Photovoltaic Module Outdoor Analysis and Power Estimation

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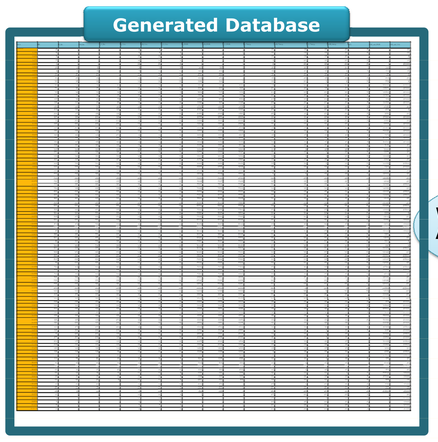
Motivation & Initiation

PV Outdoor Test Site

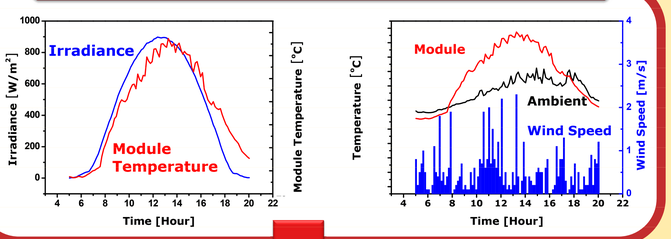
When power is maximum?
How high module temperature?

Generated Database



Wow!! What are these?
A whole lot of data...

Hourly Weathering Data and Module Temperature



Module Temperature Equation

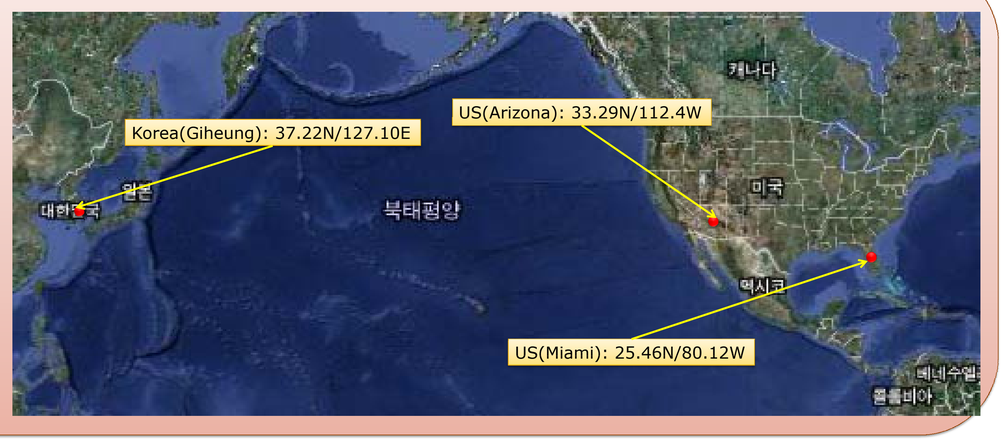
- Module Temperature Parameters
  - T_{module}: Module Temperature [°C]
  - $T_{ambient}$: Ambient Temperature [°C]
  - $I_{irradiance}$: Solar Irradiance [W/m²]
  - a: Slope parameter @ Wind speed items
  - b: Intercept parameter @ Wind speed items
  - X_{ws}: Wind Speed [m/s]

$$T_{module} = T_{ambient} + I_{irradiance} \times \exp(aX_{ws} + b)$$

Equation??
Looks complicated!!
What does that mean?

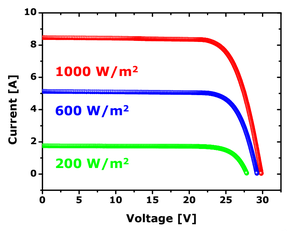
Irradiance, Ambient Temperature, Windspeed Summary

