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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

NREL System Advisor Model (SAM)
NATIONAL RENEWABLE ENERGY LABORATORY

PVSYST

PVPerformance MODELING COLLABORATIVE

SMA SUNNY DESIGN WEB

Skelion

HELiOS 3D

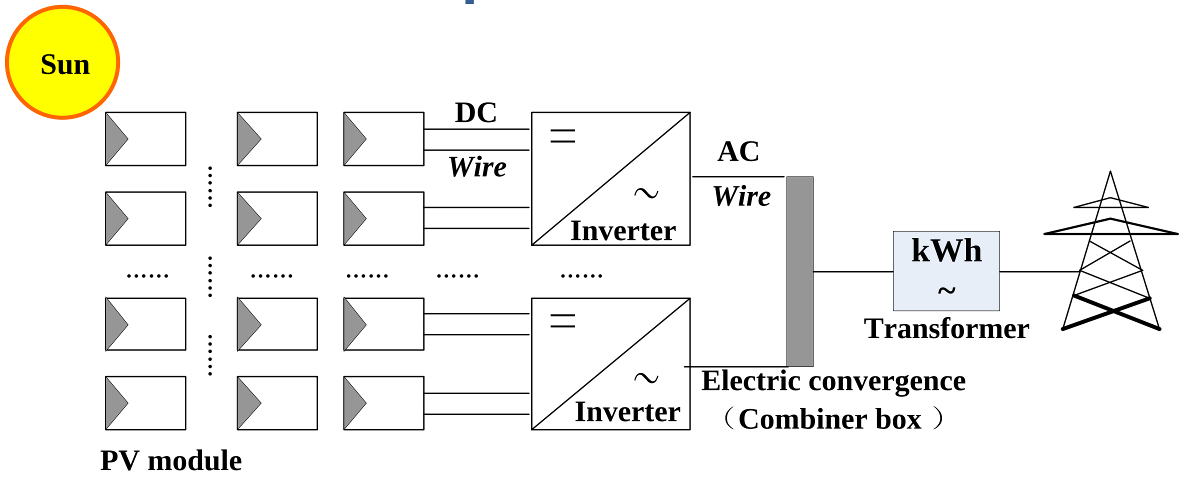
RETScreen® Expert

SOLARPV

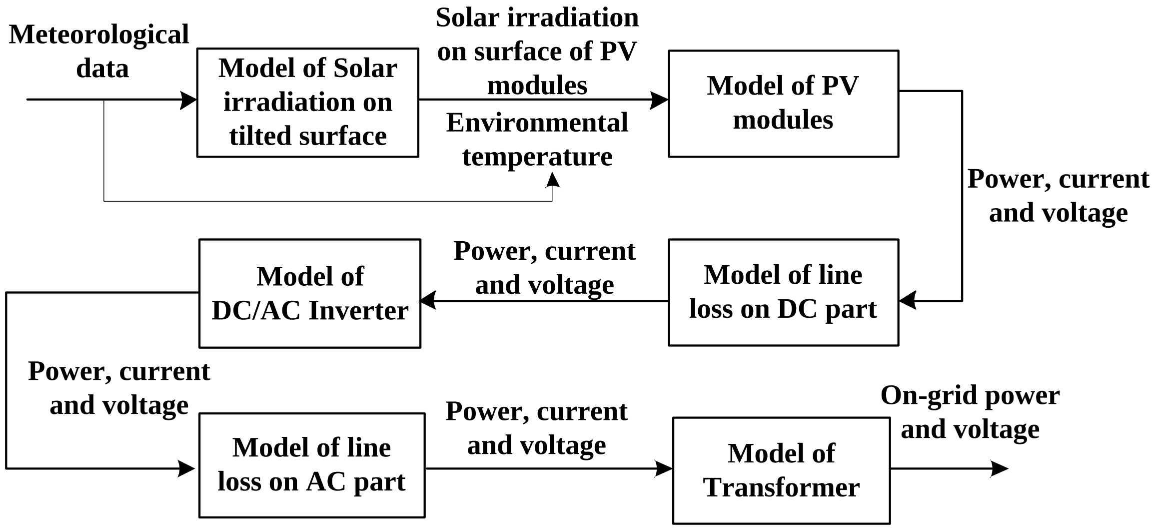
PV*SOL premium

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

Infrastructure of a Gird-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 date（Ⅰ）

