Assessment of CO_2 Reduction by Renewable Energy Generators

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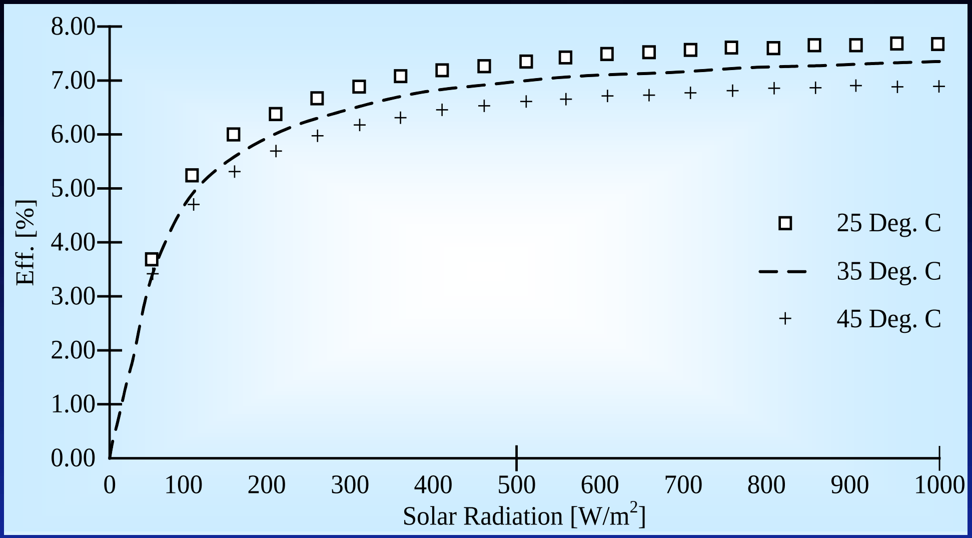
1. Introduction

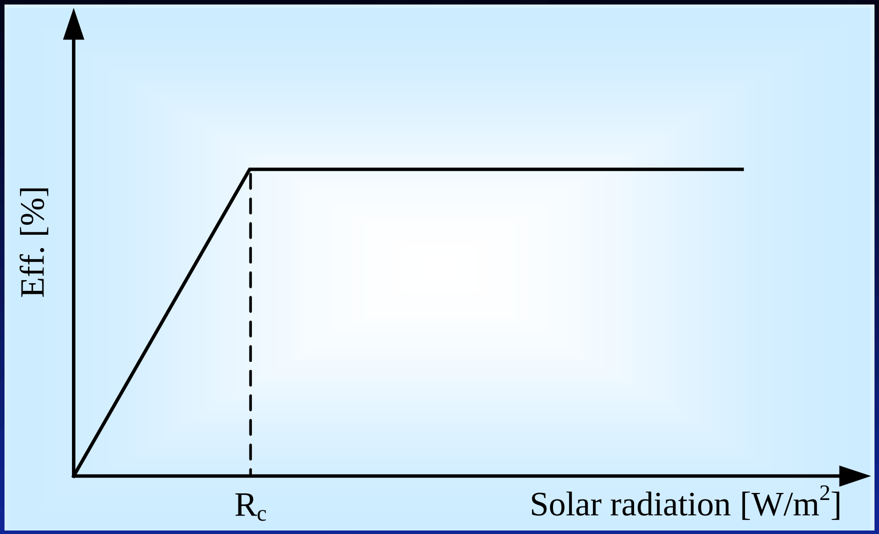
The application of renewable energy in electric power systems is growing rapidly due to its advantages that are minimal pollution, non-depletion and low operating cost.

The proposed method can be used for reliability evaluation of power system including SCG. The use of convolution integral in order to construct the ELDC considering the multi-state model of the SCG

It is possible not only to evaluate of reliability of power system but also to calculate the reduction of CO_2 using the proposed method.

2. Power Output Model of SCG

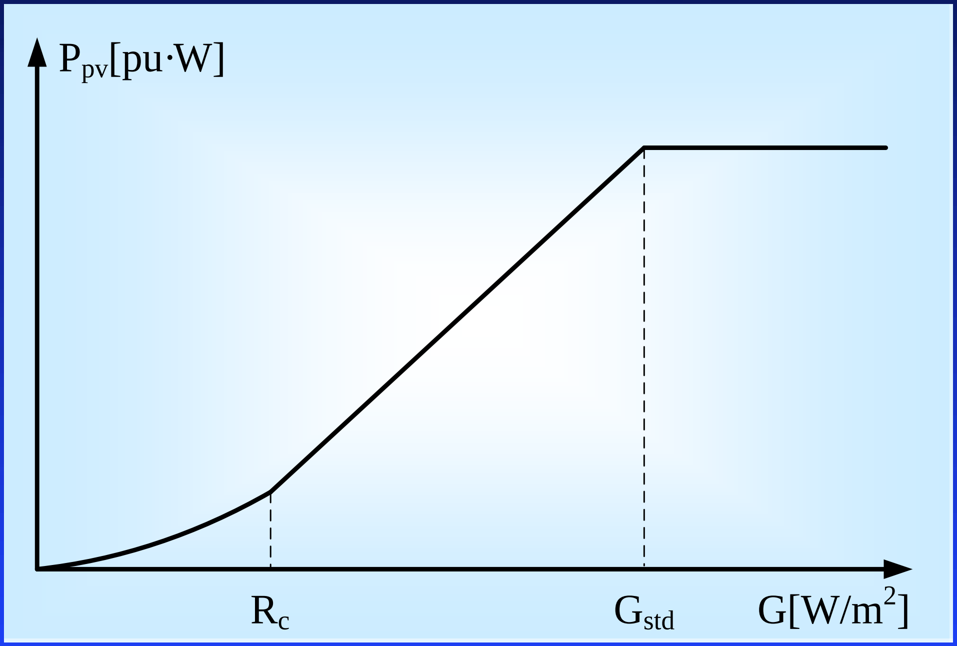




$$Eff_{pv}(G_{bi}) = \frac{\eta_c}{R_c} G_{bi} \quad , \qquad 0 \le G_{bi} < R_c$$

$$= \eta_c \quad , \qquad R_c \le G_{bi}$$

$$
\begin{aligned}
P_{bi}(G_{bi}) &= \frac{\eta_c}{R_c}(G_{bi}{}^2), \quad 0 \le G_{bi} < R_c \\
&= \eta_c G_{bi}, \quad R_c < G_{bi} \le G_{std} \\
&= P_{sn}, \quad G_{bi} > G_{std}
\end{aligned}
$$



