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THERMODYNAMIC ANALYSIS OF A 10 kWp GRID-CONNECTED PHOTOVOLTAIC ARRAY SYSTEM

CIOSTA CONFERENCE 2011
June 29 – July 1, 2011, Vienna, Austria

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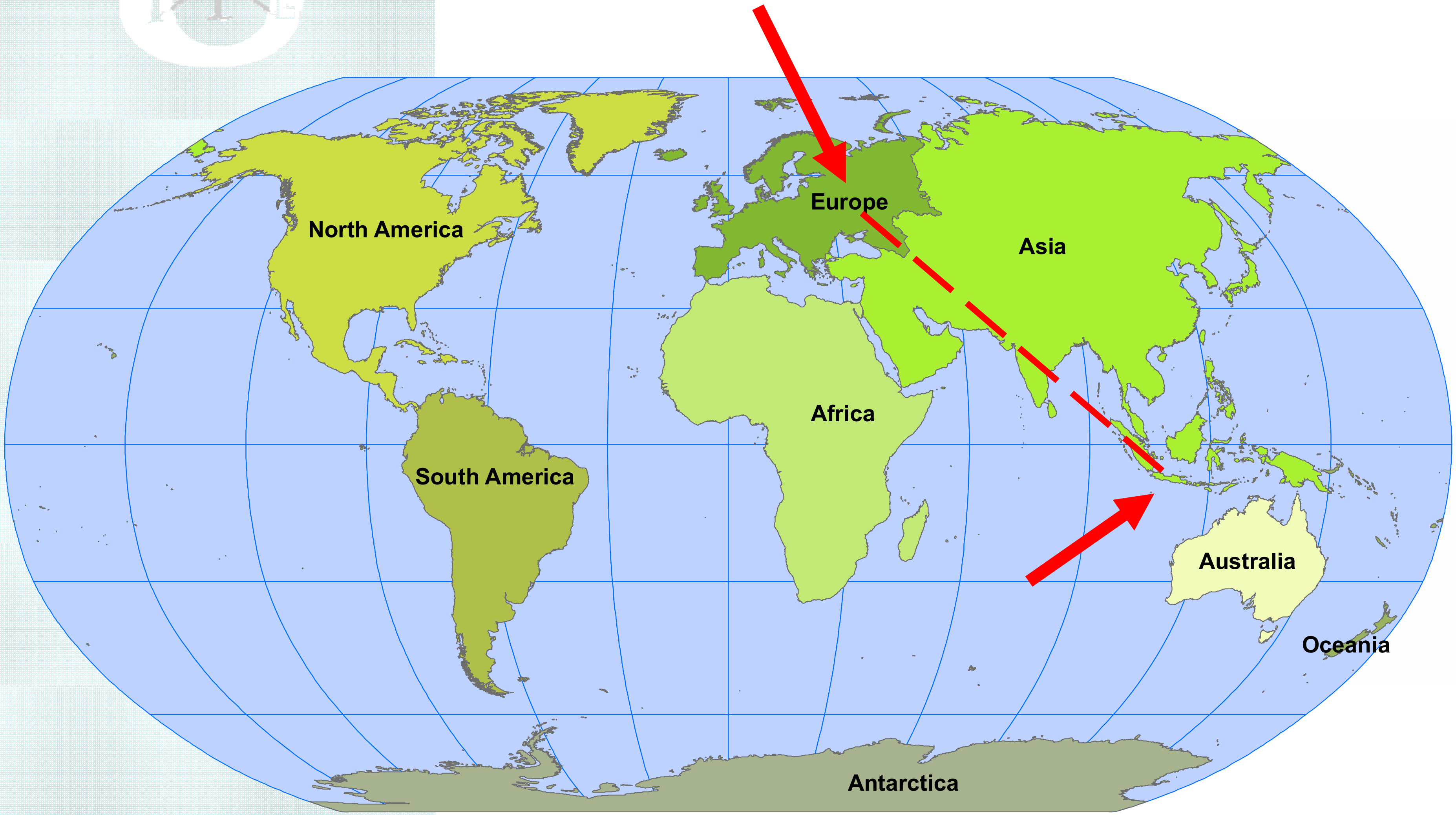
PERSONAL INTRODUCTION



INSTALLATION OF A 10 KWP GRID-CONNECTED PHOTOVOLTAIC ARRAY AT SZENT ISTVÁN UNIVERSITY

LOCATION AT THE ROOF OF C DORMITORY BUILDING

OUTLINE OF PRESENTATION

BACKGROUND

RESEARCH OBJECTIVES

SYSTEM DESCRIPTIONS

PHOTOVOLTAIC (PV) MODELS

TERMODYNAMIC ANALYSIS OF PV

RESULTS AND DISCUSSIONS

CONCLUSIONS

BACKGROUND

- In the photovoltaic field, manufacturers provide ratings for PV modules for conditions referred to as standard test conditions (STC) [T = 25^{O}C, S = 1000 W/m^2, AM = 1.5]
- Such conditions rarely occur outdoors, so the usefulness and applicability of the indoors' characterization in standard test conditions of PV modules are a controversial issue.
- To carry out photovoltaic engineering well, a suitable characterization of PV module electrical behaviour (I–V curves) is necessary.
- Testing (conducted to experimental data) and modelling efforts are typically to quantify and then to replicate the measured phenomenon of interest.
- Testing and modelling of photovoltaic module/array performance in the outdoor environment is very complicated and influences by a variety of interactive factors related to the environment and solar cell physics.

CURRENT RESEARCH OBJECTIVES

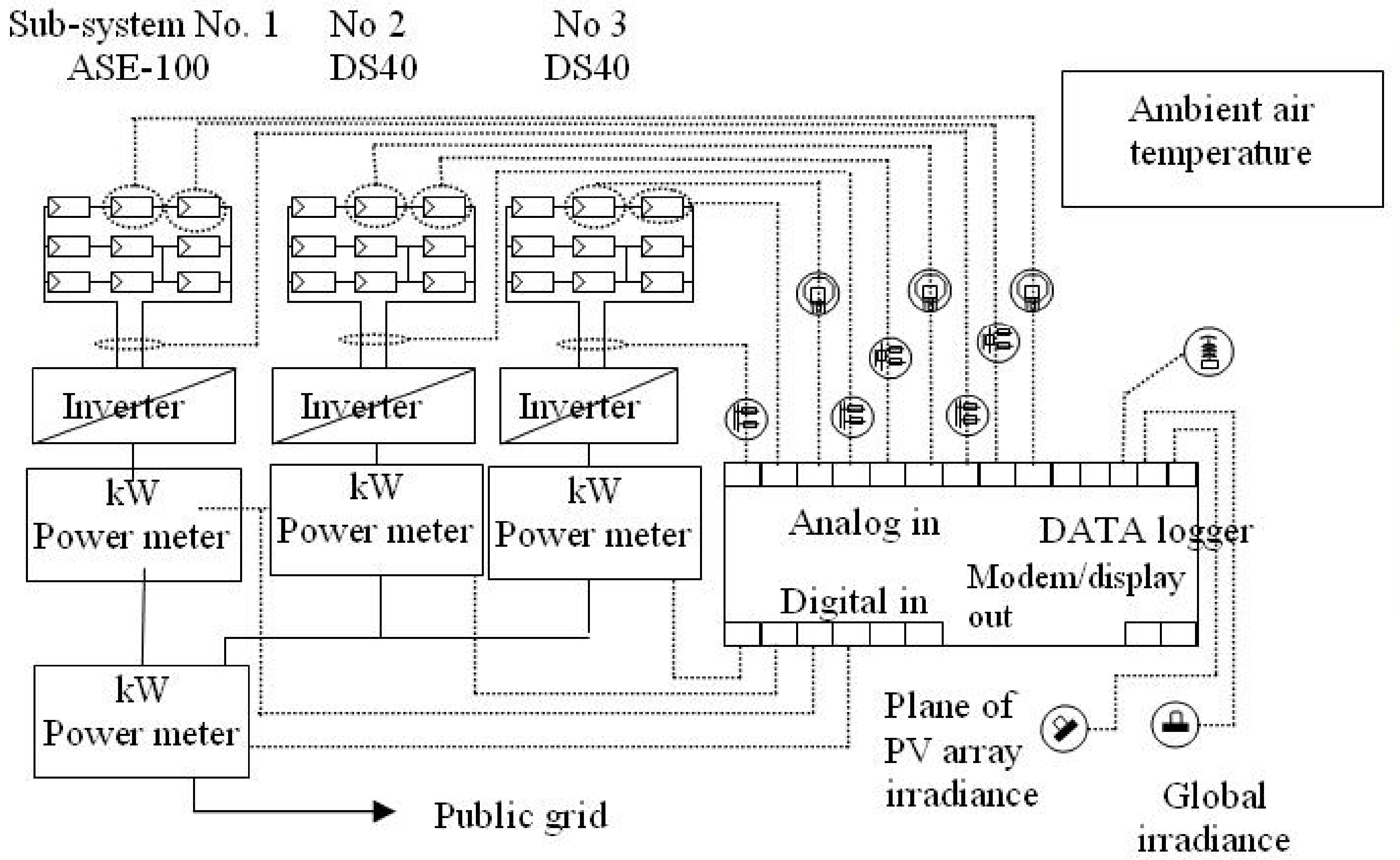
Thermodynamic evaluation of PV module in view of energetic and exergetic performance.

LONG TERM RESEARCH OBJECTIVES

Development of physical model of grid-connected PV array system, refer to an existing of PV array system at Szent Istvan University.