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

Jianbo Bai [a,b,*], Sheng Liu [a], Yuzhe Hao [a], Zhen Zhang [c], Meng Jiang [c], Yu Zhang [a]
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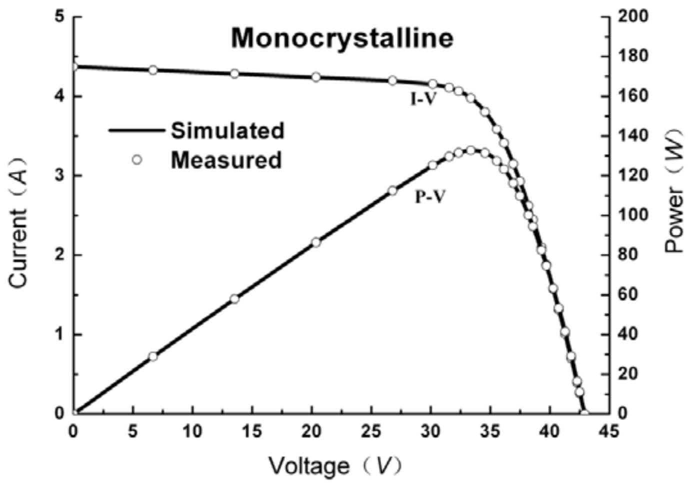
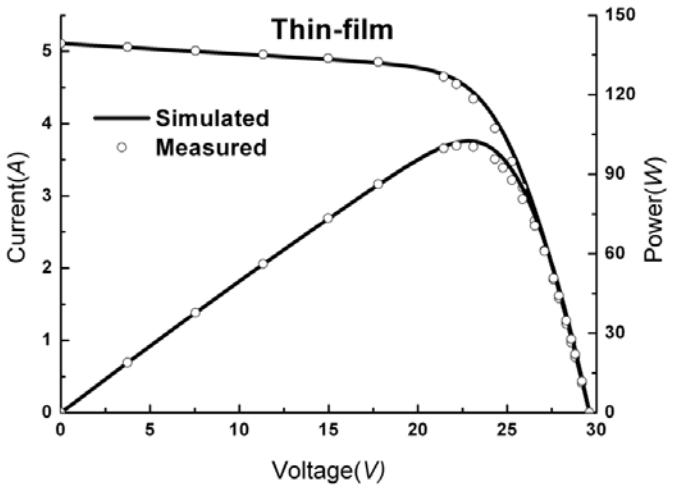
I–V curves
Five-parameter method
Prediction of PV power generation

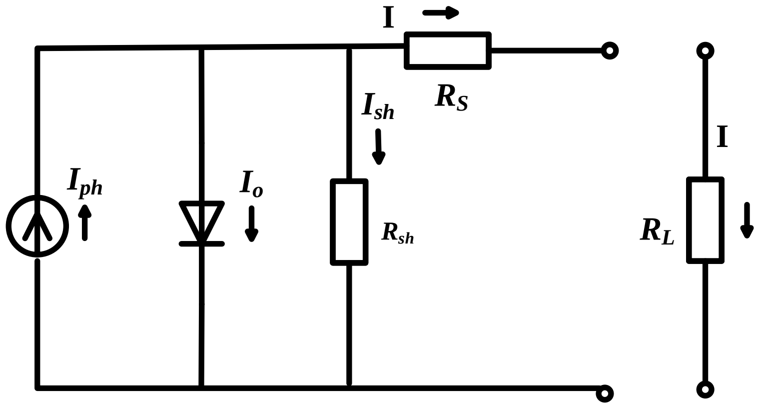
ABSTRACT
The five-parameter photovoltaic (PV) mathematical model has been considered a reliable and accurate method for simulating the performance of PV modules. This paper puts forth a new compound method to extract the five parameters of the model with the basic manufacture template data. As the two 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.