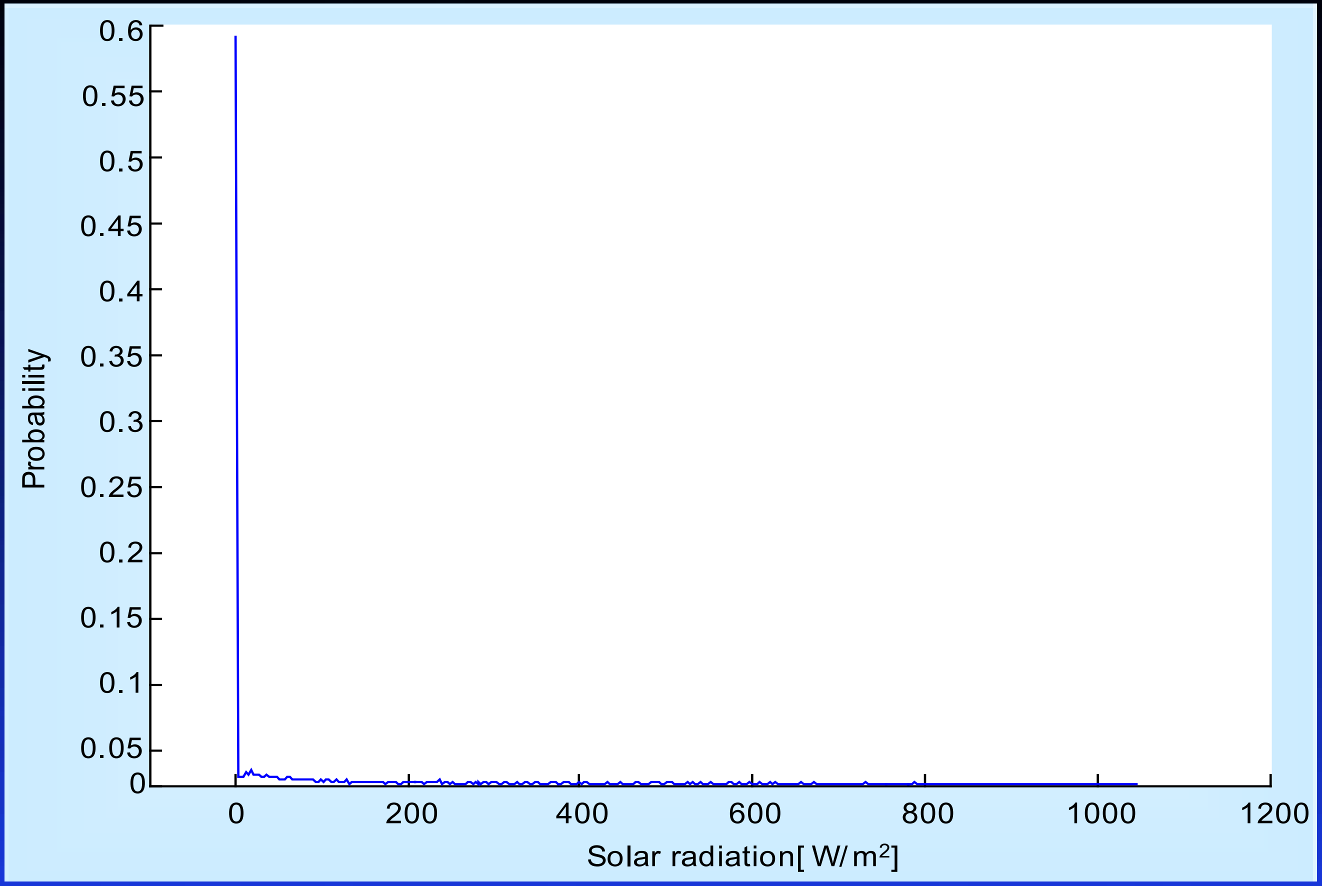
Where,

P_{pv}: Solar radiation-to-energy conversion function of the SCG [MW]

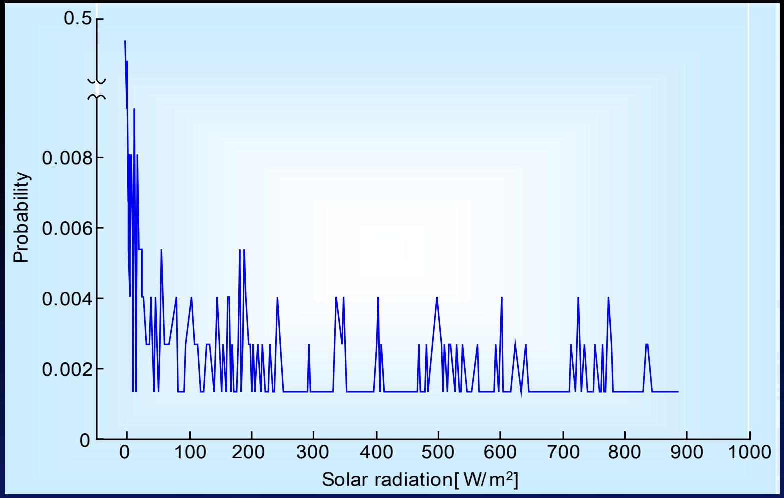
R_c: A certain radiation point set as 150W/m^2

G_{std}: Solar radiation in the standard environment set as 1,000W/m^2

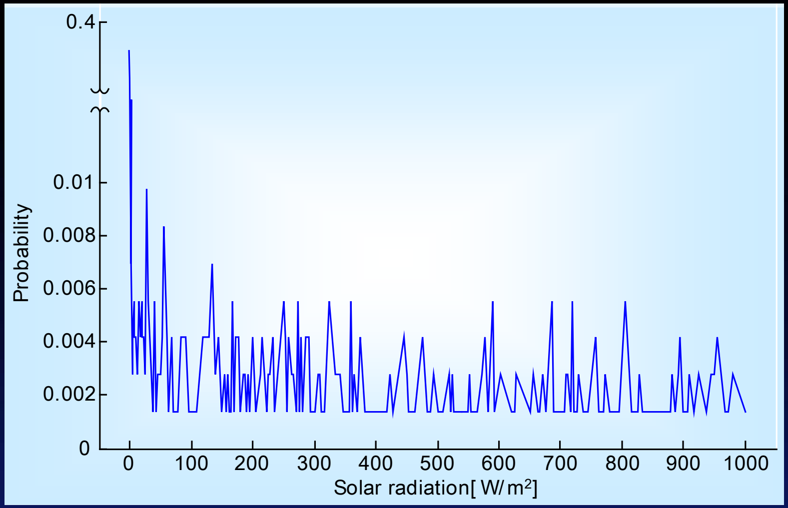
3 . Solar radiation model



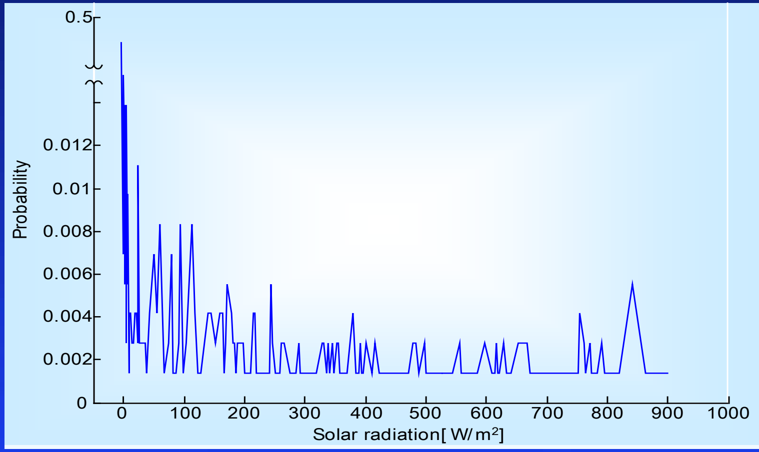
The solar radiation *pdf* at Jeju Island for ten years (1998-2007)