SYSTEM DESCRIPTION

SCHEMATIC DIAGRAM OF A 10 KWP GRID-CONNECTED PV ARRAY



SPECIFICATION OF A 10 kWp PV ARRAY AT SIU

Latitude :	47, 43 ° N	Azimuth :	5° to East for South facing
Longitude :	19, 35° E	Tilt angle :	30°
Country :	Hungary		

Specification	Sub-system 1	Sub-system 2	Sub-system 3
Nominal power [kWp]	3,3	3,1	3,1
Total system power [kWp]		9,5	
PV module supplier	RWE Solar Gmbh	DunaSolar Rt	DunaSolar Rt
Module type	ASE-100 GT-FT	DS40	DS40
PV cell technology	EFG	a-Si	a-Si
P_{stc}, PV module power at STC, [W]	105	40	40
Total number of modules	32	77	77
No. of modules in series (per string)	16	7	7
No. of strings in parallel (per inverter)	2	11	11
Inverter type (Sunpower)	SP3100/600	SP2800/500	SP2800/500
No. of inverters within the Sub-system	1	1	1
Total module area [m^2]	28	65	65

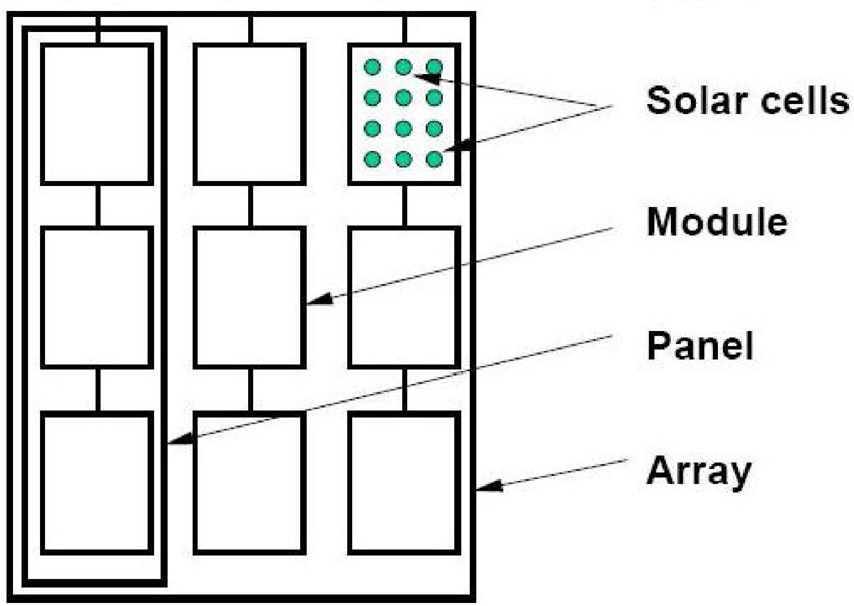
MODULE TECHNOLOGY IN A 10 KWP GRID-CONNECTED PV ARRAY AT SIU

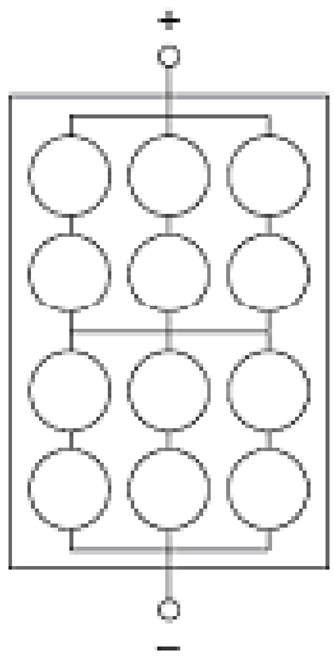
ASE 100 : POLYCRYSTALLINE TECHNOLOGY

DS 40 : AMORPHOUS SILICON TECHNOLOGY

PHOTOVOLTAIC MODELS

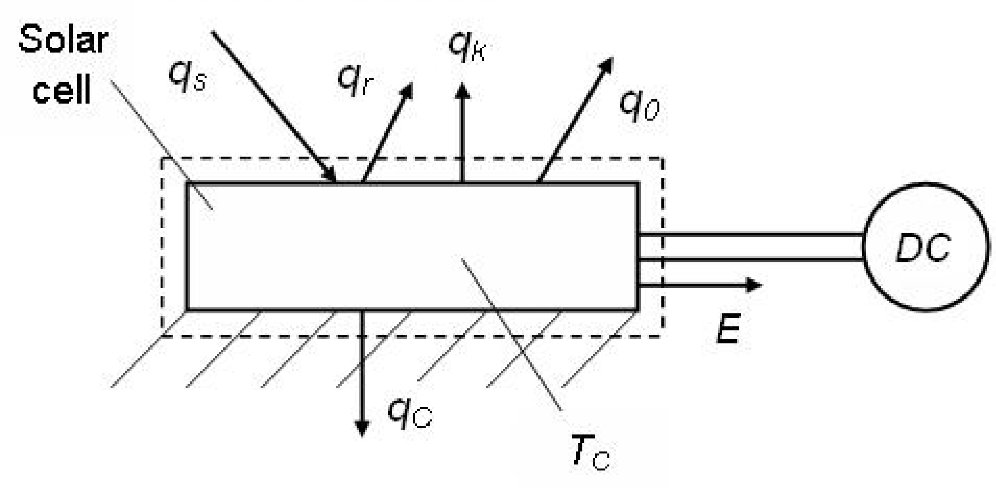
TERMINOLOGY OF PV HIERARCHY AND GENERAL SOLAR CELL CIRCUIT DIAGRAM





module
3 parallel strings
2 series blocks
2 cells per substring

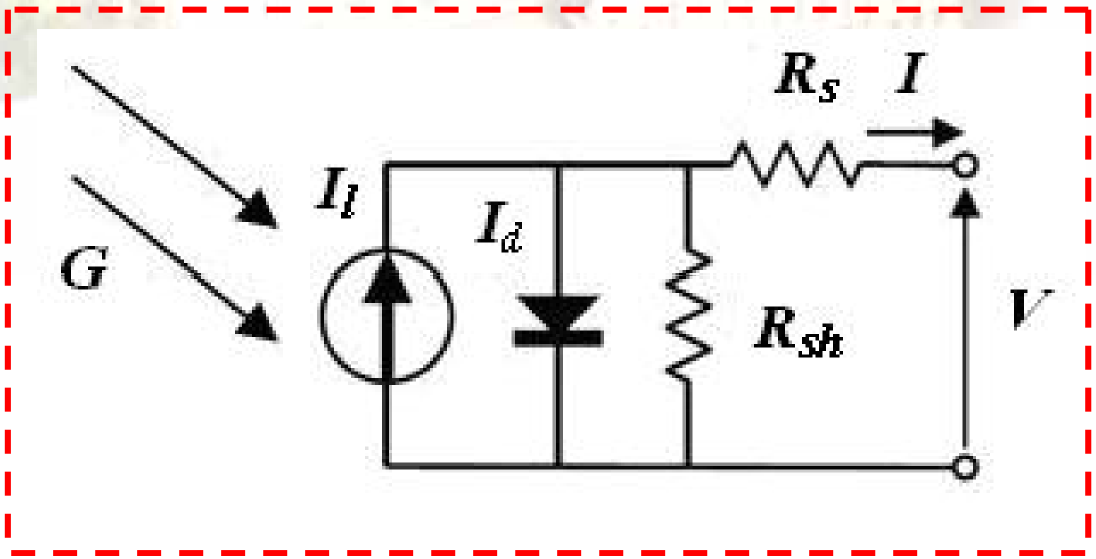
MODEL DESCRIPTION OF SOLAR CELL IN DIFFERENT POINT OF VIEW



Scheme of the energy streams model of a solar cell (Thermal energy)

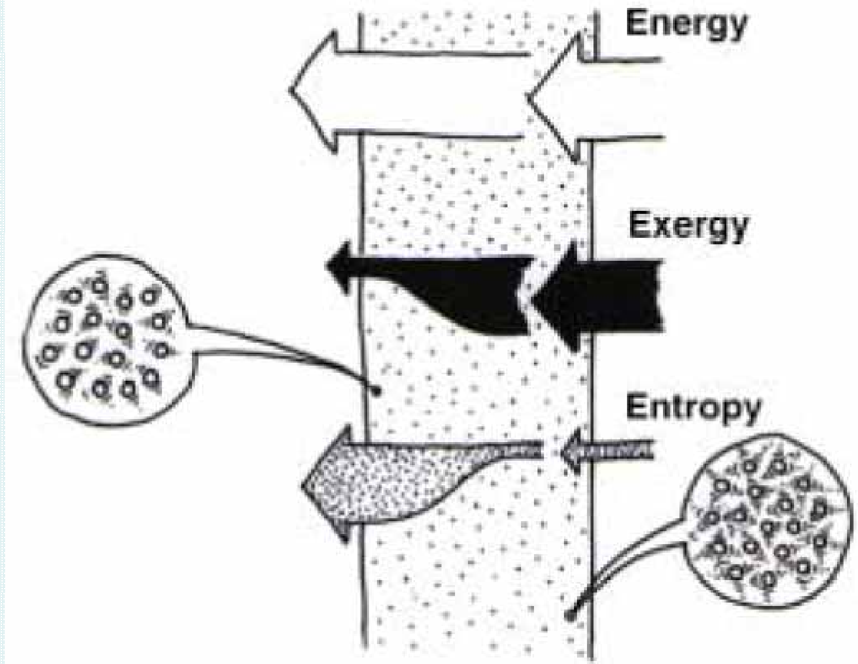
General model of solar cell circuit in a single diode model (Electric energy)

