



 SOLAR PV

11th PVPMC

Develop a System-level Model for Grid-connected PV stations based on Energy Flow

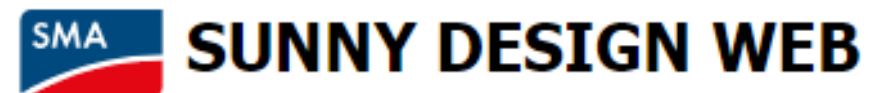
Dr. & Prof. Jianbo Bai (白建波)

Hohai University, *China* (河海大学)

2018.12.4

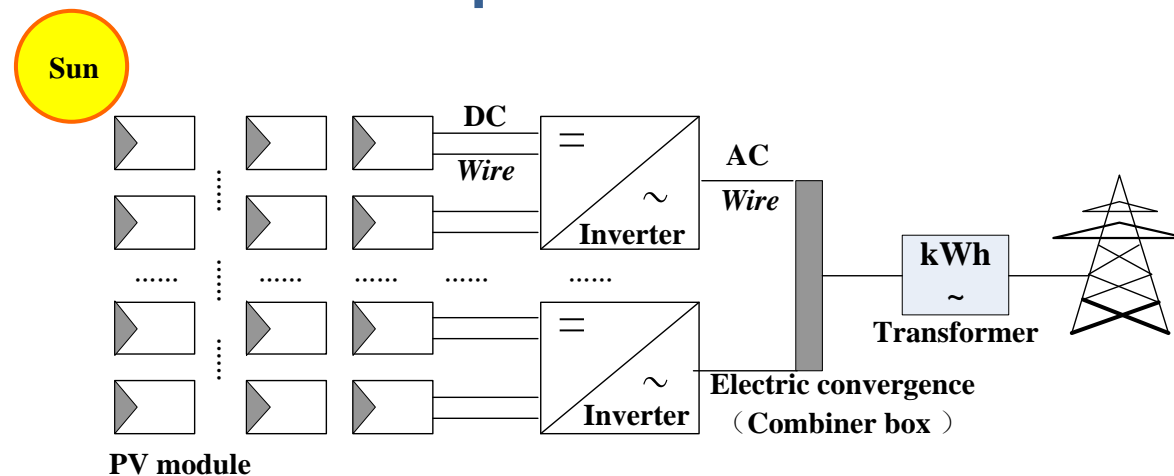


Current PV Simulation Softwares

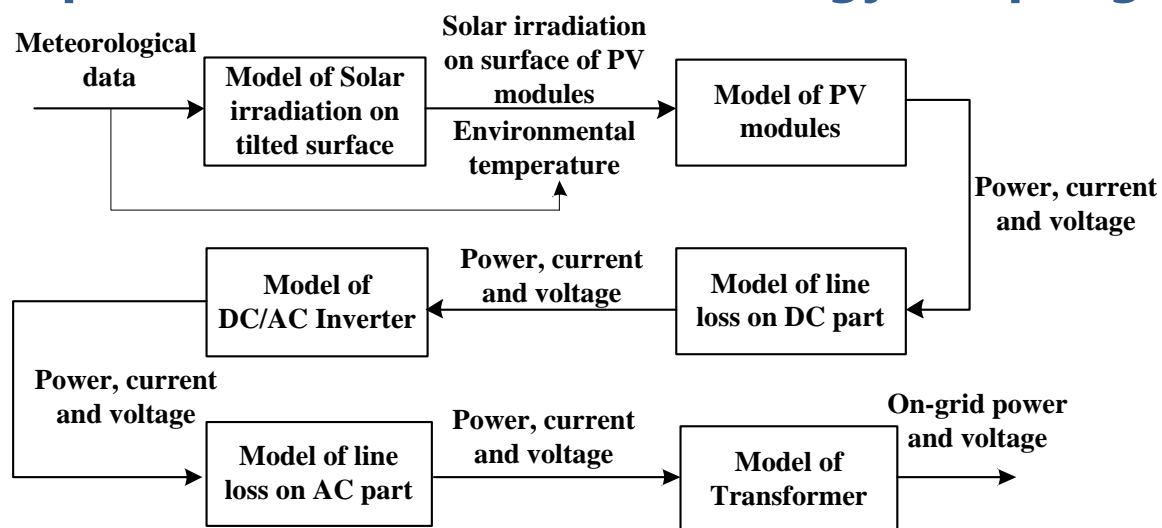


System-level Modeling for PV Power Stations based on Energy Flow

Infrastructure of a Grid-connected PV power Station



Transit diagram for a PV power station based on energy coupling and transfer





Modeling of components and power losses in a PV system

- Average Radiation on Sloped Surface(S.A. Klein, 1977,1981)
- Photovoltaic Panels (Bai JB,2014)
- Grid-connected PV Inverters (D.L. King,2007)
- I-V output under partial shading conditions(Bai JB,2015)
- Losses
 - Shading
 - Wires
 - Soil
 - Mismatch
 - Reflection
 - Performance degradation



Key issues

- Improve the commonality of simulated models by **using only template data**
- Surface radiation and generation evaluation method for PV modules under shading or more complex conditions
- Build **coupling relationship** with component' s electricity performance based on energy flow in a PV system
- Accurate quantitative evaluation method for each loss in a PV system
- Develop an application software based on the system-level model.
- Accuracy and credibility

Modeling PV panels with only template data (I)



Development of a new compound method to extract the five parameters of PV modules

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ARTICLE INFO

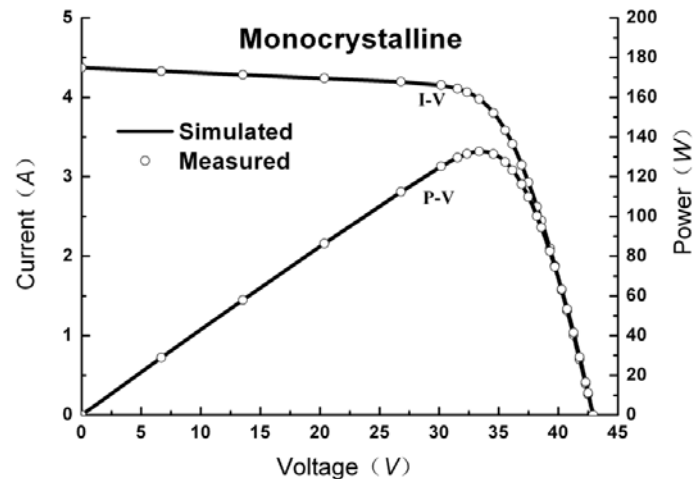
Article history:
 Received 3 September 2013
 Accepted 21 December 2013
 Available online 8 January 2014

Keywords:
 Photovoltaic (PV) modules
 I-V curves
 Five-parameter method
 Prediction of PV power generation