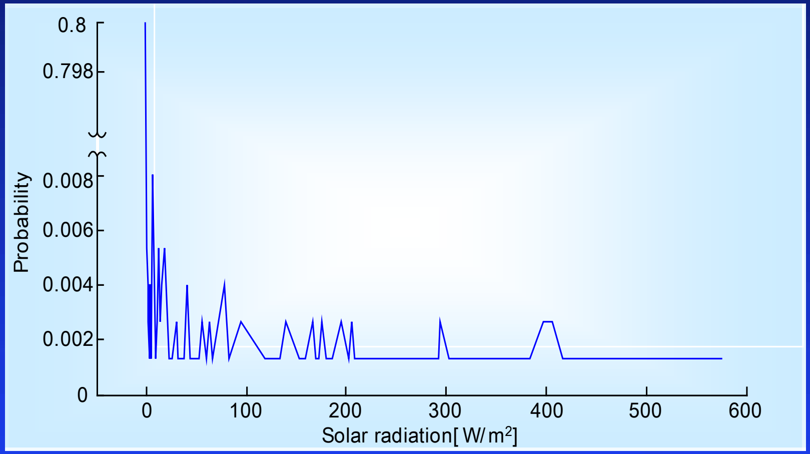
Solar radiation *pdf* model in March



Solar radiation *pdf* model in June

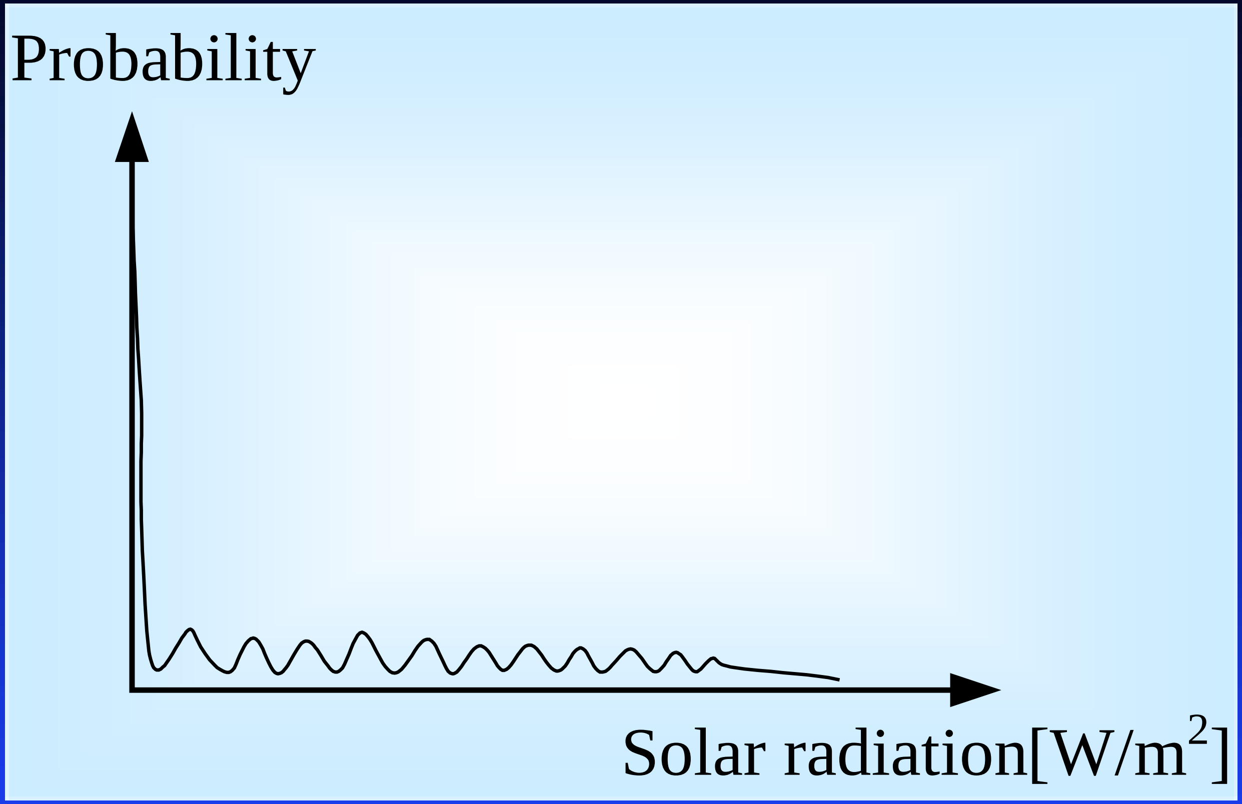


Solar radiation *pdf* model in September

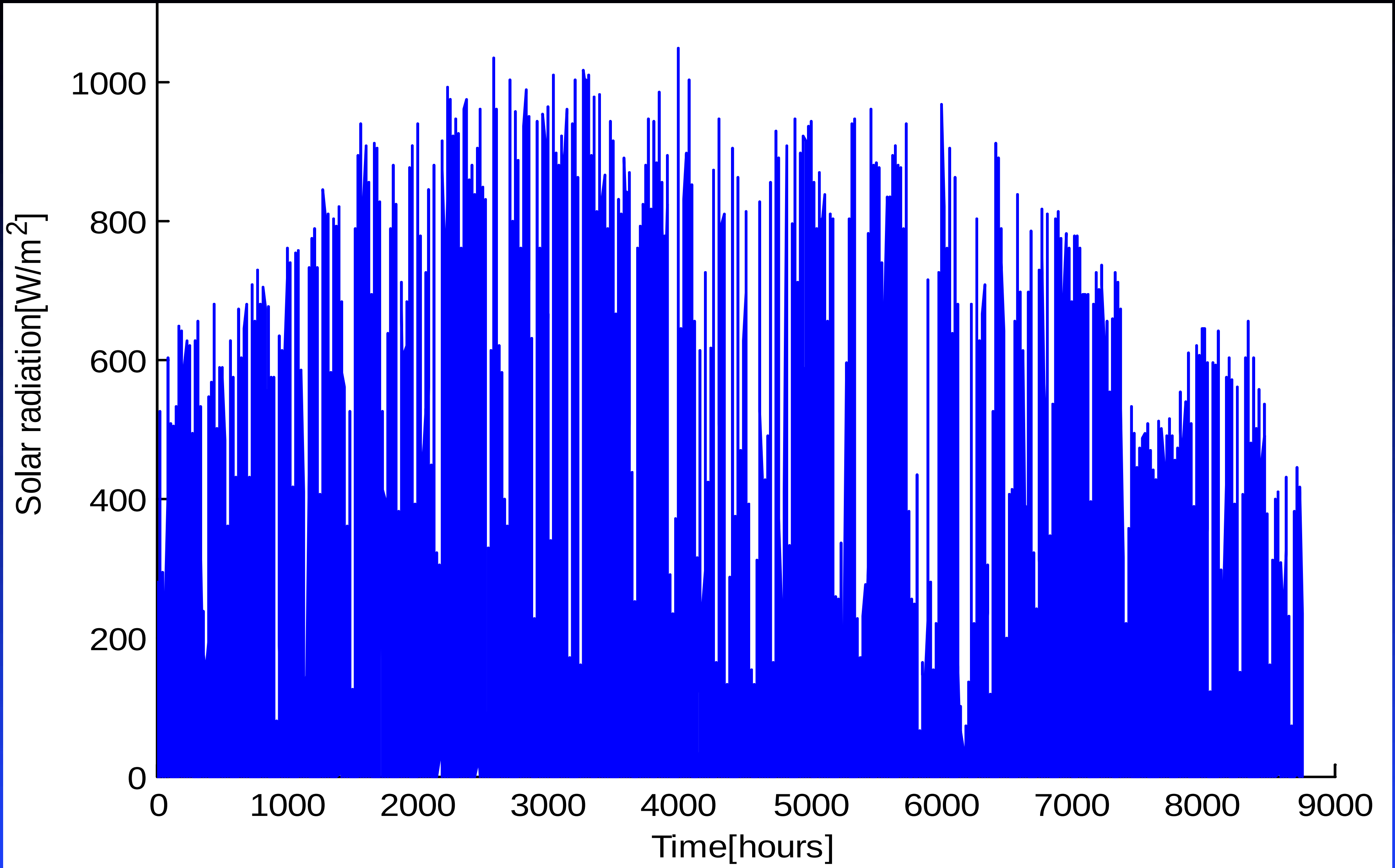


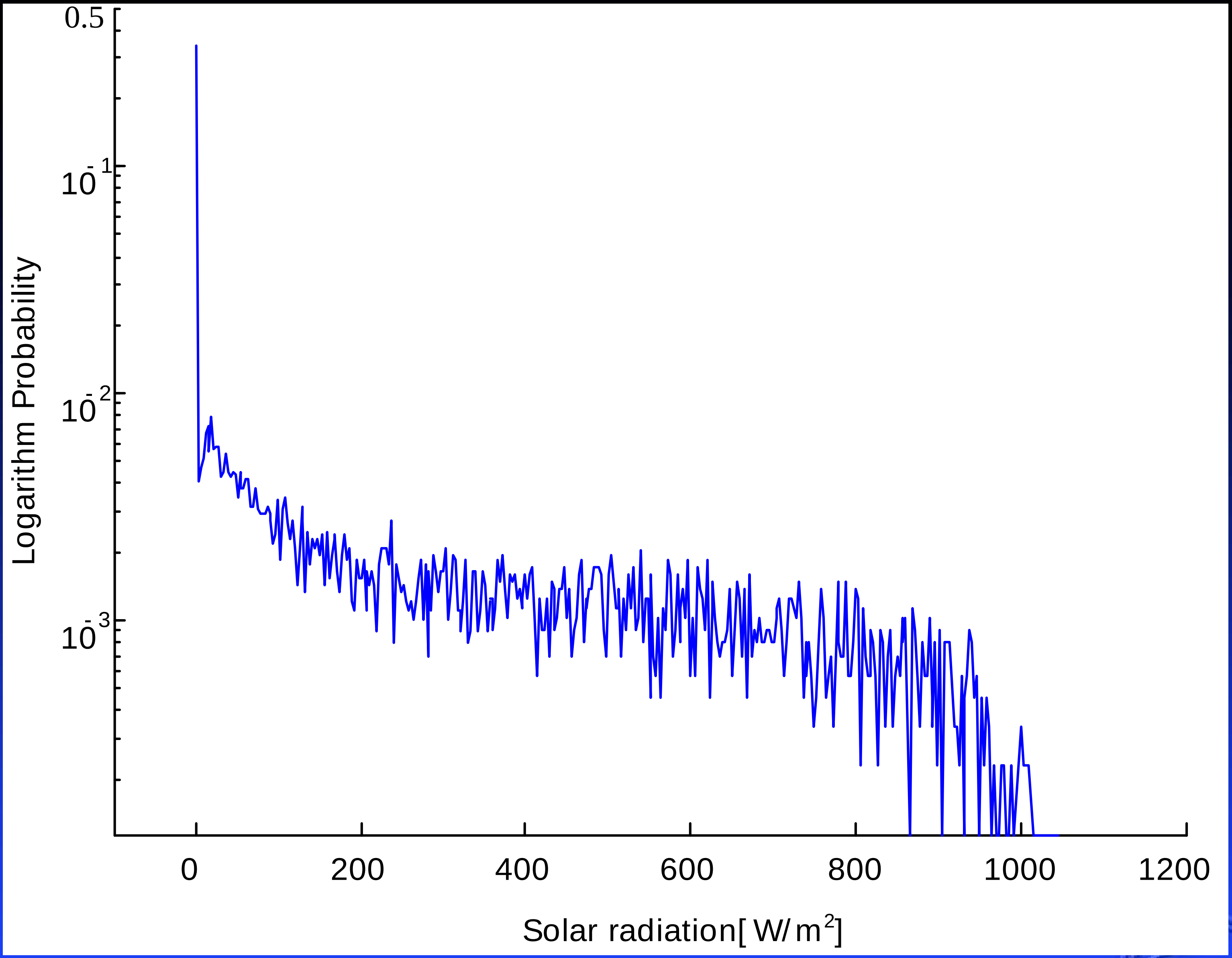
Solar radiation *pdf* model in December

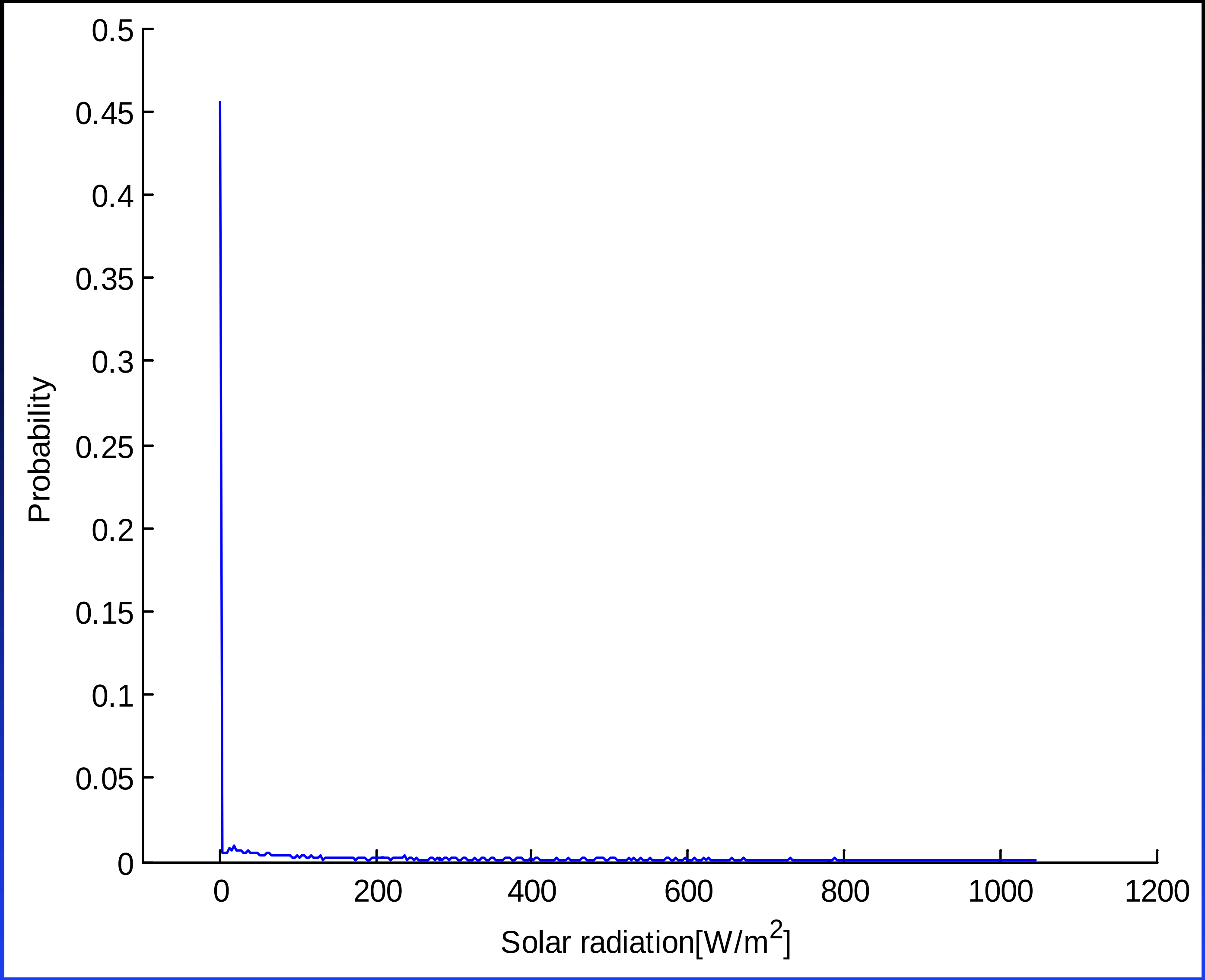