Focus



THERMODYNAMIC ANALYSIS OF PV

CONCEPTS OF ENERGY AND EXERGY



ENERGY, EXERGY AND ENTROPY FLOW IN AND FLOW OUT ON A SYSTEM

ILLUSTRATION ENERGY AND EXERGY FROM THE SUN

GUIDANCE FOR ENERGY AND EXERGY ANALYSIS

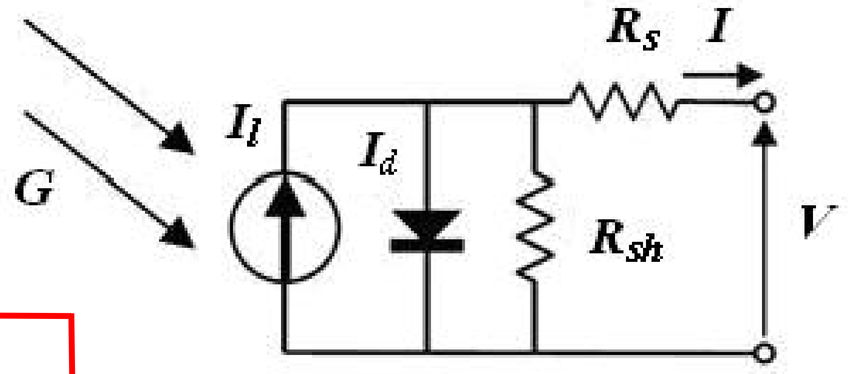
ENERGY	EXERGY
Dependent on the parameters of matter or energy flow only, and independent of the environment parameters.	Dependent both on the parameters of matter or energy flow and on the environment parameters.
Guided by the first law of thermodynamics for all processes	Guided by the first and second law of thermodynamics for all irreversible processes
Measure of quantity	Measure both quantity and quality

PV CELL/MODULE MODEL ANALYSIS

$$I = I_l - I_o\left[exp\left(\frac{V+IR_S}{\left(\frac{nkTc}{q}\right)}\right) - 1\right] - \frac{V+IR_S}{R_{sh}}$$

$$I_l = \frac{G}{G_{ref}}\left[I_{l,ref} + K_I\left(T_c - T_{c,ref}\right)\right]$$

$$I_o = I_{o,ref}\left(\frac{T_c}{T_{c,ref}}\right)^3 exp\left[\frac{qE_G}{nk}\left(\frac{1}{T_{c,Ref}} - \frac{1}{T_c}\right)\right]$$



$$I = I_l - I_d$$

Five Model Parameters of Cells

$(I_l, n, I_o, R_s, R_{sh})$

n = Ideality factor (a number between 1 and 2)

k = The Boltzmann's constant (= 1.381 x 10^{-23} J/K)

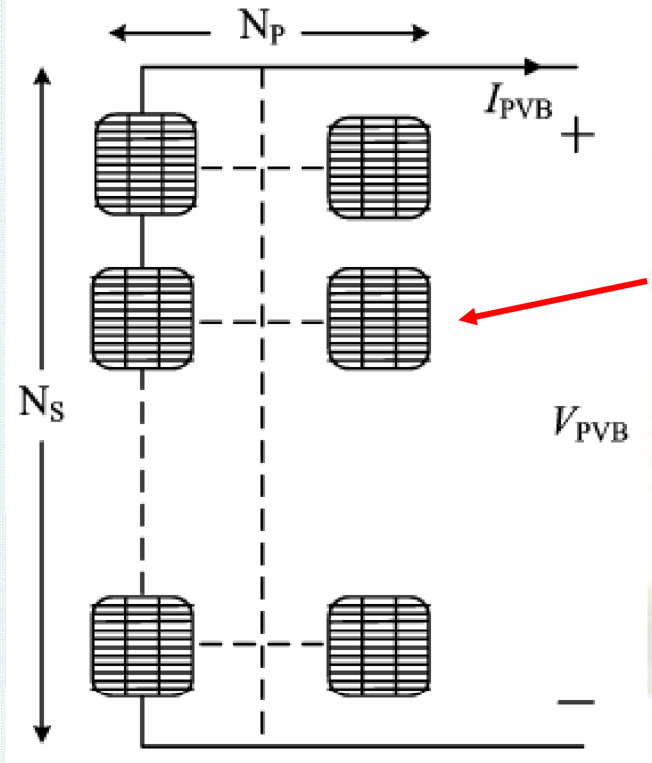
q = Electron charge (=1.602 x 10^{-19} C)

I_o = Dark saturation current for diode [A]

K_I = The cell's short-circuit current temperature coefficient [A/K]

E_G = The band gap energy of the semiconductor used in the cell [eV]

PHOTOVOLTAIC ANALYSIS MODELS FOR ARRAY SYSTEM



$$I = I_l - I_o\left[\exp\left(\frac{V+IR_s}{\left(\frac{nkTc}{q}\right)}\right)-1\right]-\frac{V+IR_s}{R_{sh}}$$

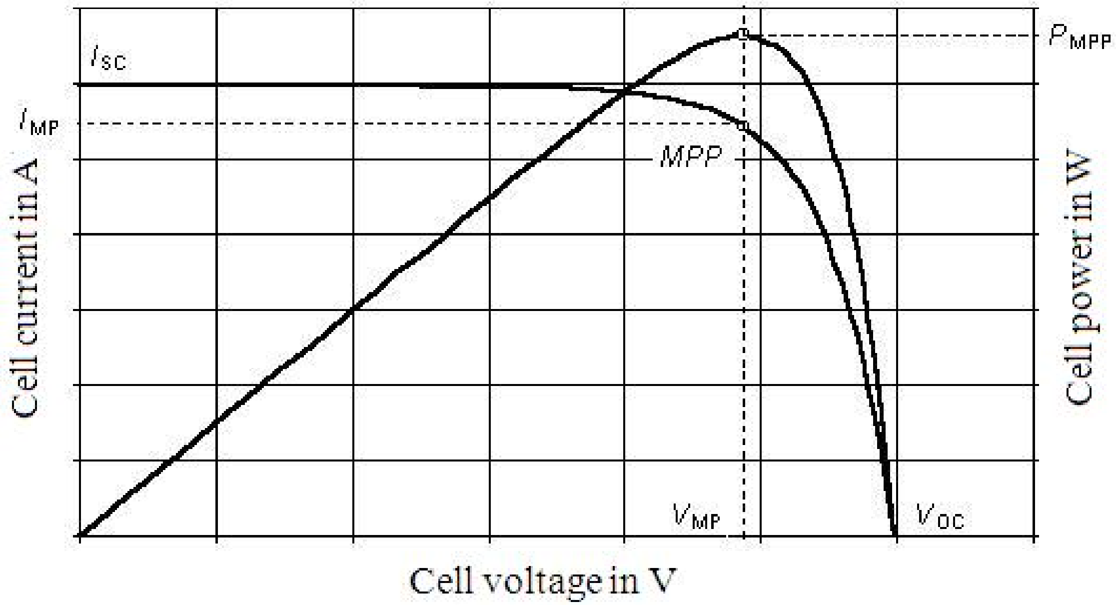
$$I = N_pI_l - N_pI_o\left[\exp\frac{\frac{V}{N_s}+\frac{IR_s}{N_p}}{\frac{nkT_c}{q}}-1\right]-\frac{\left(\frac{N_pV}{N_s}+IR_s\right)}{R_{sh}}$$

CELL/MODULE CHARACTERISTIC CONCEPT

$$\eta_{max} = \frac{V_{oc} I_{sc}}{G \times A}$$

Efficiency Max.

I–V and P–V solar cell characteristics and MPP



$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}}$$

$$\eta_{pc} = \frac{\dot{E}_{elec.}}{G \times A} = \frac{V_{mp} \times I_{mp}}{G \times A}$$

$$\eta_{pc} = \frac{FF \times V_{oc} \times I_{sc}}{G \times A}$$

Efficiency power conversion

EFFICIENCY ANALYSIS

ENERGY EFFICIENCY

$$\eta_{en} = \frac{\dot{E}n_{out}}{\dot{E}n_{in}} = \frac{\dot{E}n_{electrical} + \dot{E}n_{thermal}}{\dot{E}n_{in}}$$

