see absolute value
- This time, set "Rectangular" to see positive and reactive part.

- "Check" for NCSFC
- When considering Generator P,Q, "Uncheck"

- To see only result, "Fault current summary table"
- This time, to see detail, "I"k contributions to "N" levels away"

Subtransient

NCSFC (Result)

■ Case : WF_base.sav
(Considering synchronous and asynchronous machine P and Q power)

```
AT BUS      1     [FARM MV     33.000] AREA    1  *** FAULTED BUS IS:      1     [FARM MV     33.000] ***   0 LEVELS AWAY ***
PRE  FAULT (kV L-G)  VA:18.10+j0.22
POST FAULT (kV L-G)  V+:0.00+j0.00  VA:0.00+j0.00  VB:0.00+j0.00  VC:0.00+j0.00
THEVENIN IMPEDANCE, X/R  (PU)  Z+:0.002167+j0.218856, 101.00845
                                                   X---------------------------------------THREE PHASE FAULT--------------------------------------X
X---------- FROM ------------X AREA CKT I/Z         RE(I+)    IM(I+)   RE(IA)    IM(IA)   RE(IB)    IM(IB)   RE(IC)    IM(IC)   RE(Z+)    IM(Z+)   APP X/R
SYNCHRONOUS MACHINE                  1   AMP/PU      165.7       2.0    165.7       2.0    -81.2    -144.5    -84.6     142.6
     3     [POC MV       33.000]     1 @1  AMP/PU        0.3   -7593.6      0.3   -7593.6  -6576.4    3796.5   6576.1    3797.0 0.000000 0.000000   0.00000
INITIAL SYM. S.C. CURRENT(I''k)(RMS)       AMP       166.0   -7591.6    166.0   -7591.6  -6657.5    3652.0   6491.5    3939.6
                      I''k (MAG/ANG)       AMP      7593.4    -88.75   7593.4    -88.75   7593.4    151.25   7593.4     31.25
------------------------------------------------------------------------------------------------------------------------------------------------------------
```

Generator Output : 9MW + 0MVAR (V=0.9499)

■ Case : WF_NCSFC.sav
(Set synchronous and asynchronous machine P and Q power outputs to 0)

```
AT BUS      1     [FARM MV     33.000] AREA    1  *** FAULTED BUS IS:      1     [FARM MV     33.000] ***   0 LEVELS AWAY ***
PRE  FAULT (kV L-G)  VA:17.90+j0.02
POST FAULT (kV L-G)  V+:0.00+j0.00  VA:0.00+j0.00  VB:0.00+j0.00  VC:0.00+j0.00
THEVENIN IMPEDANCE, X/R  (PU)  Z+:0.002167+j0.218857, 101.00823
                                                   X---------------------------------------THREE PHASE FAULT--------------------------------------X
X---------- FROM ------------X AREA CKT I/Z         RE(I+)    IM(I+)   RE(IA)    IM(IA)   RE(IB)    IM(IB)   RE(IC)    IM(IC)   RE(Z+)    IM(Z+)   APP X/R
NON-CONVENTIONAL FAULT SOURCE        1   AMP/PU        0.0    -192.5      0.0    -192.5   -166.7      96.2    166.7      96.2
     3     [POC MV       33.000]     1 @1  AMP/PU     -177.7   -7604.6   -177.7   -7604.6  -6496.9    3956.2   6674.6    3648.4 0.000000 0.000000   0.00000
INITIAL SYM. S.C. CURRENT(I''k)(RMS)       AMP       -90.2   -7700.8    -90.2   -7700.8  -6624.0    3928.5   6714.2    3772.3
                      I''k (MAG/ANG)       AMP      7701.4    -90.67   7701.4    -90.67   7701.4    149.33   7701.4     29.33
```

0MW + 11 MVAR (Rated Capacity 10MVA×1.1)

Comparison of Short-Circuit Calculation

	PSS@E *	Chubu Electric Power
Reactance of Generator	• Xd" (Xd', Xd)	• Xd' (Xd" is used for calculation of electromagnetic induction voltage)
P, Q of Generator (Conventional Machine)	• Add P to active current & Add Q to reactive current (Based on the steady- state power flow calculation) • Not considered	• Not considered
P, Q of Generator (Inverter)	• Add P to active current & Add Q to reactive current (Based on the steady- state power flow calculation) • Voltage dependent (Per unit of rated current) • Time dependent	• Add rated current of inverter times X to reactive current (Grid Interconnection Rule in Japan : X=1.1 ~1.5)
Terminal Voltage of Generator	• Vt : Result of power flow calculation • Vt = Specified Voltage (e.g. 1.0pu)	• Vt = 1.0pu

* PSS@E has many other optional functions for short circuit calculations.

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PSS/E Renewable Energy Model

Sep, 2022

Chubu Electric Power Co., Inc.
Nippon Koei Co., Ltd.

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3. 2nd generation RE model
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4. SIM result example
    1. frequency control
    2. voltage control

PSS/E Renewable Energy Model overview

IEEE 1547 Evolution of Grid Support Functions

IEEE 1547-2003

- **Shall NOT** actively regulate voltage
- **Shall trip** on abnormal voltage/frequency.

IEEE 1547a-2014 (Amendment 1)

- **May** actively regulate voltage
- **May** ride-through abnormal voltage/frequency
- **May** provide frequency response[1] (frequency droop).

IEEE 1547-2018

- **Shall be capable of** actively regulating voltage
- **Shall be capable of** frequency response[2]
- **Shall ride-through** abnormal voltage/frequency
- **May** provide inertial response.[3]

First Generation Model (IEEE 1547-2003)

Second Generation Model (IEEE 1547a-2014 and IEEE 1547-2018)

[1]Frequency response is the capability to modulate power output as a function of frequency.
[2]Mandatory capability for categories II and III under high-frequency conditions, mandatory for categories II and III under low-frequency conditions, optional for Category 1
[3]Inertial response is the capability for DERs to modulate active power in proportion to the rate of change of frequency.

NREL | 24

Source : Highlights of IEEE Standard 1547-2018 (NREL) (Revised by Chubu)

Grid Support Function

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■ Second Generation

- ➢ LVRT (Low Voltage Ride Through)
- ➢ Voltage Control (Droop Control)
- ➢ Frequency Control (Droop Control)
- ➢ Momentary Cessation (Inverter Block and Recovery)

■ In the Future

- ➢ Inertia Control (Synthetic Inertia)

PSS/E Renewable Energy Model

■ First Generation

Model	Wind				PV	BESS (Battery Energy Storage System)
	W1	W2	W3	W4		
Generator /Converter	WT1G1	WT2G1	WT3G1, WT3G2	WT4G1, WT4G2	PVGU1	CBEST
Electrical Control		WT2E1	WT3E1	WT4E1, WT4E2	PVEU1	
Mechanical (Drive Train)	WT12T1		WT3T1		PANELU1 (Panel's output curve)	
Pitch Control			WT3P1		IRRADU1 (Solar irradiance profile)	
Aero Dynamic /Pseudo Governor	WT12A1					

PSS/E Renewable Energy Model

■ Second Generation

Model	Wind (W3&W4)	PV	BESS Battery Energy Storage System
Generator /Converter	REGCA1 (Current source model) REGCB (New model : Voltage source model)		
Electrical Control	REECA1 (Wind, PV)	REECA1 (Wind, PV) REECB1	REECC1
	REECDU1 (New model: Recommended for Wind, large scale PV, BESS)		
Mechanical (Drive Train)	WTDTA1, WTDTB*		
Pitch Control	WTPTA1, WTPTB*		
Aero Dynamic	WTARA1		
Torque Control	WTTQA1		
Plant Control (Auxiliary Control)	REPCA1, REPCC*		
Weak Grid	WTGWGOA* (Reduce Pref for post-fault recovery)		
IBFFR (Inertia Based Fast Frequency Response Mode)	WTGIBFFRA* (Synthetic Inertia)		

* Currently under development and/or being tested

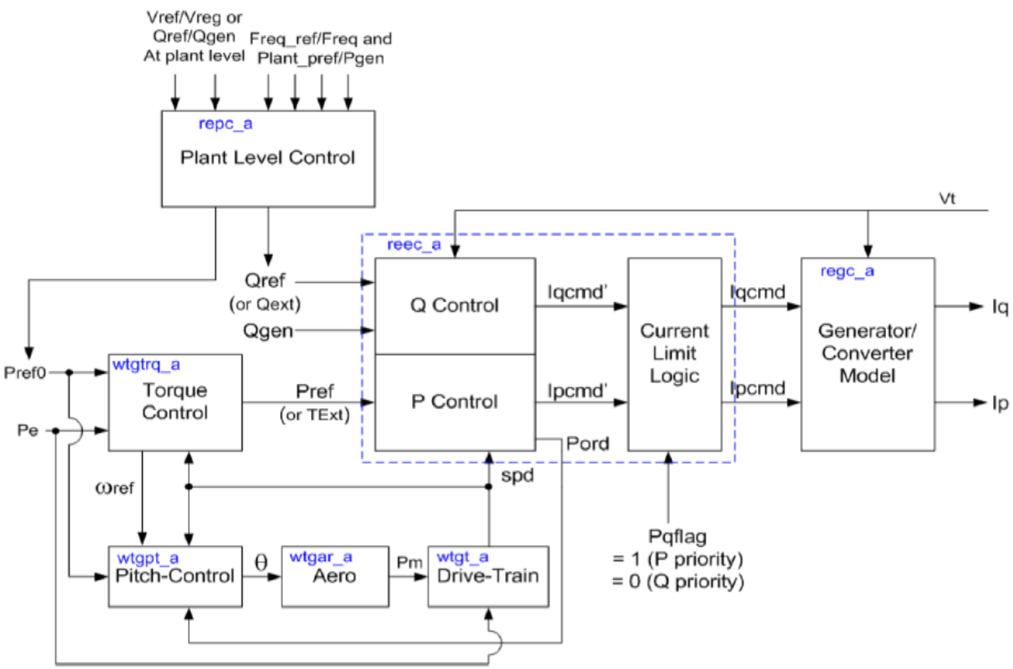
PSS/E Renewable Energy Model

■ Grid Support Function (Second Generation)

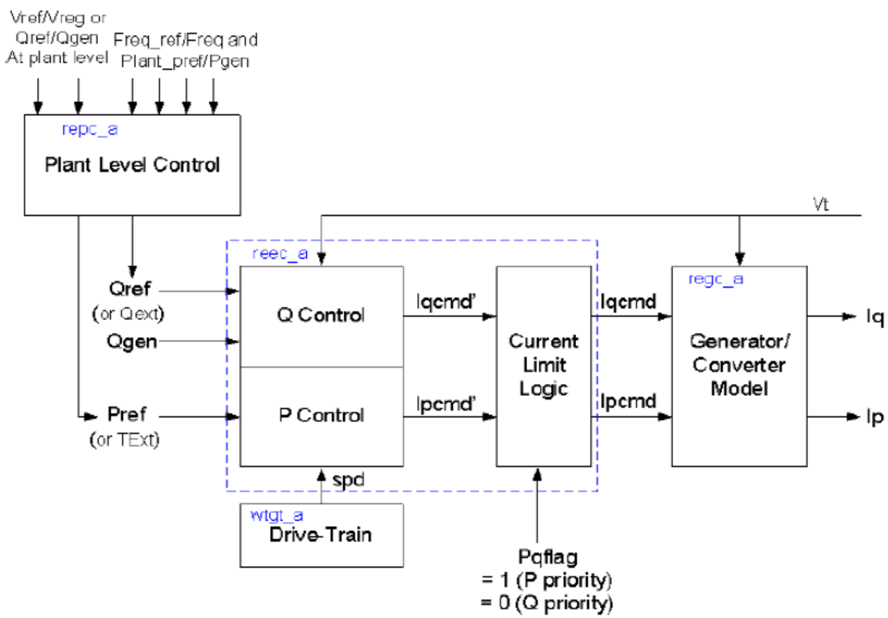
Support Function	PSS@E Model			Note
	Local (each unit)		Plant Level (Total units)	
	Inverter	Electrical		
LVRT (Low Voltage Ride Through)	REGCA1 (by LVPL(Low Votage Power Logic))	REECA1, REECC1, EECDU1 (by VDL(Voltage Dependent Limit))		If VDL is used, LVPL should be off.
Voltage Control		REECA1, REECB1, REECC1, REECDU1	REPCA1	Droop control (PI control)
Frequency Control			REPCA1	Droop control (PI control)
Momentary Cessation (Inverter Block and Recovery)		REECA1, REECC1 (by VDL)		REECA1 : Delay in P Recovery (using Thld2)
		REECDU1 (by Vblkl , Vblkh)		Delay in PQ Recovery (using Tblk)
Inertia Control (Synthetic Inertia)		WTGIBFFRA*		Under development

Wind Power Generic Model schematic

Type 3

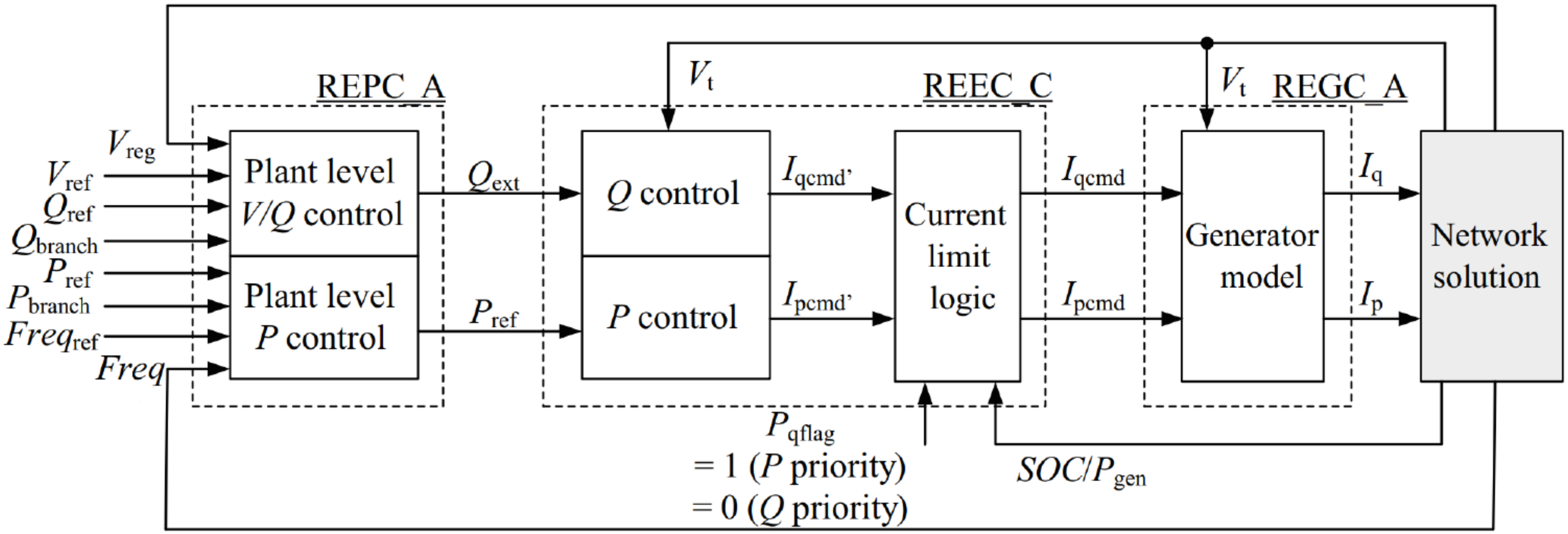


Type 4



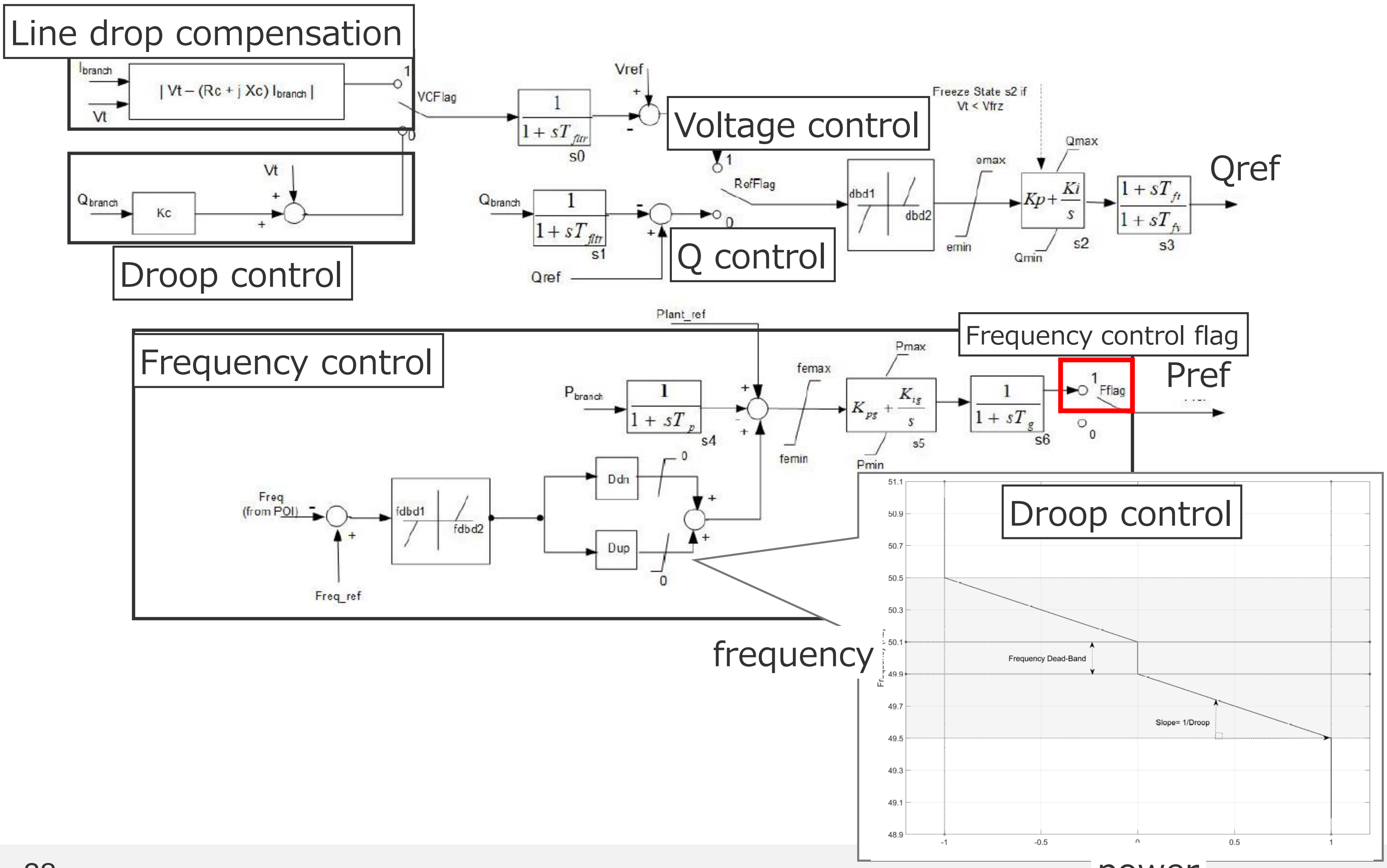
Source: Siemens 19-21 June 2018 | European PSS® UGM

BESS Generic Model schematic



Source: Wecc battery storage dynamic modeling guideline

Plant Control model (REPCA1 (Wind, PV, Battery))



Plant Control model (REPCA1 (Wind, PV, Battery))