The typical pattern of the solar radiation *pdf* model



Solar Radiation at Jinju 2007

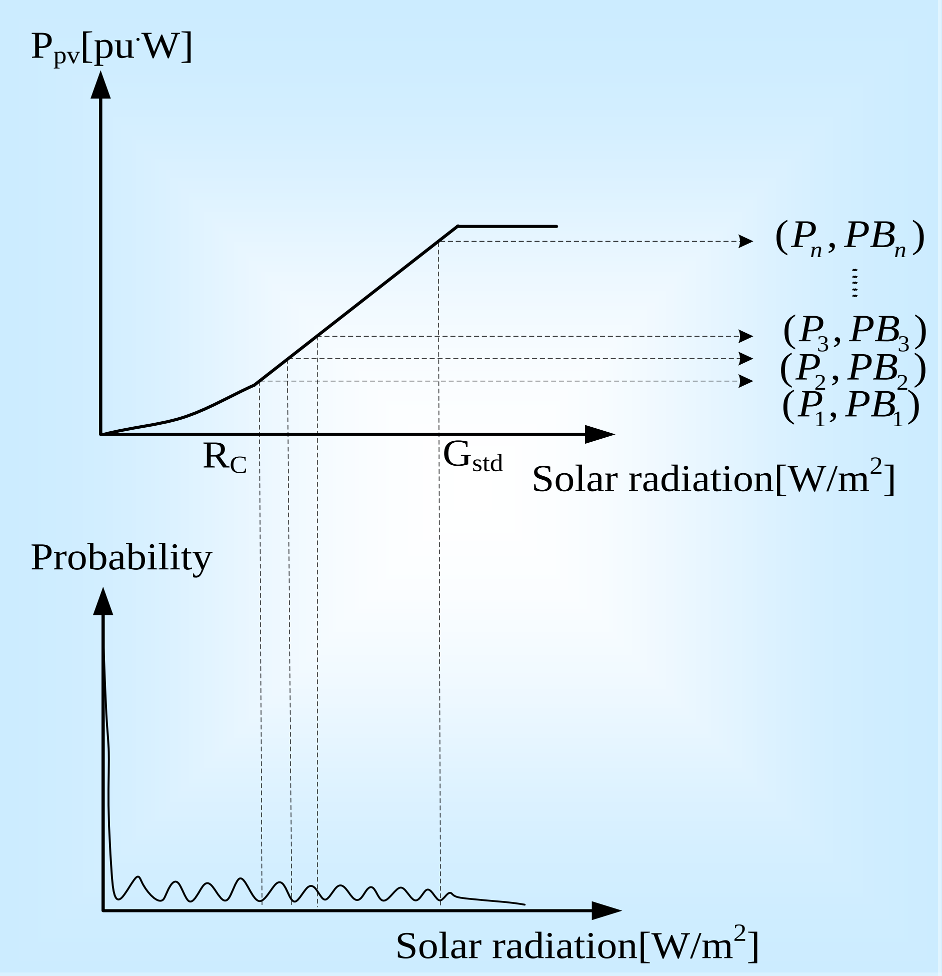



0.5
10^{-1}
10^{-2}
10^{-3}
Logarithm Probability
0
200
400
600
800
1000
1200
Solar radiation[W/m²]



Probability
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
200
400
600
800
1000
1200
Solar radiation[W/m2]