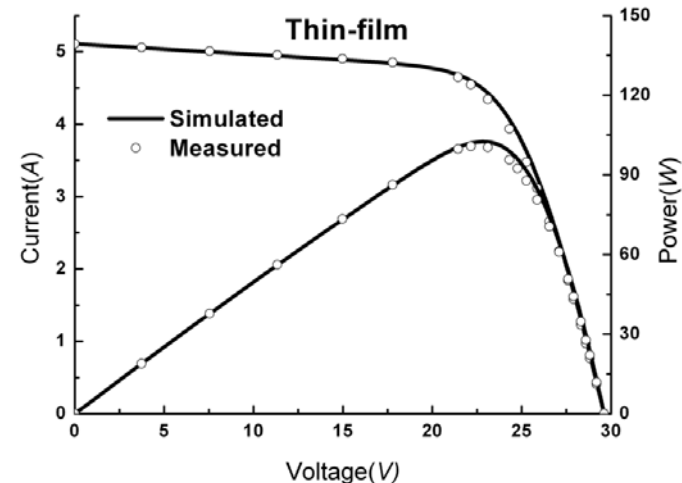
ABSTRACT

The five-parameter photovoltaic (PV) mathematical model has been considered a reliable and accurate method for simulating the performance of PV modules. This paper puts forth a new compound method to extract the five parameters of the model with the basic manufacture template data. As the two differential values at the short and open circuit points of the I-V curve at standard testing conditions (STC) are fundamental data to obtain the five parameters and not normally available from the template data, we use a piecewise I-V curve-fitting method combined with the four-parameter PV model to calculate them with which an explicit extraction method is then presented to extract the five parameters at STC conditions by using five individual algebraic equations. Furthermore, the five parameters are revised according to certain operating conditions. In order to evaluate the effectiveness of the proposed method, the simulated I-V characteristic curves for three types of PV modules over a range of operating conditions are compared with the measured data. The experimental results demonstrate that the method has high accuracy. This method is also used to predict the generation power of an actual PV power station; the simulation results show good agreement with the field data. This proposed method is easy to carry out and especially useful for simulating the actual performances of PV modules or arrays at various operating conditions and predicting the output power of real PV power stations.

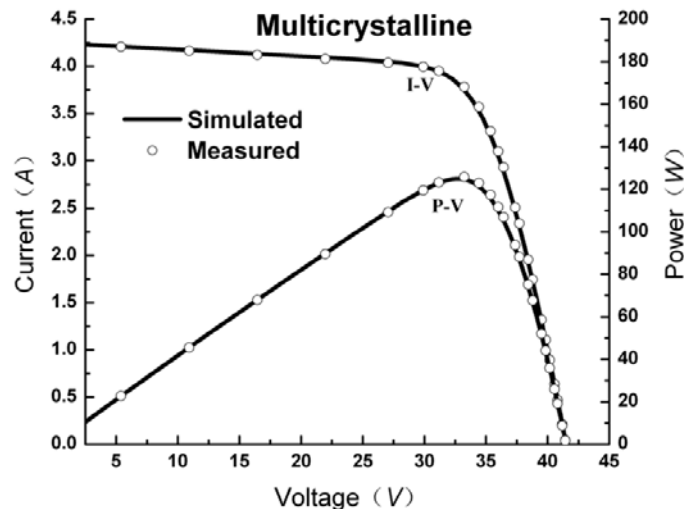
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(a) Monocrystalline

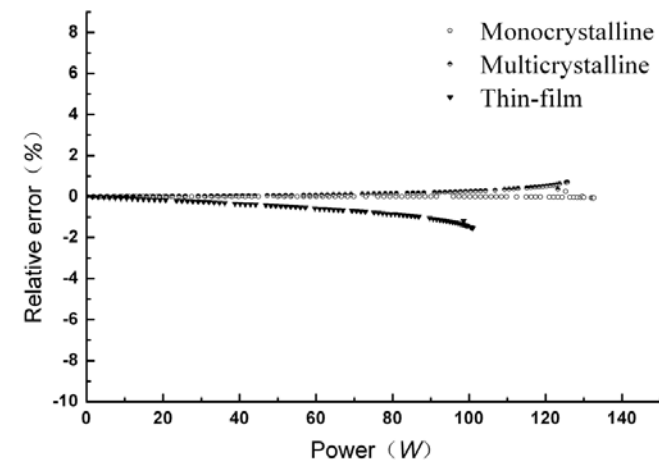


(c) Thin-film

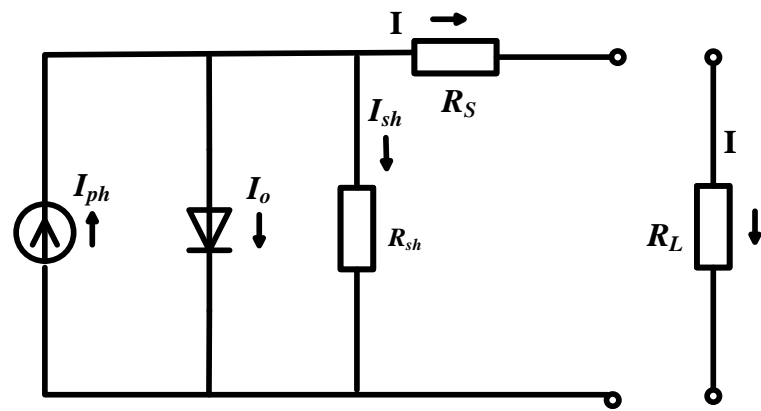


(b) Multicrystalline

Comparison of I-V curves at STC conditions



Relative error for the three types of PV modules

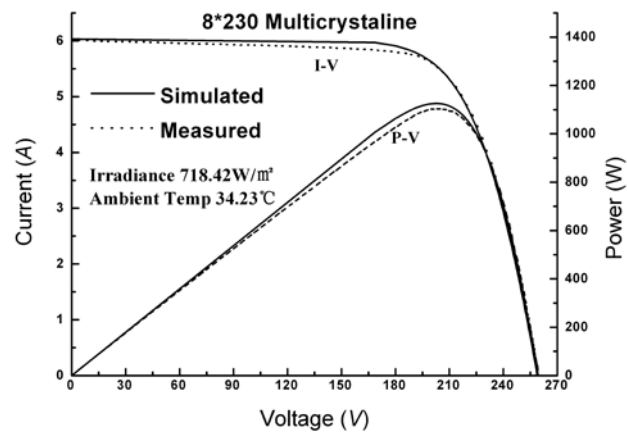


One-diode equivalent circuit

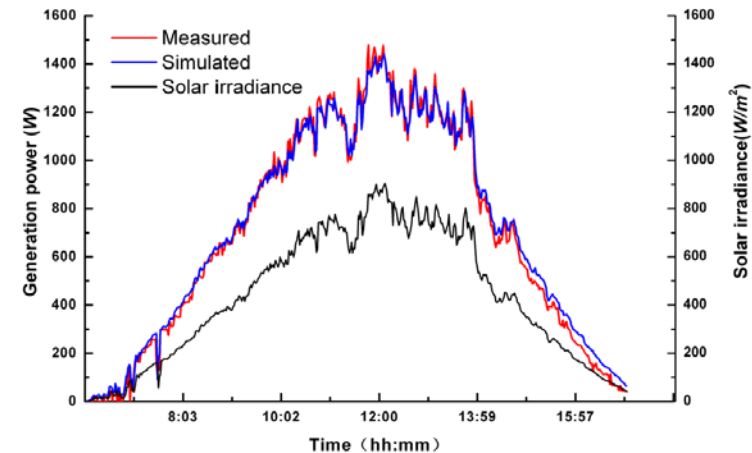
Modeling PV panels with only template data (II)



(a) Multicrystalline (TSM-230PC05)



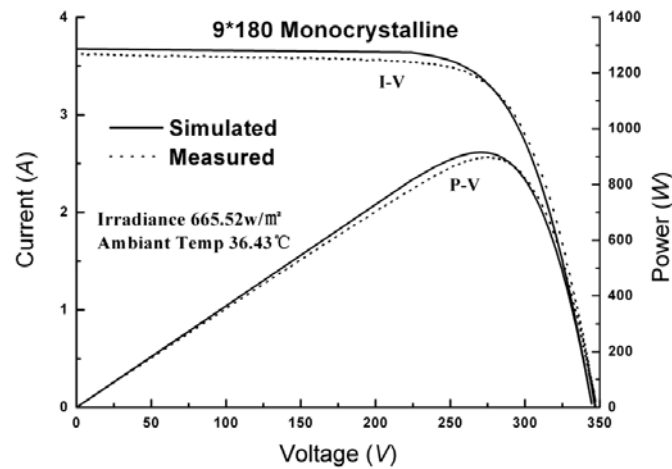
(a) Multicrystalline (TSM-230PC05)