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ICONs	Value	Description
M		Bus number for voltage control; local control if 0
M+1		Monitored branch FROM bus number for line drop compensation (if 0 generator power will be used)
M+2		Monitored branch TO bus number for line drop compensation (if 0 generator power will be used)
M+3		Branch circuit id for line drop compensation (enter in single quotes) (if 0 generator power will be used)
M+4		VC Flag (droop flag): • 0: with droop if power factor control • 1: with line drop compensation
M+5		RefFlag (flag for V or Q control): • 0: Q control • 1: voltage control
M+6		Fflag (flag to disable frequency control): • 1: enable control • 0: disable

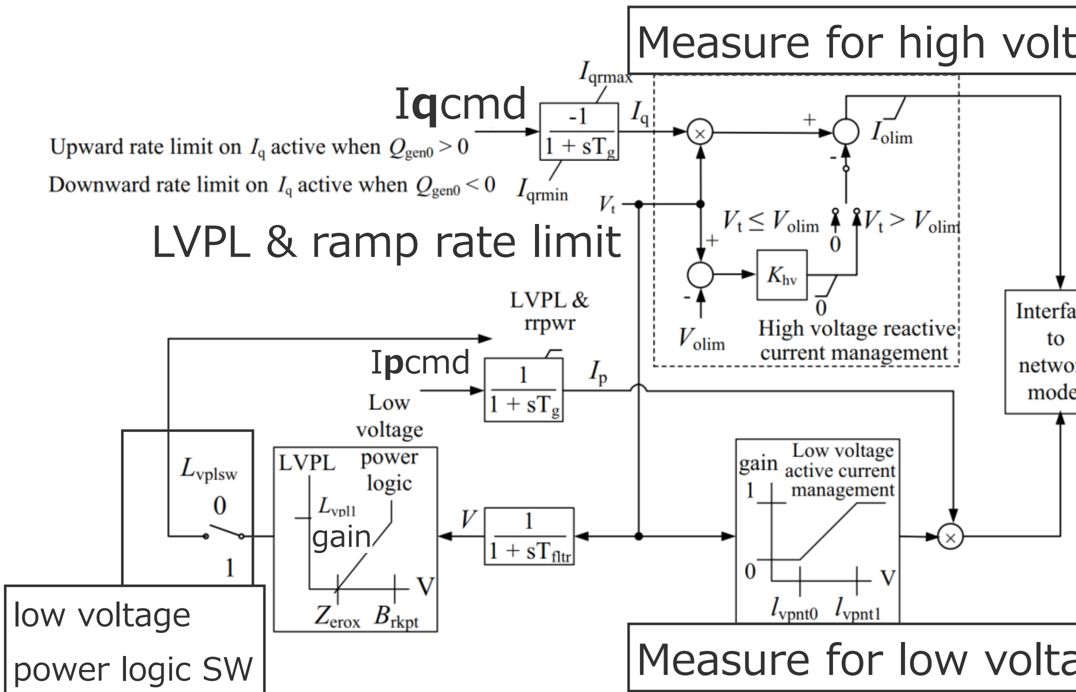
CONs	Value	Description
J		Tfltr, Voltage or reactive power measurement filter time constant (s)
J+1		Kp, Reactive power PI control proportional gain (pu)
J+2		Ki, Reactive power PI control integral gain (pu)
J+3		Tft, Lead time constant (s)
J+4		Tfv, Lag time constant (s)
J+5		Vfrz, Voltage below which State s2 is frozen (pu)
J+6		Rc, Line drop compensation resistance (pu)
J+7		Xc, Line drop compensation reactance (pu)
J+8		Kc, Reactive current compensation gain (pu)
J+9		emax, upper limit on deadband output (pu)
J+10		emin, lower limit on deadband output (pu)
J+11		dbd1, lower threshold for reactive power control deadband (<=0)
J+12		dbd2, upper threshold for reactive power control deadband (>=0)
J+13		Qmax, Upper limit on output of V/Q control (pu)
J+14		Qmin, Lower limit on output of V/Q control (pu)
J+15		Kpg, Proportional gain for power control (pu)
J+16		Kig, Integral gain for power control (pu)

CONs	Value	Description
J+17		Tp, Real power measurement filter time constant (s)
J+18		fdbd1, Deadband for frequency control, lower threshold (specified as per unit frequency deviation) (<=0)
J+19		fdbd2, Deadband for frequency control, upper threshold (specified as per unit frequency deviation) (>=0)
J+20		femax, frequency error upper limit (pu)
J+21		femin, frequency error lower limit (pu)
J+22		Pmax, upper limit on power reference (pu)
J+23		Pmin, lower limit on power reference (pu)
J+24		Tg, Power Controller lag time constant (s)
J+25		Ddn, reciprocal of droop for over-frequency conditions (pu)
J+26		Dup, reciprocal of droop for under-frequency conditions (pu)

STATEs	Description
K	Voltage Measurement filter
K+1	Reactive power control filter
K+2	PI controller for reactive power
K+3	Lead-lag in reactive power path
K+4	Real power filter
K+5	PI controller for real power
K+6	Power controller first order lag

VARs	Description
L	Reference for voltage control (Vref)
L+1	Reactive power reference (Qref)
L+2	Frequency reference (Freq_ref)
L+3	Active Power reference (Plant_pref)
L+4	Line flow P MW
L+5	Line flow Q MVAr
L+6	Line flow MVA
L+7	Q/V Deadband output
L+8	Frequency deadband output

Generator model (REGCA1 (Wind, PV, Battery))



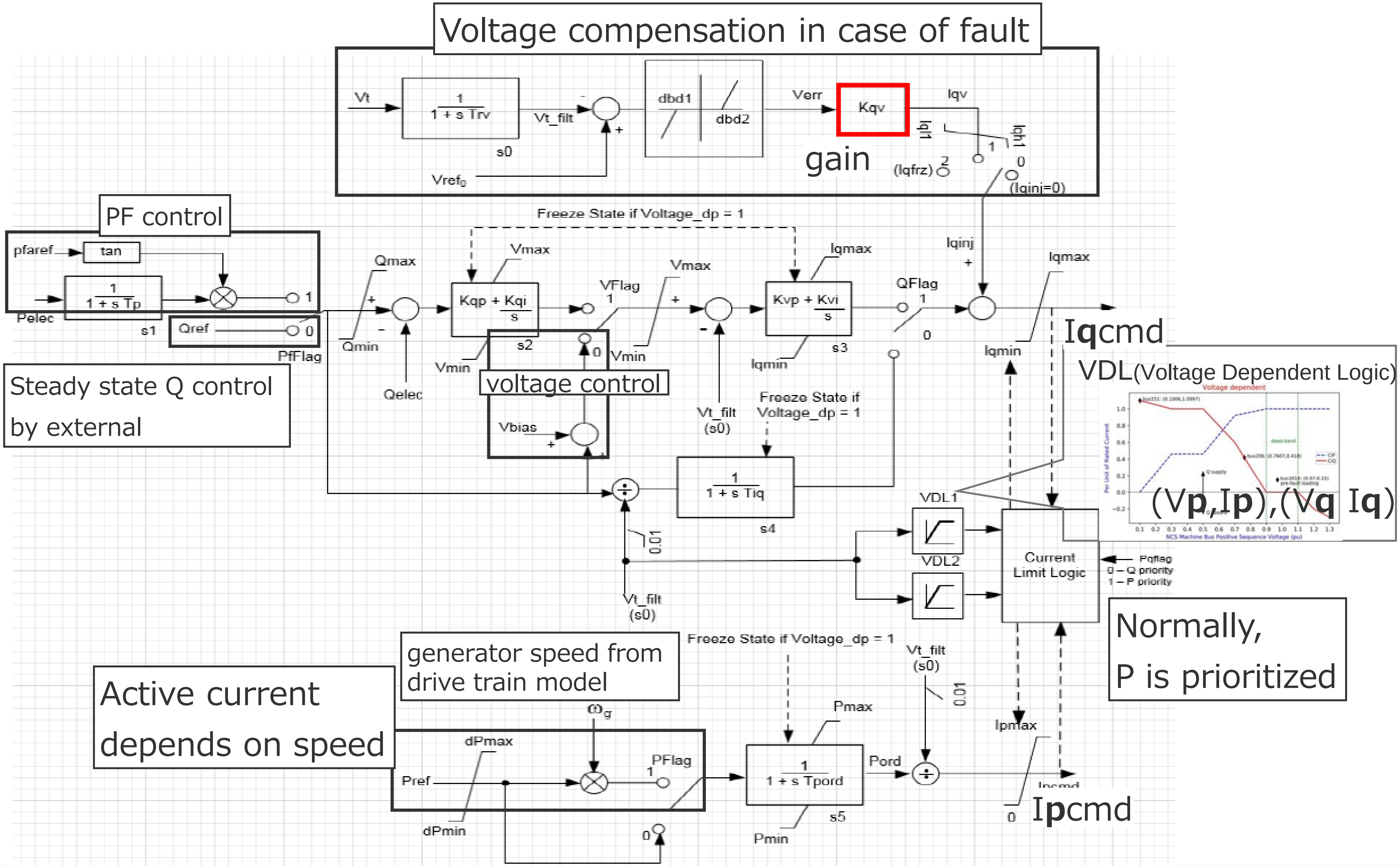
ICON	Value	Description
M		Lvplsw (Low Voltage Power Logic) switch (0: LVPL not present, 1:LVPL present)

CONS	Value	Description
J		T_g, Converter time constant (s)
J+1		Rrpwr, Low Voltage Power Logic (LVPL) ramp rate limit (pu/s)
J+2		Brkpt, LVPL characteristic voltage 2 (pu)
J+3		Zerox, LVPL characteristic voltage 1 (pu)
J+4		Lvpl1, LVPL gain (pu)
J+5		Volim, Voltage limit (pu) for high voltage reactive current management
J+6		Lvpnt1, High voltage point for low voltage active current management (pu)
J+7		Lvpnt0, Low voltage point for low voltage active current management (pu)
J+8		Iolim, Current limit (pu) for high voltage reactive current management (specified as a negative value)
J+9		Tfltr, Voltage filter time constant for low voltage active current management (s)
J+10		Khv, Overvoltage compensation gain used in the high voltage reactive current management
J+11		Iqrmax, Upper limit on rate of change for reactive current (pu)
J+12		Iqrmin, Lower limit on rate of change for reactive current (pu)
		Accel, acceleration factor (0 < Accel <= 1)

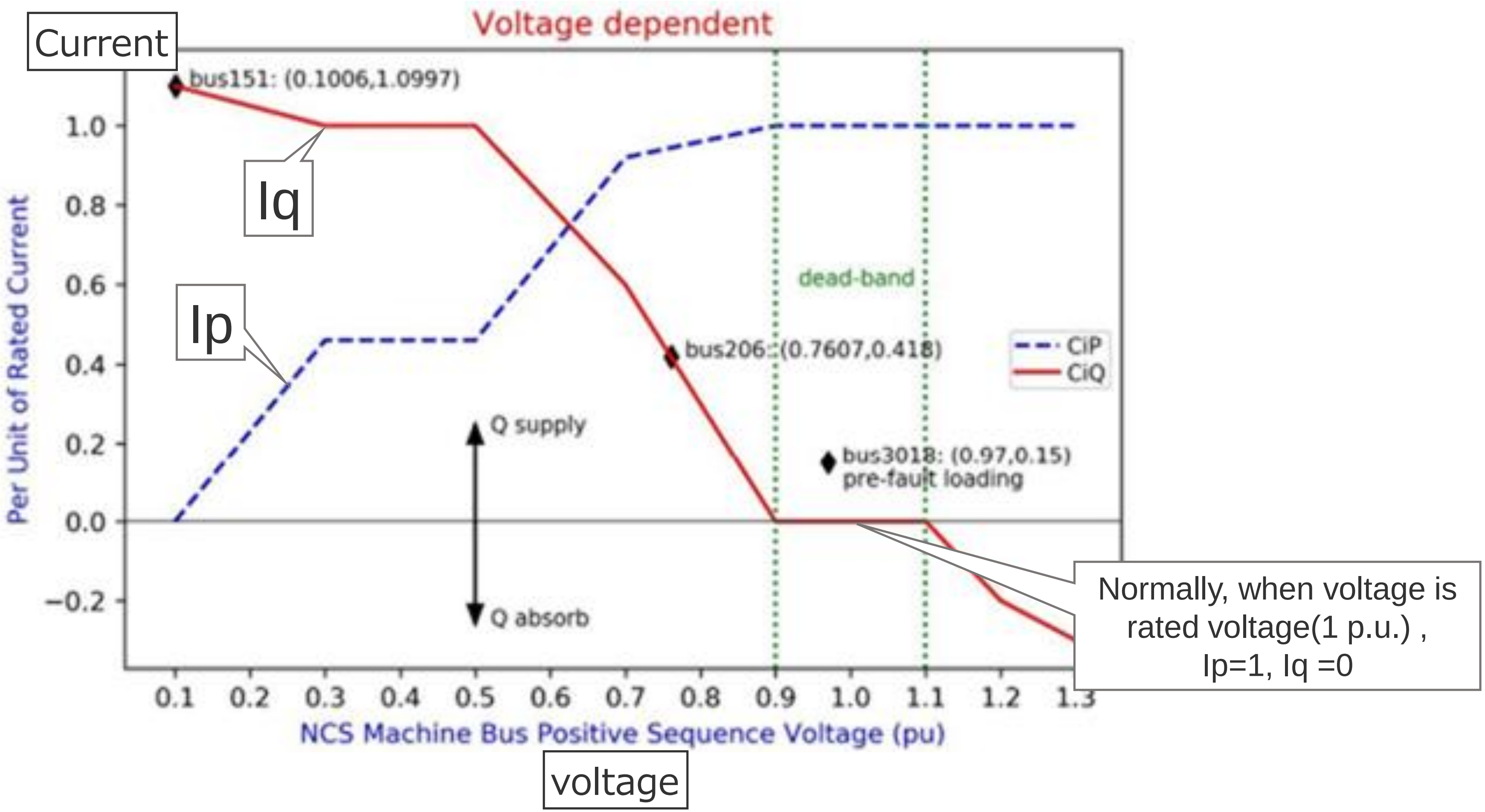
STATEs	Description
K	Converter lag for Ipcmd
K+1	Converter lag for Iqcmd
K+2	Voltage filter for low voltage active current management

VARs	Description
L	Previous terminal voltage
L+1	Previous terminal voltage angle
L+2	Reactive current overvoltage correction
L+3	Initial machine reactive power from power flow

Electrical Control model (REECA1 (Wind, PV))



VDL(Voltage Dependent Logic)



In case of voltage drop, Ip is reduced and Iq is increased

Electrical Control model (REECA1 (Wind, PV))

ICONs	Value	Description
M		Bus number for voltage control; local control if 0
M+1		PFFLAG: • 1 if power factor control • 0 if Q control (which can be controlled by an external signal)
M+2		VFLAG: • 1 if Q control • 0 if voltage control
M+3		QFLAG: • 1 if voltage or Q control • 0 if constant pf or Q control
M+4		PFLAG: • 1 if active current command has speed dependency • 0 for no dependency
M+5		PQFLAG, P/Q priority flag for current limit: • 0 for Q priority • 1 for P priority

CONs	Value	Description
J		Vdip (pu), low voltage threshold to activate reactive current injection logic
J+1		Vup (pu), Voltage above which reactive current injection logic is activated
J+2		Trv (s), Voltage filter time constant
J+3		dbd1 (pu), Voltage error dead band lower threshold (≤0)
J+4		dbd2 (pu), Voltage error dead band upper threshold (≥0)
J+5		Kqv (pu), Reactive current injection gain during over and undervoltage conditions
J+6		Iqh1 (pu), Upper limit on reactive current injection Iqinj
J+7		Iql1 (pu), Lower limit on reactive current injection Iqinj
J+8		Vref0 (pu), User defined reference (if 0, model initializes it to initial terminal voltage)
J+9		Iqfrz (pu), Value at which Iqinj is held for Thld seconds following a voltage dip if Thld > 0

CONs	Value	Description
J+10		Thld (s), Time for which Iqinj is held at Iqfrz after voltage dip returns to zero (see Note 3)
J+11		Thld2 (s) (≥0), Time for which the active current limit (IPMAX) is held at the faulted value after voltage dip returns to zero
J+12		Tp (s), Filter time constant for electrical power
J+13		QMax (pu), limit for reactive power regulator
J+14		QMin (pu) limit for reactive power regulator
J+15		VMAX (pu), Max. limit for voltage control
J+16		VMIN (pu), Min. limit for voltage control
J+17		Kqp (pu), Reactive power regulator proportional gain
J+18		Kqi (pu), Reactive power regulator integral gain
J+19		Kvp (pu), Voltage regulator proportional gain
J+20		Kvi (pu), Voltage regulator integral gain
J+21		Vbias (pu), User-defined bias (normally 0)
J+22		Tiq (s), Time constant on delay s4
J+23		dPmax (pu/s) (>0) Power reference max. ramp rate
J+24		dPmin (pu/s) (<0) Power reference min. ramp rate
J+25		PMAX (pu), Max. power limit
J+26		PMIN (pu), Min. power limit
J+27		Imax (pu), Maximum limit on total converter current
J+28		Tpord (s), Power filter time constant
J+29		Vq1 (pu), Reactive Power V-I pair, voltage
J+30		Iq1 (pu), Reactive Power V-I pair, current
J+31		Vq2 (pu) (Vq2>Vq1), Reactive Power V-I pair, voltage
J+32		Iq2 (pu) (Iq2>Iq1), Reactive Power V-I pair, current
J+33		Vq3 (pu) (Vq3>Vq2), Reactive Power V-I pair, voltage
J+34		Iq3 (pu) (Iq3>Iq2), Reactive Power V-I pair, current
J+35		Vq4 (pu) (Vq4>Vq3), Reactive Power V-I pair, voltage
J+36		Iq4 (pu) (Iq4>Iq3), Reactive Power V-I pair, current
J+37		Vp1 (pu), Real Power V-I pair, voltage
J+38		Ip1 (pu), Real Power V-I pair, current
J+39		Vp2 (pu) (Vp2>Vp1), Real Power V-I pair, voltage
J+40		Ip2 (pu) (Ip2>Ip1), Real Power V-I pair, current
J+41		Vp3 (pu) (Vp3>Vp2), Real Power V-I pair, voltage
J+42		Ip3 (pu) (Ip3>Ip2), Real Power V-I pair, current
J+43		Vp4 (pu) (Vp4>Vp3), Real Power V-I pair, voltage
J+44		Ip4 (pu) (Ip4>Ip3), Real Power V-I pair, current

Electrical Control model (REECA1 (Wind, PV))

STATEs	Description
K	Voltage Measurement filter
K+1	Real power filter
K+2	PI controller for reactive power
K+3	PI controller for voltage error
K+4	First Order lag for reactive current
K+5	First order lag for Pord

VAR	Description
L	Bus reference voltage (Vref0)
L+1	Storage of current state for state transition (possible values: 0, 1 or 2)
L+2	Power factor reference angle (pfaref), radians
L+3	user defined bias as calculated by the model
L+4	Timer for Thld counter
L+5	Previous value of power reference
L+6	Stored Ipmax value
L+7	Timer for Thld2 counter
L+8	Storage for voltage_dip (used only when Thld2 > 0)

Electrical Control model (REECA1 (Wind, PV))

1. This model can be used with Type 3 and 4 wind machines. When used for modeling of Type 3 wind machine, the other models to be used along with this model are regca1, repcta1 (optional), wtdta1,wtpta1, wtara1, wttqa1. When used for modeling of Type 4 machines, the other models to be used along with this control model are regca1, wtdta1, and repca1 (optional).