$$\eta_{en} = \frac{(V_{oc} \times I_{sc}) + \dot{Q}}{G \times A}$$

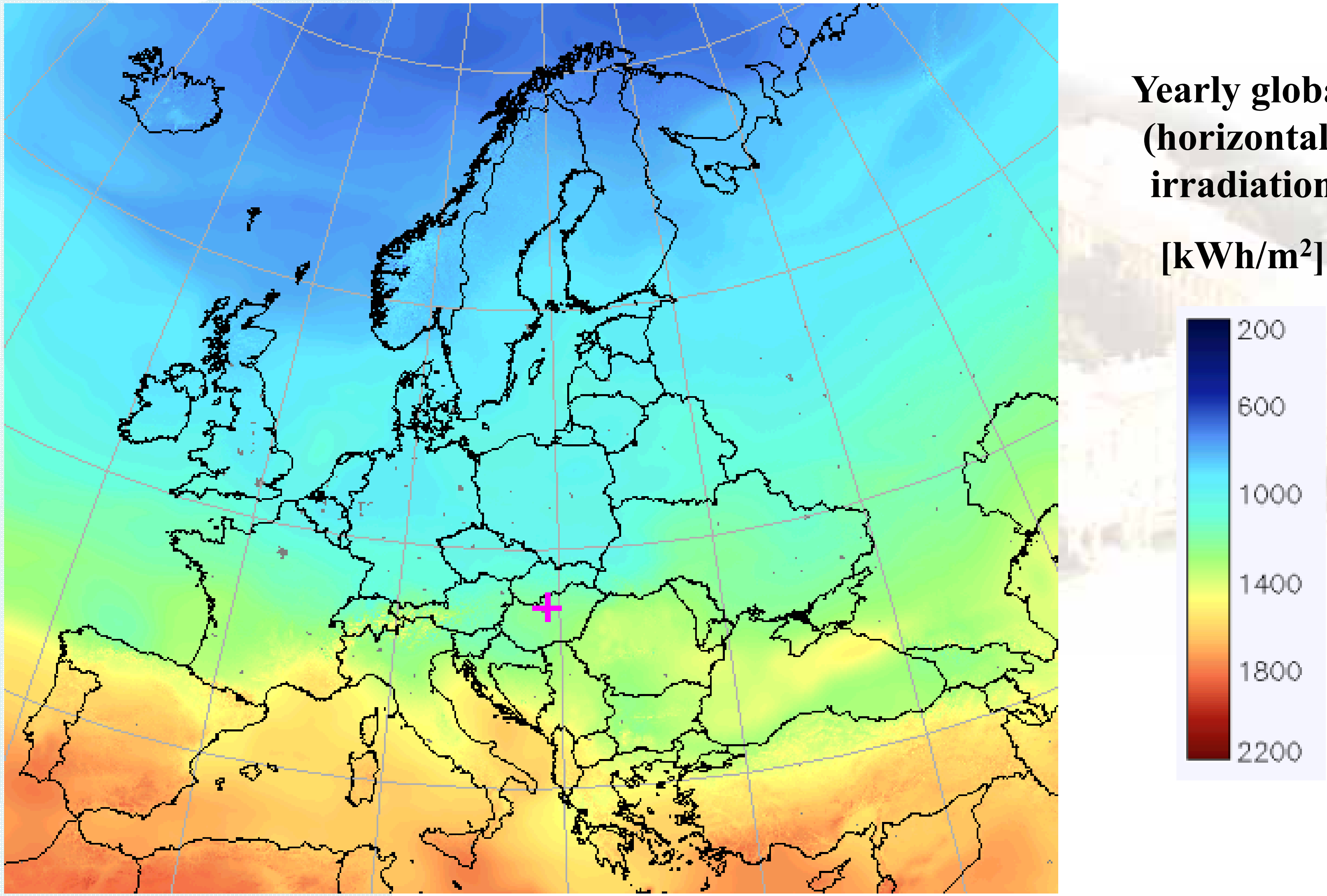
EXERGY EFFICIENCY

$$\eta_{ex} = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} = \frac{\dot{E}x_{electrical} + \dot{E}x_{thermal} + \dot{E}x_{dest.}}{\dot{E}x_{solar}}$$

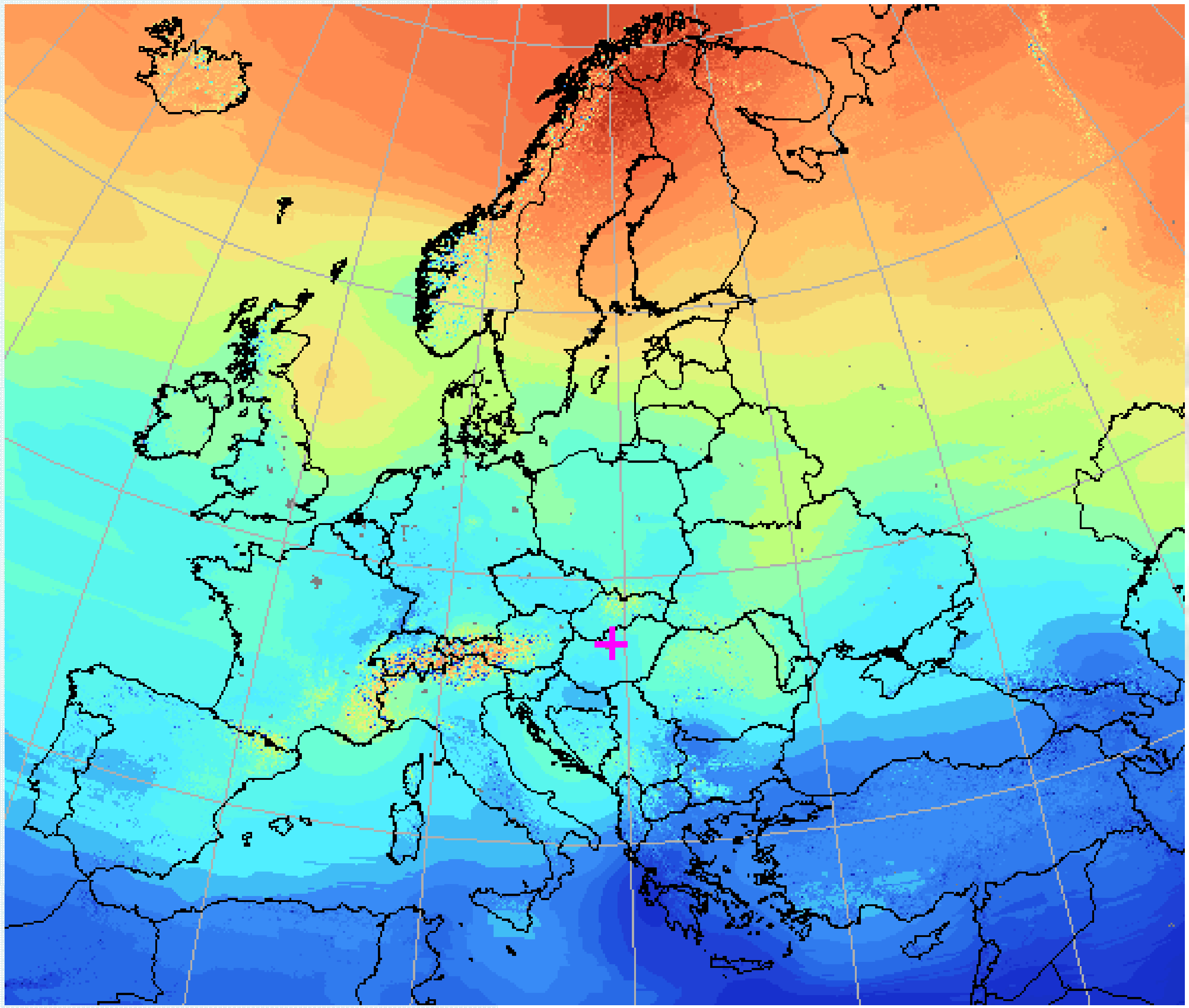
$$\eta_{ex} = \frac{V_{mp} \times I_{mp} - \left(1 - \left(\frac{T_a}{T_c}\right)\right) \times [(5.7 + (3.8 \times v)) \times A \times (T_c - T_a)]}{\left(1 - \left(\frac{T_a}{T_s}\right)\right) \times G \times A}$$

RESULTS AND DISCUSSIONS

HUNGARY IRRADIATION BASED ON GIS PREDICTION

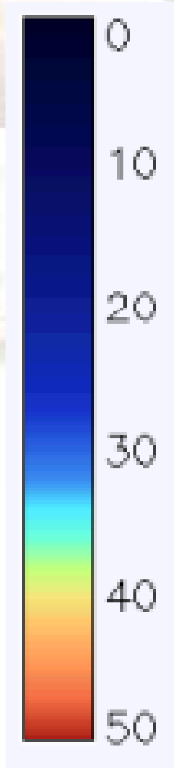


OPTIMUM INCLINATION ANGLE BASED ON GIS PREDICTION FOR HUNGARY



Optimum inclination angle

degree



ANNUAL CLIMATE DATA FOR GÖDÖLLŐ, HUNGARY
SITE LOCATION

Month	G_{hor} [kWh/m2.m]	G_{arr} [kWh/m2.m]	v [m/s]	T_a [°C]	*Sun-hours** (h)	$G_{arr} = G$ [W/m2]
January	29.79	44.57	2.65	-0.94	9	159.75
February	46.35	62.82	2.70	1.70	10	224.34
March	86.25	104.16	2.82	6.20	12	279.99
April	127.23	140.31	2.91	11.54	14	334.07
May	162.17	163.76	2.67	16.48	15	352.16
June	172.06	167.49	2.76	19.30	16	348.93
July	182.90	182.05	2.75	21.42	15	391.51
August	153.71	164.99	2.38	20.82	14	380.16
September	109.33	130.47	2.29	16.54	12	362.42
October	70.55	98.39	2.12	11.37	10	317.39
November	35.31	52.03	2.49	5.30	9	192.71
December	23.06	33.38	2.64	1.14	8	134.60

* Based on sun-path diagram

Acquired data from MeteoSyn, Meteonorm, PVGIS, NASA SSE, SWERA (Klise et al., 2009)