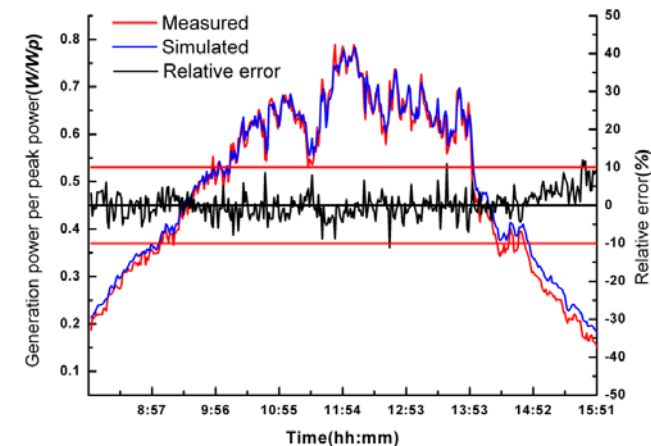
Comparison of generation power and solar irradiance



(b) Monocrystalline (TSM-180DC01)



(b) Monocrystalline (TSM-180DC01)



Comparison of generation per peak power and relative errors

Experimental PV arrays

Output Comparison of PV arrays

Modeling PV output under partial shading conditions (I)



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Solar Energy 112 (2015) 41–54

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Characteristic output of PV systems under partial shading or mismatch conditions

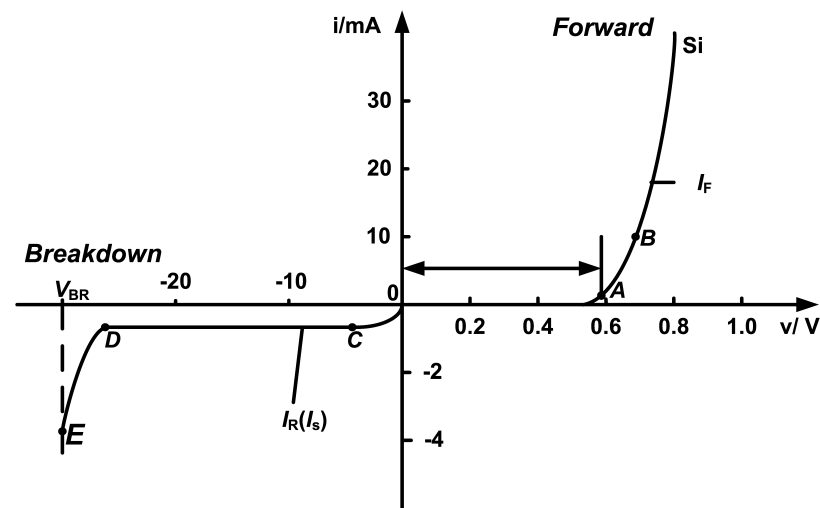
Jianbo Bai^{a,b,*}, Yang Cao^a, Yuzhe Hao^a, Zhen Zhang^a, Sheng Liu^a, Fei Cao^a^a College of Mechanical and Electrical Engineering, Hohai University, 2000 Jintan Bell, Changzhou, 213022 Jiangsu, China^b Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, Southeast University, Nanjing, 210096 Jiangsu, China

Received 23 January 2014; received in revised form 16 July 2014; accepted 22 September 2014

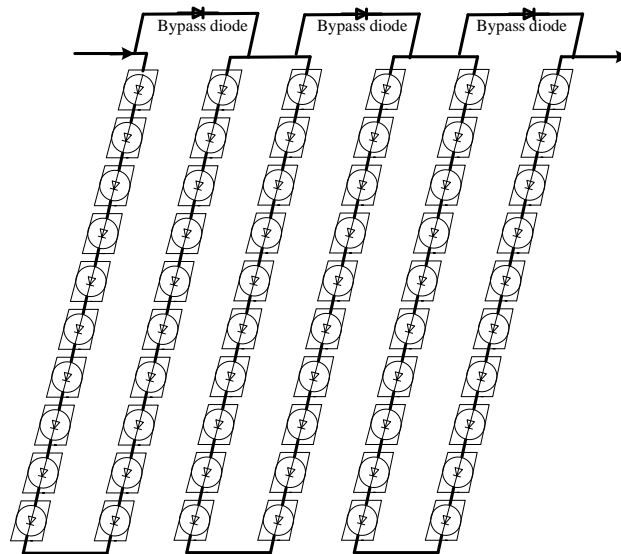
Communicated by: Associate Editor Elias K. Stefanakos

Abstract

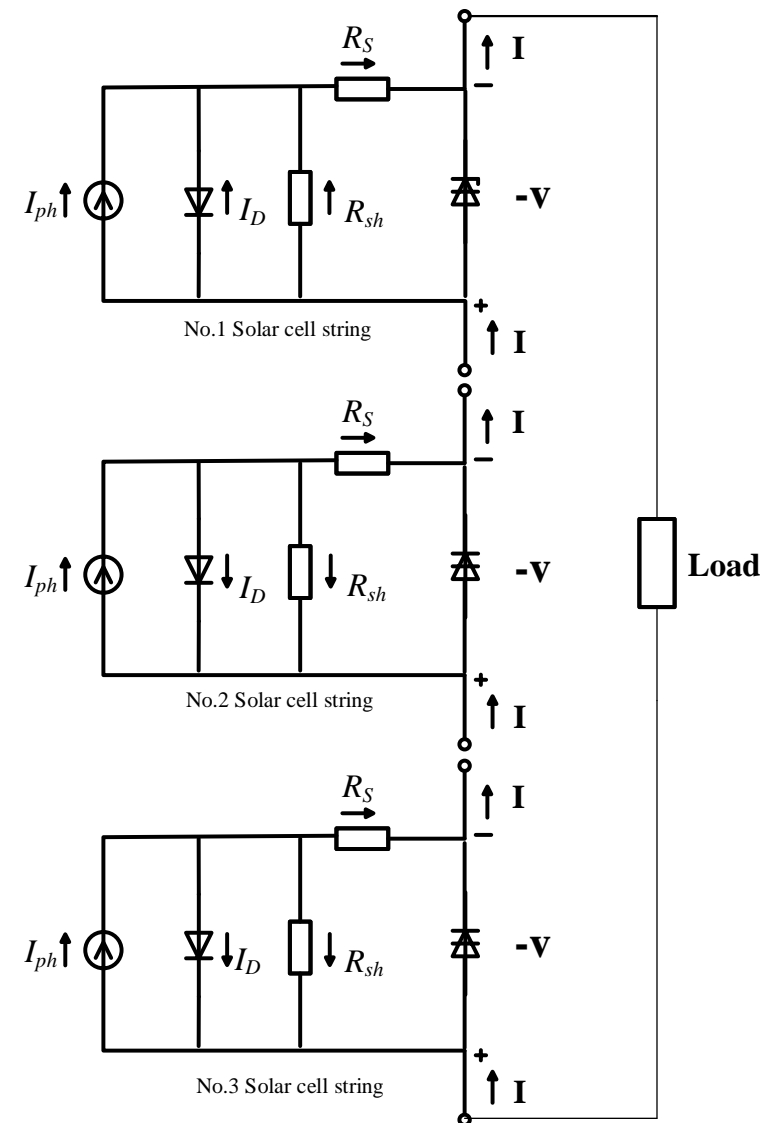
This paper presents a simple and accurate method to simulate the characteristic output of a PV system under either partial shading or mismatch conditions, that are caused by the interconnection of solar cells or modules which do not have identical properties or which experience different conditions from one another. First, a five-parameter equivalent circuit is used to represent the characteristics of a PV module or PV array under normal conditions (without partial shading or mismatch). Then an analytical method is developed to extract the five parameters using the basic manufacturer template data. In this way, the I - V characteristics of the PV module or array at normal operating conditions can be achieved. Additionally, the electrical characteristics of the PV module or array with bypass diodes under partial shading or mismatch conditions are analyzed in detail. To describe the I - V characteristic equations of the PV module or array under complex shading conditions, a calculation algorithm with several subsection functions is proposed. Lastly, a judgment method for the states of the bypass diodes in PV modules is designed to synthesize the subsection functions. Thus, the multi-peak characteristics of a PV system under partial shading or mismatch conditions can be achieved. To evaluate the effectiveness of the proposed method, experiments have been conducted to compare the experimental and simulated I - V and P - V curves of a PV system under some predefined partial shading and mismatch conditions. The experimental results demonstrate that the method has high accuracy in simulating the I - V and P - V characteristics of a PV module or array under either partial shading or mismatch conditions. © 2014 Elsevier Ltd. All rights reserved.