2. When used for modeling Type 3 machines set Pflag (i.e., ICON (M+4)) to 0. Speed dependency will be simulated by the Torque controller (WTTQA1).

3. Thld could be either zero, or less than zero or greater than zero.

a) If Thld > 0, then once voltage_dip (voltage_dip is a flag which is set and reset in the model. Voltage_dip is 0 if the Vdip<VT<Vup, else it is 1) becomes 0, Iqinj is held at Iqfrz for Thld seconds.

b) If Thld < 0, then once voltage_dip goes to 0, Iqinj remains state (equal to Iqv) for Thld seconds.

c) If Thld = 0 , then Iqinj goes back to zero as soon as Voltage_dip becomes 0.

4. pfaref (the power factor angle reference) value is initialized by the model based on initial real and reactive power outputs from the machine.

5. wg is the per unit generator speed and is set in the drive train model.

6. Qref is initialized by the model to a constant or can be connected to an external plant controller model).

7. Pref is initialized by the model to a constant or can be connected to an external plant controller model).

8. Normally Vbias is zero. The user specified Vbias value (which is in CON(J+21)) is used only when the QFlag=1, VFlag=0 and PfFlag=0. For all other combinations of QFlag, VFlag and PfFlag values, the Vbias value is either not required or is calculated and stored in VAR(L+3).

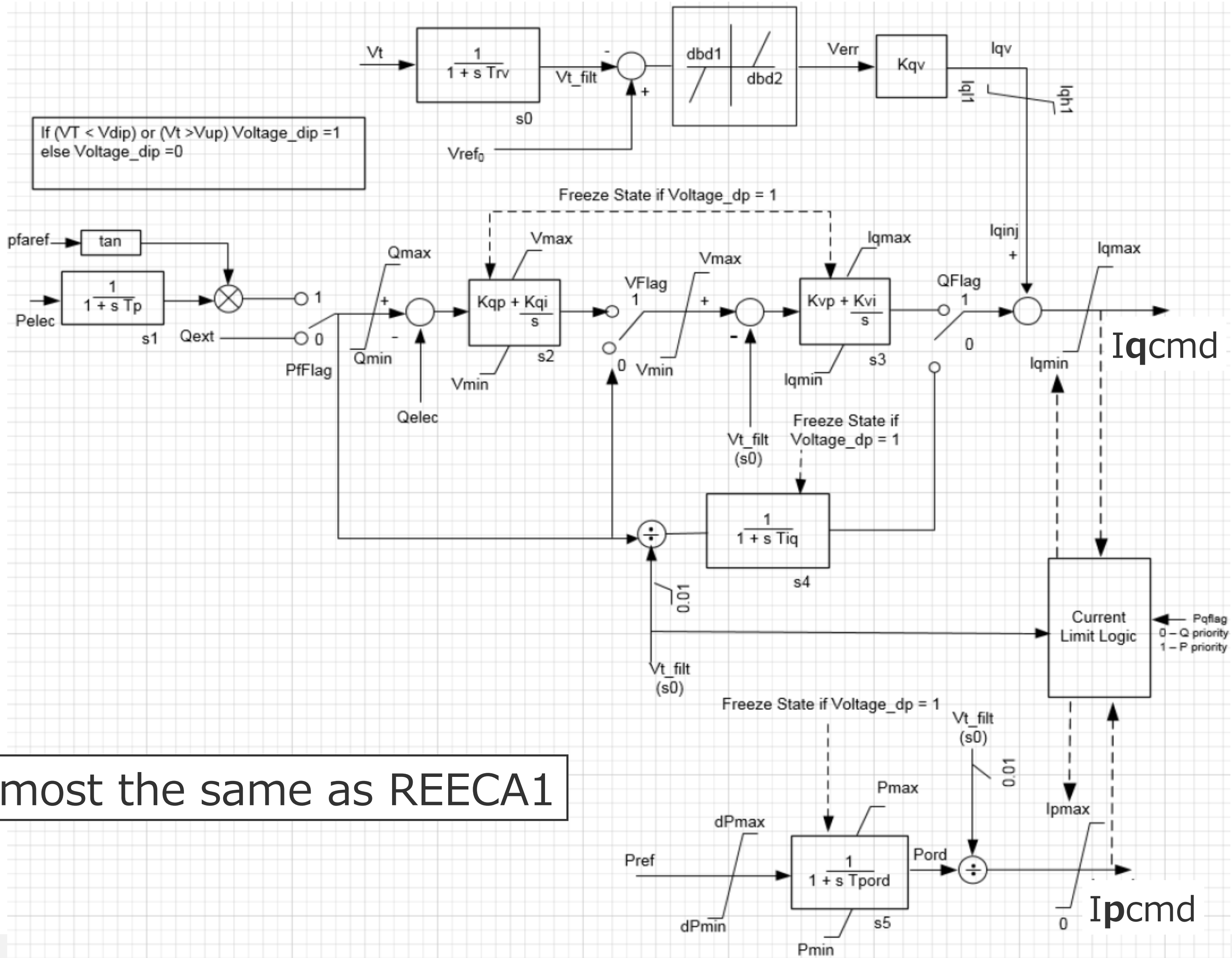
9. ICON(M) contains the remote bus number. If this is 0 or if the remote bus number is not specified then the local bus is used for control.

10. The VDL1 characteristics are defined by 4 pairs of Vq-Iq points (pu voltage versus reactive current).

Data for the first two pairs (Vq1, Iq1) and (Vq2, Iq2) is mandatory (i.e., these cannot be specified as zero). A maximum of 4 pairs of Vq-Iq points can be specified. The first Vq entry that has a zero value, signals the end of Vq-Iq data. Unused Vq- Iq pairs should be entered as zero. The Vq-Iq values should be such that Vq1 < Vq2 < Vq3 < Vq4, and Iq1 ≤ Iq2 ≤ Iq3 ≤ Iq4.

11. The VDL2 characteristics are defined by 4 pairs of Vp-Ip points (pu voltage versus active current). Data for the first two pairs (Vp1, Ip1) and (Vp2, Ip2) is mandatory (i.e., these cannot be specified as zero). A maximum of 4 pairs of Vp-Ip points can be specified. The first Vp entry that has a zero value, signals the end of Vp-Ip data. Unused Vp- Ip pairs should be entered as zero. The Vp-Ip values should be such that Vp1 < Vp2 < Vp3 < Vp4, and Ip1 ≤ Ip2 ≤ Ip3 ≤ Ip4

Electrical Control model (REECB1 (PV))



Almost the same as REECA1

Electrical Control model (REECB1 (PV))

ICONs	Value	Description
M		Bus number for voltage control; local control if 0
M+1		PFFLAG (Power factor control flag): • 1 if power factor control • 0 if Q control (which can be controlled by an external signal)
M+2		VFLAG: • 1 if Q control • 0 if voltage control
M+3		QFLAG: • 1 if voltage or Q control • 0 if constant pf or Q control
M+4		PQFLAG, P/Q priority flag for current limit: • 0 for Q priority • 1 for P priority

CONs	Value	Description
J		Vdip (pu), low voltage threshold to activate reactive current injection logic
J+1		Vup (pu), Voltage above which reactive current injection logic is activated
J+2		Trv (s), Voltage filter time constant
J+3		dbd1 (pu), Voltage error dead band lower threshold (≤0)
J+4		dbd2 (pu), Voltage error dead band upper threshold (≥0)
J+5		Kqv (pu), Reactive current injection gain during over and undervoltage conditions
J+6		Iqh1 (pu), Upper limit on reactive current injection Iqinj
J+7		Iql1 (pu), Lower limit on reactive current injection Iqinj
J+8		Vref0 (pu), User defined reference (if 0, model initializes it to initial terminal voltage)
J+9		Tp (s), Filter time constant for electrical power
J+10		QMax (pu), limit for reactive power regulator
J+11		QMin (pu) limit for reactive power regulator
J+12		VMAX (pu), Max. limit for voltage control
J+13		VMIN (pu), Min. limit for voltage control

CONs	Value	Description
J+14		Kqp (pu), Reactive power regulator proportional gain
J+15		Kqi (pu), Reactive power regulator integral gain
J+16		Kvp (pu), Voltage regulator proportional gain
J+17		Kvi (pu), Voltage regulator integral gain
J+18		Tiq (s), Time constant on delay s4
J+19		dPmax (pu/s) (>0) Power reference max. ramp rate
J+20		dPmin (pu/s) (<0) Power reference min. ramp rate
J+21		PMAX (pu), Max. power limit
J+22		PMIN (pu), Min. power limit
J+23		Imax (pu), Maximum limit on total converter current
J+24		Tpord (s), Power filter time constant

STATEs	Description
K	Voltage Measurement filter
K+1	Real power filter
K+2	PI controller for reactive power
K+3	PI controller for voltage error
K+4	First Order lag for reactive current
K+5	First order lag for Pord

VAR	Description
L	Bus reference voltage (Vref0)
L+1	Power factor reference angle (pfaref), radians
L+2	Real current command (Ipcmd)
L+3	Reactive current command (Iqcmd)

Electrical Control model (REECB1 (PV))

1. pfaref (the power factor angle reference) value is initialized by the model based on initial real and reactive power outputs from the machine.

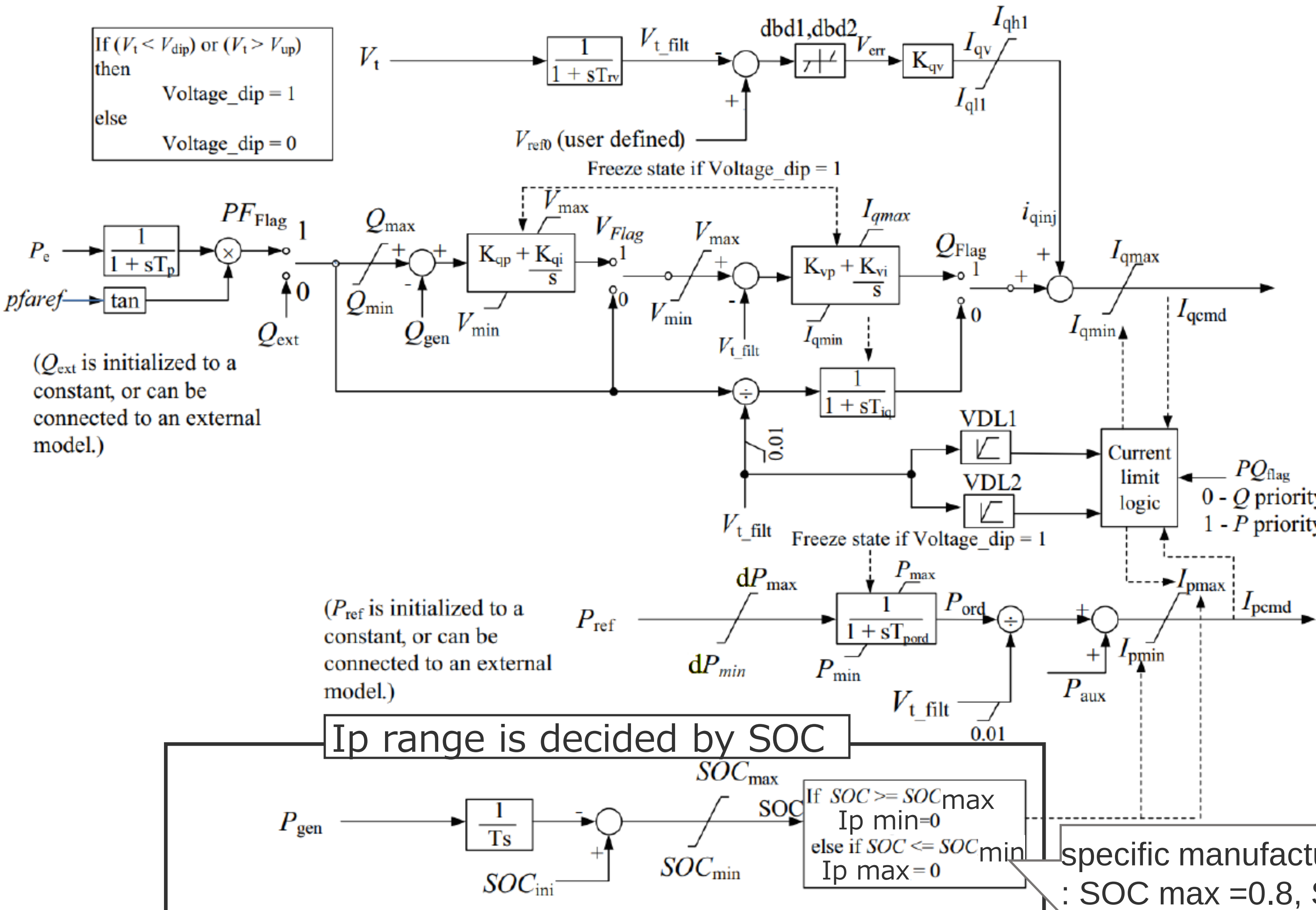
2. Qref is initialized by the model to a constant or can be connected to an external plant controller model).

3. Pref is initialized by the model to a constant or can be connected to an external plant controller model).

4. ICON(M) contains the remote bus number. If this is 0 or if the remote bus number is not specified then the local bus is used for control.

5. In using REECB1 to model large scale PV, the other models to be used along with this model are REGCA1 and REPCA1 (optional)

Electrical Control model (REECCU1(Battery))



specific manufacturer requirements
: SOC max =0.8, SOC min = 0.2

Full charge → discharge
Empty →charge

Electrical Control model (REECCU1(Battery))

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ICONs	Value	Description
M		Bus number for voltage control; local control if 0
M+1		PFFLAG (Power factor control flag): • 1 if power factor control • 0 if Q control (which can be controlled by an external signal)
M+2		VFLAG: • 1 if Q control • 0 if voltage control
M+3		QFLAG: • 1 if voltage or Q control • 0 if constant pf or Q control
M+5		PQFLAG, P/Q priority flag for current limit: • 0 for Q priority • 1 for P priority

CONs	Value	Description
J		Vdip (pu), low voltage threshold to activate reactive current injection logic
J+1		Vup (pu), Voltage above which reactive current injection logic is activated
J+2		Trv (s), Voltage filter time constant
J+3		dbd1 (pu), Voltage error dead band lower threshold (≤0)
J+4		dbd2 (pu), Voltage error dead band upper threshold (≥0)
J+5		Kqv (pu), Reactive current injection gain during over and undervoltage conditions
J+6		Iqh1 (pu), Upper limit on reactive current injection Iqinj
J+7		Iql1 (pu), Lower limit on reactive current injection Iqinj
J+8		Vref0 (pu), User defined reference (if 0, model initializes it to initial terminal voltage)
J+9		Tp (s), Filter time constant for electrical power
J+10		QMax (pu), limit for reactive power regulator
J+11		QMin (pu) limit for reactive power regulator
J+12		VMAX (pu), Max. limit for voltage control
J+13		VMIN (pu), Min. limit for voltage control
J+14		Kqp (pu), Reactive power regulator proportional gain

CONs	Value	Description
J+15		Kqi (pu), Reactive power regulator integral gain
J+16		Kvp (pu), Voltage regulator proportional gain
J+17		Kvi (pu), Voltage regulator integral gain
J+18		Tiq (s), Time constant on delay s4
J+19		dPmax (pu/s) (>0) Power reference max. ramp rate
J+20		dPmin (pu/s) (<0) Power reference min. ramp rate
J+21		PMAX (pu), Max. power limit
J+22		PMIN (pu), Min. power limit
J+23		Imax (pu), Maximum limit on total converter current
J+24		Tpord (s), Power filter time constant
J+25		Vq1 (pu), Reactive Power V-I pair, voltage
J+26		Iq1 (pu), Reactive Power V-I pair, current
J+27		Vq2 (pu) (Vq2>Vq1), Reactive Power V-I pair, voltage
J+28		Iq2 (pu) (Iq2>Iq1), Reactive Power V-I pair, current
J+29		Vq3 (pu) (Vq3>Vq2), Reactive Power V-I pair, voltage
J+30		Iq3 (pu) (Iq3>Iq2), Reactive Power V-I pair, current
J+31		Vq4 (pu) (Vq4>Vq3), Reactive Power V-I pair, voltage
J+32		Iq4 (pu) (Iq4>Iq3), Reactive Power V-I pair, current
J+33		Vp1 (pu), Real Power V-I pair, voltage
J+34		Ip1 (pu), Real Power V-I pair, current
J+35		Vp2 (pu) (Vp2>Vp1), Real Power V-I pair, voltage
J+36		Ip2 (pu) (Ip2>Ip1), Real Power V-I pair, current
J+37		Vp3 (pu) (Vp3>Vp2), Real Power V-I pair, voltage
J+38		Ip3 (pu) (Ip3>Ip2), Real Power V-I pair, current
J+39		Vp4 (pu) (Vp4>Vp3), Real Power V-I pair, voltage
J+40		Ip4 (pu) (Ip4>Ip3), Real Power V-I pair, current
J+41		T, battery discharge time (s) (>0)
J+42		SOCini (pu), Initial state of charge
J+43		SOCmax (pu), Maximum allowable state of charge
J+44		SOCmin (pu), Minimum allowable state of charge

Electrical Control model (REECCU1(Battery))

STATEs	Description
K	Voltage Measurement filter
K+1	Real power filter
K+2	PI controller for reactive power
K+3	PI controller for voltage error
K+4	First Order lag for reactive current
K+5	First order lag for Pord
K+6	Energy output from battery

VAR	Description
L	Bus reference voltage (Vref0)

VAR	Description
L+1	Power factor reference angle (pfaref), radians
L+2	Real current command (Ipcmd)
L+3	Reactive current command (Iqcmd)
L+4	Battery Residual Energy
L+5	Auxiliary input signal, Paux

Electrical Control model (REECCU1(Battery))

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1. pfaref (the power factor angle reference) value is initialized by the model based on ini- tial real and reactive power outputs from the machine.

2. Qref is initialized by the model to a constant or can be connected to an external plant controller model).

3. Pref is initialized by the model to a constant or can be connected to an external plant controller model).

4. ICON(M) contains the remote bus number. If this is 0 or if the remote bus number is not specified then the local bus is used for control.

5. SOCini represents the initial state of charge on the battery and is a user entered value. This is entered in pu; with 1 pu meaning that the batter is fully charged and 0 means the battery is completely discharged.