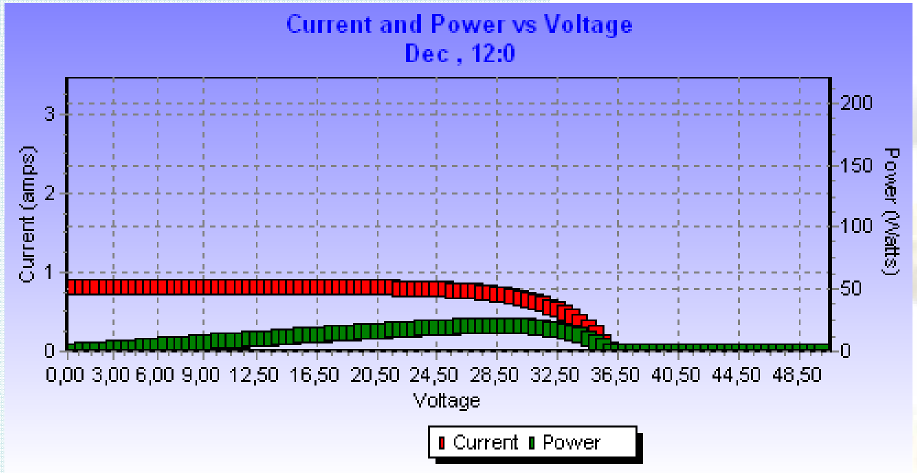
THE ELECTRICAL AND OTHER PARAMETERS OF ASE-100 AND DS-40

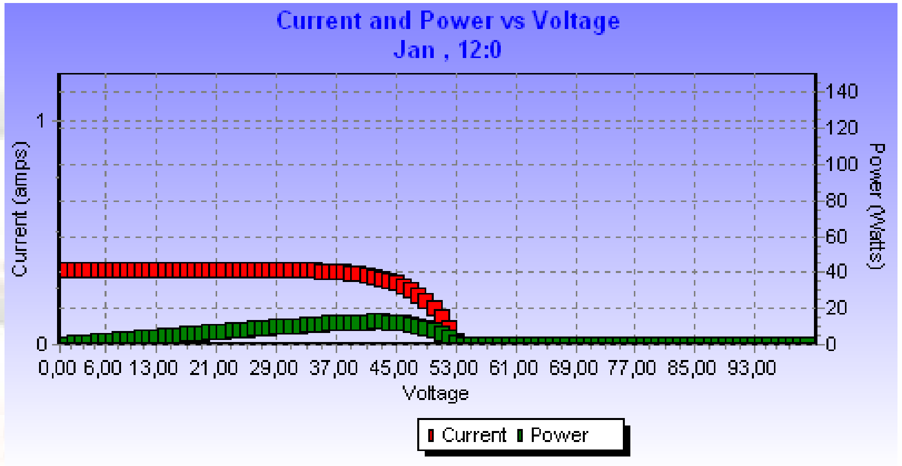
Module parameters	Sub-system 1	Sub-system 2	Sub-system 2
Electrical Module *	ASE-100	DS-40	DS-40
Typical peak power (W)	105	40	40
Voltage at peak power (V)	35	44.8	44.8
Current at peak power (A)	3	0.8	0.8
Short circuit current (A)	3.3	1.15	1.15
Open circuit voltage (A)	42.6	62.2	62.2
Temp. coeff. of open circuit voltage (%/°C)	-0.38	-0.2797	-0.2797
Temp. coeff. of short circuit current (%/°C)	0.10	0.0897	0.0897
Approx. effect of temp. On power (%/°C)	-0.47	-0.190	-0.190
Nominal operating cell temp./NOCT (°C)	45	50	50
Others			
Active surface area (m^2)	0.83	0.79	0.79
Specific heat capacity (J/kg.K)	920	920	920
Absorption coefficient (%)	70	70	70
Weight (kg)	8.5	13.5	13.5
Array			
No. of modules in series (per string)	16	7	7
No. of strings in parallel (per inverter)	2	11	11
Total module area (m^2)	27	61	61

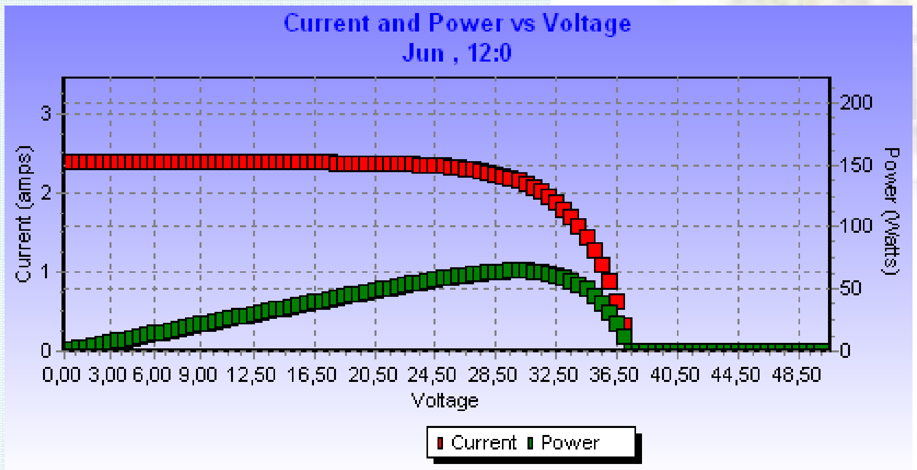
* Under Standard Test Conditions (G = 1000 W/m^2, AM = 1.5 and T_c = 25°C).