I-V curve of a diode with silicon (Si)



Internal structure of a PV module



Internal structure of a PV array

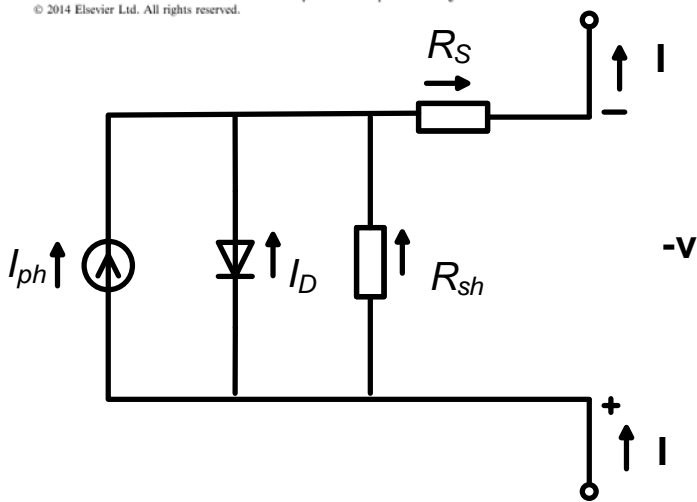
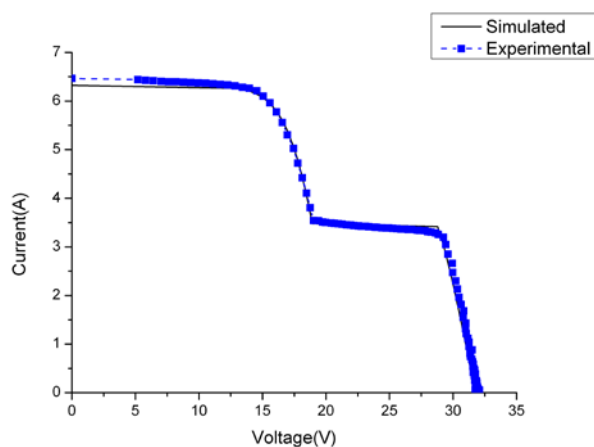
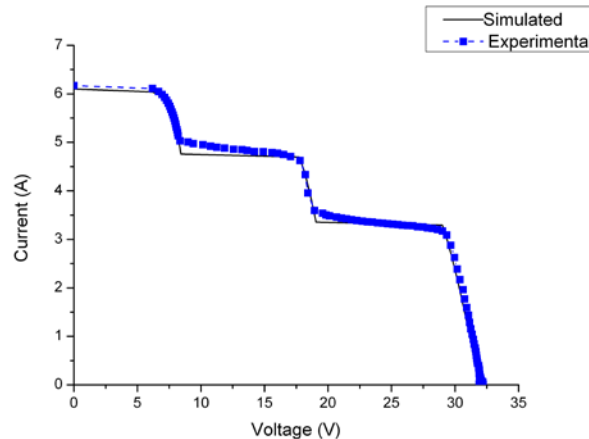


Diagram of a reverse biased solar cell

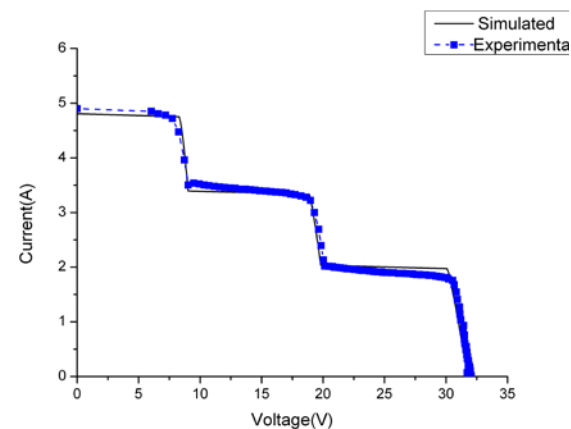
Modeling PV output under partial shading conditions (II)



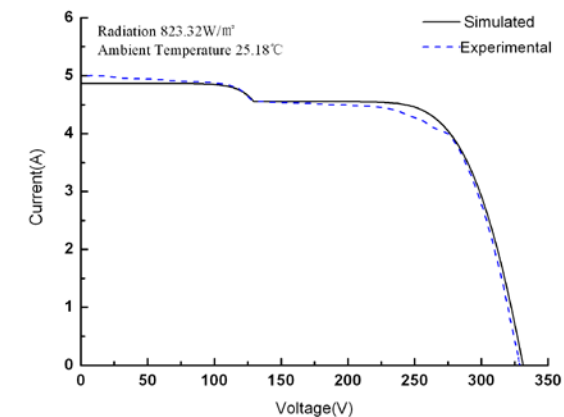
I-V curves under shading testing scheme 1



I-V curves under shading testing scheme 2



I-V curves under shading testing scheme 2



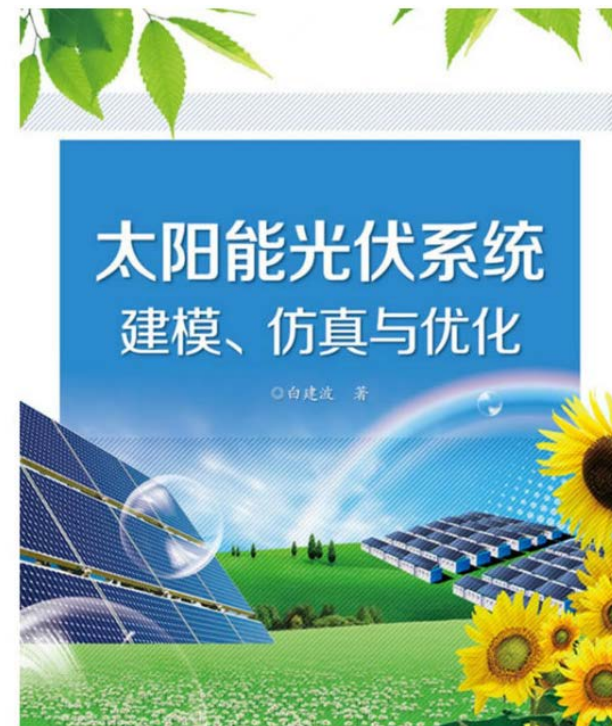
I-V curve under PV array mismatch condition



Book - Modeling, Simulation and Optimization for Photovoltaic systems

Directory

1. Introduction
2. Solar Radiation
3. Modeling of PV cells, modules and arrays
4. Modeling of Inverters
5. Modeling of PV auxiliary equipment and other losses
6. Modeling of PV output under shading or mismatch conditions
7. Optimization method and life prediction for PV systems
8. Modeling of thermoelectric coupling characteristics for PV panels
9. Economical and environmental analysis for PV systems
10. Modeling of Grid-connected PV systems and generation prediction
11. Functions and examples of SolarPV software