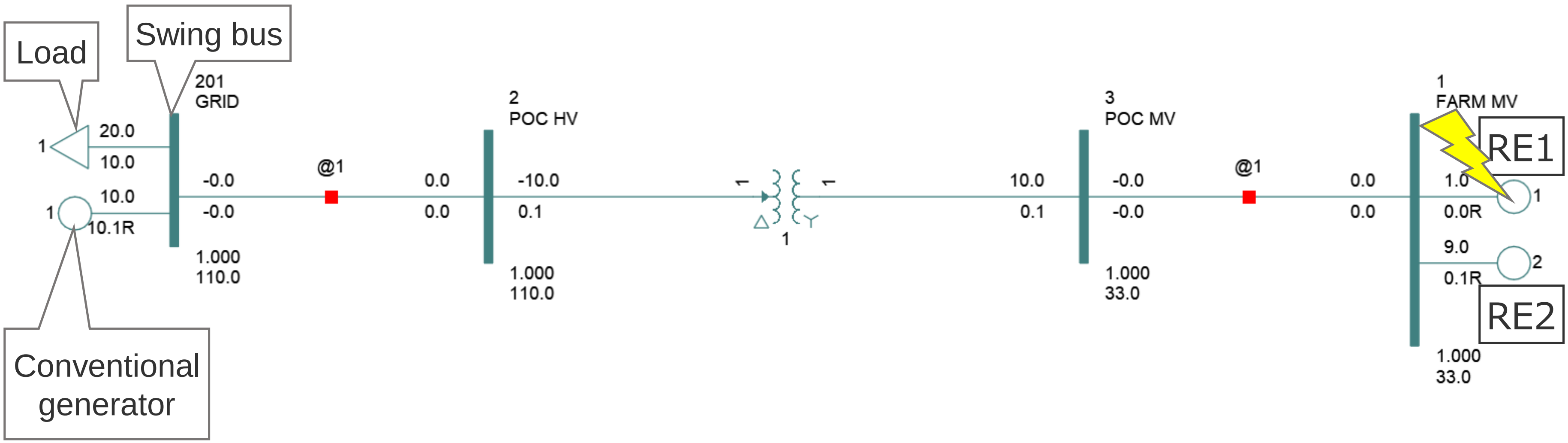
6. SOCmax is the maximum allowable state of charge. By definition the maximum value would be 1 pu; however it may be set to a smaller value (e.g., 0.8 pu) to represent specific manufacturer requirements that the battery will remain at or below a certain charging level (e.g., 80 %).

7. SOCmax is the minimum allowable state of charge. By definition the minimum value would be 0 pu; however it may be set to a larger value (e.g., 0.2 pu) to represent specific manufacturer requirements that the battery will remain at or above a certain charging level (e.g., 20 %).

8. Other models to be used with REECC1 are, REGCA1, and REPCA1

9. An auxiliary signal model can be attached to the signal represented as Paux. This can be used for interfacing with supplemental models like power oscillation damping control.

SIM example of frequency control



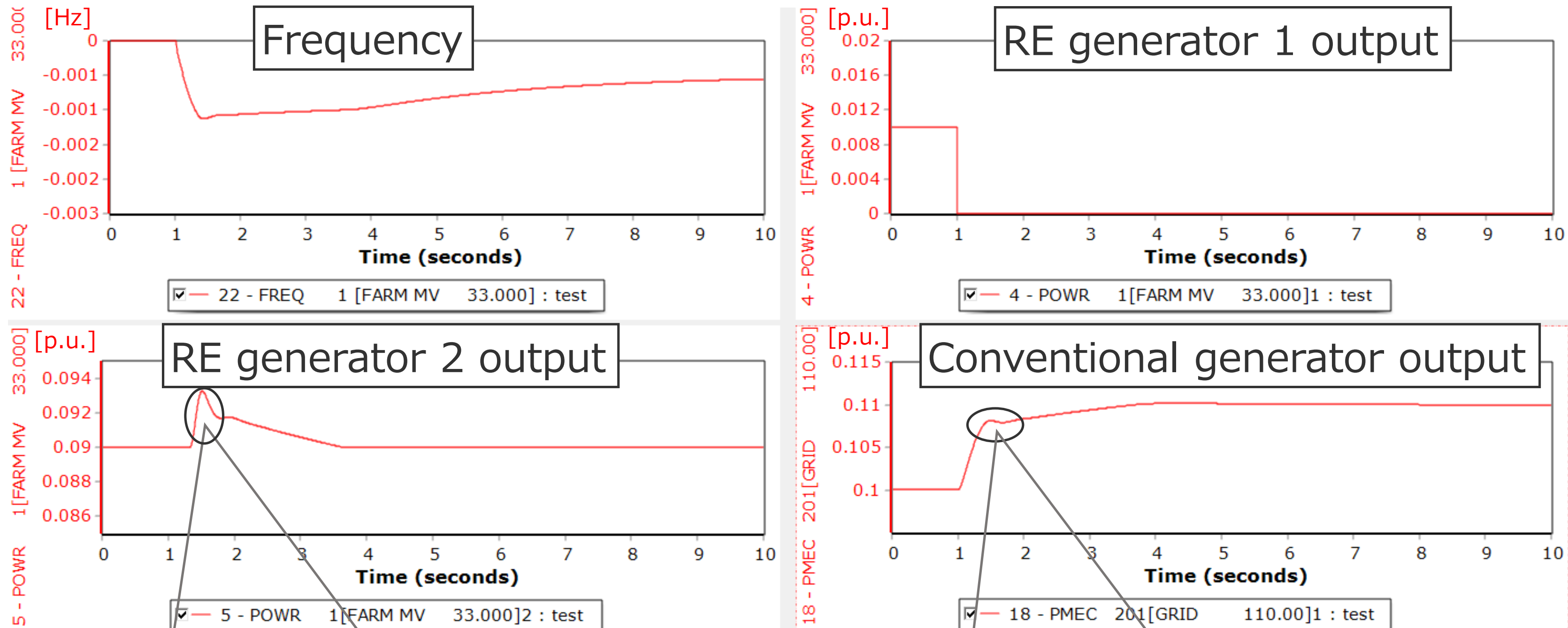
Fault condition

1 Fault occurs at RE1 generator at 1sec.

2 Fault continues for 10sec.

With frequency control at RE generator

REPCA : Fflag = 1



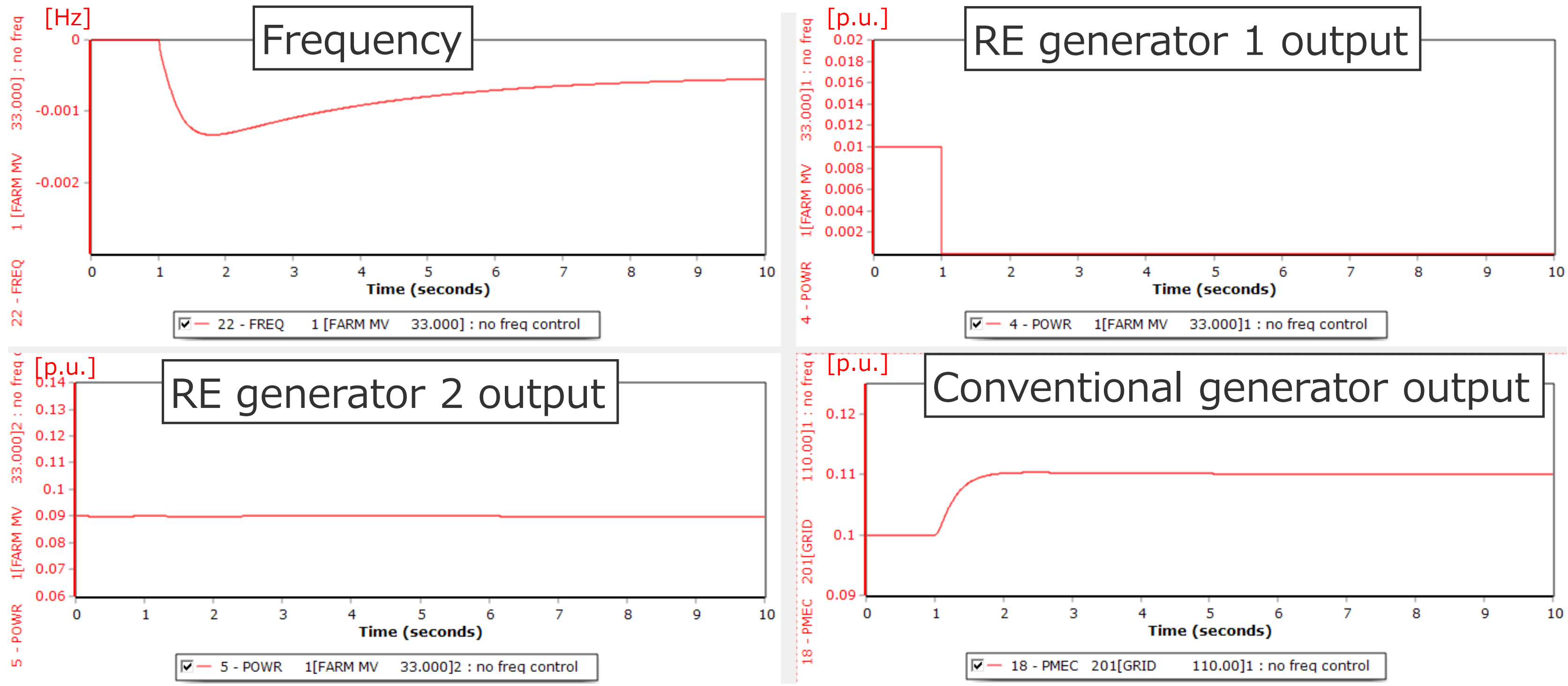
RE2 contributes to improvement of frequency.

Conventional generator output drops slightly, because RE2 output increases.

RE2 contributes to improvement of frequency.

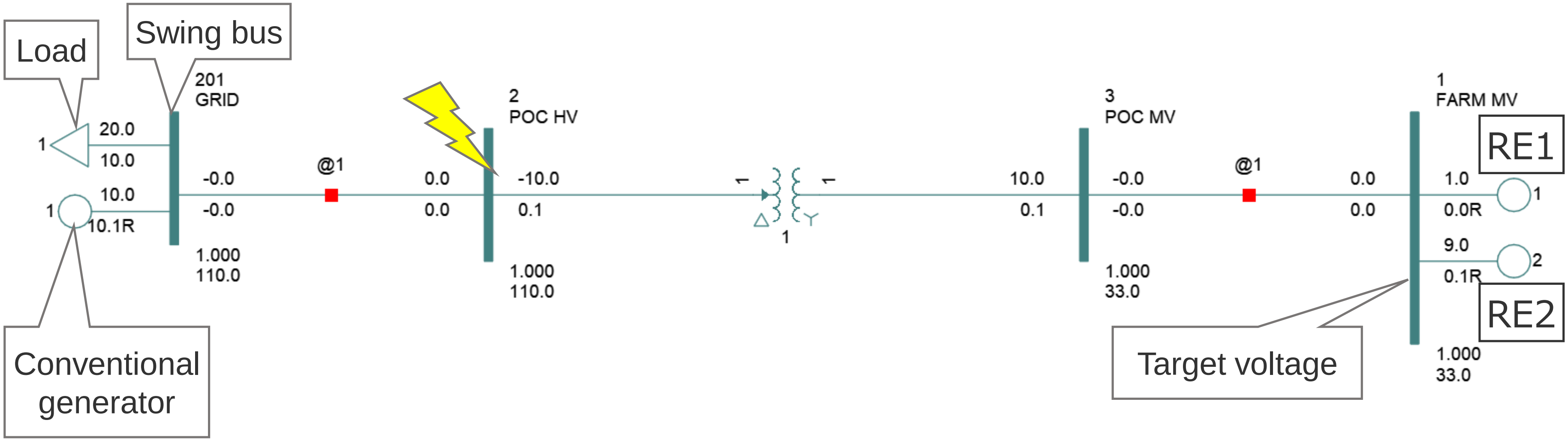
Without frequency control at RE generator

REPCA : Fflag = 0



RE2 does not contributes to improvement of frequency.

SIM example of voltage control



Fault condition

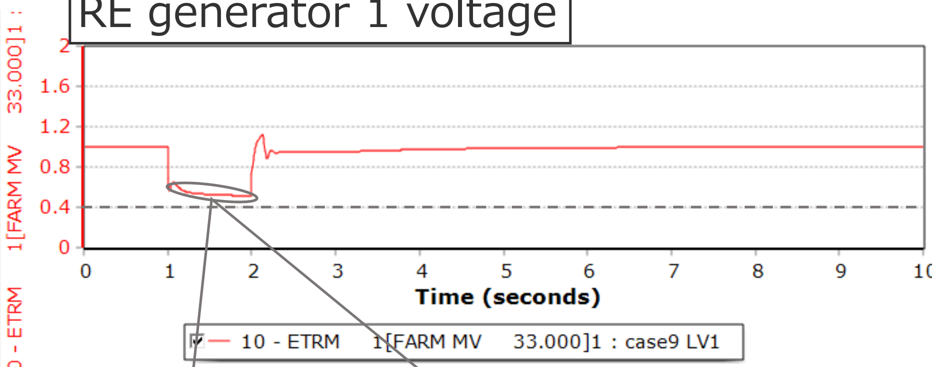
1 Fault occurs at No2 Bus(add -50Var) at 1.0s.

2 Clear fault at 2.0s

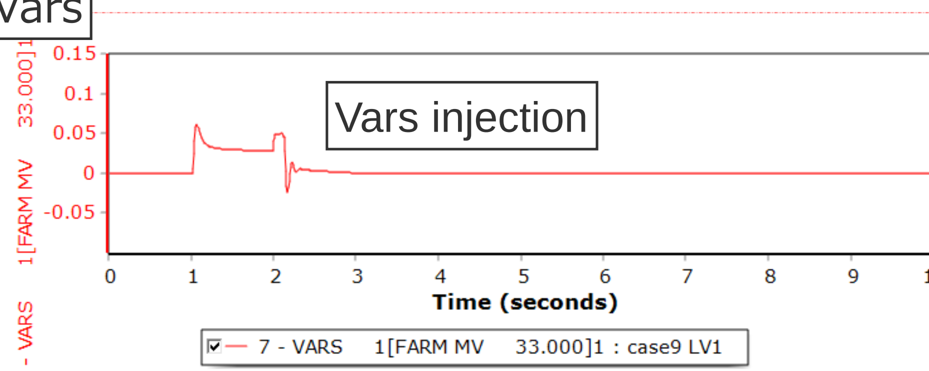
voltage control

REECDU1 : Kqv = 20 (with voltage compensation in case of fault)

RE generator 1 voltage



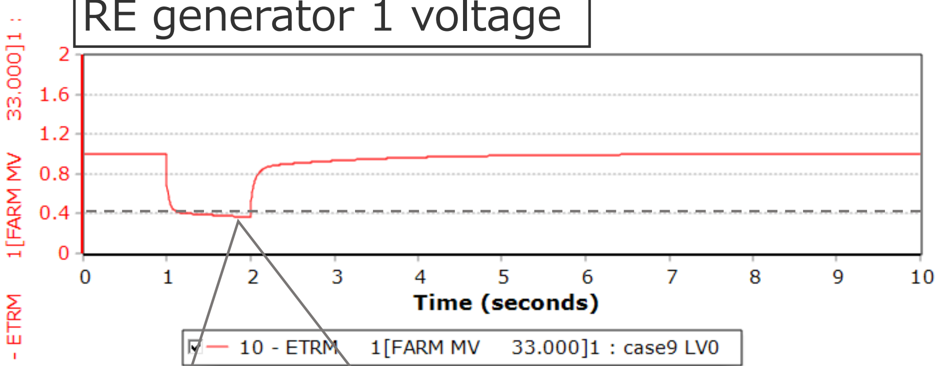
Vars



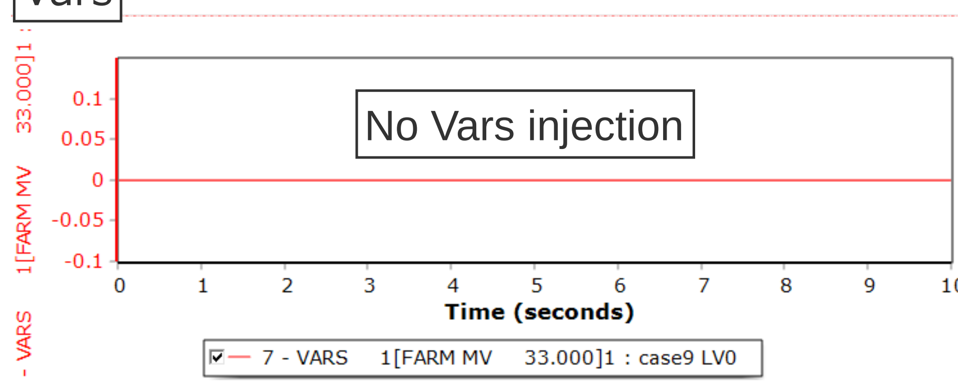
Even in case of fault, voltage is improved to over 0.4pu, because of Vars injection

REECDU1 : Kqv = 0 (without voltage compensation in case of fault)

RE generator 1 voltage



Vars



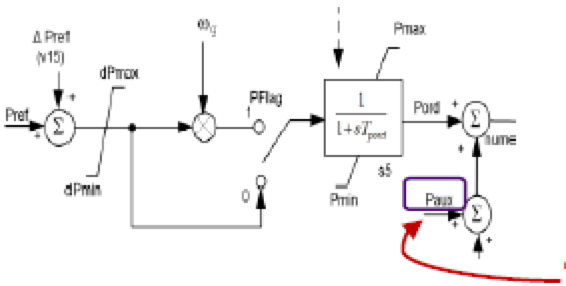
In case of fault, voltage is under 0.4pu

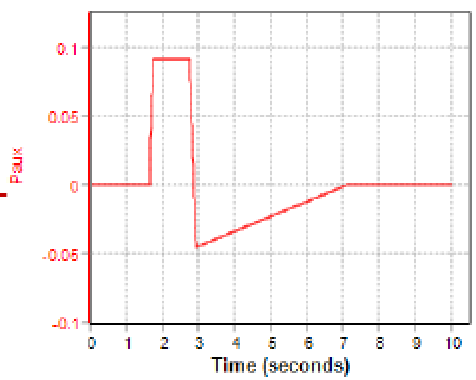
(FYI) IBFFR

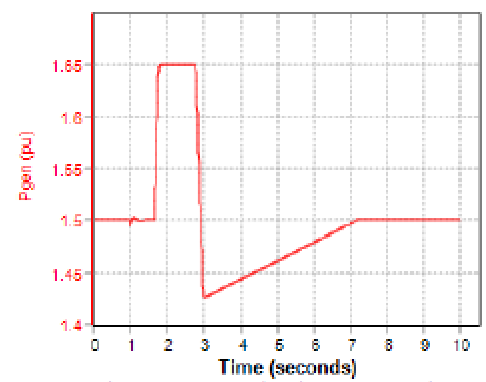
IBFFR Model (Modeled as Paux Controller)

WTGIBFFRA:

- new model, currently being tested.
- Used for Type 3 & 4 wind machines. IBFFR stands for Inertia-Based Fast Frequency Response.
- This is also referred to as “synthetic inertia” or “emulated inertia”. This is a supplemental control and is initiated only for under-frequency events







Resulting Pgen output of generator

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(FYI) Momentary Cessation

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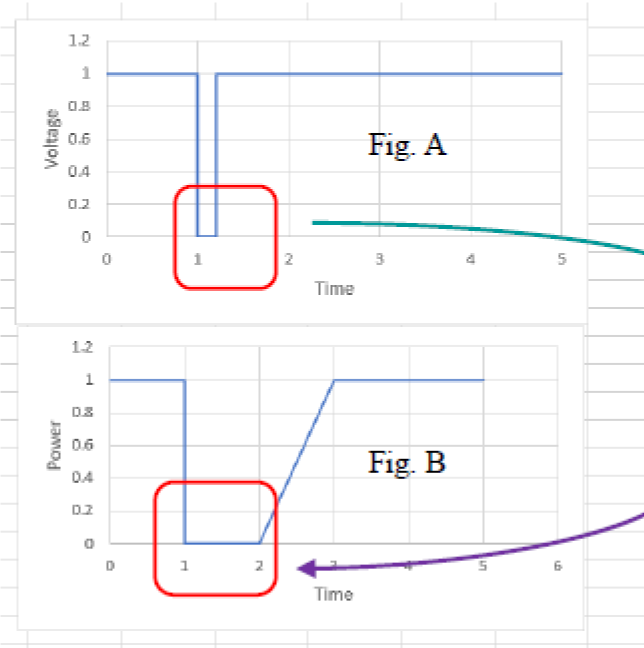
Using REECD for Modeling Large Scale PV with Momentary Cessation