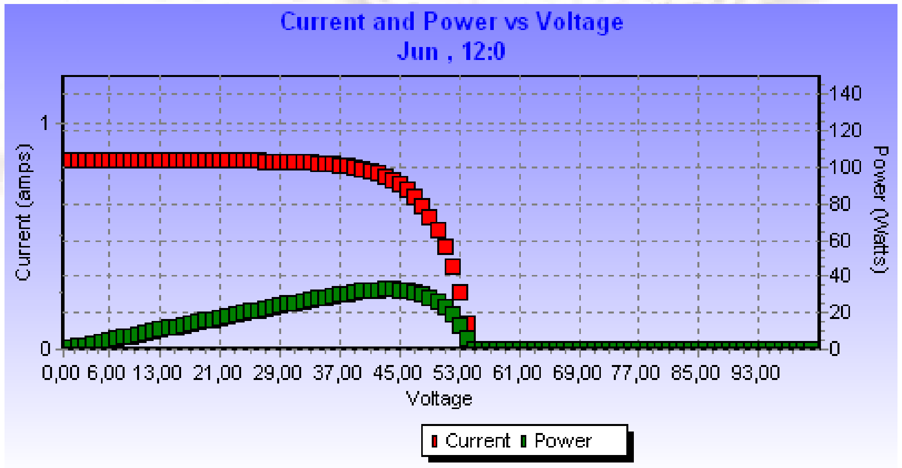
SIMULATION RESULTS

I-V CHARACTERISTICS OF SINGLE MODULE



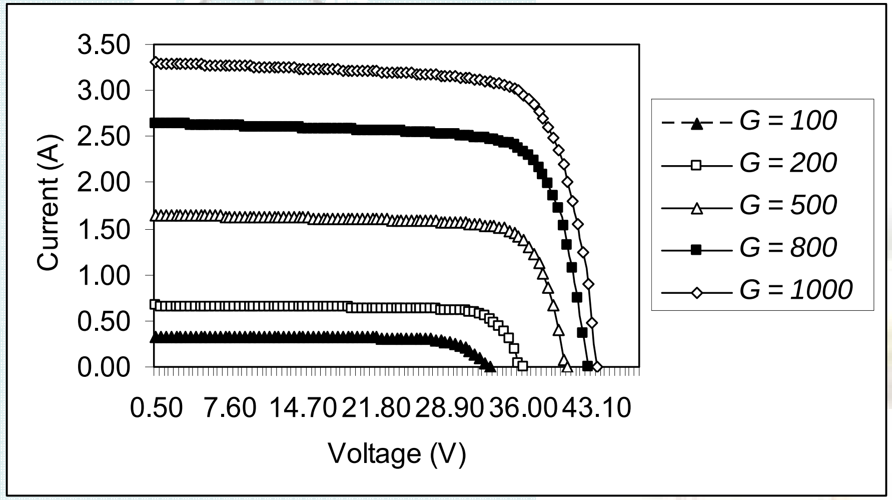


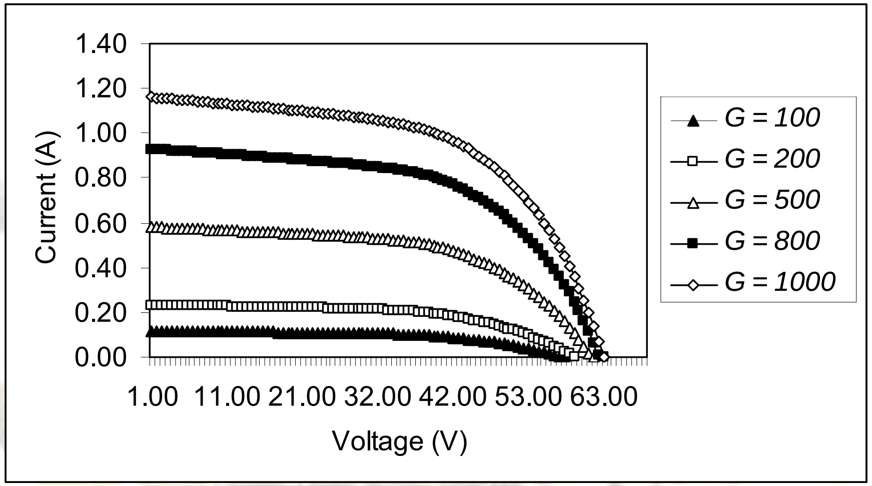


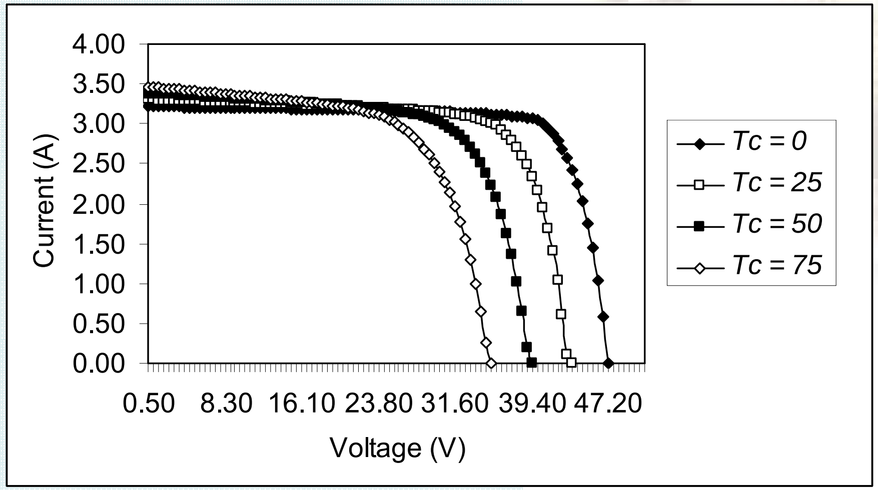


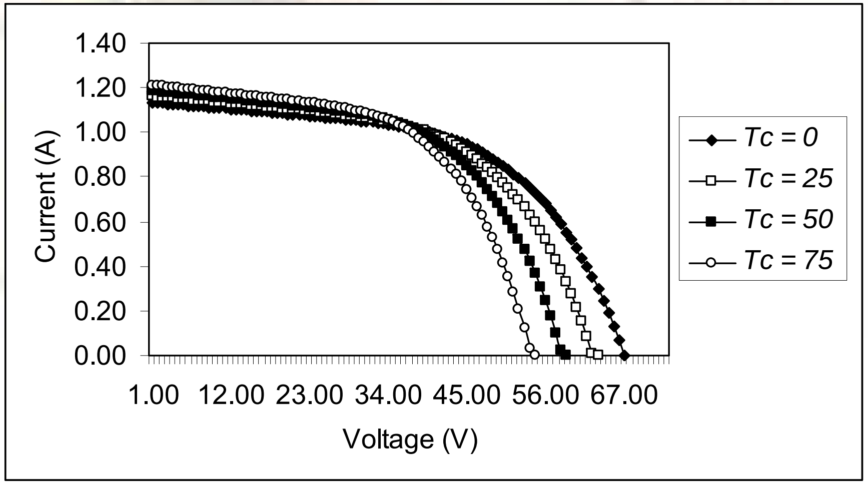
ASE - 100 **DS - 40**

CALCULATED RESULTS OF I-V CHARACTERISTICS





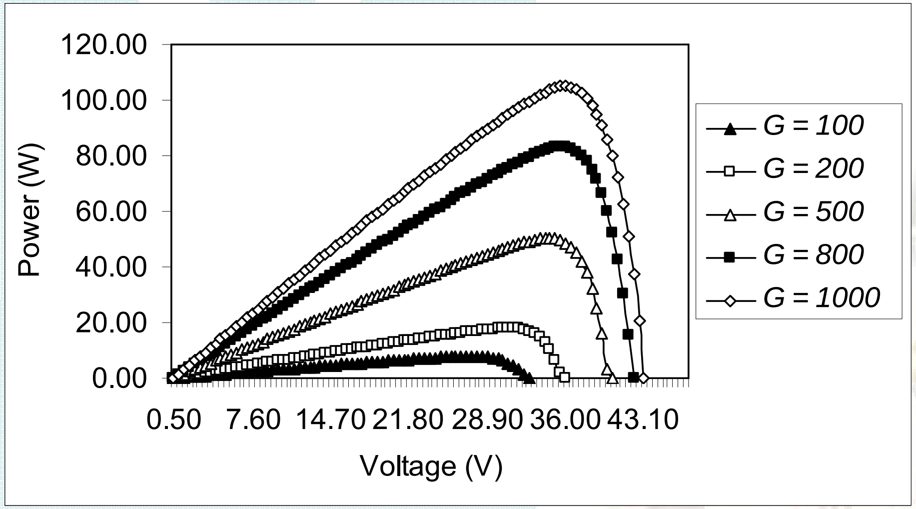


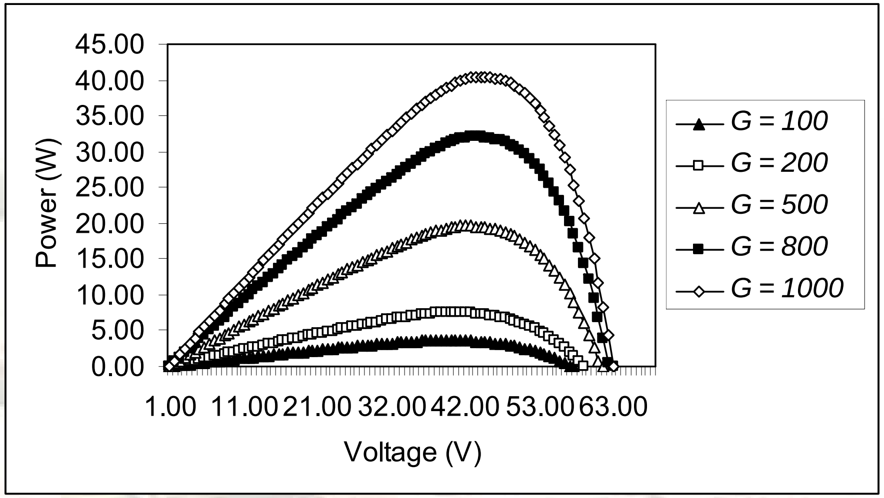


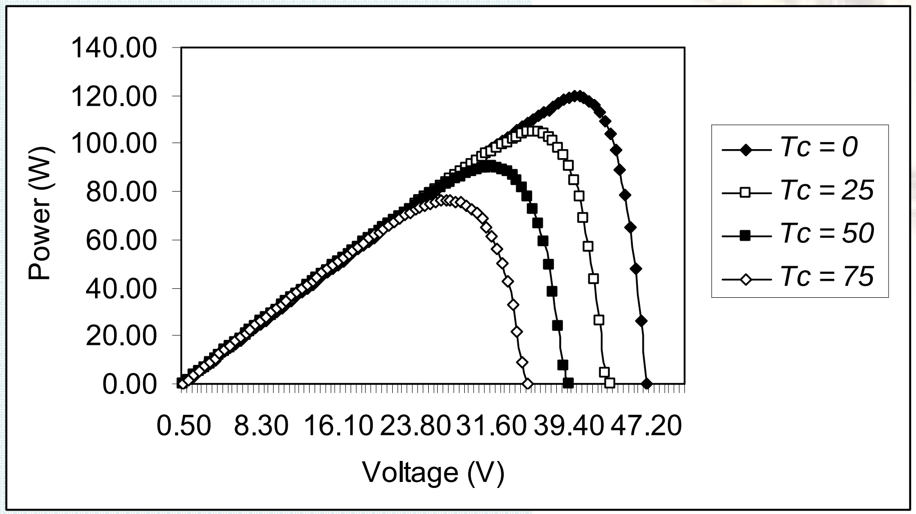
ASE – 100 (POLYCRISTALLINE)

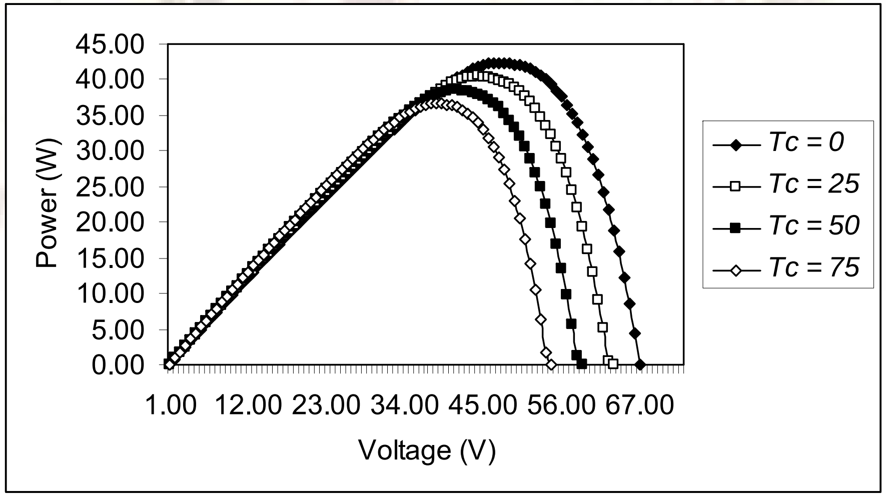
DS – 40 (AMORPHOUS SILICON)