4. Reliability Evaluation of SCG

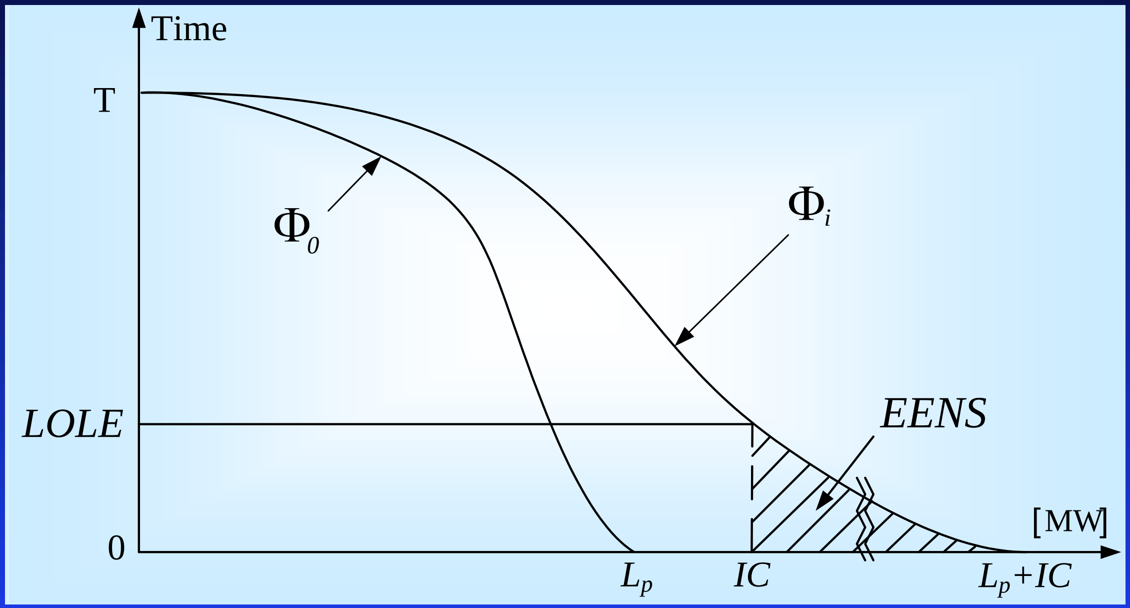


PDF Table of SCG multi-state model

Power	Probability
P_1	PB_1
P_2	PB_2
.	.
.	.
.	.
P_n	PB_n

$$\Phi_j = \Phi_{j-1} \otimes f_{oj}$$

$$= (1 - \sum_{k=1}^{NS} q_{kj}) \Phi_{j-1}(x) + \sum_{k=1}^{NS} q_{kj} \Phi_{j-1}(x - C_{kj})$$



$\otimes$: The convolution integral operator

Φ_0: Original inverted load duration curve (ILDC)

x: Random variable of Φ

NS: The total number of states

f_{oi}: The outage capacity *pdf* of generator *i*

Q_{kj}: Forced outage rate (FOR) of generator *k* at state *j*

C_{kj}: Outage capacity of generator *k* at state *j*

Jeongje Park, Wu Liang, Jaeseok Choi, A. A. El-Keib, Mohammad Shahidehpour and Roy Billinton, "Probabilistic Reliability Evaluation of Power System Including Solar/Photovoltaic Cell Generator" IEEE PES GM2009, July 26-30, 2009, Calgary, AB, Canada.

$$\mathrm{LOLE} = \Phi_{NG}(x)\Big|_{x=IC} \qquad \text{[hours/year]}$$

$$\mathrm{EENS} = \int_{IC}^{IC+L_p} \Phi_{NG}(x)dx \qquad \text{[MWh/year]}$$

$$\mathrm{EIR} = 1 - \frac{\mathrm{EENS}}{\mathrm{ED}} \qquad \text{[pu]}$$

$$\Delta \mathrm{E}_i = \mathrm{EENS}_{i\text{-}1} - \mathrm{EENS}_i \qquad \text{[MWh]}$$

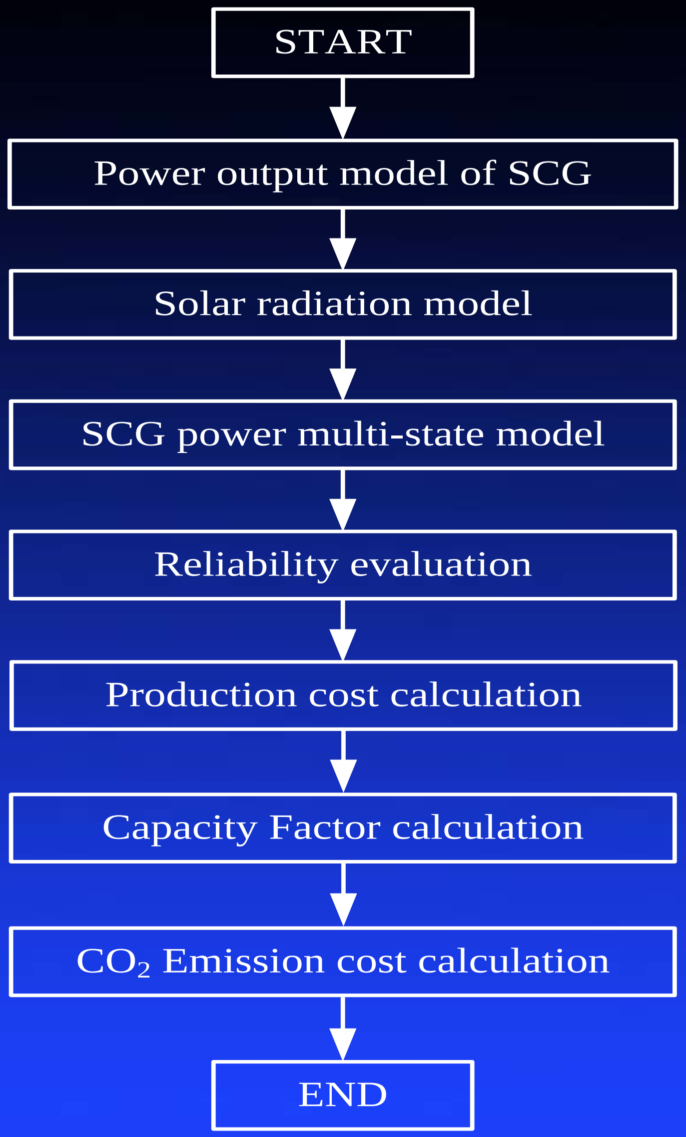
$$\Delta \mathrm{PC}_i = \lambda_a \times \Delta \mathrm{E}_i + \lambda_b \times (1 - \sum_{1}^{i} \mathrm{FOR}) \times \mathrm{LOLE}_{i-1} \qquad \text{[\$/year]}$$

$$\mathrm{CF}_i = (\Delta \mathrm{E}_i / \mathrm{CAP}_i / \mathrm{T}) \times 100 \qquad \text{[\%]}$$

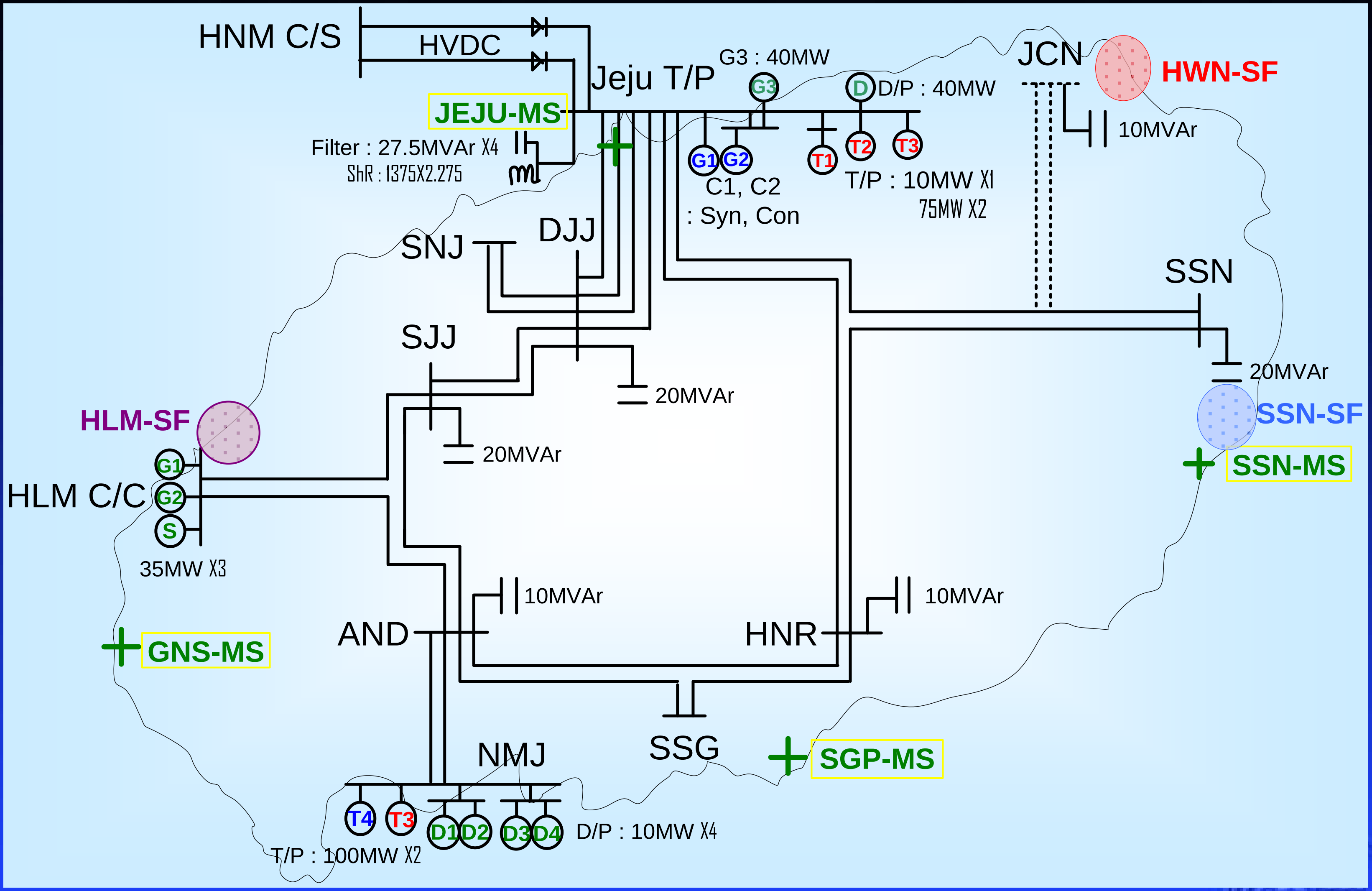
$$\mathrm{CO2}_i = \Delta \mathrm{E}_i \rho_i \qquad \text{[Ton/year]}$$