REECD CON	REECD model CON number	Typical Values used
Vblkl, Vblkh, Tblk	J+74 through J+76	0.5 pu, 1.2 pu, 0.5 s

V < Vblkl

When the voltage at the inverter bus (Fig. A) is less than Vblkl, the inverter blocks (Fig. B)

Inverter blocks (momentary cessation)

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(FYI) LVRT LFRT by using PLBVF1 model

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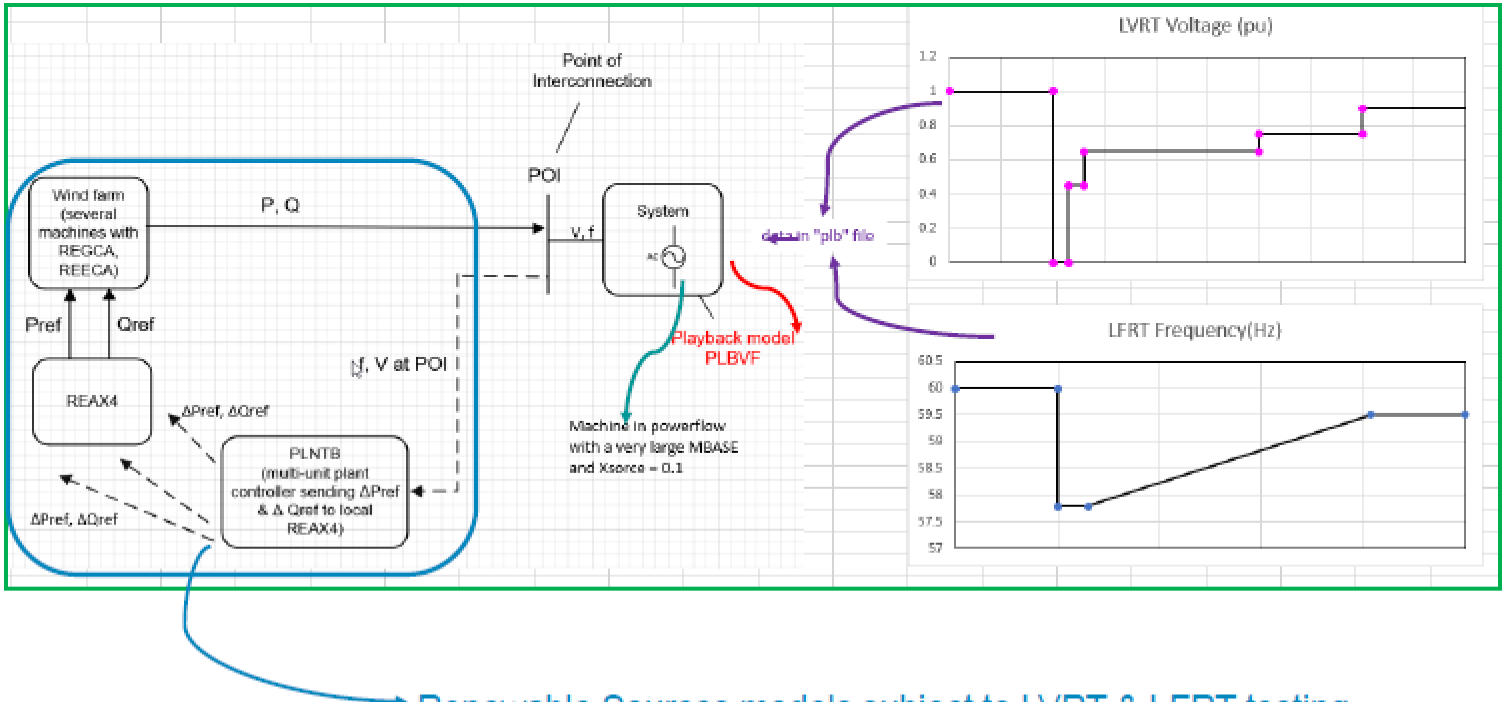
PLBVF1 Model use case for performing LVRT & LFRT studies



Renewable Sources models subject to LVRT & LFRT testing

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SIEMENS

Review Result of Grid Code

Oct, 2022

Chubu Electric Power Co., Inc.
Nippon Koei Co., Ltd.

Introduction

Reviewed Documents

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In the review of Grid Code of Sri Lanka, JICA Expert Team mainly focused on the following 2 documents.

- GRID CODE, TRANSMISSION DIVISION CEYLON ELECTRICITY BOARD October 2018 (Final Draft)
- GRID CONNECTION REQUIREMENT FOR SOLAR/WIND POWER PLANTS – ADDENDUM TO THE CEB GUIDE FOR GRID INTERCONNECTION OF EMBEDDED GENERATORS, DECEMBER 2000

GRID CODE

TRANSMISSION DIVISION
CEYLON ELECTRICITY BOARD
October 2018 (Final Draft)

GRID CONNECTION REQUIREMENT FOR SOLARPOWER PLANTS – ADDENDUM TO THE CEB GUIDE FOR GRID INTERCONNECTION OF EMBEDDED GENERATORS, DECEMBER 2000

GRID CONNECTION REQUIREMENT FOR WIND POWER PLANTS – ADDENDUM TO THE CEB GUIDE FOR GRID INTERCONNECTION OF EMBEDDED GENERATORS, DECEMBER 2000

Comparison with Grid Code of Japan and Ireland

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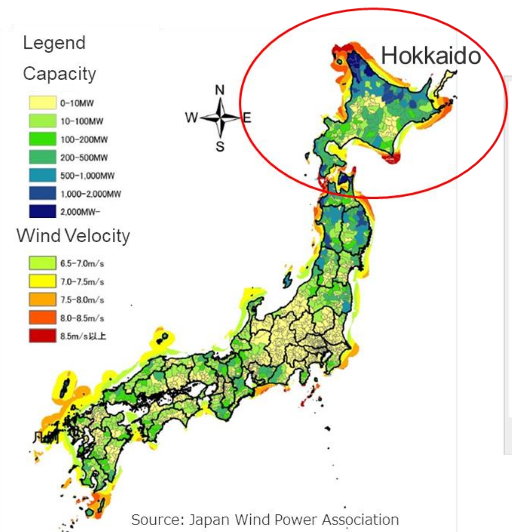
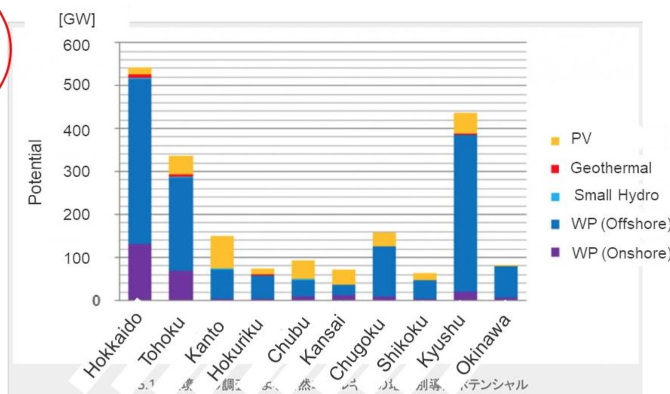
In order to review them, JICA Expert Team referred to Grid Code of Hokkaido in Japan and Ireland.

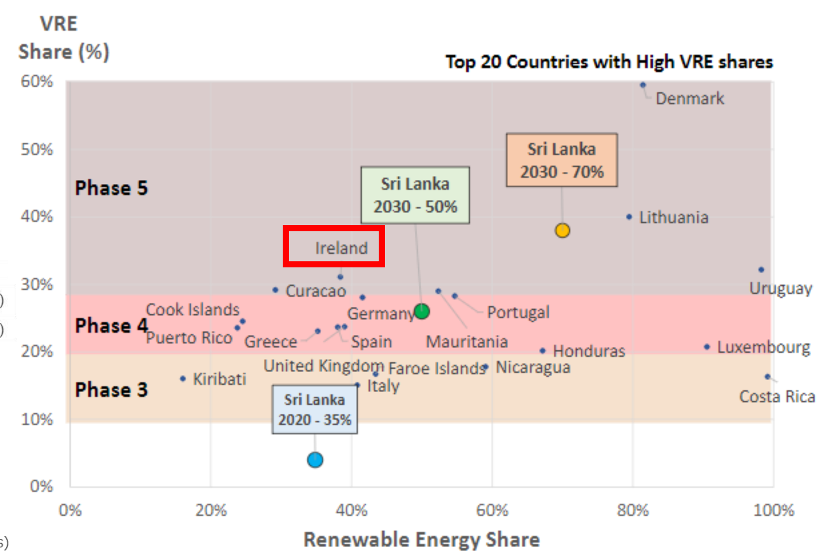
- Why Hokkaido?
  For both solar and wind, limited rates of output change are defined
  Annual Peak demand is 5GW that is close to predicted annual peak demand of Sri Lanka in 2030
  Has only DC interconnection with other areas
- Why Ireland?
  Advancing country with respect to installed capacity of VRE and belongs to phase 5 presently
  Annual Peak demand o is 5GW that is close to predicted annual peak demand of Sri Lanka in 2030
  Has only DC interconnection with Great Britain



Source: Japan Wind Power Association



Source: isep (Institute for Sustainable Energy Policies)



Segmentation of Generation Equipment and Description corresponding to each

Generation types	Specification
Generating Units	Conventional generation connected to transmission system (132kV – 400kV) (Thermal, Hydro etc.)
IRBGS (Intermittent Resource Based Generating Systems)	Intermittent generation connected to transmission system(132kV – 400kV)
Embedded Generators	All types of generation connected to distribution system (– 33kV)

GRID CODE

TRANSMISSION DIVISION
CEYLON ELECTRICITY BOARD
October 2018 (Final Draft)

GRID CONNECTION REQUIREMENT FOR SOLARPOWER PLANTS – ADDENDUM TO THE CEB GUIDE FOR GRID INTERCONNECTION OF EMBEDDED GENERATORS, DECEMBER 2000

GRID CONNECTION REQUIREMENT FOR WIND POWER PLANTS – ADDENDUM TO THE CEB GUIDE FOR GRID INTERCONNECTION OF EMBEDDED GENERATORS, DECEMBER 2000

Examination Steps of GRID CODE

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Input of state-of-the-art technical knowledge

Understanding CEB GRID CODE

Comparison with Japan and Ireland

PSSE simulation for numerical criterion changes

Analysis for PSSE simulation

The following red boxes are attached to the simulation needed items

To be examined with PSSE

If simulations are not needed, recommendations are described in the red boxes

02 GRID CODE

Highlighted Table Contents for Description Changes of GRID CODE

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Highlighted Table Contents for Description Changes of GRID CODE

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System Communication

3.13 SCADA & COMMUNICATION | *Sri Lanka*

A fully functional communication and SCADA System will be established and maintained by the Transmission Licensee.

The Transmission Licensee will provide the necessary facilities at the Interconnection Point for the User to upload data to the SCADA system and to receive control signals from the SCADA system in accordance with the Connection Agreement.

Communication and SCADA systems shall have the capability for the System Operator to carry out switching operations in the Transmission System and data acquisition. Voice and data communication facilities shall be secured against unauthorised access in accordance with the standards specified.

The above requirement shall also apply to all IRBGS directly connected to grid substations.

It is necessary to write communication requirement with dedicated line for certain amount solar and wind(1MW- or 10MW-)

Pros and Cons

Step by step installation of grid code would be better considering cost impact for small VRE power plant and possibility of installing storage battery

	10MW－ solar and wind	1MW－ solar and wind
Controllable capacity(Grid code revision prior to 2025)	△Solar 1460MW/4209MW(35%) 〇Wind 1090MW/1523MW(72%)	〇Solar 1720MW/4209MW(41%) 〇Wind 1090MW/1523MW(72%)
Cost burden of constructing communication equipment	〇Less burden for large scale VRE	△would be big cost impact for small capacity VRE that could leads to avoid new construction
Stable supply	△Surplus power can't be covered completely → 〇can be covered with installation of 1,000MW battery in 2030 described on LTGEP	〇Surplus power can be covered completely

(System Communication)
Controllable VRE considering curtailment volume in 2030

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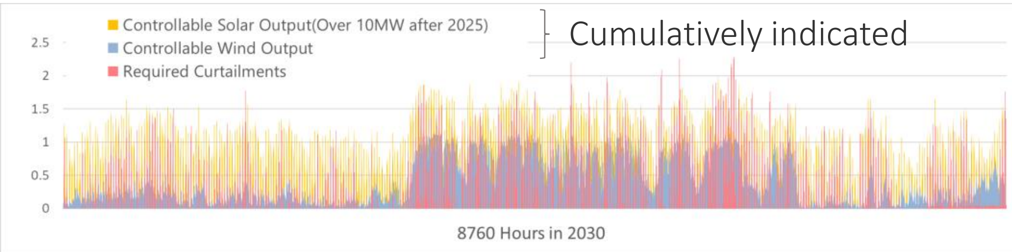
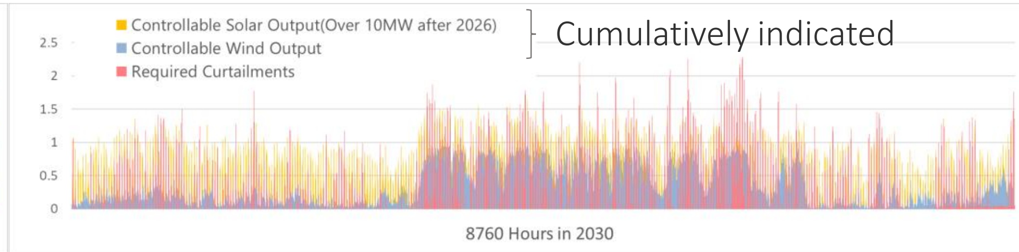
GW **Over 10MW solar + Wind installed after 2025 is controllable**



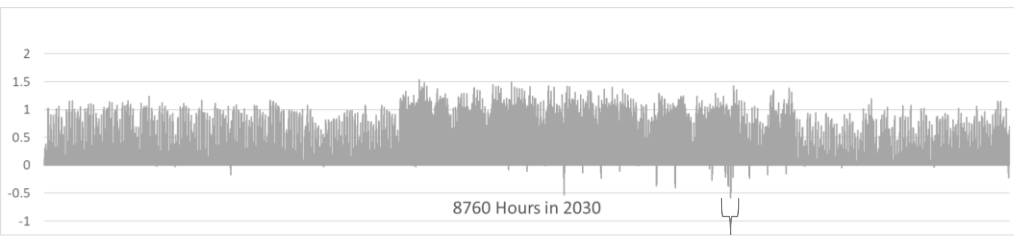
GW **Over 10MW solar + Wind installed after 2026 is controllable**



Battery Requirement = Negative side

(Controllable solar & wind output – Required Curtailments)

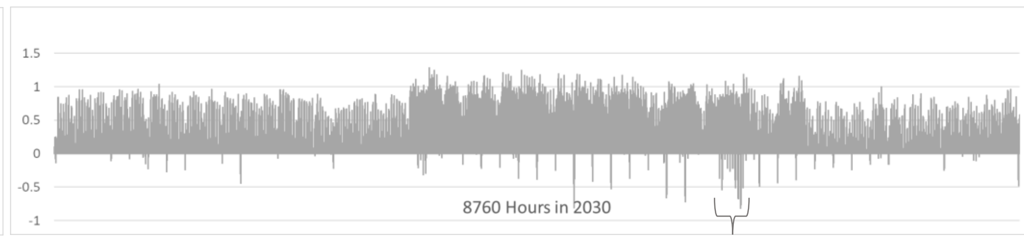
GW



Battery Requirement = Negative side

(Controllable solar & wind output – Required Curtailments)

GW



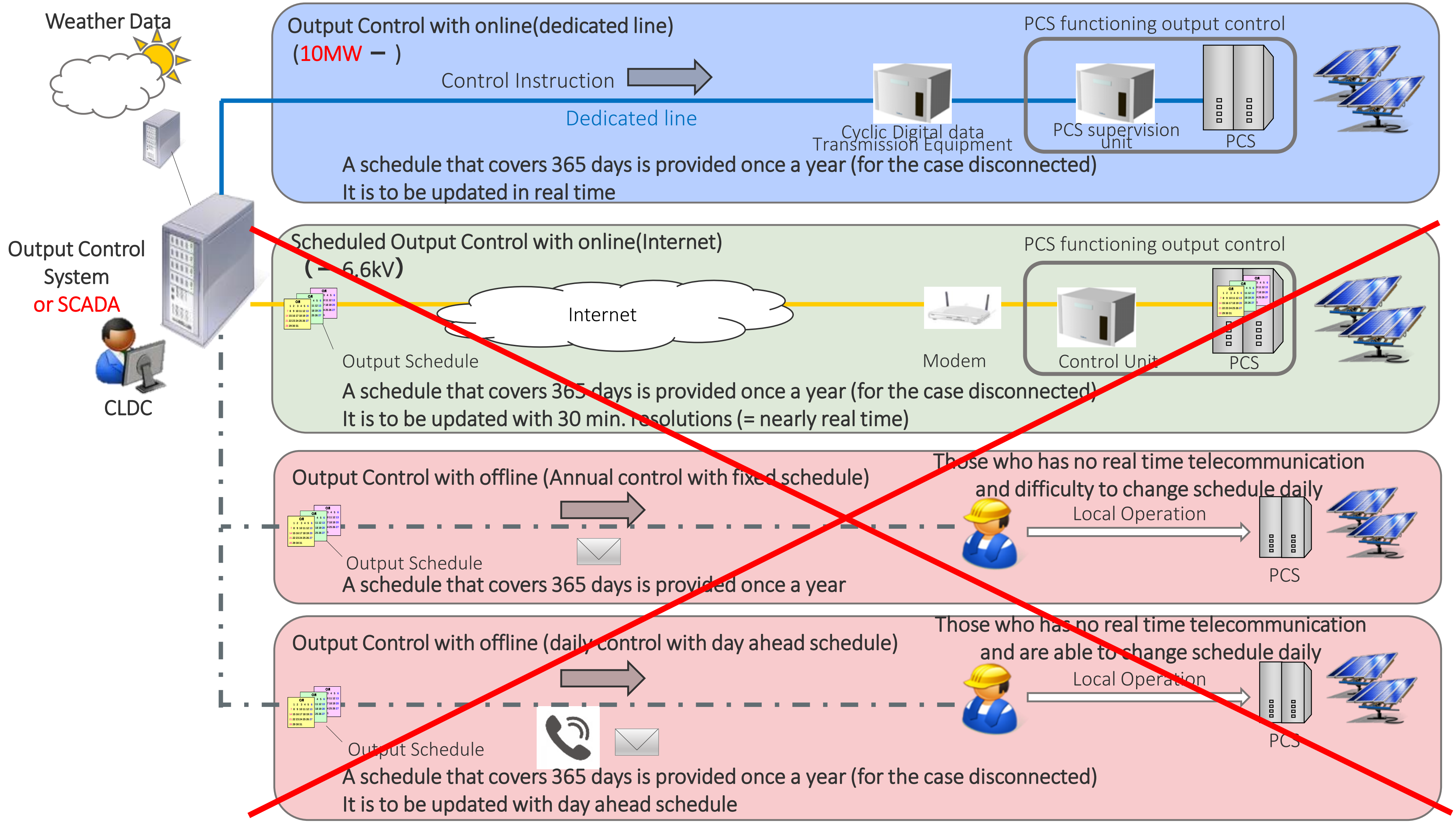
- Maximum Battery Requirement : 0.6GW < 1GW(from LTGEP)
- Maximum Charged Energy : 3GWh < 4GWh(from LTGEP)

- Maximum Battery Requirement : **0.82GW** < 1GW(from LTGEP)
- Maximum Charged Energy : **5.1GWh** > 4GWh(from LTGEP)

It is better to **revise Grid Code prior to 2025 and validate it from 2025**.