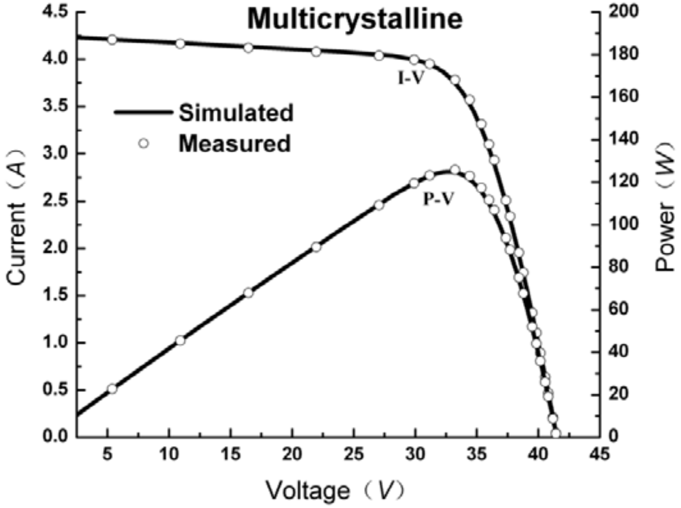
(a) Monocrystalline



(c) Thin-film

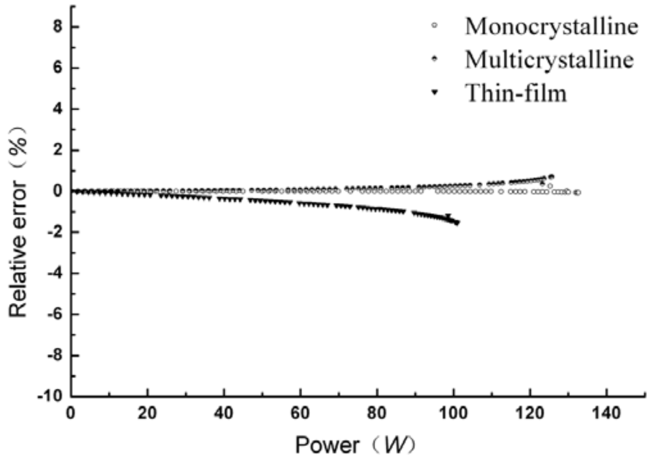


One-diode equivalent circuit



(b) Multicrystalline

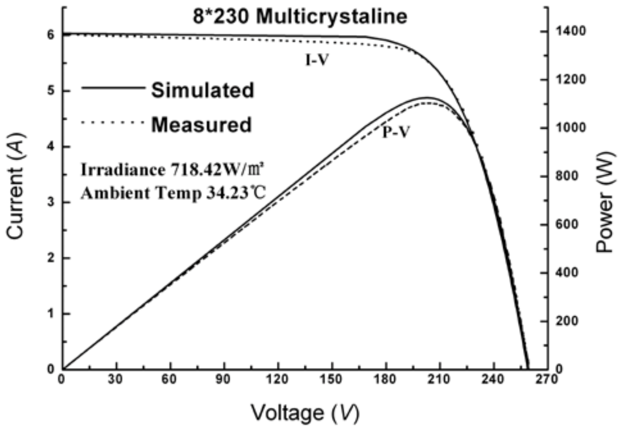
Comparison of I-V curves at STC conditions



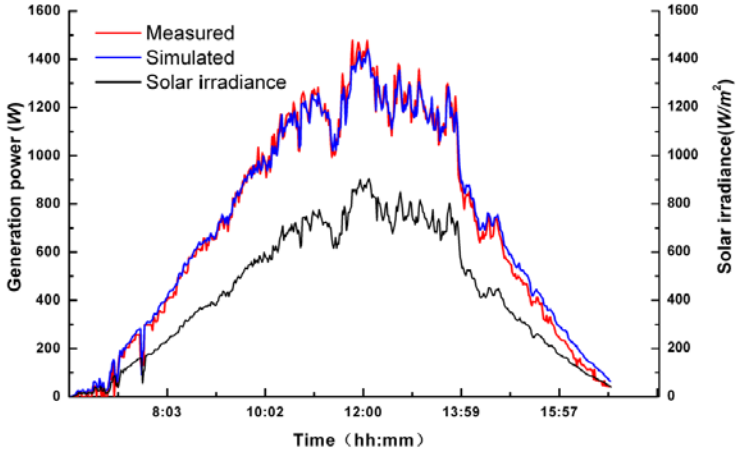
Relative error for the three types of PV modules