CALCULATED RESULTS OF P-V CHARACTERISTICS









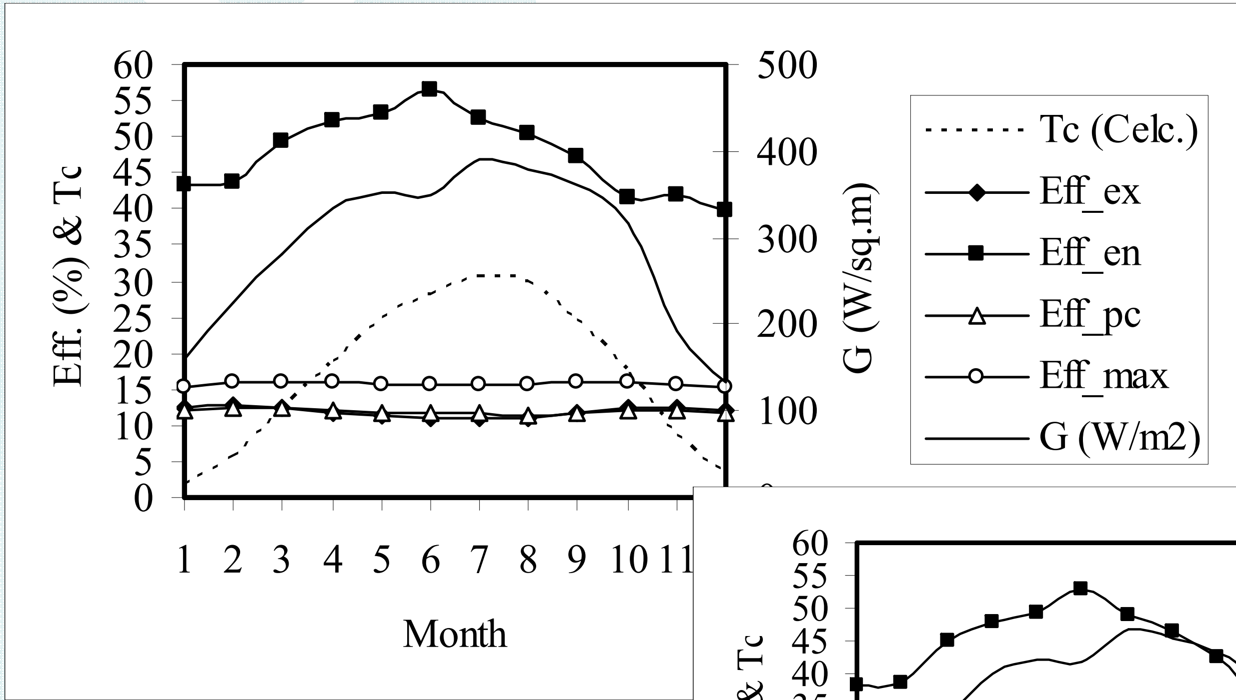
ASE – 100 (POLYCRISTALLINE)

DS – 40 (AMORPHOUS SILICON)

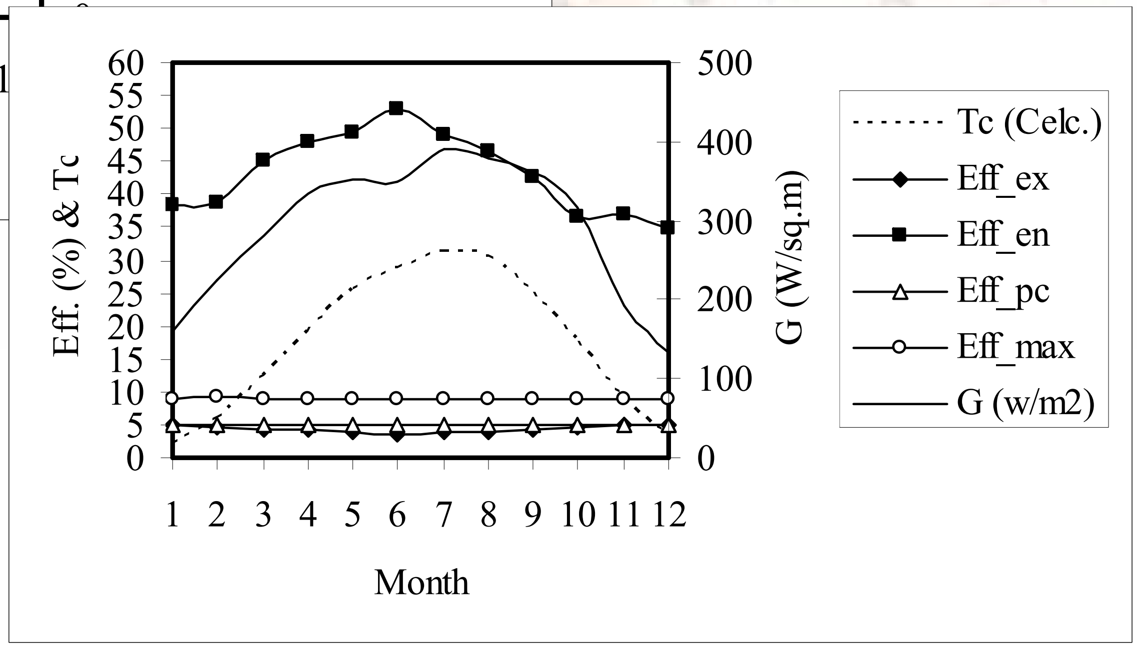
CHARACTERISTICS INTERPRETATIONS

- Increasing of irradiation at constant module temperature, give big affect (proportional) on a short circuit current (I_{SC}) value but small effect on the open circuit voltage (V_{OC}) value.
- Increasing of module temperature at constant irradiation will increase a short circuit current (I_{SC}) slightly and decrease the open circuit voltage (V_{OC}) proportional.
- Increasing of irradiation at constant module temperature, give significant affect on the output power of PV module (P).
- Increasing of module temperature at constant irradiation will great affect on decreasing of output power (P) PV module.

CALCULATED RESULTS OF MODULE PERFORMANCE IN SEVERAL EFFICIENCIES (THERMODYNAMIC TERMINOLOGY)



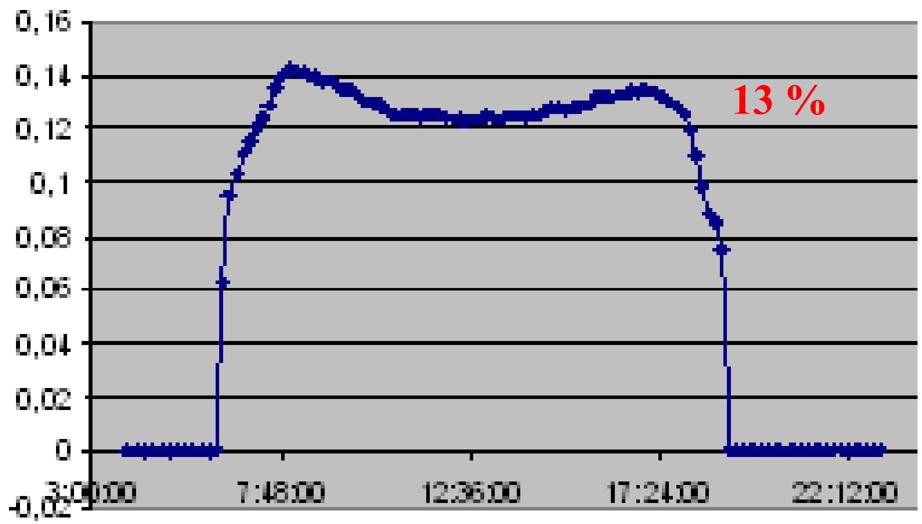
ASE-100 PV module



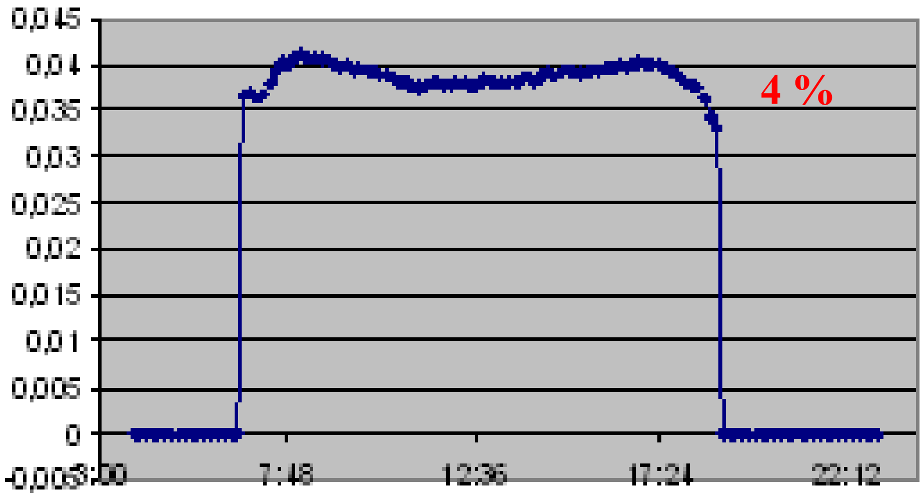
DS-40 PV module

AVERAGE VALUE OF SEVERAL EFFICIENCIES IN THERMODYNAMIC TERMINOLOGY FOR PV

Parameters	Average values in year		
	Sub-sys 1	Sub-sys 2	Sub-sys 3
G = Solar irradiation (W/m^2)	289.84	289.84	289.84
Tc = Module temperature (°C)	17.6	17.6	17.6
η_{en} (Eff_en) = Eff. of energy (%)	47.66	43.20	43.20
η_{ex} (Eff_ex) = Eff. of exergy (%)	11.82	4.30	4.30
η_{pc} (Eff_pc) = Eff. of power conversion (%)	11.94	4.91	4.91
η_{max} (Eff_max) = Eff. of electrical max. (%)	15.72	8.88	8.88