Otherwise, it will be needed to revise Grid Code again in order to expand the controllable RE borderline from 10MW to lower capacity or to increase battery duration.

(System Communication)
Specification of VRE Control System in Sri Lanka



(System Communication)
Specification of VRE Control System in Japan

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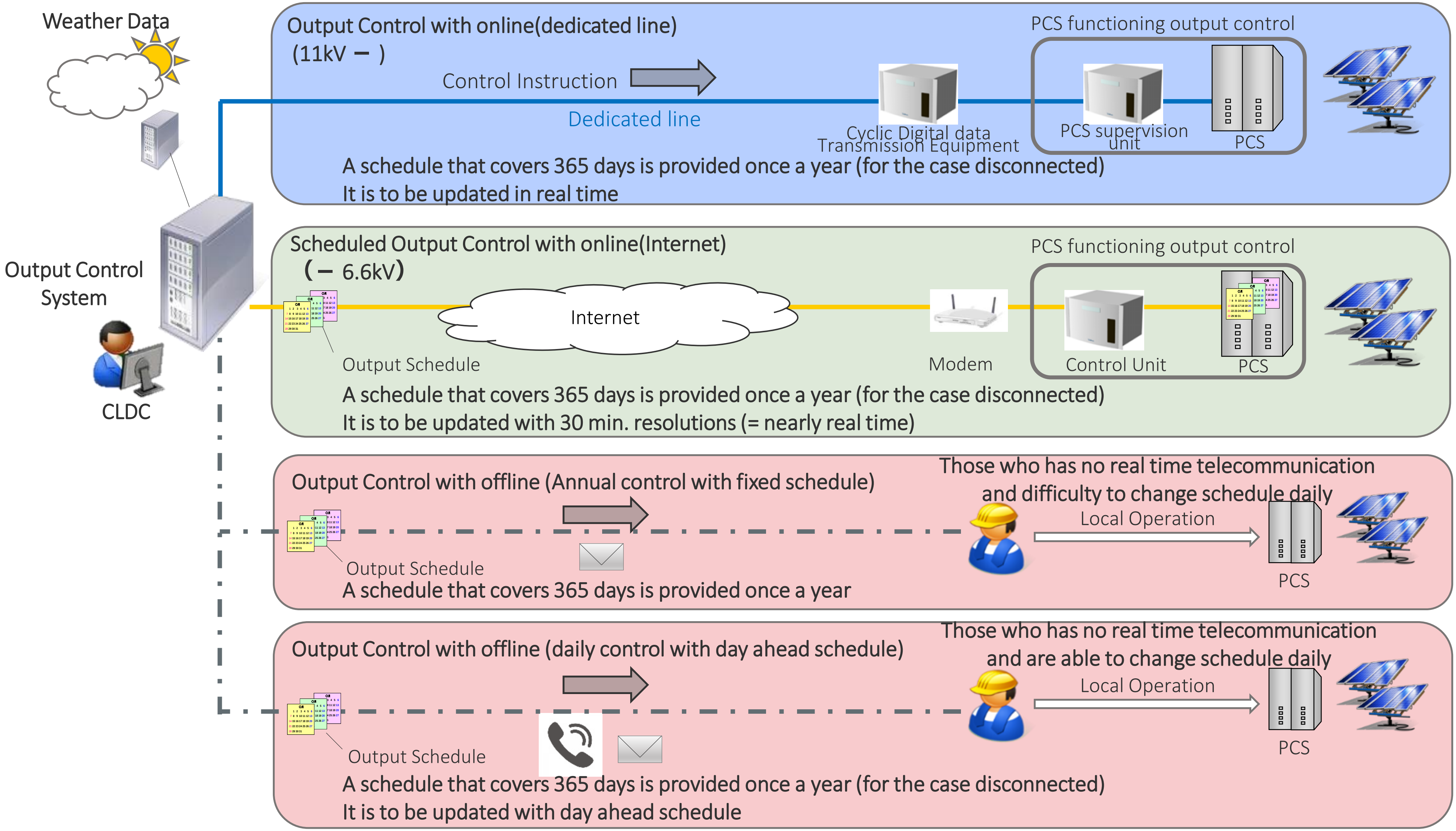

Generating Units | IRBGS | Embedded Generators

Frequency Variation Capability

All requirements specified in generating units part 3.16 shall apply to IRBGS

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Sri Lanka

3.16 SPECIAL CONNECTION REQUIREMENTS FOR GENERATING UNITS

3.16.1 FREQUENCY VARIATION CAPABILITY

Generating Units shall be capable of delivering the declared active and reactive power outputs within the system Frequency variations, specified in this GCC.

The Transmission Licensee and a User may agree to lower active power delivering capability when system Frequency falls below one percent (1%) of the rated Frequency.

Generating Units shall be protected against Frequency excursions outside the ranges specified in Appendix A Section 3.2(A).

Sri Lanka

3.2 GENERATION LICENSEES WITH GENERATION FROM CONVENTIONAL RESOURCES

(A) FREQUENCY VARIATION CAPABILITY (GCC 3.16.1)

Table 3.2.A: Frequency Variation Capability

Frequency (Hz)	Duration
50.5 - 52.0	60 minutes
49.5 - 50.5	Continuous
47.5 - 49.5	60 minutes
47.0 – 47.5	30 seconds

Lower threshold is higher than others(49.5Hz)

Ireland case

<Former Description(roughly connected prior to 2019)>

(a) operate continuously at normal rated output at Transmission System Frequencies in the range 49.5Hz to 50.5Hz;

(b) remain synchronised to the Transmission System at Transmission System Frequencies within the range 47.5Hz to 52.0Hz for a duration of 60 minutes;

(c) remain synchronised to the Transmission System at Transmission System Frequencies within the range 47.0Hz to 47.5Hz for a duration of 20 seconds required each time the Frequency is below 47.5Hz;

⇩

<Present Description(roughly connected after 2019) only for Generating Unit>

(w) Remain synchronised to the Transmission System and operate within the frequency ranges and time periods specified in *Table CC.7.3.1.1.*

Table CC.7.3.1.1: Minimum Time Periods for Generation Units to Remain Operational without Disconnecting

Frequency Range	Time Period
47 – 47.5 Hz	20 seconds
47.5 – 48.5 Hz	90 minutes
48.5 – 49 Hz	90 minutes
49 – 51 Hz	Unlimited
51 – 51.5 Hz	90 minutes
51.5 – 52 Hz	60 minutes

Japan case

Connected at	Continuous operation range
All voltage	48.5Hz - 50.5Hz

Japanese lower threshold was determined based on the historical requirements.

Ireland's lower threshold was determined based on commission regulation 2016/631 that integrated EU wide "Unlimited" range.

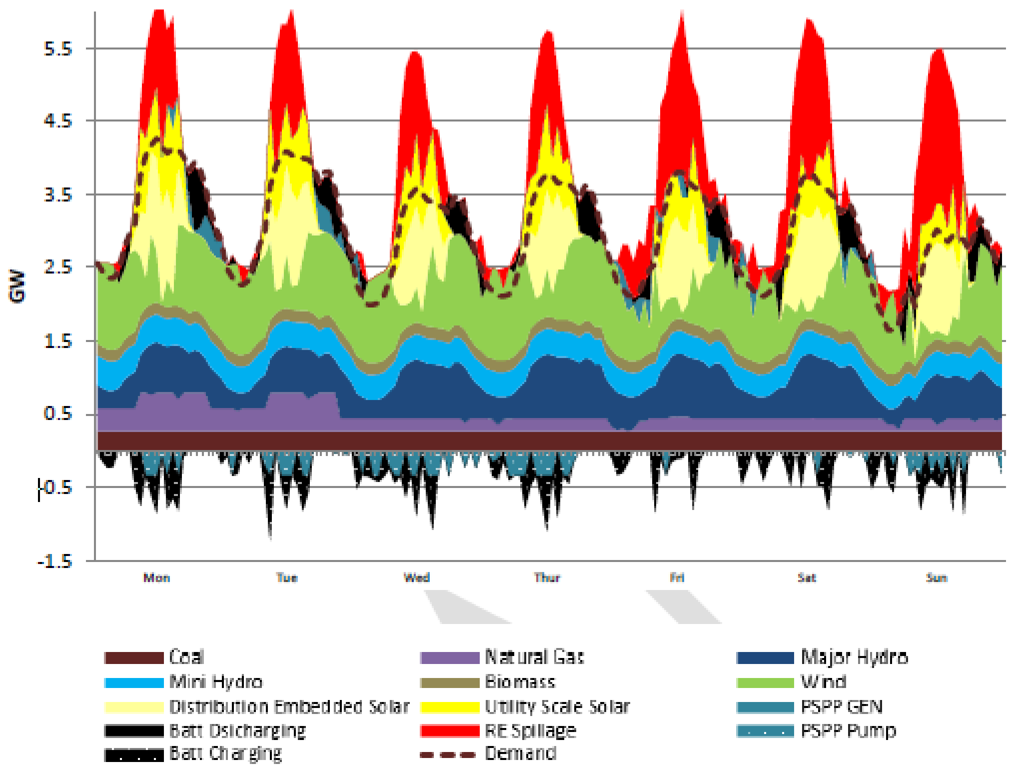
However, it was confirmed by Japanese vendors there is almost no additional cost for generators to expand "continuous" range over the operational lowest frequency(Sri Lankan case : 47.0Hz)

Generating Units | IRBGS | Embedded Generators

Frequency Variation Capability

1. Present continuous operation range is 49.5 – 50.5Hz in CEB Grid Code.
2. Assuming that system coefficient K is equal to 5%(Hz/MW) approximately, it would be frequently to violate 49.5Hz in 2030 under 70% RE situation.
   Offpeak : 2,000MW × 5% (Hz/MW)× (0.5Hz/1Hz) = 50MW fluctuation leads to frequency violation (50MW out of ～1,000MW wind output)
   Peak : 3,500MW × 5% (Hz/MW)× (0.5Hz/1Hz) = 87.5MW fluctuation leads to frequency violation (87.5MW out of ～1,000MW wind output & ～2,000MW solar output)

High Wind Season



Source : LTGEP 2023 - 2042

Rate of Change of Frequency

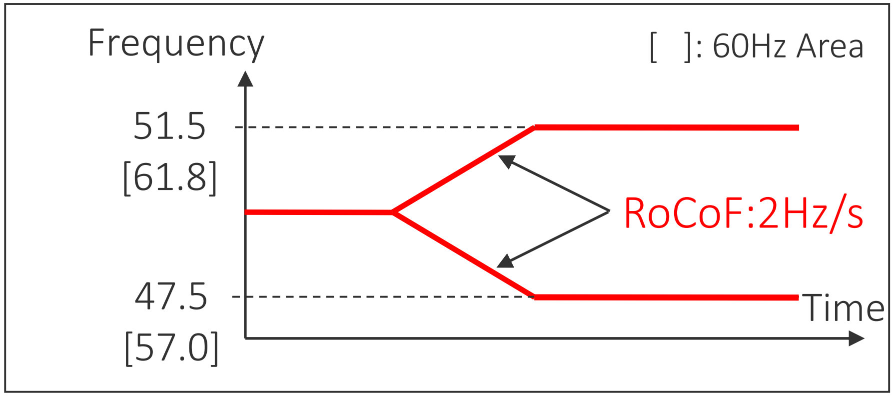
No description regarding Rate of Change of Frequency in Clause 3.16.1

Sri Lanka

To be examined with PSSE

Japan case

<Operation Continuity with Ramp Change(UP & DOWN)>



Ireland case

<Former Description(roughly connected prior to 2019)>

(d)

(i) remain synchronised to the **Transmission System** during rate of change of **Transmission System Frequency** of values up to and including 0.5 Hz per second;

<Present Description(roughly connected after 2019)>

(ii) remain synchronised to the **Transmission System** for a **Rate of Change of Frequency** up to and including 1 Hz per second as measured over a rolling 500 milliseconds period. **Voltage** dips may cause localised **Rate of Change of Frequency** values in excess of 1 Hz per second for short periods, and in these cases, the **Fault-Ride Through** clause CC.7.3.1.1(y) supersedes this clause (CC.7.3.1.1(d)). For the avoidance of doubt, this requirement relates to the capabilities of **Generating Units** only and does not impose the need for **Rate of Change of Frequency** protection nor does it impose a specific setting for anti-islanding or loss-of-mains protection relays;

Generating Units | IRBGS | Embedded Generators

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Power Factor Variation Capability

Sri Lanka

3.16 SPECIAL CONNECTION REQUIREMENTS FOR GENERATING UNITS

3.16.3 POWER FACTOR VARIATION CAPABILITY

Generating Units shall be capable of continuously delivering the declared outputs at any point between the Power Factors of **0.8 lagging and 0.9 leading**, in accordance with its reactive power Capability Curve, unless otherwise agreed in the Connection Agreement, and operate in voltage control mode to support dynamic reactive power requirements during disturbances.

Japan case

Connected at	Power factor range
110V – 6.6kV	Between 0.85 lagging and 1.0
11kV -	Between 0.90 lagging and 0.95 leading

Ireland case

CC.7.3.6.1 Each **Generation Unit** shall have the following **Reactive Power** capability as measured at their alternator terminals:

Voltage Range	Connected at:	At Registered Capacity between:	At 35% of Registered Capacity between:
99kV ≤ V ≤ 123kV	110kV	0.93 power factor leading to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
85kV ≤ V < 99kV		Unity power factor to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
200kV ≤ V ≤ 245kV	220kV	0.93 power factor leading to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
190kV ≤ V < 200kV		Unity power factor to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
360kV ≤ V ≤ 420kV	400kV	0.93 power factor leading to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
350kV ≤ V < 360kV		Unity power factor to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging

To be examined with PSSE

Power Factor Variation Capability

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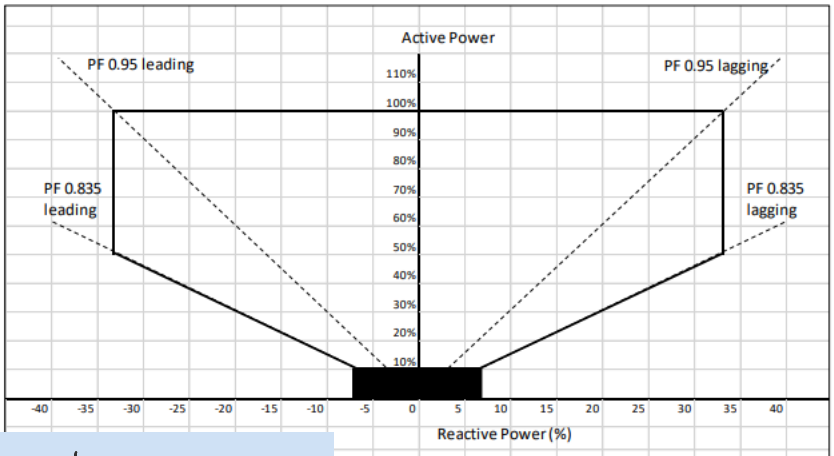
3.17.2 REACTIVE POWER CAPABILITY

Sri Lanka

IRBGS shall be capable of operating at any point within the Power Factor ranges given in Appendix A Section 3.3.1 unless otherwise agreed in the Connection Agreement, and operate in voltage control mode to support dynamic reactive power requirements during disturbances.

3.3 GENERATION LICENSEES WITH INTERMITTENT RESOURCE BASED GENERATION SYSTEMS

3.3.1 POWER FACTOR VARIATION CAPABILITY (GCC 3.17.1) AND REACTIVE POWER CAPABILITY (GCC 3.17.2)



Japan case

Connected at	Power factor range
110V – 6.6kV	Between 0.85 lagging and 1.0
11kV -	Between 0.90 lagging and 0.95 leading

CC.7.3.6.1 Each Generation Unit shall have the following Reactive Power capability as measured at their alternator terminals:

Ireland case

Voltage Range	Connected at:	At Registered Capacity between:	At 35% of Registered Capacity between:
99kV ≤ V ≤ 123kV	110kV	0.93 power factor leading to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
85kV ≤ V < 99kV		Unity power factor to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
200kV ≤ V ≤ 245kV	220kV	0.93 power factor leading to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
190kV ≤ V < 200kV		Unity power factor to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
360kV ≤ V ≤ 420kV	400kV	0.93 power factor leading to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
350kV ≤ V < 360kV		Unity power factor to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging

To be examined with PSSE

Generating Units | IRBGS | Embedded Generators

Fault Ride-through Capability

All requirements specified in generating units part 3.16 shall apply to IRBGS

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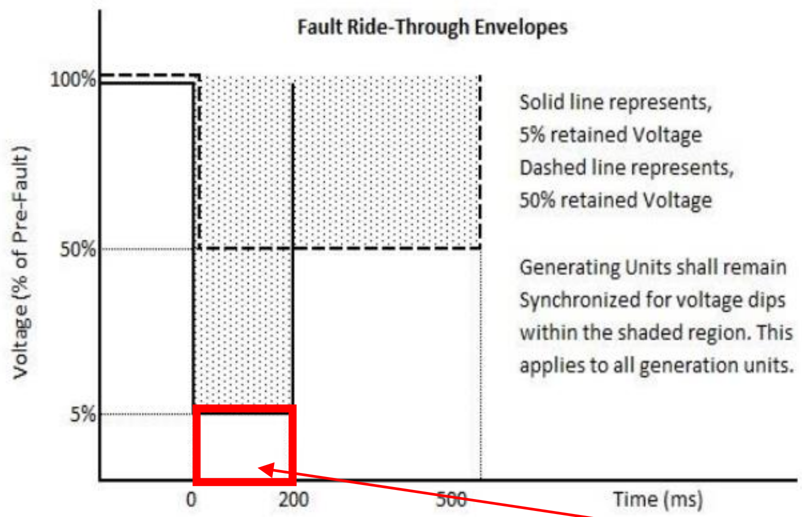
3.16.6 FAULT RIDE-THROUGH CAPABILITY

Sri Lanka

Generating Units shall be capable of remaining synchronised during and following any fault disturbance anywhere on the Transmission System which could result in voltage dips at the HV terminals of the generator transformer of no greater than 95% of nominal voltage (5% retained) for fault durations up to and including the fault ride-through times as defined in Appendix A Section 3.2(C) and voltage dips of no greater than 50% of nominal Voltage. (i.e. 50% retained) for fault durations up to and including the fault ride through times as defined in Appendix A Section 3.2(C) (see also fault ride through envelopes in Appendix A Section 3.2(D)).