SOLAR PV

Introduction of SolarPV



可设计光伏电站及
屋顶工程



提供全球1000余座城市
地理气象数据及众多知名
光伏组件、逆变器厂家
产品数据



实时发电量计算及累积
年发电量、系统效率分析



光伏系统经济性、投资及
运行成本分析

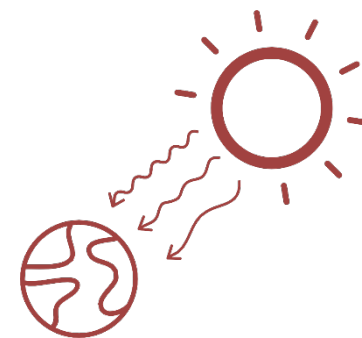


温室气体减排量和标煤
节约量等环保效益分析



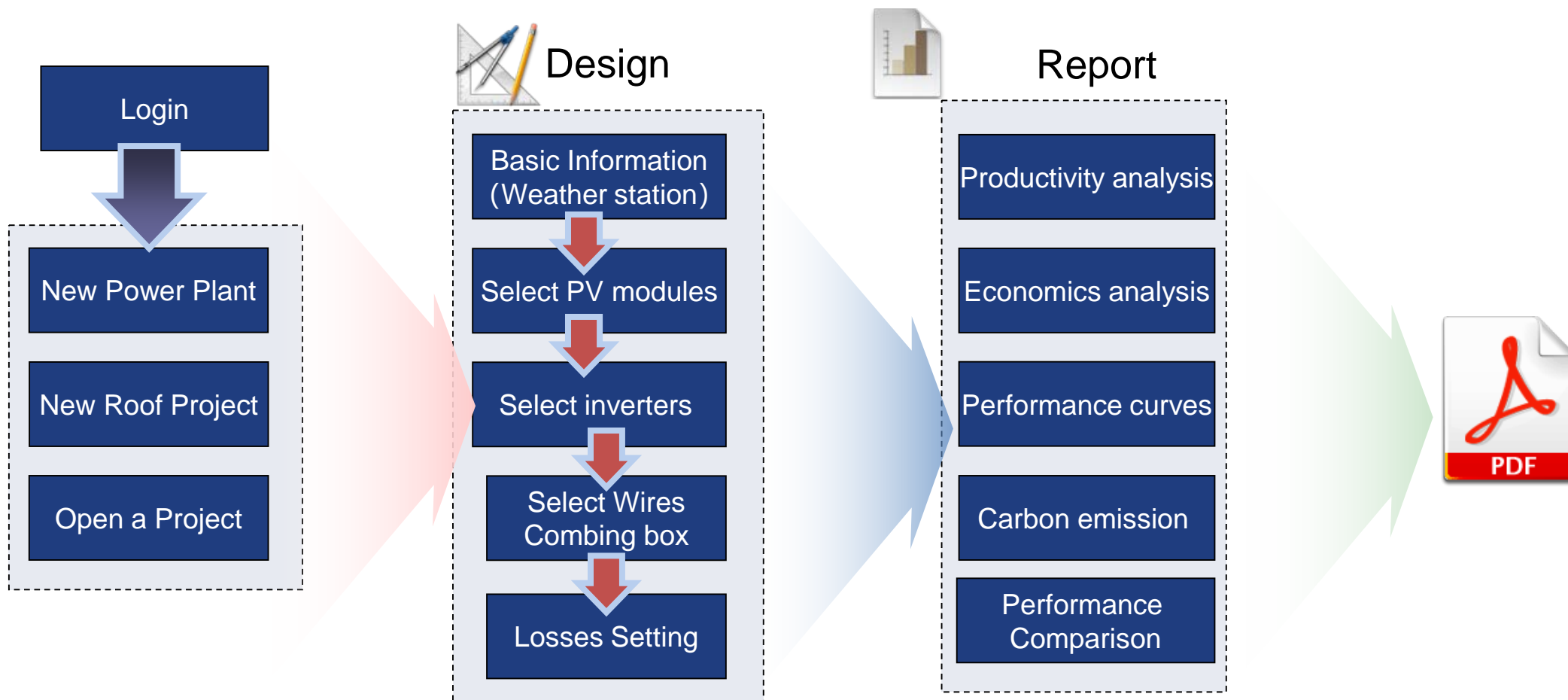
Features of SolarPV

1. Design of different PV systems: Plant projects , Roof projects.
2. Detail design of PV systems : Weather station selection, Capacity design , PV modules selection, Inverters selection, Wires design, various Loss settings.
3. Shading simulation for flat or pitched roofs during a whole year.
4. Various report: radiation, generation , system efficiency, economical and carbon analysis.
5. Database for updating PV modules, weather stations and inverters information.
6. Detail PDF document : describing PV systems and simulation performance data.
7. Optimization functions: Optimum tilt angle, Optimum Series-parallel matching.
8. Various tools.





Procedures of using software





Project design

ID	Module
1	Basic Information
2	PV modules selection
3	Inverters selection
4	Wires and Combiner boxes selection
5	Losses Setting

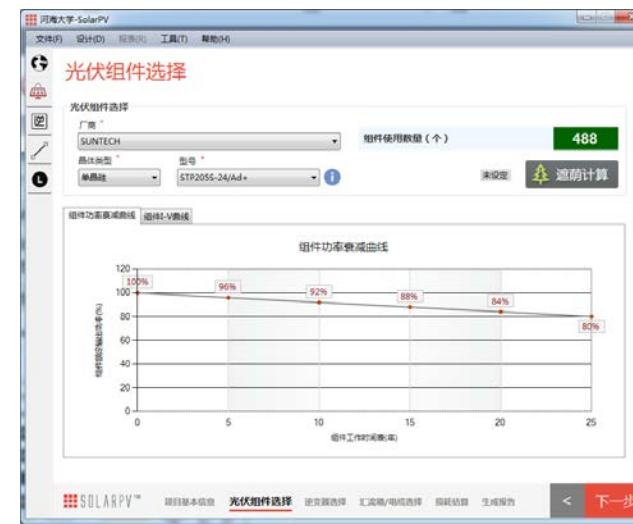
项目基本信息

项目名称: 河南大学实验楼屋顶工程
项目单位: 河南大学常州校区

地址: 中国 江苏 常州
经纬度: 119.90° 31.77°
海拔: 7.0m
年平均最高温度: 26.2°C
年平均最低温度: 3.8°C

设计容量: 30 kWp
屋顶类型: 彩钢
朝向: 正南
方位角: 0.00°

Basic Information



PV modules selection

逆变器选择

逆变器选择
品牌: SMA
型号: SUNNY BOY 3800-US(4200W)
逆变器使用数量 (个): 8

运行方式: MPPT

逆变器配置

统一配置逆变器: 7
单一配置逆变器: 1

MPP跟踪口: 1

所有串口

总串联数: 11
总并联数: 2

组件数: 9

最大允许串数: 12
最小允许串数: 6
MPP口最大允许并联数: 3
输入功率: 96.90%

最高温度(°C): 26.20
最低温度(°C): 3.80
电压(V): 44.4
电压(V): 47.4
电流(A): 5.5
电流(A): 5.5

Inverters selection

汇流箱及线缆选择

线缆 (直流侧)
材料类型: Cu
规格: 62
单根线缆长度: 10 m
STC线缆压降(V): 0.64
STC相对功率损耗: 0.221%

建议截面积 (mm²): 1.50
工作温度 (85 ~ -40) °C

线缆 (交流侧)
材料类型: Cu
规格: 61
单根线缆长度: 10 m
电压: 110 V
STC线缆压降(V): 0.57
STC相对功率损耗: 0.523%