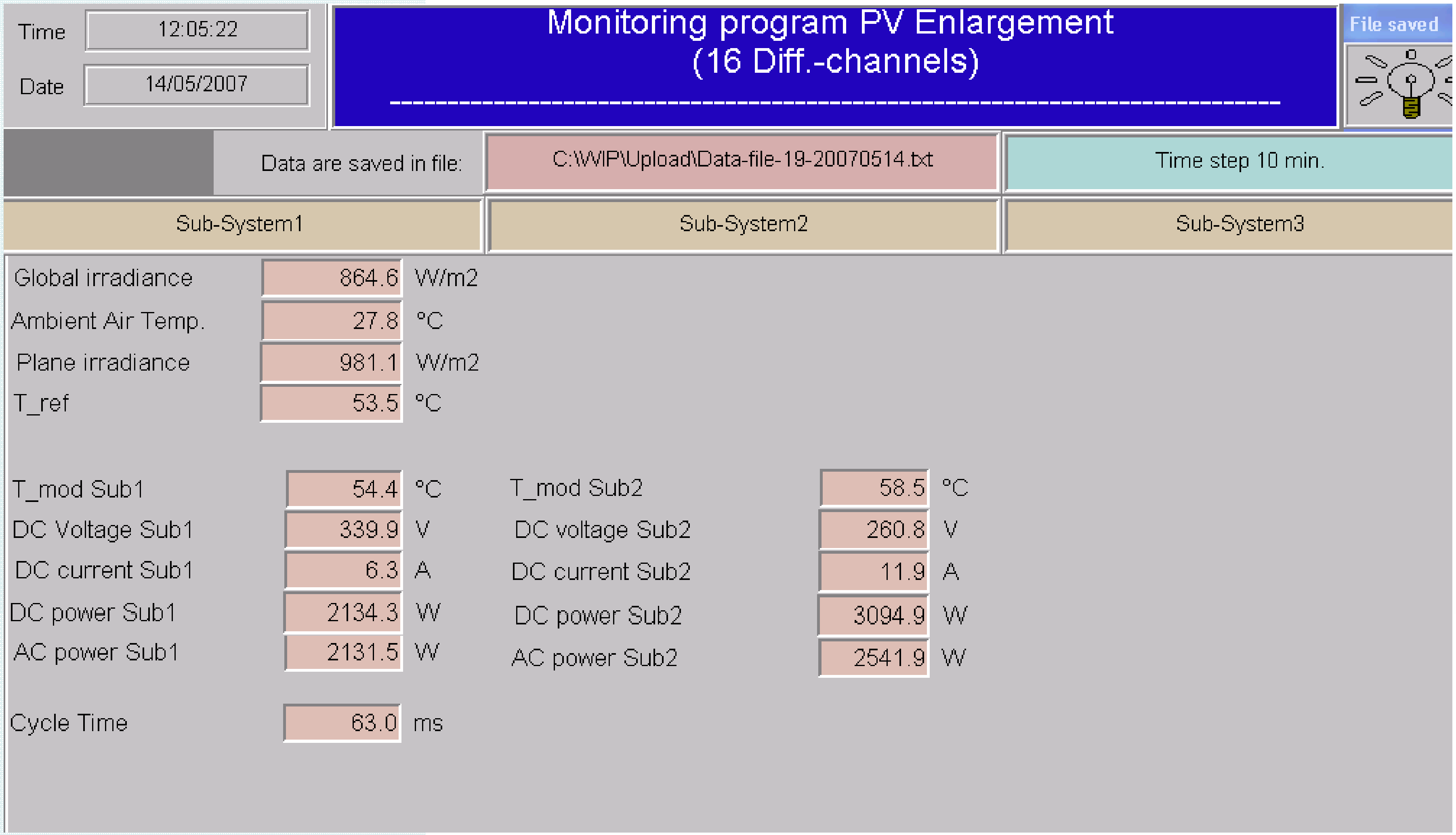


ASE-100 module efficiency based on exp.

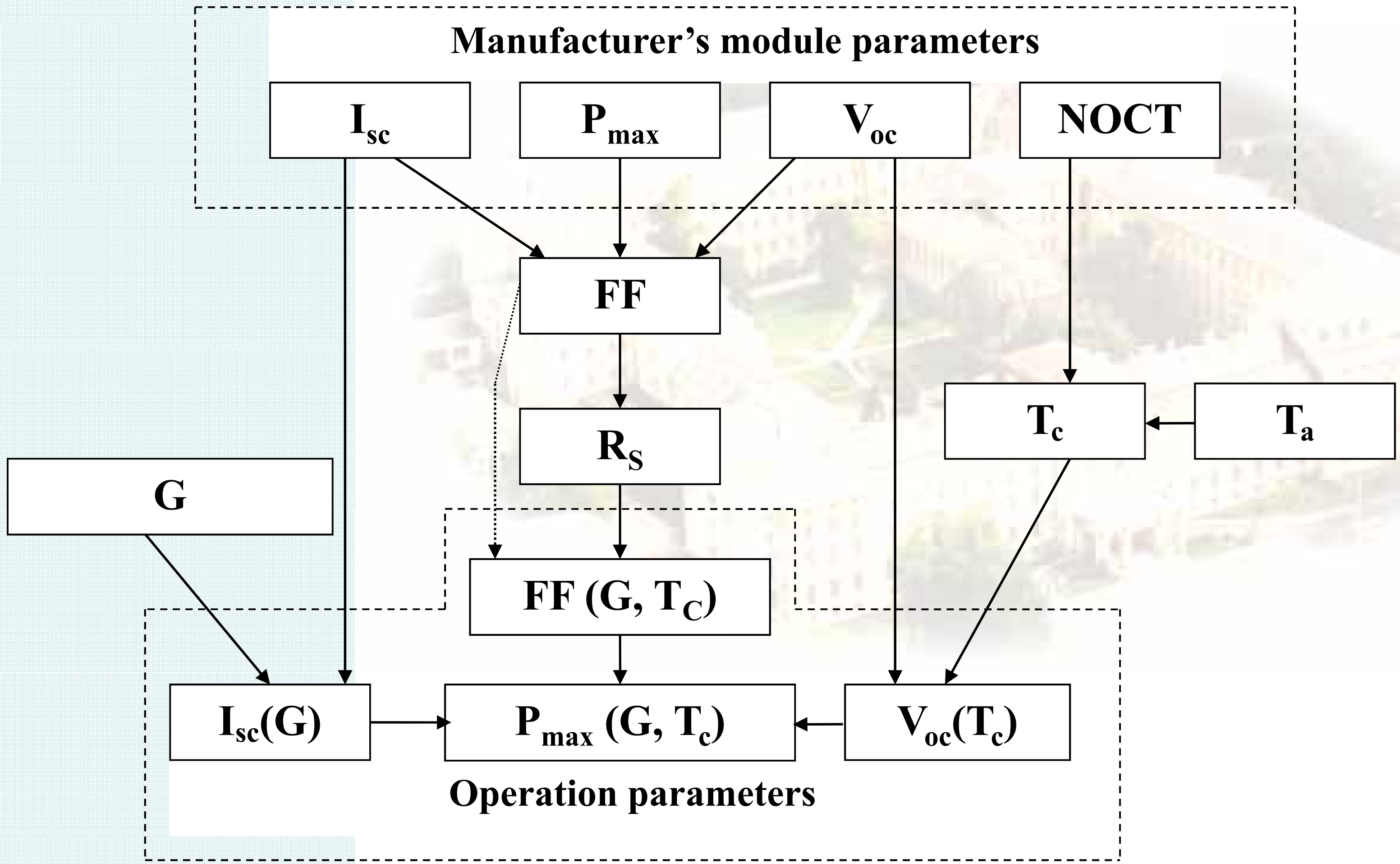


DS-40 module efficiency based on exp.

SCREENSHOT OF THE DATA LOGGER PC DURING DATA ACQUISITION PROCESS



”BRIDGE” EVALUATION MODULE OPERATION PARAMETER



CONCLUSION

- Energetic and exergetic approach to evaluate a PV module performance have been performed, theoretically. Some definition of efficiencies (refers to terminology of energy and exergy) are implemented to calculate a performance module components viz. polycrystalline technology (ASE-100) and amorphous silicon technology (DS-40), which is part of a 10 kWp grid-connected PV array at Szent István University, Gödöllő, Hungary.
- From the *I*-*V*-*P* characteristics, it can be seen that the open circuit voltage (V_{oc}) is dominated by temperature, and irradiation has strong influence on short circuit current (I_{sc}). Based on this characteristic, it can be concluded that high temperature and low irradiation conditions will reduce the power conversion capability.

CONCLUSION

- Further parametric studies are needed in order to obtain a deep correlation between climatic, operating and design parameters so that a possibility to increase a real actual electrical efficiency can be studied and observed.
- This work is part of our research in order to develop a dynamic model of a 10 kWp grid-connected PV array and the final objective of long term work is to develop an accurate model, in order to simulate the electrical behaviour and energy production of the PV array systems in a grid connected application, conducted to a grid-connected PV array installations.


SOLAR PHOTOVOLTAIC IS THE FUTURE
ACTION FIGURE

THANK YOU FOR YOUR ATTENTION

KÖSZÖNÖM SZÉPEN

TERIMA KASIH

SZENT ISTVAN UNIVERSITY

GÖDÖLLŐ - HUNGARY

ITENAS

BANDUNG - INDONESIA