Modeling PV panels with only template date （II）

(a) Multicrystalline (TSM-230PC05)



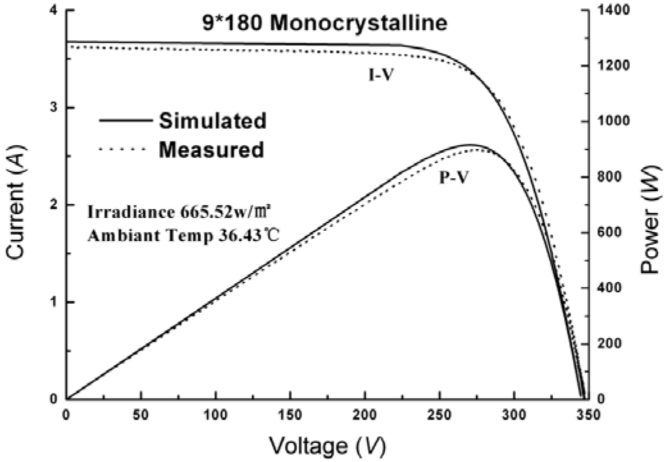
(a) Multicrystalline (TSM-230PC05)



Comparison of generation power and solar irradiance

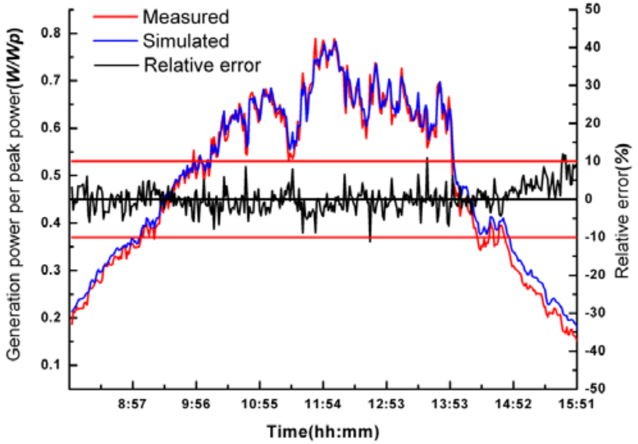
(b) Monocrystalline (TSM-180DC01)

Experimental PV arrays



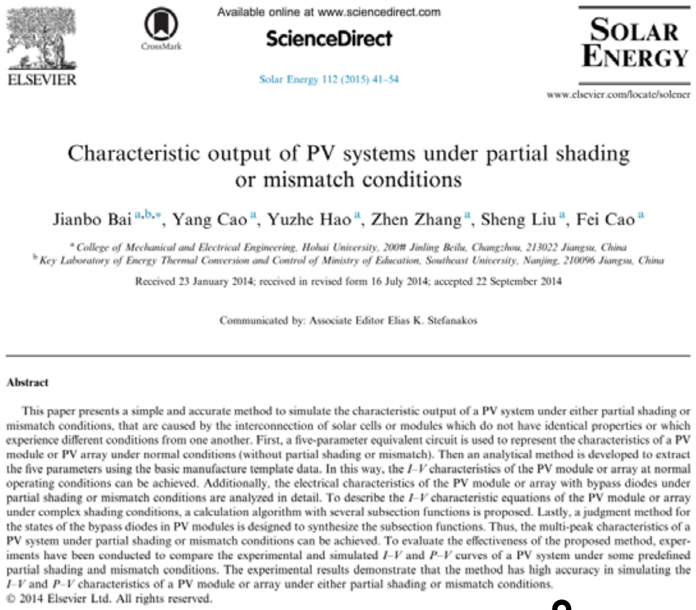
(b) Monocrystalline (TSM-180DC01)