建议截面积 (mm²): 1.50
工作温度 (85 ~ -40) °C

配置汇流箱
汇流箱品牌: AGF-M4R
单路最大输入电流 (A): 12
直流允许输入路数: 4
汇流箱数量: 16

Wires and Combiner boxes selection

损耗估算

地面损失
固定地面
地面反射率: 20%
使用默认反射率

空气和积灰损失
降尘量: 微量
风速: 少风
清扫周期: 每周一次

失配损失
失配系数: 5%
使用默认失配系数

组件功率衰减表

组件使用年限	0	5	10	15	20	25
组件额定输出功率	100%	96%	92%	88%	84%	80%

其他损耗
直流侧损耗: 0.150%
交流侧损耗: 0.368%
光学损失 (0-5) %
组件品质损耗 (0-5) %
选择计算模型: 复杂 (四参数模型)
选择系统模型: 并网

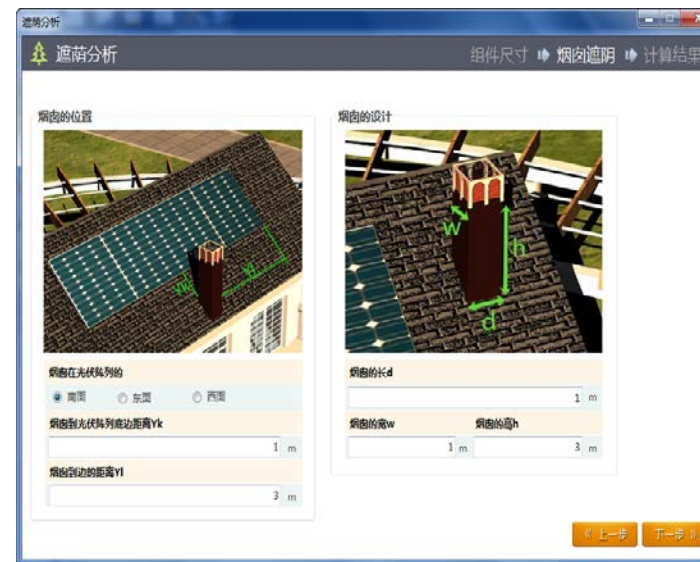
Losses Setting



Shading simulation



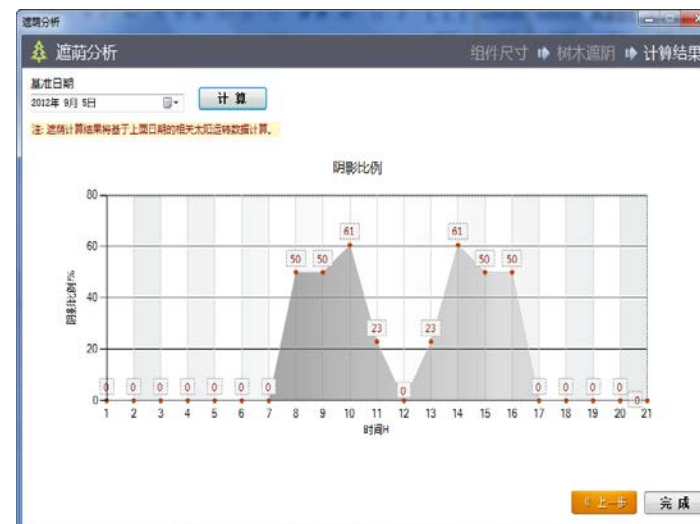
Simulated pitched roof



Shading configuration(chimney)



Simulated flat roof



Simulation shading data



Project report

ID	Module
1	Productivity report
2	Economical report
3	Carbon emission report
4	Equipment performance report
5	System performance comparison



产能分析报告

月份	产能分析报告					透时水平面辐射量	透时阵列发电电量	透时阵列面辐射量	未来25年发电量预测		
	月水平面接收辐射量 (kWh/m ²)	斜面接收总辐射量 (kWh/m ²)	斜面接收直射辐射量 (kWh/m ²)	斜面接收散射辐射量 (kWh/m ²)	斜面接收反射辐射量 (kWh/m ²)	组件输出电量 (MWh)	逆变器输出电量 (MWh)	一次能源总损失 (MWh)	净输出电量 (MWh)	电站系统运行效率 (%)	一次能源利用效率 (%)
一月	87.42	119.19	86.73	31.74	0.72	11.66	10.74	63.60	10.66	89.37	14.35
二月	92.96	111.56	71.48	39.32	0.76	10.85	9.99	59.58	9.92	88.88	14.27
三月	113.77	122.36	67.67	53.76	0.93	11.71	10.71	65.60	10.63	86.87	13.95
四月	133.50	132.73	70.01	61.62	1.09	12.36	11.35	71.43	11.26	84.82	13.62
五月	154.38	144.90	73.68	69.95	1.26	13.24	12.09	78.27	12.00	82.79	13.29
六月	145.20	133.21	62.36	69.66	1.19	12.03	10.96	72.11	10.88	81.63	13.11
七月	151.28	140.13	68.07	70.82	1.24	12.53	11.42	75.97	11.33	80.85	12.98
八月	142.29	137.94	70.89	65.89	1.17	12.37	11.31	74.71	11.23	81.35	13.06
九月	120.60	125.83	69.41	55.43	0.99	11.43	10.46	68.01	10.38	82.44	13.24
十月	103.54	118.99	71.63	46.51	0.85	11.02	10.09	64.11	10.02	84.14	13.51
十一月	89.70	119.09	85.99	32.37	0.73	11.28	10.38	63.89	10.31	86.51	13.89
十二月	83.08	117.62	87.56	29.37	0.68	11.40	10.49	62.86	10.41	88.48	14.21
全年	1417.72	1523.54	885.48	626.44	11.62	141.88	129.99	820.15	129.02	84.65	13.59

Productivity report

初始投资	小计	相对成本 (%)
可行性研究	68,300.0	1.2
项目开发	102,500.0	1.8
工程设计	375,800.0	6.5
配套设备	4,112,260.0	71.4
其它	1,096,778.0	19.1
总计	5,755,638.0	

年度成本和债务	小计	成本汇总
运行及维护	6,111.0	初始投资总计 5,755,638.0
债务偿还(元/年)	337,435.8	
总计	343,546.8	
总计	343,546.8	年度成本和债务总计 343,546.8

周期性成本	小计	周期性成本总计
逆变器修理/更换	341,700.0	690,234.0
项目寿命期末	0.0	
其他周期性维护	0.0	
总计	690,234.0	周期性成本总计 690,234.0

合计 15,034,543.1

Economical report

二氧化碳评估报告

单燃料系统对比 多燃料系统对比

煤炭 VS 太阳能

燃料发电系统	二氧化碳排放因子 (kg/kWh)	甲烷排放因子 (E ⁻⁵ kg/kWh)	氧化亚氮排放因子 (E ⁻⁵ kg/kWh)	温室气体排放因子 (kg/kWh)	燃料转化效率 (%)	电力传输损失 (%)
理论排放值	0.341	0.72	1.08	1.070	35	8
并网后实际排放值	1.059	2.236	3.354	1.070	-	-