(D) FAULT RIDE-THROUGH CAPABILITY ENVELOPES (GCC 3.16.6)



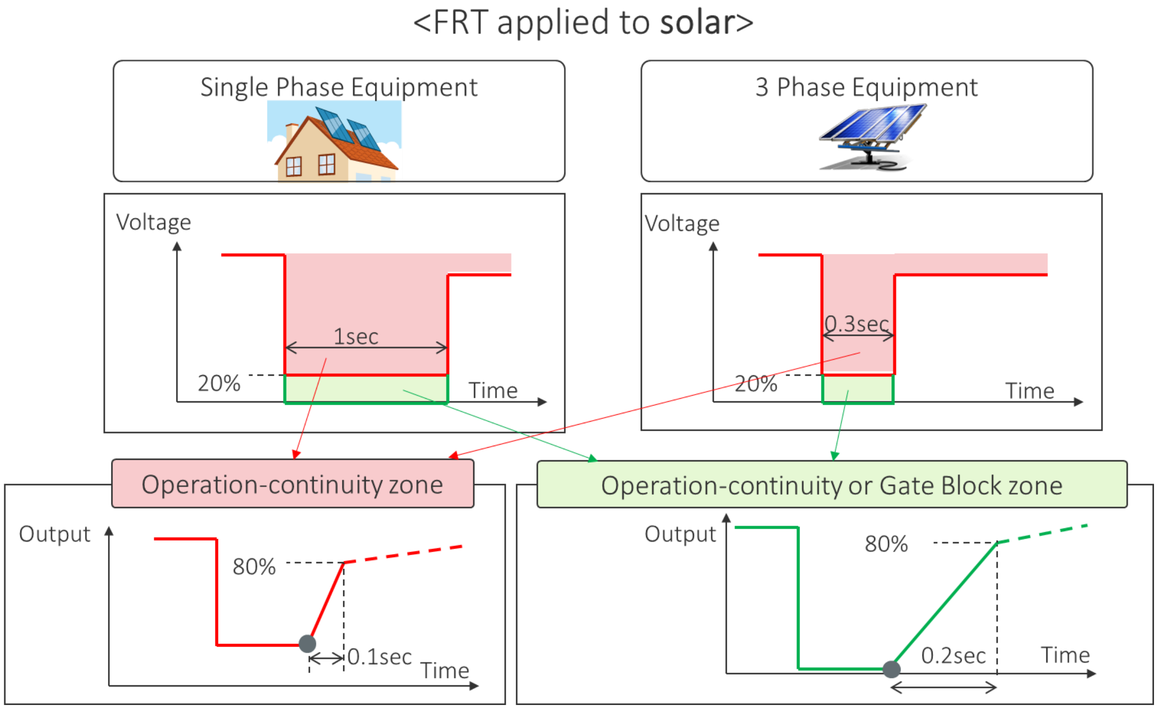
No output recovery criteria designated

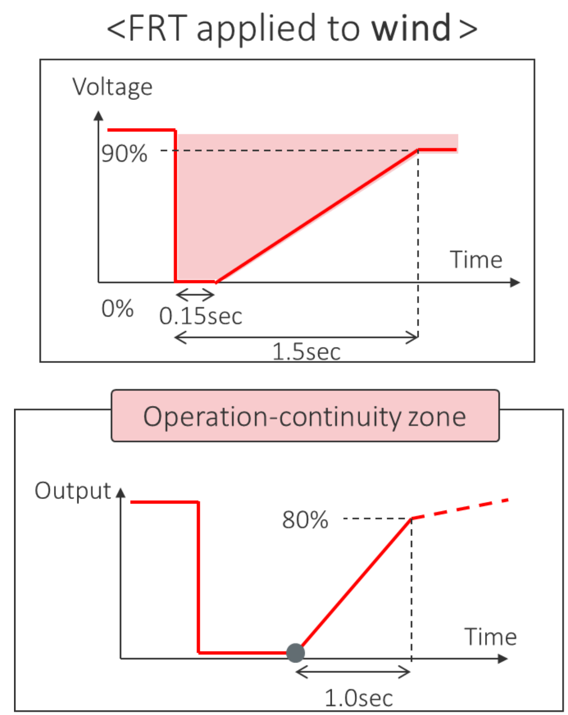
Not Covered

To be examined with PSSE

(Fault Ride-through Capability)
Japan Case

Japan case



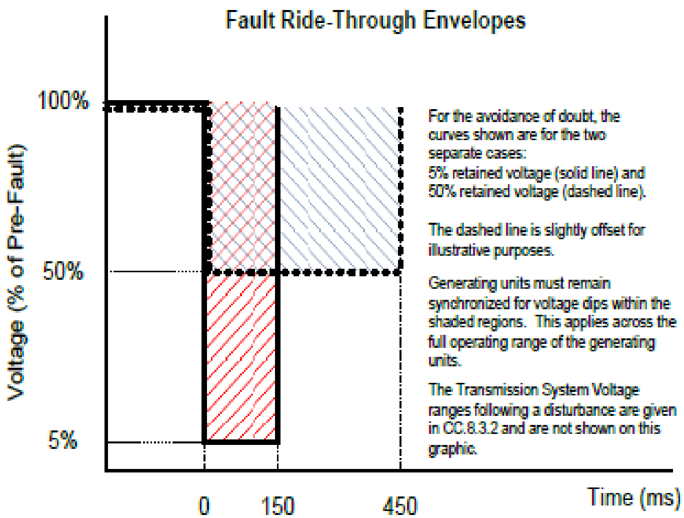


(Fault Ride-through Capability)
Ireland Case of Synchronised Generation

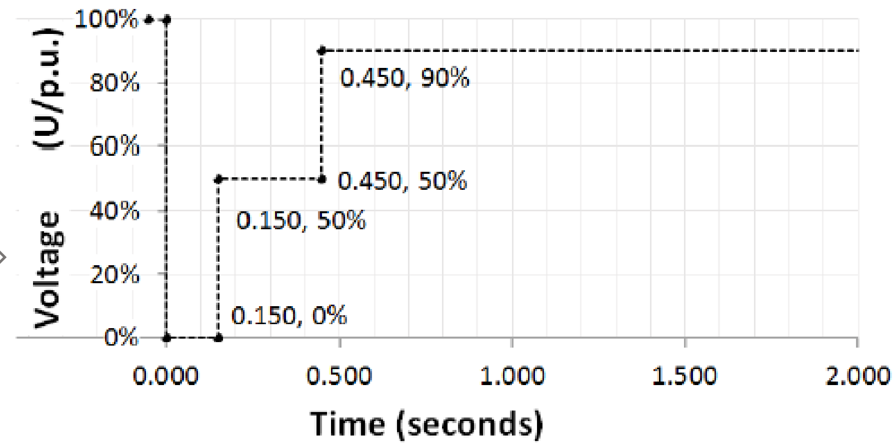
Ireland case

<Former FRT(roughly connected prior to 2019)>

VOLTAGE DIP MAGNITUDE	Fault Ride-Through Times		
	400 kV System	220 kV System	110 kV System
95% (5% retained)	150 ms	150 ms	150 ms
50% (50% retained)	450 ms	450 ms	450 ms



<Present FRT(roughly connected after 2019)>



(Fault Ride-through Capability)
Ireland Case of Intermittent Generation

Ireland case

<Former FRT(roughly connected prior to 2019)>

A Controllable PPM shall remain connected to the Transmission System for Transmission System Voltage Dips on any or all phases, and shall remain Stable, where the Transmission System Phase Voltage measured at the HV terminals of the Grid Connected Transformer remains above the heavy black line in *Figure PPM 1.1*.

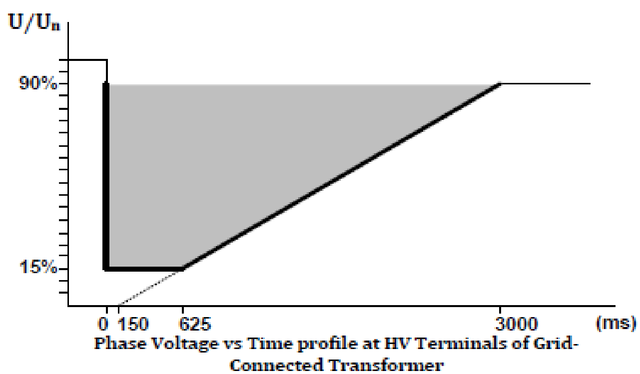
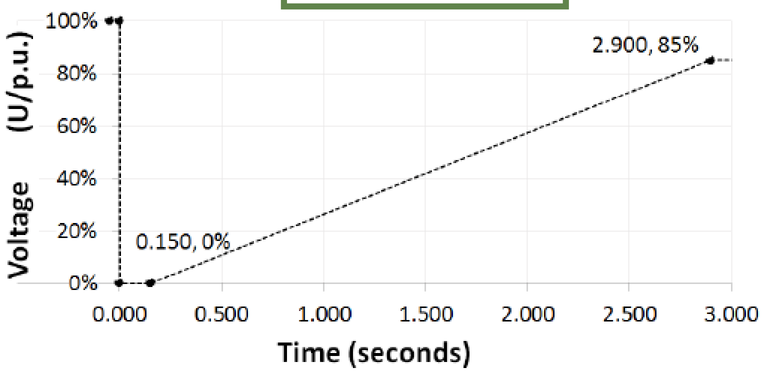


Figure PPM 1.1 - Fault Ride-Through Capability of Controllable PPMs

<Present FRT(roughly connected after 2019)>

(f) Controllable PPMs connected to the Transmission System shall be capable of staying connected to the Transmission System and continuing to operate stably during Voltage Dips. The voltage-against-time profile specifies the required capability for the minimum voltage and Fault Ride-Through Time at the Connection Point before, during and after the Voltage Dip. That capability shall be in accordance with the voltage-against-time profile as specified in Figure PPM1.4.2.



<Output Recovery (Unchanged in 2019)>

(b) The Controllable PPM shall provide at least 90 % of its maximum Available Active Power or Active Power Set-point, whichever is lesser, as quickly as the technology allows and in any event within 500 ms of the Transmission System Voltage recovering to 90% of nominal Voltage, for Fault Disturbances cleared within 140 ms. For longer duration Fault Disturbances, the Controllable PPM shall provide at least 90% of its maximum Available Active Power or Active Power Set-point, whichever is lesser, within 1 second of the Transmission System Voltage recovering to 90% of the nominal Voltage.

Generating Units | IRBGS | Embedded Generators

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Specification of Thermal Generators

Regarding designated specification of conventional generators, no description other than adjustable governor speed droop settings (2-10%) and inherent dead band (within ±0.05Hz) are in Clause 3.16.10

Sri Lanka

To be described referring to Japanese case , because they have been technically confirmed to be realizable with little additional cost (a few ten's of thousand dollars only with changing control logics, no need to change the specifications of generators, turbines and boilers) compared to existing thermal power plants in Japan.

	Japan case		
Designated Specification Items	**GT, GTCC**	**Thermal and mixed combustion biomass (e.g. with coal) other than GT, GTCC**	**Comments for Sri Lankan requirements**
Target capacity	≧100MW		Most of thermal units described in Annex 8.3 in the latest LTGEP are more than 100MW, so it's applicable
GF[*1] droop	≦4%		No need to revise because there is a already adjustable droop setting and it includes 4% below
GF output range	≧5%(Nominal output basis)	≧3%(Nominal output basis)	Technically applicable
LFC[*2] ramp rate	≧5%/min(Nominal output basis)	≧1%/min(Nominal output basis)	Technically applicable
LFC output range	≧±5%(Nominal output basis)		Technically applicable
EDC[*3] ramp rate	≧5%/min(Nominal output basis)	≧1%/min(Nominal output basis)	Technically applicable
Ramp rate in using EDC & LFC simultaneously	≧10%/min(Nominal output basis)	≧1%/min(Nominal output basis)	Technically applicable
Lower threshold of output range enabling to use LFC, EDC	≦50%(Nominal output basis)	≦30%(Nominal output basis)	Technically applicable
DSS Capability	Required (Down time Interval ≦8 hours)	–	Technically applicable
Output Reduction Preventing Function[*4]	Required	–	Technically applicable

*1 Governor Free, *2 Load Frequency Control, *3 Economic load Dispatching Control

*4 Function to keep output if frequency drops down to 48.5Hz, or be able to recover even if output decreases once with frequency drops

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Specification of Thermal Generators

Ireland case | *(Reference) Japanese case*

(k) **Minimum Load** not greater than 50% of **Registered Capacity** for **CCGT Installations** and not greater than 35% of **Registered Capacity** for all other **Generation Units**. For **CCGT Installations** whilst operating in **Open Cycle Mode** as a result of combined cycle plant capability being unavailable, the **Minimum Load** of each **Combustion Turbine Unit** must be not greater than 35% of the **Registered Capacity** divided by the number of **Combustion Turbine Units**.

← 50% for CCGT & GT, 30% for thermal and mixed combustion biomass

(l) **Ramp up capability** not less than 1.5% of **Registered Capacity** per minute when the **Unit** is in the **Normal Dispatch Condition**.

(m) **Ramp down capability** not less than 1.5% of **Registered Capacity** per minute when the **Unit** is in the **Normal Dispatch Condition.**

← 5%/min for CCGT & GT, 1%/ min for thermal and mixed combustion biomass

(n) **Minimum up-time** not greater than 4 hours for **Thermal Units.**

(o) **Minimum down-time** not greater than 4 hours for **Thermal Units.**

← 8 hours only for CCGT & GT

(p) **Forbidden Zones** within the range between normal **Minimum Load** plus 5% and **Registered Capacity** less 10%, not more than 2 specified zones each not greater than 10% of **Registered Capacity.**

(q) **Block Loading** not greater than 10% of **Registered Capacity.**

(r) Time off-load before going into longer standby conditions remain in a hot condition for at least 12 hours and remain in a warm condition for at least 60 hours.

Ireland's requirements are similar to Japanese ones or a little severer.
So, to refer to Japanese requirements is suitable in the meaning of covering minimum requirements.

Roughly connected prior to 2019

as at the time when the installation of which it forms a part was designed. Normal governor regulation shall be between 3% and 5%.

Roughly connected after 2019

Generation Units shall be capable of setting governor regulation between 2% and 12%. The default governor regulation setting shall be 4%.

← 4% below

(u) **Operating Reserve**

(i) **POR** not less than 5% **Registered Capacity**

(ii) **SOR** not less than 5% **Registered Capacity**

← 5% each for GF, LFC for CCGT & GT
5%, 3% each for GF, LFC for thermal and mixed combustion biomass

Ramp Rate Limitation

No description regarding ramp rate limitation for intermittent resources in Clause 3.17

Sri Lanka

(In Clause 5.9, there is a operational description, however, to conduct the limitation of output changes, it is needed to install batteries etc with solar and wind)

To be examined with PSSE

Japan case

Type	Technical requirements
Solar >2,000kW and Wind >20kW	At all times, the rate of change of power plant output shall be "1% or less / minute of the rated output of the power plant".

Ireland case

<Former Description(roughly connected prior to 2019)>

These deviations should not be allowed to exceed 3% of Registered Capacity.

⇩

<Present Description(roughly connected after 2019)>

These deviations should not exceed the greater of 3% of Registered Capacity or +/- 0.5 MW.

Control Prioritization

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5.6 Dispatch Procedures

Sri Lanka

System Operator will prepare a daily dispatch schedule and Generators will be requested to generate according to this schedule. All dispatchable Generating Units will be subject to central Dispatch instructions. The Dispatch shall be a least-cost, security-constrained Dispatch, meaning that generating unit commitments will be optimized with full recognition of unit availability, unit start-up and operating costs, and grid constraints due to system operating limits and irrigation constraints in the case of multi-purpose hydropower Generating Units. Log notes shall be maintained regarding any deviation from the Daily Dispatch Plan, including the reasons for the same.

→There is a description " The Dispatch shall be a least-cost", however any concrete orders by types of generation are not described

To be described for transparent operation referring to Japan case. That was discussed with NSCC in Sep 2022.

Japan case

The order in which the output is controlled ↓

0	Output control of thermal power and PSPP pumping, battery charging (dispatchable)
1	Ditto(Non-dispatchable including mixed combustion biomass (e.g. with coal) , except for biomass, renewables and long-term fixed power sources*1)
2	Export to other regions using interconnected lines
3	Biomass(except for those using local resources*2) output control
4	Biomass using local resources
5	Solar and wind power control
6	Output control of long-term fixed power sources (hydro(other than PSPP), nuclear, geothermal)

*1 Generation types that has technical difficulties to control their output
*2 Unutilized local biomassresources that potentially exist at power plants' location

Ireland case

No description

03 GRID CONNECTION REQUIREMENT FOR SOLAR/WIND POWER PLANTS

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Output Control / Remote Control Facility

(Wind)3.1 Output Control

Sri Lanka

The wind farm shall provide the necessary controlling facility to limit the out put variation of the wind farm by incorporating necessary controls to individual wind turbines. The ramp rate will be defined for the grid substation and shall not exceed 10 MW/minute. The ramp rates applicable for individual wind farms will be distributed in terms of their installed capacity. The ramp rate shall be applicable to wind farms connected to a particular grid substation as depicted below.

Ramp rate is to be examined with PSSE

(a) If the wind farm capacity is equal or greater than 5 MW.

(b) If the cumulative installed capacity of wind farms connected to a particular grid substation equal or exceeds 20 MW. (Wind farms having installed capacities less than 1 MW will be exempted though the capacities of such wind farms will be considered for calculation of cumulative installed capacity)

Extent is to be examined with PSSE

(Wind)3.2 Remote Control Facility

Sri Lanka

Remote controlling facility from System Control Centre shall be provided for the main circuit breaker of the wind farm if the cumulative installed capacity of wind farms connected to a particular grid substation exceeds or equal 20 MW. The wind farms having installed capacities less than 1 MW will be exempted though the capacities of such wind farms will be considered for calculation of cumulative installed capacity.

This requirement will be waive off for first 40 MW of wind farms. However, CEB reserve the right to control out puts of those plants, during an emergency situation such as restoration of power supply after an Islandwide supply failure, during very volatile wind situation and situations where wind farm out puts are not responsive to the ramp rates stipulated in section 3.1.

Procedure of output control is adaptable and flexible not by circuit breaker but by PCS?

It is necessary to write communication requirement with dedicated line for certain amount solar and wind(1MW- or 10MW-) for solar as well

Low Voltage Ride Through Capability

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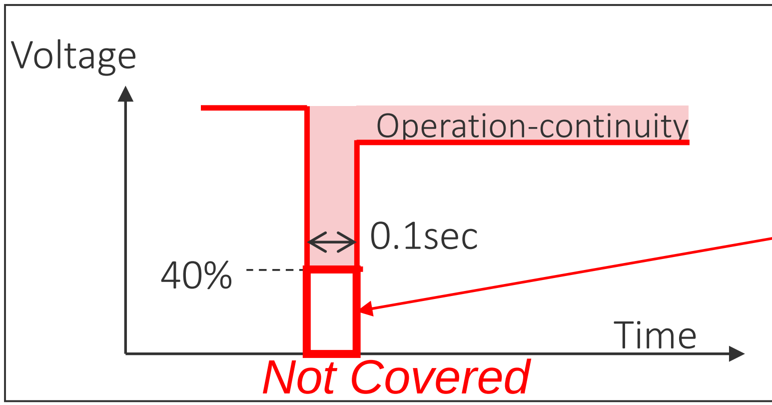
(Solar)4.5/(Wind)4.6 Low Voltage Ride Through (LVRT) Capability

Sri Lanka

The solar/wind power plant shall be connected to the grid during voltage disturbances (Under voltage conditions) of the power system for a short period of time. The low voltage margin required in the LVRT capability is beyond the low voltage margin stipulated under ''4.2 Voltage Requirement''. If the grid voltage at the point of interconnection reduces to 40% of the nominal voltage and remain at 40% of nominal voltage for a period less than 100 ms and then recover to a voltage level of 90% or higher within 3 seconds, the solar PV plant/wind farm shall remain connected to the grid. If the voltage during the disturbance reduces below the aforesaid voltage profile, the solar PV plant/wind farm shall trip.