Mon	Solar [KWh/m²]			UV [KWh/m²]		UV [%]		T_{amb} [°C]			RH [%]		WS [m/s]		
	AZ	FL	KOR	AZ	FL	AZ	FL	AZ	FL	KOR	AZ	FL	AZ	FL	KOR
1	6861.1	7194.4	5249.4	241.67	297.22	3.52	4.13	19	22	7.5	57	92	3.3	2.3	0.6
2	7638.9	7666.7	6089.7	294.44	350.00	3.85	4.57	19	23	10.5	74	96	2.8	2.3	0.9
3	8055.6	7722.2	6731.5	358.33	383.33	4.45	4.96	21	24	19.5	67	97	2.9	2.6	1.0
4	8194.4	7416.7	6785.4	377.78	397.22	4.61	5.36	26	28	21.9	44	90	3.0	2.6	1.0
5	7833.3	6444.4	7329.1	391.67	388.89	5.00	6.03	31	32	26.1	59	90	2.9	2.3	0.9
6	7388.9	6194.4	6794.7	388.89	383.33	5.26	6.19	38	35	29.4	63	94	2.5	2.1	0.9
7	7166.7	6277.8	6554.3	383.33	380.56	5.35	6.06	40	34	29.6	70	96	2.7	2.1	1.0
8	7305.6	6583.3	6915.4	377.78	380.56	5.17	5.78	38	34	33.2	59	99	2.7	1.6	0.9
9	7777.8	6944.4	7044.4	372.22	372.22	4.79	5.36	39	32	28.1	33	98	2.8	2.0	0.7
10	7527.8	7111.1	6292.8	327.78	358.33	4.35	5.04	30	31	30.9	56	96	2.9	1.9	0.7
11	6944.4	7111.1	5649.9	272.22	302.78	3.92	4.26	23	28	20.1	42	98	3.2	1.8	0.8
12	6416.7	6888.9	5141.6	216.67	266.67	3.38	3.87	21	22	8.9	58	91	2.7	2.2	0.7
AVG	7425.9	6962.9	4000.5	333.56	355.09	4.47	5.13	28.75	28.75	22.14	56.83	94.75	2.87	2.15	0.84



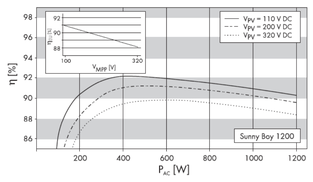
PV I-V Characteristics

Items	Values
I_{sc} [A]	8.5
V_{oc} [V]	30
P_{max} [W]	195
I_{pm} [A]	8
V_{pm} [V]	24.3
Reference Temp. [°C]	25



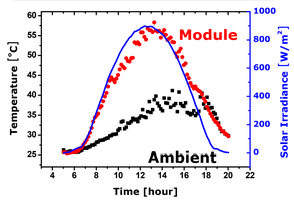
Inverter Characteristics

Items	Param	Values
Maximum DC power at cos ϕ = 1	P_{DC}	1320W
Maximum DC voltage	V_{DCmax}	400V
MPP voltage range at 230 V AC	V_{PV}	100V ~ 320V
DC nominal voltage	V_{DCnom}	120V
Minimum DC voltage at 230 V AC	V_{DCmin}	100V
Start voltage, adjustable	$V_{PVStart}$	120V
Maximum input current	I_{PVmax}	12.6A
Number of MPP trackers		1
Maximum number of parallel strings		2
Voltage ripple of input voltage	V_{pp}	< 10%
Internal consumption during operation		< 4W