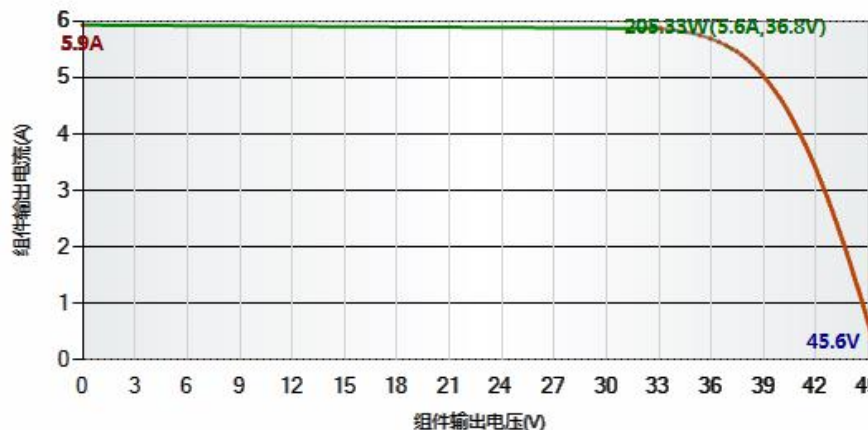
太阳能发电系统	二氧化碳排放因子 (kg/kWh)	甲烷排放因子 (E ⁻⁵ kg/kWh)	氧化亚氮排放因子 (E ⁻⁵ kg/kWh)	温室气体排放因子 (kg/kWh)	燃料转化效率 (%)	电力传输损失 (%)
理论排放值	100	-	-	-	100	8.0

单燃料系统对比可以定量计算利用光伏发电比利用某种燃料发电所减排的温室气体量。

开始评估

Carbon emission report 温室气体年减排量 138.05t

组件I-V曲线



Equipment performance report

性能比较

当前选用光伏组件 VS 对照选用光伏组件

当前选用光伏组件: SUNTECH STP205S-24/Ad+

对照选用光伏组件: Trina Solar TSM-205DC80

比较结果	当前选用组	对照组
水平面年总辐射量 (MWh/m ²)	1.42	1.42
阵列面年总辐射量 (MWh/m ²)	949.17	949.17
光伏系统额定容量 (KW)	100.00	100.00
单位面积发电量 (MWh/m ²)	0.23	0.22
阵列每功率年发电量 (kWh/Wp)	1.42	1.37
系统阵列年总发电量 (MWh)	141.88	137.37
提供给用户的电量 (MWh)	129.02	124.77
光伏系统总效率 (%)	13.59	13.12

选取与原系统不同型号的、峰值功率相等的组件对系统年发电量进行比较。

System performance comparison



Project tools

ID	Module
1	Lifetime prediction for PV modules
2	PV modules performance under different conditions
3	PV modules performance of different manufactures
4	Mismatch analysis under shading conditions
5	Series resistance influence on PV modules

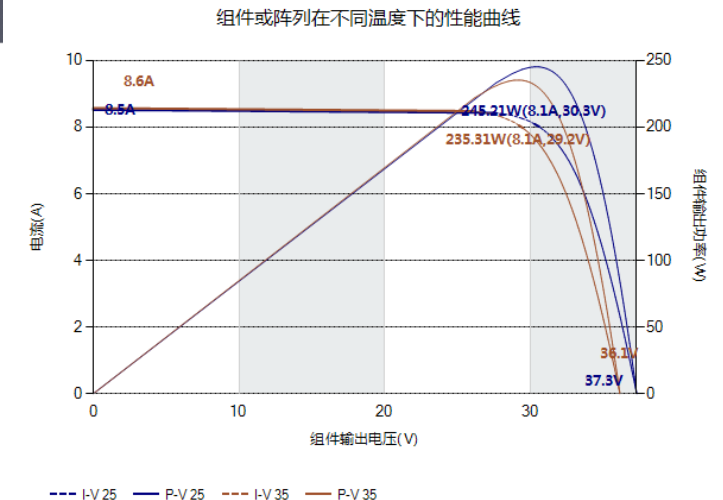
组件寿命预测

厂商: 请选择
 晶体类型: 请选择
 型号: 请选择
 平均衰减率: 1 %

运行的可靠性: 80 %
 运行极限功率比: 80 %
 组件寿命约为: 年

开始预测

组件寿命预测根据组件的年衰减率、极限功率比、运行的可靠性得到。



Lifetime prediction for PV modules

PV modules performance under different conditions

相同环境下不同组件发电性能比较

比较方式: 单组件 / 阵列
 辐照度: 1000 W/m²
 组件温度: 25 °C

组件1: Trina Solar, TSM-185DC/DA01A
 组件2: SUNTECH, STP200S-24/Ad+

PV modules performance of different manufactures

电池片遮挡失配分析

组件: M1-1

注: 单击电池片可设置遮挡率及透光率。

0%	0%	0%	0%	0%	0%
100%	24	25	48	49	72
0%	0%	0%	0%	0%	0%
100%	23	28	47	50	71
0%	0%	0%	0%	0%	0%
100%	22	27	46	51	70
0%	0%	0%	0%	0%	0%
100%	21	28	45	52	69
0%	0%	0%	0%	0%	0%
100%	20	29	44	53	68
0%	0%	0%	0%	0%	0%
100%	19	30	43	54	67
0%	0%	0%	0%	0%	0%
100%	18	31	42	55	66
0%	0%	0%	0%	0%	0%
100%	17	32	41	56	65
0%	0%	0%	0%	0%	0%
100%	16	33	40	57	64
0%	0%	0%	0%	0%	0%
100%	15	33	40	57	64

I-V output under shading conditions

组件串阻对发电功率影响

厂商: Trina Solar
 晶体类型: 单晶硅
 型号: TSM-190DC/DA01A
 组件接收辐照度: 1000 W/m²
 组件温度: 25 °C
 串联电阻: 0.54(Ω)
 最大功率: 189.95(W)

串联电阻(Rs/Ω)	最大功率点电流(A)	最大功率点电压(V)	最大功率点功率(W)	效率(%)
0.27	5.24	37.63	197.33	0.18
0.32	5.24	37.35	195.84	0.17
0.38	5.24	37.06	194.35	0.17
0.43	5.19	37.17	192.87	0.17
0.49	5.19	36.89	191.41	0.17
0.54	5.19	36.61	189.95	0.17
0.60	5.19	36.33	188.49	0.17
0.65	5.19	36.05	187.04	0.17
0.70	5.19	35.77	185.58	0.16
0.76	5.19	35.48	184.12	0.16

Series resistance influence on PV modules performance



Project setting

ID	Modules
1	Weather information setting
2	PV modules setting
3	Inverters setting
4	Combining boxes setting
5	Currency setting

新增气象数据

区域: 国家:

省份: 城市:

经度: 纬度: 海拔: m

水平面月平均日辐射量(kWh/m2) 周围环境月平均气温(°C)

1月	2月	1月	2月
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
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<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

Weather information setting

新增光伏组件

厂商: 最大功率点温度因子: %/°C 参考条件短路电流: A

新厂商 开路电压温度因子: %/°C 参考条件组件效率: %

晶体类型: 短路电流温度因子: %/°C NOCT最大功率: W

型号: 参考条件峰值功率: W NOCT最大功率点电压: V

组件面积: m2 参考条件最大功率点电压: V NOCT最大功率点电流: A

长: m 宽: m 厚: m 有效旁路二极管数: 个 NOCT开路电压: V

单个组件串联电池片数: 片 参考条件最大功率点电流: A NOCT短路电流: A

工作温度上限: °C 工作温度下限: °C 参考条件开路电压: V NOCT组件温度: °C

组件功率质保: 年 损耗: %

请设置合理的光伏组件参数, 非合理数据可能导致设计工程无法工作。

PV modules setting

新增逆变器

厂商: 最大输入直流功率: W 输出端最大交流电流: A

新厂商 最大输入直流电压: V 每个跟踪端最大输入电流: A

型号: 最大功率点电压跟踪上限: V 可以跟踪的输入端数: 个

最大效率: % 最大功率点电压跟踪下限: V 每个跟踪端可以连接串数: 串

启动电压: V 额定输入电压: V 每串中最大输入电流: A

启动功率: W 最小输入电压: V 输入端最大交流电压: V

拟合数据: 有 无 X:输入直流功率(W), Y:实时效率(%)