L_p : Peak load [MW]
IC_i : Installed capacity of generator i [MW]
ED : Total demand energy [MWh]
NG : The total generator number
Φ_{NG} : The final effective load duration curve
λ_a: Incremental cost coefficient
λ_b: cost constant
TCE_i : Total CO_2 Emission of i^{th} generator
CE_i : CO_2 emission of i^{th} generator

Flow chart


START
Power output model of SCG
Solar radiation model
SCG power multi-state model
Reliability evaluation
Production cost calculation
Capacity Factor calculation
CO_2 Emission cost calculation
END

5. Case Studies
A map of Jeju Island



Model System

1. It is a Juju island power system sized similar model system.

2. Total capacity is 945MW (CG845MW+SCG100MW).

3. Peak load is 681MW.

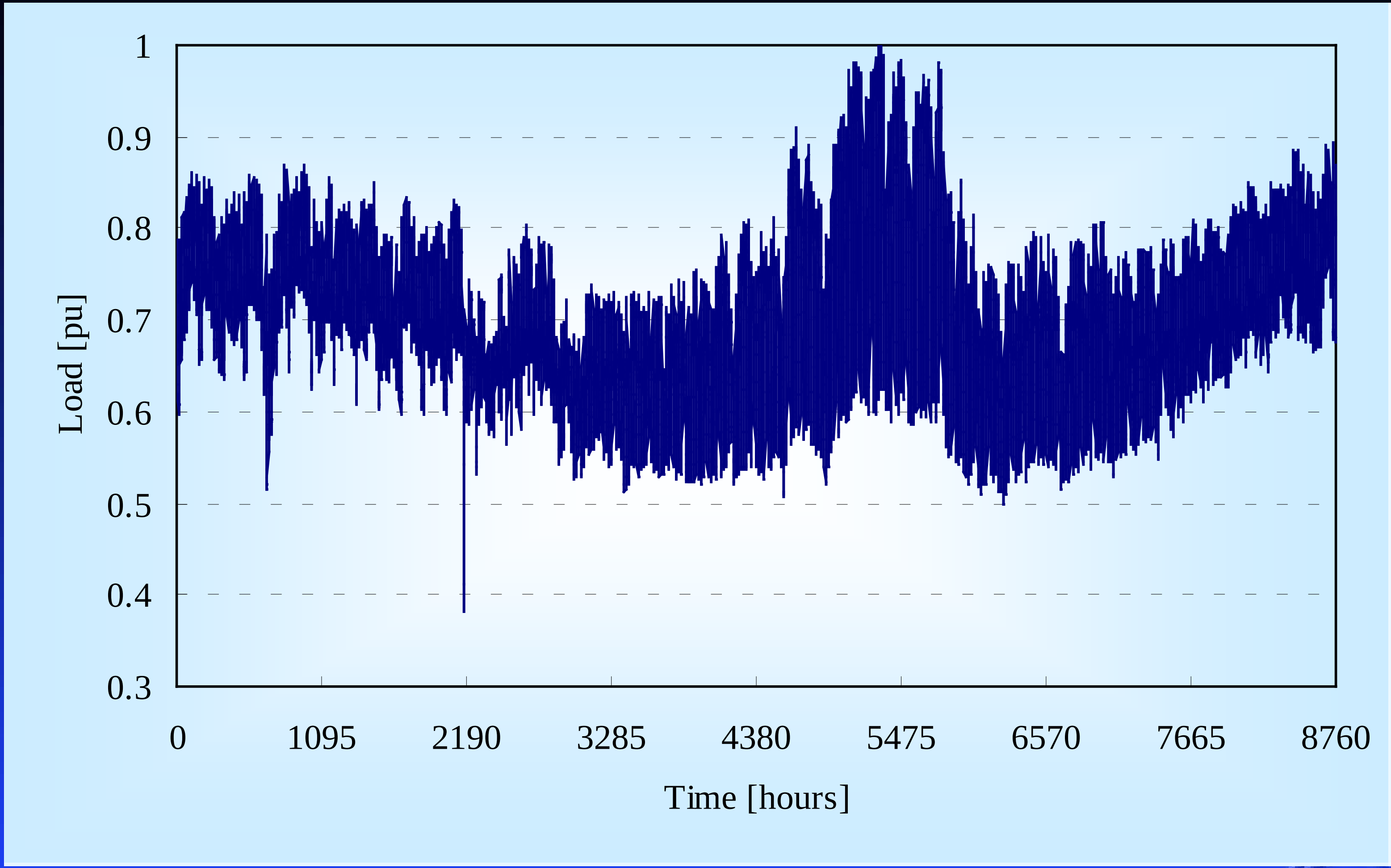
4. The OCPDF (outage capacity probability distribution function)

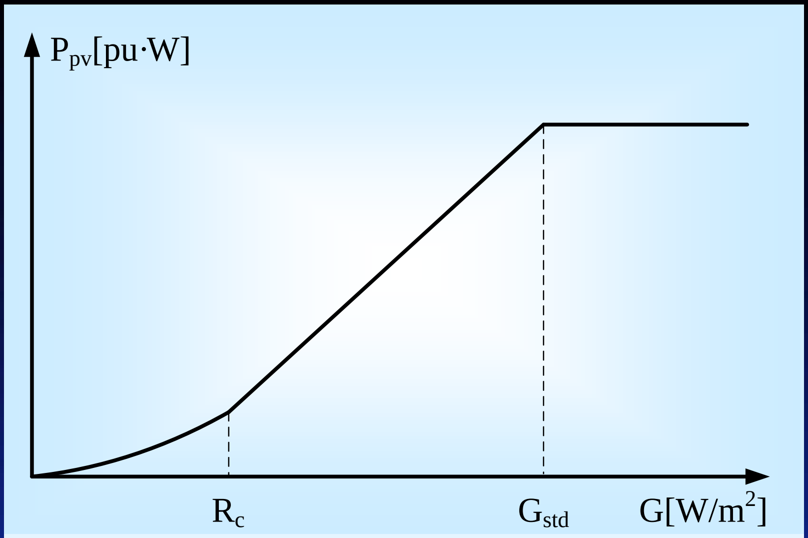
comes from three SCGs at JCN, SSN and HWN.

The generators data of Jeju island power system

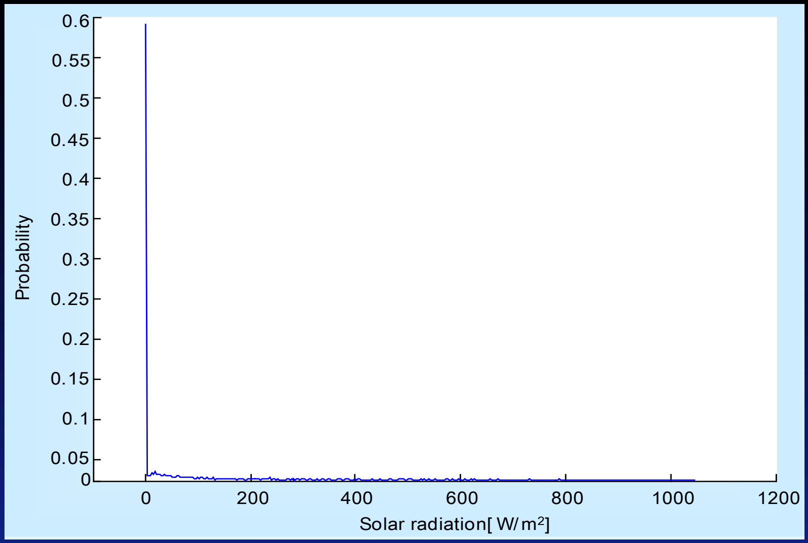
	Name	Type	Capacity [MW]	Num.	α [Gcal/ MW^2h]	β [Gcal/ MWh]	γ [Gcal /hr]	Fuel cost [$/Gcal]	CO_2 emission [Ton/MWh] ρ_i	FOR
1	HWN	WTG	50	1	-	-	-	-	-	-
2	SSN	WTG	30	1	-	-	-	-	-	-
3	HLM	WTG	20	1	-	-	-	-	-	-
4*	HVDC	DC	75/ 150*	2	0.004	1.512	45.207	43.300	0.65	0.010/ 0.028*
5	NMJ3	T/P	100	2	0.004	1.512	45.207	43.300	0.65	0.012
6	JJU1	T/P	55	3	0.062	2.100	5.971	43.599	0.96	0.015
7	JJU2	T/P	75	2	0.003	1.832	30.231	43.599	0.70	0.012
8	HLM1	G/T	35	2	0.004	2.401	20.320	77.909	0.95	0.013
9	HLM1	S/T	35	1	0.004	2.401	20.320	77.909	0.95	0.013
10	JJU3	D/P	40	2	0.025	0.364	28.484	43.599	0.59	0.018
11	NMJ1	D/P	10	4	0.006	1.999	1.360	43.300	0.62	0.018
Total			990	21	-	-	-	-	-	