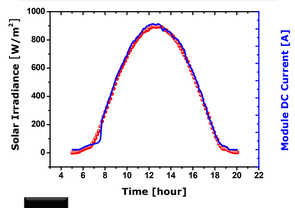


Hourly PV Module and Weathering Characteristics

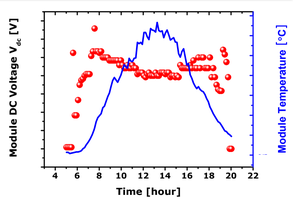
Weathering Data



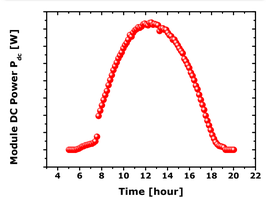
Irradiance & DC current



Voltage & Temperature

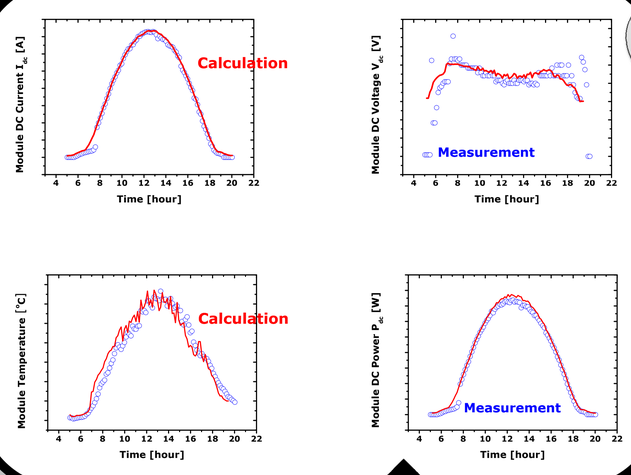


Power Characteristics



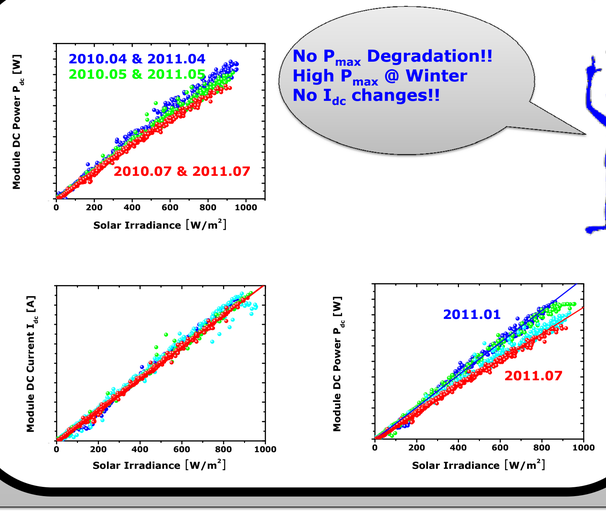
They are NOT linear...
How to fit them???

Measurement and Calculation Correlation



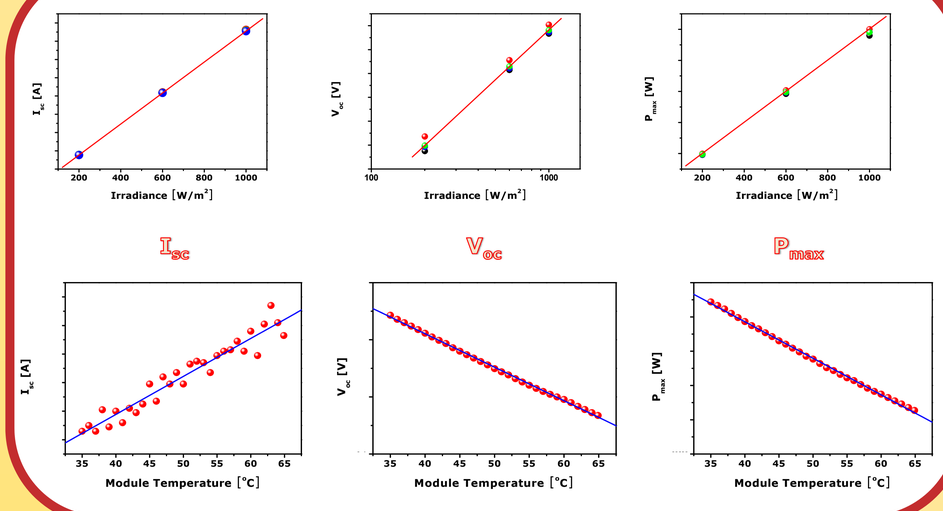
Looks well matched!!
Do you agree??

Yearly and Monthly PV Characteristics Comparison



No P_{max} Degradation!!
High P_{max} @ Winter
No I_{dc} changes!!

PV Module Irradiance and Temperature Coefficient



PV module irradiance and temperature coefficients are extracted at various irradiance intensities and temperature

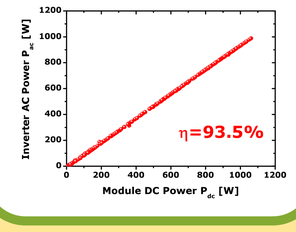
Power Estimation Fomular

$$P_{dc}(I_{irr}, T_{amb}, WS) = I_{dc}(I_{irr}, T_{amb}, WS) \times V_{dc}(I_{irr}, T_{amb}, WS)$$

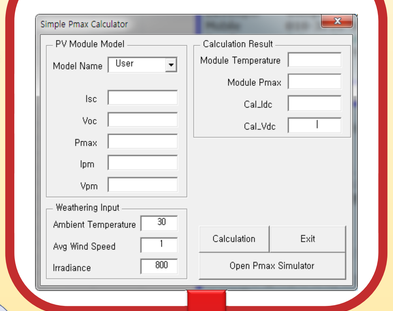
$$P_{ac}(I_{irr}, T_{amb}, WS) = \eta_{inv} \times P_{dc}(I_{irr}, T_{amb}, WS)$$

No More Equations

Inverter Efficiency



P_{max} Calculation Tool



We're able to estimate the P_{max} and module temperature at different weather conditions!!

Power Estimation

I_{irr}	T_{amb}	WS	T_m	I_{dc}	V_{dc}	P_{dc}	P_{ac}	Remarks
1000	-10	2	7.19	7.91	26.17	207.0	192.6	Maximum Power
1000	7	2	25.0	8.00	24.3	194.7	181.1	STC
1000	40	2	27.9	8.19	20.7	169.6	157.7	How Weather
800	7	1	23.1	6.41	24.3	155.8	144.9	KOR(Winter)
800	35	1	51.1	6.54	21.2	139.0	129.3	KOR(Summer)

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