第1组数据(X,Y)	第5组数据(X,Y)
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>

请设置合理的逆变器参数, 非合理数据可能导致设计工程无法工作。

Inverters setting

新增汇流箱

厂商:

新厂商

型号:

最大输入回路数:

单路最大输入电流: A

Combining boxes setting

设置

基本数据设定后, 请重新启动系统。

光伏组件

逆变器

汇流箱

线缆

气象数据

货币

我的位置

货币单位

美元USD 日元JPY 欧元EUR 英镑GBP 人民币CNY

汇率设定

1 美元 = 人民币CNY

日元JPY

欧元EUR

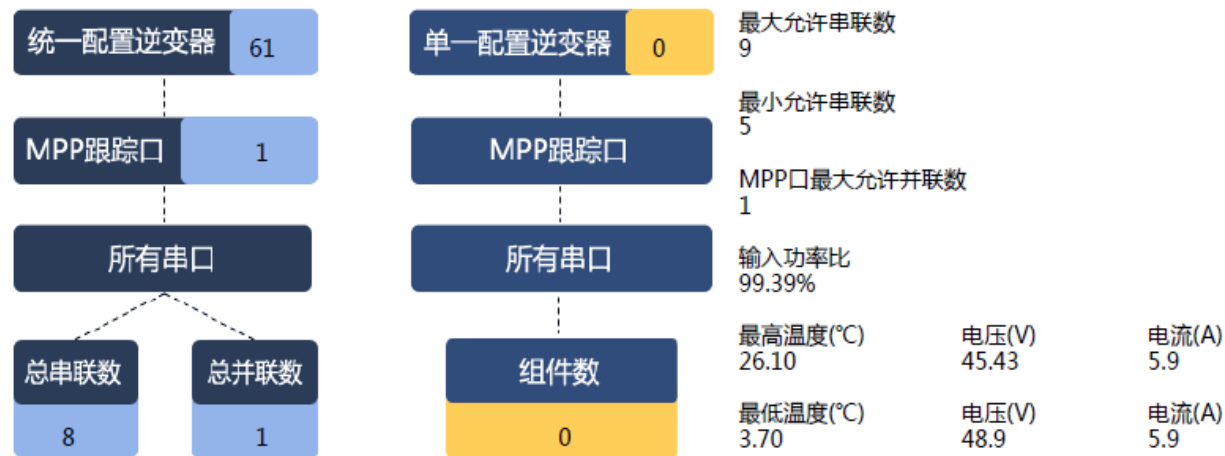
英镑GBP

Currency conversion setting



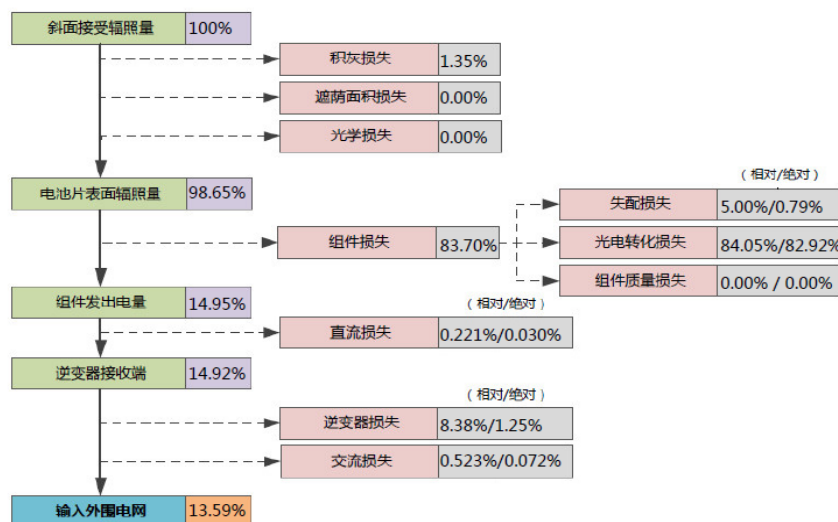
PDF document

设计类型	电厂工程	线缆 (直流侧)	厂商	N/A
			材料类型	Cu
倾斜/方位角模式	固定倾斜角/方位角 (28°/0°)	线缆截面积	1.5mm ²	
系统容量	100kWp	单根线缆长度	10m	
预测年发电量	129.02MWh	线缆数	62	
光伏组件		线缆 (交流侧)	厂商	N/A
线缆 (交流侧)	SUNTECH		材料类型	Cu
晶体类型	单晶硅	线缆截面积	1.5mm ²	
型号	STP205S-24/Ad+	单根线缆长度	10m	
组件使用数量	488	线缆数	61	
组件最佳间距(竖排)	1.50m			
逆变器		汇流箱	厂商	A
厂商	GSO NEW ENERGY		型号	AGF-M4R
型号	GSG 1.5K(1650W)	单路最大输入电流	12A	
逆变器使用数量	61	直流实际输入路数	62	
运行方式	MPPT	汇流箱数量	16	



Design overview

损耗估算 (*以光伏阵列面接收的太阳能为参考基准)



Detail loss analysis

Series-parallel optimization scheme for a PV array

月份	月水平面接收辐照量 (kWh/m ²)	斜面接收总辐照量 (kWh/m ²)	斜面接收直射辐照量 (kWh/m ²)	斜面接收散射辐照量 (kWh/m ²)	斜面接收反射辐照量 (kWh/m ²)	组件输出电量 (MWh)	逆变器输出电量 (MWh)	一次能源总损失 (MWh)	净输出电量 (MWh)	电站系统运行效率 (%)	一次能源利用效率 (%)
一月	87.42	119.19	86.73	31.74	0.72	11.66	10.74	63.60	10.66	89.37	14.35
二月	92.96	111.56	71.48	39.32	0.76	10.85	9.99	59.58	9.92	88.88	14.27
三月	113.77	122.36	67.67	53.76	0.93	11.71	10.71	65.60	10.63	86.87	13.95
四月	133.50	132.73	70.01	61.62	1.09	12.36	11.35	71.43	11.26	84.82	13.62
五月	154.38	144.90	73.68	69.95	1.26	13.24	12.09	78.27	12.00	82.79	13.29
六月	145.20	133.21	62.36	69.66	1.19	12.03	10.96	72.11	10.88	81.63	13.11
七月	151.28	140.13	68.07	70.82	1.24	12.53	11.42	75.97	11.33	80.85	12.98
八月	142.29	137.94	70.89	65.89	1.17	12.37	11.31	74.71	11.23	81.35	13.06
九月	120.60	125.83	69.41	55.43	0.99	11.43	10.46	68.01	10.38	82.44	13.24
十月	103.54	118.99	71.63	46.51	0.85	11.02	10.09	64.11	10.02	84.14	13.51
十一月	89.70	119.09	85.99	32.37	0.73	11.28	10.38	63.89	10.31	86.51	13.89
十二月	83.08	117.62	87.56	29.37	0.68	11.40	10.49	62.86	10.41	88.48	14.21
全年	1417.72	1523.54	885.48	626.44	11.62	141.88	129.99	820.15	129.02	84.65	13.59

Detail simulation data of a PV array



Future development plan

1. Web Interface platform for PV design, simulation and online PDF report.
2. 3D Design for PV arrays based on SketchUp.
3. Expand database for PV modules, inverters and weather stations.
4. Support new type of PV modules (Double-sided photovoltaic modules, etc.)
5. Support design and simulation of stand-alone PV systems.



THANKS
谢谢!

SolarPV Official Website
<http://www.ansolarpv.com>