Patterns of hourly peak load variation curve





➢ Power output model of SCG



➢ The solar radiation *pdf* at Jeju Island for ten years (1998-2007)

➢ The Parameters of SCG

SF Name	HLM-SF	SSN-SF	HWN-SF
SCG capacity	20MW	30MW	50MW
G_{std}	1,000W/m^2	1,000W/m^2	1,000W/m^2
R_c	150W/m^2	150W/m^2	150W/m^2

Results of case studies

	without SCG	with SCG	difference
IRR [%]	24.08	38.77	14.69
EENS [MWh/year]	83.92	60.04	23.88
LOLE [hours/year]	2.25	1.66	0.59
Total production cost [M$/year]	426.91	413.36	13.55
Total CO_2 Emission [10^3Ton/year]	2,727.88	2,641.35	86.53
Total CO_2 Emission Cost [M$/Ton]	65.47	63.39	2.08

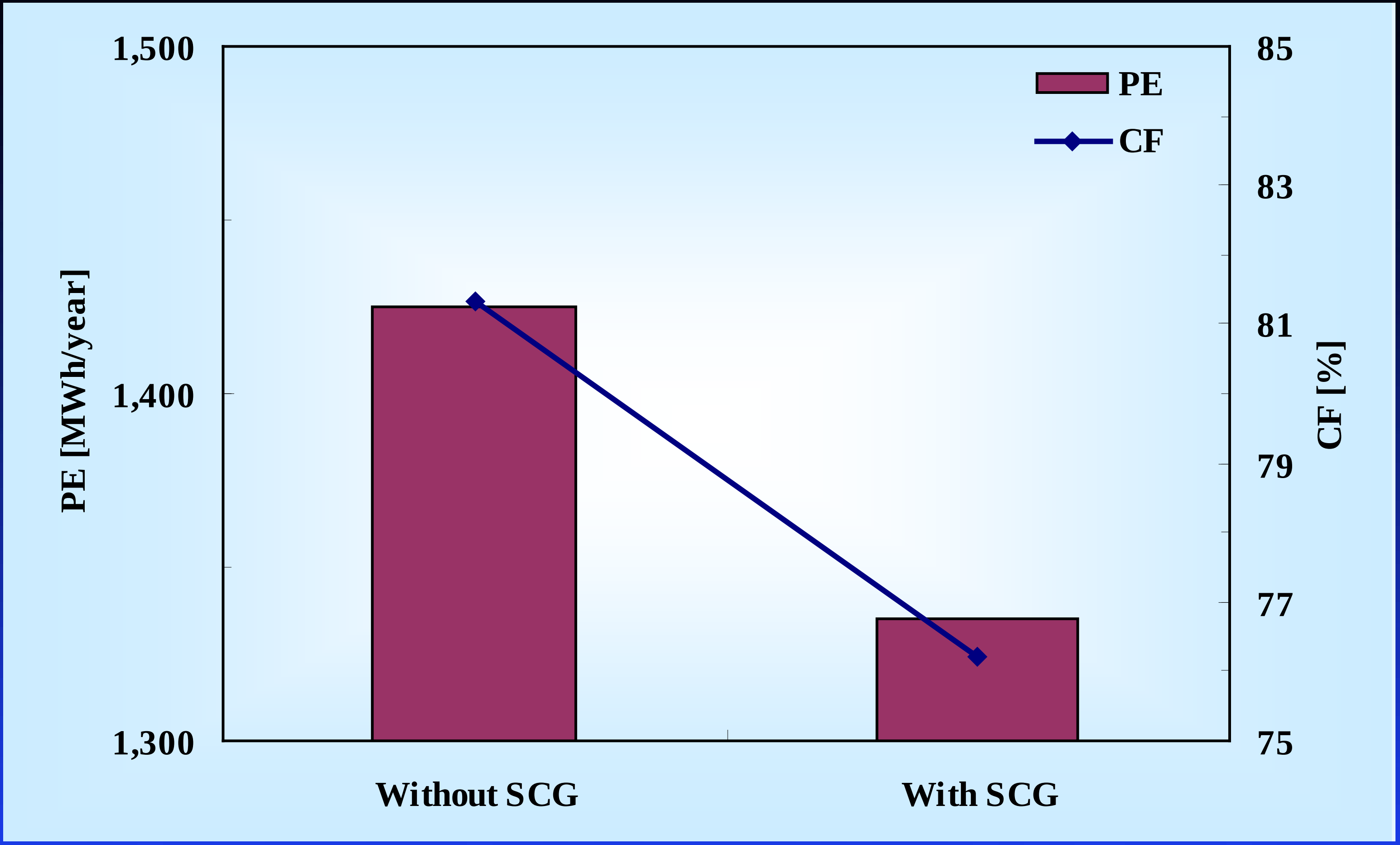
Production energy and capacity factor of each generators

Num. of Gen.	Without SCG		With SCG	
	Production energy [GWh/year]	Capacity factor [%]	Production energy [GWh/year]	Capacity factor [%]
1	-	-	63.73	14.55
2	-	-	38.24	14.55
3	-	-	25.49	14.55
4	2,541.20	96.7	2,541.20	96.7
5	1,424.80	81.33	1,335.50	76.23
6	29.41	33.57	24.27	27.7
7	161.77	12.31	131.02	9.97
8	7.26	1.18	5.62	0.92
9	1.17	0.38	0.9	0.29
10	0.60	0.17	0.41	0.12
11	0.16	0.05	0.12	0.03
Total	4,166.37		4,166.50	

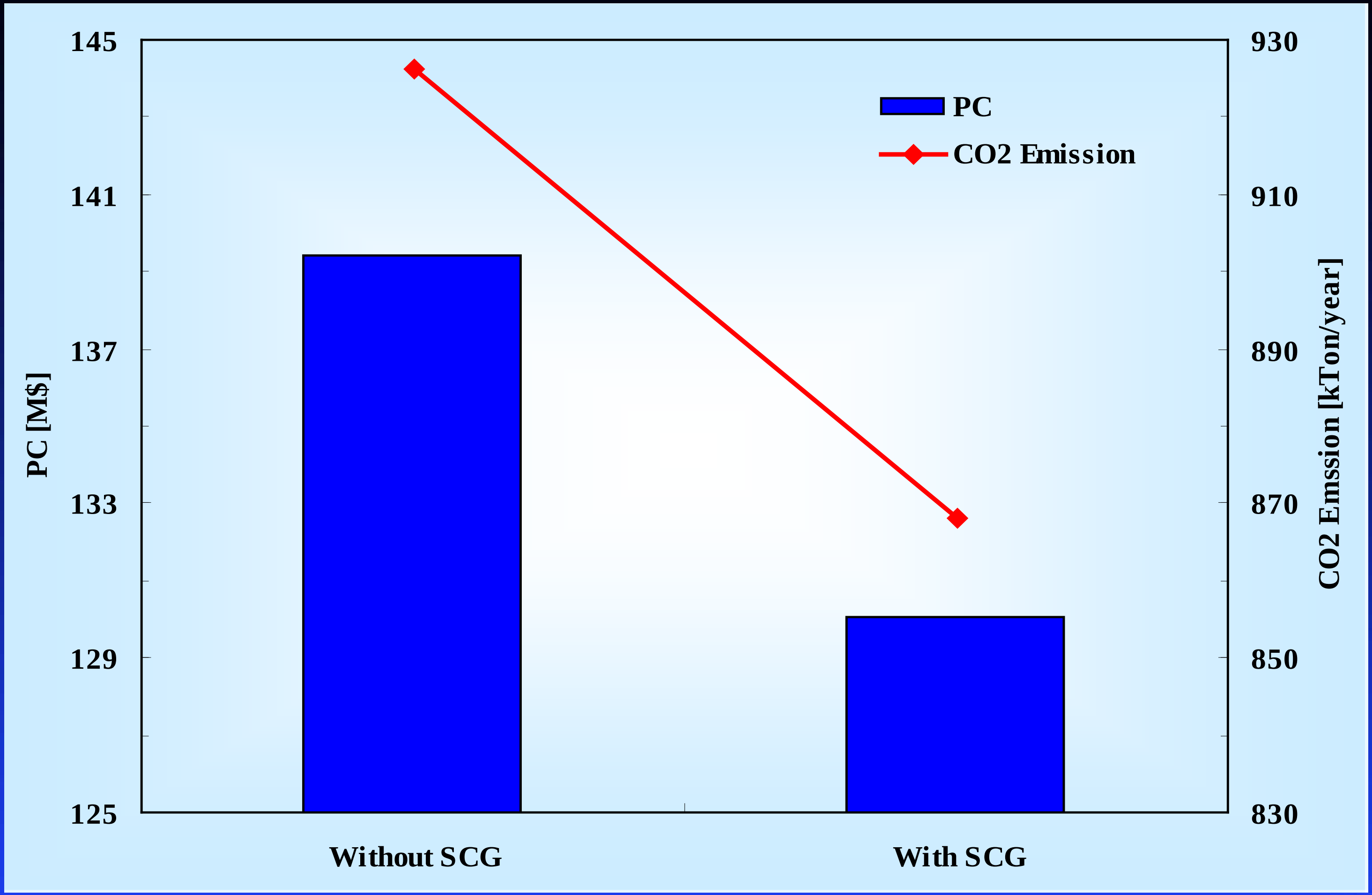
Production cost and CO_2 emission of each generators