To be examined with PSSE

No output recovery criteria designated

(Wind)4.6.1 Applicability of LVRT capability

Sri Lanka

Extent spread to all capacities to be examined with PSSE

The LVRT capability shall be applicable for any one of the cases described below.

(a) Wind farm having installed capacities 5 MW or above.

(b) If the cumulative installed capacity of wind farms connected to particular grid substation exceeds or equal to 20 MW, all the generating companies, except wind farms having installed capacities below 1 MW shall together or individually provide the LVRT facility either at point of common coupling or at 33 kV bus bar of the grid substation.

(Wind) 4.6.2. Exemptions from LVRT capability

Extent spread to all capacities to be examined with PSSE

The LVRT capability is waived off for following cases.

(a) The first wind farm developers will be exempted form LVRT capability whose total installed capacity is 40 MW.

(b) The wind farm having installed capacities less tan 1 MW

04 Scenarios for analyzing Grid Code with PSSE

Overview of Simulation Scenarios

		Fault case (N-1 fault + VRE fluctuation)	Usual case (No fault but VRE fluctuation)
Frequency regulation	FRT	✓	
	RoCoF	✓	
	Ramp Rate Limitation	✓	✓
	~~Frequency Variation Capability~~	No simulation required See chapter 02	~~✓~~
Voltage regulation	Power Factor Variation Capability		✓

(FRT simulation with battery 0MW)
・N-1 largest generator trip + VRE ramp down + VRE trip case
・VRE ramp down + VRE trip case×2

Unstable： Need to revise FRT

Stable

(RoCoF simulation with battery 0-500MW)
N-1 largest generator trip + VRE ramp down

No need to conduct RoCoF & Ramp Rate simulations
(No need to revise Grid Code regarding FRT & Ramp Rate)
<u>But only FRT is to be described on FRT simulations</u>

(Ramp Rate simulation with battery 0-500MW)
・N-1 largest generator trip + VRE ramp down
・ Only VRE ramp down

Proceed Voltage Simulation

Proceed Voltage Simulation

(PF simulation)
Low demand + high wind + much solar case

Generating Units | IRBGS | Embedded Generators

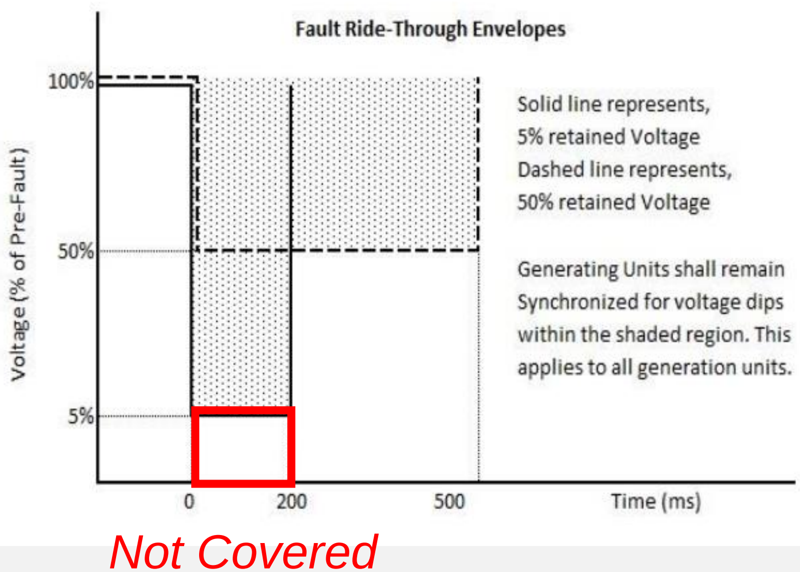
Fault Ride Through(Scenario Overview)

1. Voltage thresholds covered in CEB Grid Code are 5% beyond for generating units & IRBGS, 40% beyond for embedded generators.
2. In the PSSE simulation, **we'd like to confirm if voltage of 5% or 40% below occurs or not**, and if it occurs, **would like to confirm the amount of shedding VRE in the case of typical faults in CEB's study** (Puttalamps or Biyagama transmission fault).
3. Considering such shedding VRE amount, we'd like to confirm if the frequency can keep stable or not.
   If it can't, it is better to describe FRT requirement that covers down to 0%.

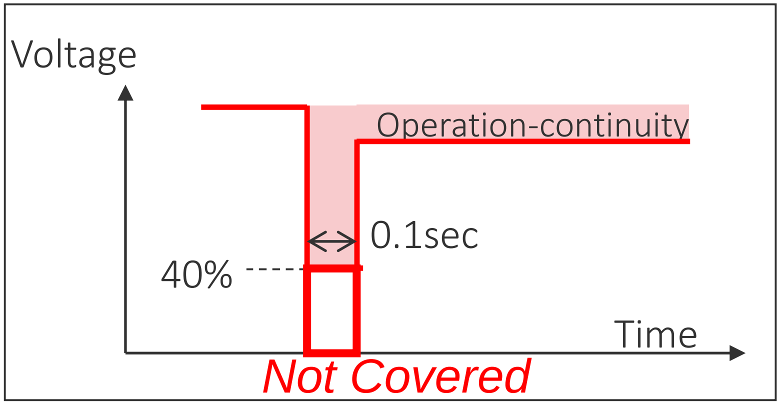
- In addition, there is no description about output recovery rate after voltage recovery.
- It is better to refer to Japanese case because Japanese electrical engineers and manufacture engineer considered technical realizations and determined such requirements.
  (In Ireland case , there is a description "As technology allows", so it is not sure that such requirement realization was confirmed with manufacture engineers)

<Other than Embedded Generators>

(D) FAULT RIDE-THROUGH CAPABILITY ENVELOPES (GCC 3.16.6)



<Embedded Generators>



Generating Units | IRBGS | Embedded Generators

Fault Ride Through(Concrete Scenarios)

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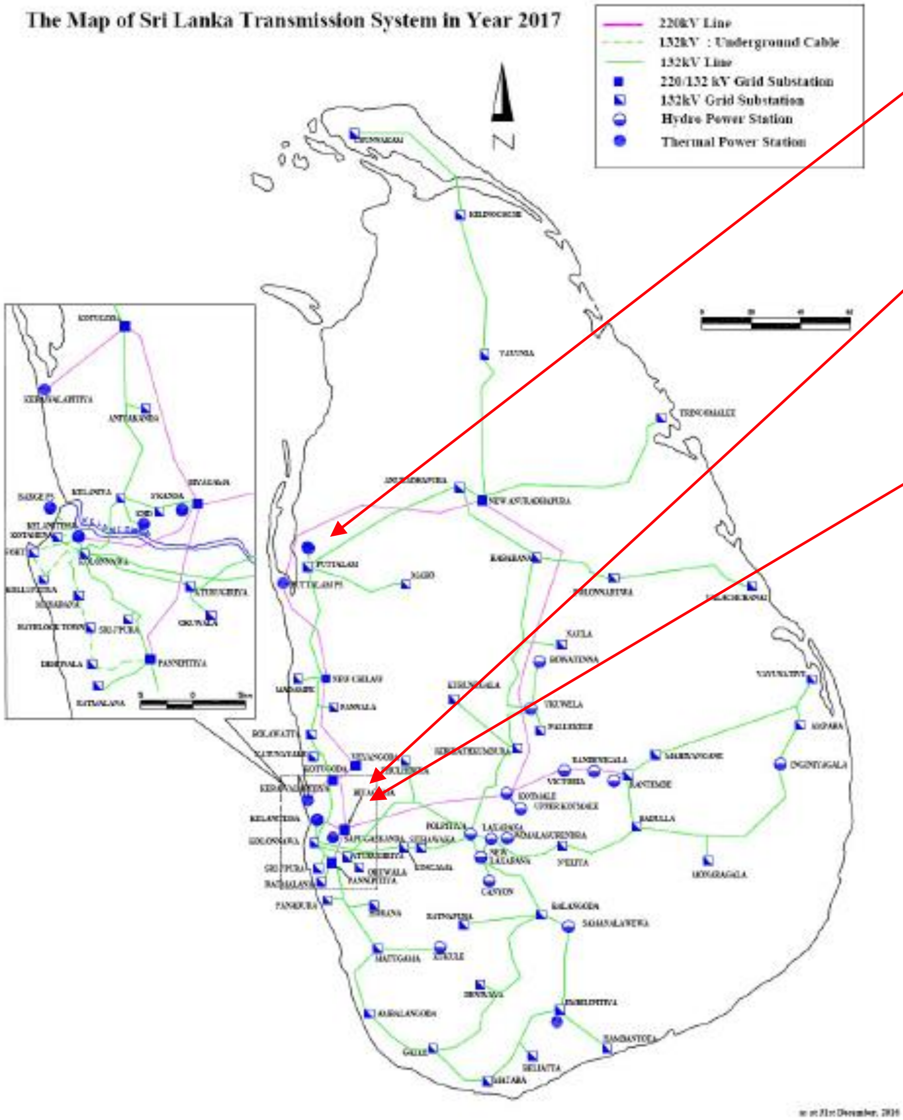
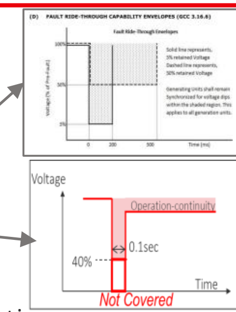


<Simulation Cases>

1. PUTTALAM Bus Fault Case
   - One coal generator trip
   - Solar ramp down
   - Over 132kV solar trip due to voltage drop under 5%
   - Under 33kV solar trip due to voltage drop under 40%
2. One 132kV/33kV Substation Bus Fault Case1
   →Substation selection with the most amount of solar connection
   - Solar ramp down
   - Over 132kV solar trip due to voltage drop under 5%
   - Under 33kV solar trip due to voltage drop under 40%
3. Another 132kV/33kV Substation Bus Fault Case2
   →Substation selection with the 2nd most amount of solar connection
   - Same as Case1



	Battery 0MW
1. PUTTALAM Bus	
2. Substation Bus Case1	
3. Substation Bus Case2	

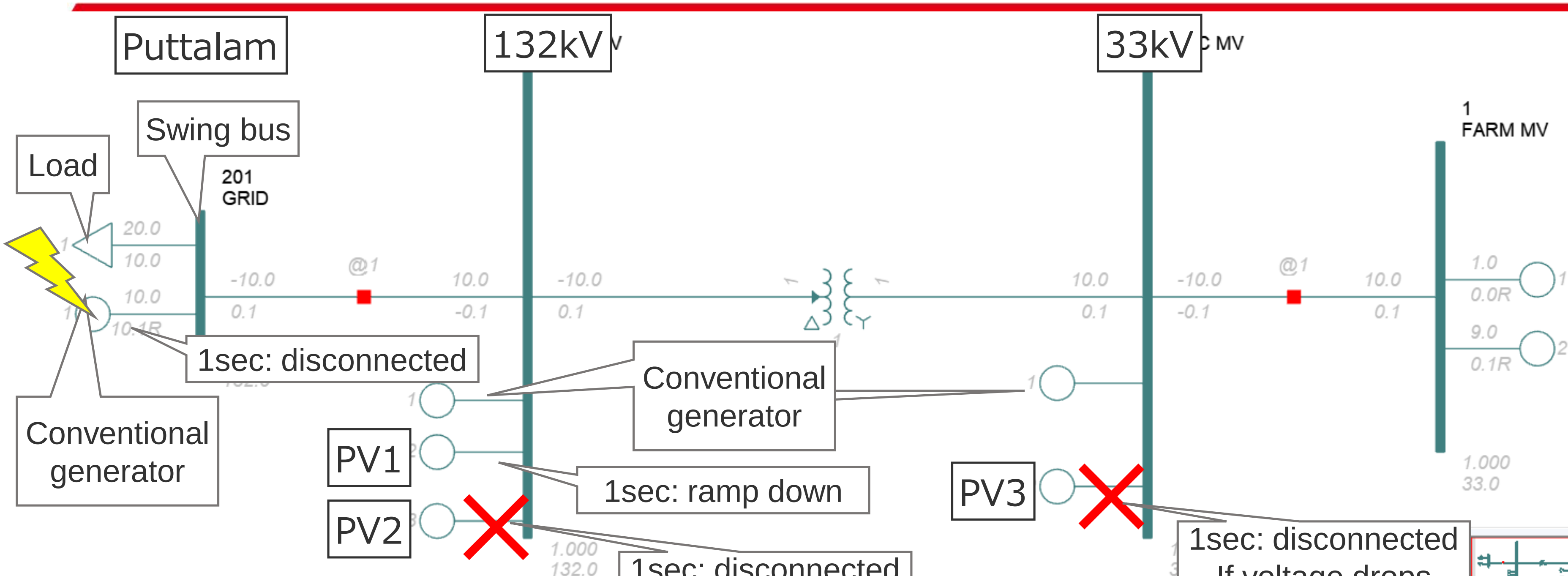
3 simulations **considering GTs' flexibility that can start up instantly**

<Evaluation Indicators @ battery 0MW case>
- RoCoF(measured within 100ms) >2Hz/s*
- Nadir with Load Shedding < 47.0Hz

or Voltage Coverage Extent Revision to 0%

*Refer to Japanese or other contries'(Finland, Spain etc) requirement

Concrete Scenarios



No	Time [sec]	Event
1	0	stable
2	1	One coal generator trip(disconnected machine) Solar ramp down
3	1	Check the voltage of buses adjacent to Puttalam
4	1	If the 132kV bus voltage is under 5% -> Trip over 132kV solar(disconnected machine) If the 33kV bus voltage is under 40% -> Trip under 33kV solar(disconnected machine)
5	1.2	Run to 1.2 sec, watch 2 indicators ・RoCoF ・Nadir

Generating Units | IRBGS | Embedded Generators

RoCoF(Concrete Scenarios)

<Simulation Cases>

1. There is no RoCoF description in CEB Grid Code.
2. In the PSSE simulation, **we'd like to confirm how much RoCoF occurs in the case of the severest fault (Puttalam bus fault + Solar ramp down) in CEB's study.**
3. RoCoF is to be described with the confirmation number above + margin.

⇩

<Evaluation Indicators @ battery 0MW case >

RoCoF(measured within 100ms) ⟶ Observed RoCoF is to be a numerical requirement in revised Grid Code

Ex.1)**RoCoF ≦ 2.0Hz/s @ Battery 0MW** → Grid Code requirement for RoCoF is 2.0Hz/s.

Ex.2)**RoCoF > 2.0Hz/s @ Battery 0MW** → This needs to be reduced with installation of batteries as per CEB's system wide protection's capability.

	Battery 0MW	Battery 100MW	Battery 200MW	Battery 300MW	Battery 400MW	Battery 500MW
PUTTALAM Bus Fault						

Prioritized cases! (Battery 0MW, Battery 100MW)

6 types of simulations **considering GTs' flexibility that can start up instantly** to identify appropriate amount of battery for frequency regulation

VRE Ramp Rate Limitation(Concrete Scenarios)

<Simulation Cases>

1. There is no description regarding ramp rate limitation for intermittent resources in CEB Grid Code.
2. In the PSSE simulation, **we'd like to confirm how much frequency is affected due to ramp rate of occur intermittent resources in the case of the severest fault (Puttalam bus fault + Solar ramp down) & usual situation(no fault but VRE output fluctuation occurs) in CEB's study.**
   (Considering solar trip due to voltage drop if FRT is not to be revised to cover down to 0%)
3. In particular, there should be no load shedding in usual situation.
4. In addition, ramp rate limitation leads to obligation of installing battery with intermittent resources, so it is to be considered that **this requirement is applicable to a certain amount of capacity considering financial impact on small size intermittent resources**.

↓

<Evaluation Indicators @ battery 0MW case >

PUTTALAM Bus Fault + Solar ramp down case : Nadir with Load Shedding < 47.0Hz

Only VRE fluctuation case : Nadir <48.75Hz(Load shedding threshold)

or

Ramp rate limitation description
(Threshold is to be calculated with further simulation with mitigation of VRE fluctuation)

	Battery 0MW	Battery 100MW	Battery 200MW	Battery 300MW	Battery 400MW	Battery 500MW
Only VRE fluctuation	Prioritized cases!					

6 types of simulations **considering GTs' flexibility that can start up instantly** to identify appropriate amount of battery for frequency regulation
(PUTTALAM Bus Fault case is the same case as RoCoF scenarios, so not need to simulate)

Generating Units | IRBGS | Embedded Generators

Power Factor Variation Capability(Concrete Scenarios)

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<Simulation Cases>

1. Ireland Grid Code describes wider power factor variation capability compared to CEB Grid Code.
2. In the PSSE simulation, **we'd like to confirm how much voltage deviation occurs in the case of usual situation**(no fault and low demand + high wind + much solar case) **with PF constraints described in CEB's Grid Code.**

<Evaluation Indicators>

Each bus voltage < Grid Code Table 4.1.B (132-400kV : ±5%, 11-33kV:±6%)

→ Expansion of PF requirement in the revised Grid Code in case of voltage breach.

- Voltage breach bus is near IRBGS connection point : Expansion of IRBGS PF requirements
- Voltage breach bus is near Embedded Generators : Newly describe PF requirements

Only one simulation with PF constraints in line with the figure below(without battery)

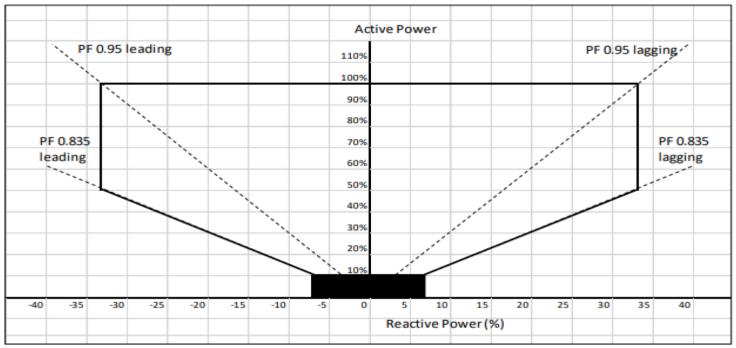
<Generating Units Constraints>

the Power Factors of **0.8 lagging and 0.9 leading,**

<IRBGS Constraints>

3.3 GENERATION LICENSEES WITH INTERMITTENT RESOURCE BASED GENERATION SYSTEMS

3.3.1 POWER FACTOR VARIATION CAPABILITY (GCC 3.17.1) AND REACTIVE POWER CAPABILITY (GCC 3.17.2)



05 Recommendation

Grid Code Revision Recommendation

<table>
<tr><th>Items</th><th>Generating Units</th><th>IRBGS</th><th>Embedded Generators</th></tr>
<tr><td>System Communication</td><td>–</td><td colspan="2">Equal to or more 10MW VREs are obligate to construct communication equipment with NSCC and keep controllable</td></tr>
<tr><td>FRT</td><td colspan="3">Expand the existing requirements if it is found to be necessary with PSS/E</td></tr>
<tr><td>RoCoF</td><td colspan="3">Newly stipulate with PSS/E simulation</td></tr>
<tr><td>Ramp Rate Limitation</td><td>–</td><td colspan="2">Newly stipulate if it is found to be necessary with PSS/E</td></tr>
<tr><td>Power Factor Capability</td><td colspan="3">Expand the existing requirements or newly stipulate regarding embedded generators if it is found to be necessary with PSS/E</td></tr>
<tr><td>Specification of Thermal Generators</td><td>Newly stipulate referring to Japanese requirements</td><td>–</td><td>–</td></tr>
<tr><td>Control Prioritization</td><td>Newly stipulate referring to Japanese requirements</td><td>–</td><td>–</td></tr>
</table>