Num. of Gen.	Without SCG		With SCG	
	Production cost [M$/year]	CO_2 Emission [10^3TON/year]	Production cost [M$/year]	CO_2 Emission [10^3TON/year]
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	265.38	1,651.79	265.37	1,651.76
5	139.39	926.15	130.07	868.07
6	4.2	28.23	3.46	23.3
7	15.95	113.24	12.92	91.72
8	1.66	6.90	1.29	5.34
9	0.27	1.11	0.21	0.85
10	0.04	0.35	0.03	0.24
11	0.02	0.10	0.01	0.07
Total	426.91	2,727.88	413.35	2,641.35

Production energy and capacity factor of 5th generator

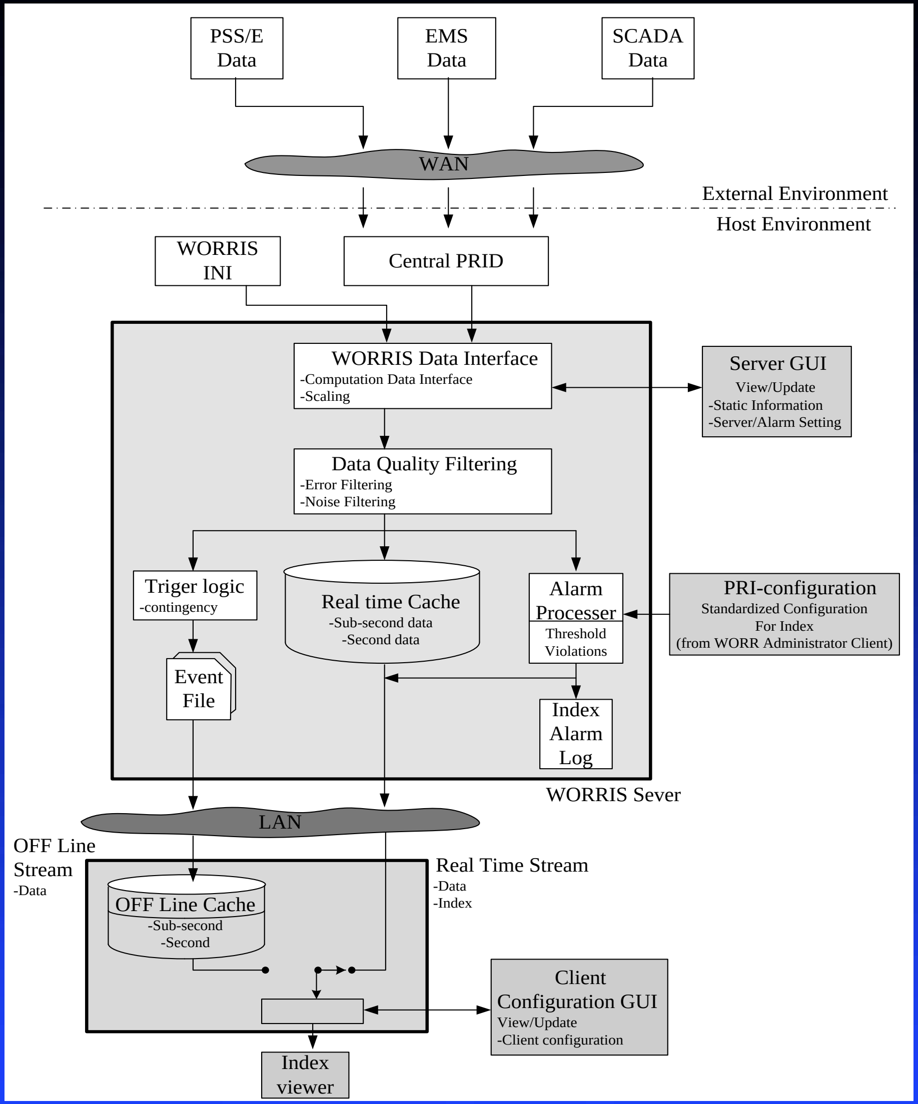


Production cost and CO_2 emission of 5th generator



WORRIS(Web based Online Realtime Reliability Information System) Version 1.0

http://worris.gsnu.ac.kr/



6. Conclusions

The one of important reasons that renewable energy has been receiving considerable attention is to reduce environmental pollution as alternative energy

It contributes to reduce emission of CO_2 and the proposed method is useful to calculate the reduction of CO_2 by adding SCG.

It is expected that proposed method can evaluate the various effects on power system by adding SCG

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Thank you for your kind attention

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Appendix

- The data of each WF

WF Name	HLM-WF	SSN-WF	HWN-WF
WTG capacity	20MW	30MW	50MW
Cut-in speed(V_{ci})	5m/sec	5m/sec	5m/sec
Rated speed(V_R)	14m/sec	15m/sec	16m/sec
Cut-out speed(V_{co})	25m/sec	25m/sec	25m/sec
Wind speed range	0~35	0~40	0~45
Mean wind speed	6.4	7.6	8.5
Standard deviation	9	10	11

Results of Case Studies

	without WTG	with WTG	difference
IRR [%]	24.08	38.77	14.69
EENS [MWh/year]	83.92	44.52	39.4
LOLE [hours/year]	2.25	1.26	0.99
Total production cost [M$/year]	426.91	400.75	26.16
Total CO_2 Emission [10^3Ton/year]	**2,727.88**	**2,561.31**	**166.57**
Total CO_2 Emission Cost [M$/Ton]	65.47	61.47	4

Production Energy and Capacity Factor of Each Generators

Num. of Gen.	Without WTG		With WTG	
	Production energy [GWh/year]	Capacity factor [%]	Production energy [GWh/year]	Capacity factor [%]
1	-	-	133.97	30.59
2	-	-	73.52	27.98
3	-	-	38.87	22.19
4	2,541.20	96.70	2,540.80	96.68
5	1,424.80	81.33	1,245.40	71.08
6	29.41	33.57	20.32	23.20
7	161.77	12.31	108.05	8.22
8	7.26	1.18	4.47	0.73
9	1.17	0.38	0.70	0.23
10	0.60	0.17	0.30	0.09
11	0.16	0.05	0.09	0.03
Total	4,166.37		4,166.49	

Production Cost and CO_2 Emission of Each Generators

Num. of Gen.	Without WTG		With WTG	
	Production cost [M$/year]	CO_2 Emission [10^3TON/year]	Production cost [M$/year]	CO_2 Emission [10^3TON/year]
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	265.38	1,651.79	265.28	1,651.54
5	139.39	926.15	120.71	809.48
6	4.20	28.23	2.90	19.51
7	15.95	113.24	10.65	75.64
8	1.66	6.90	1.02	4.25
9	0.27	1.11	0.16	0.66
10	0.04	0.35	0.02	0.18
11	0.02	0.10	0.01	0.05
Total	426.91	2,727.88	400.75	2,561.31