Output Comparison of PV arrays



Comparison of generation per peak power and relative errors

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

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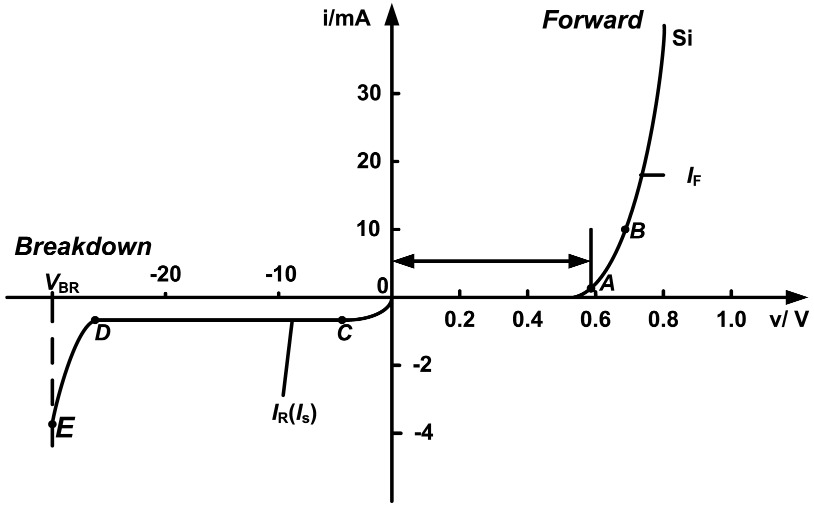
Abstract

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 manufacture 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.



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

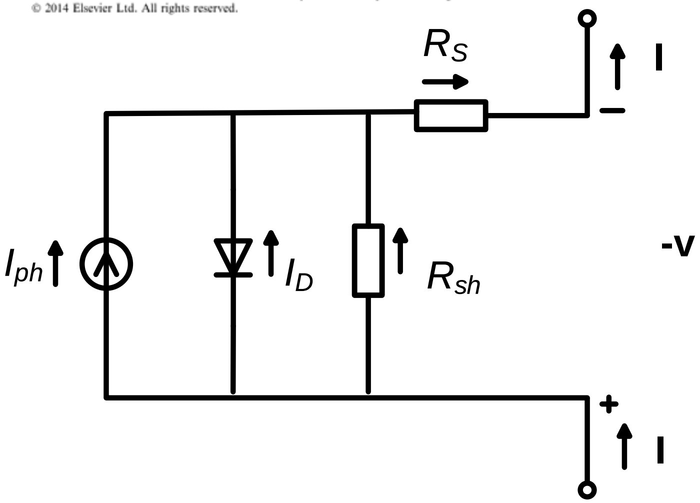
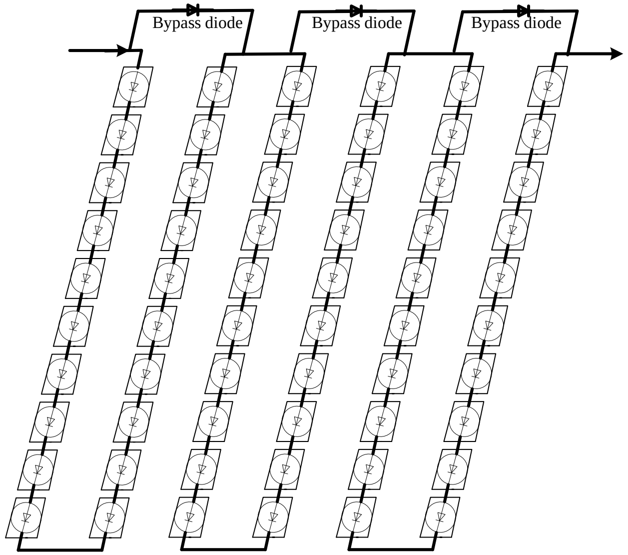
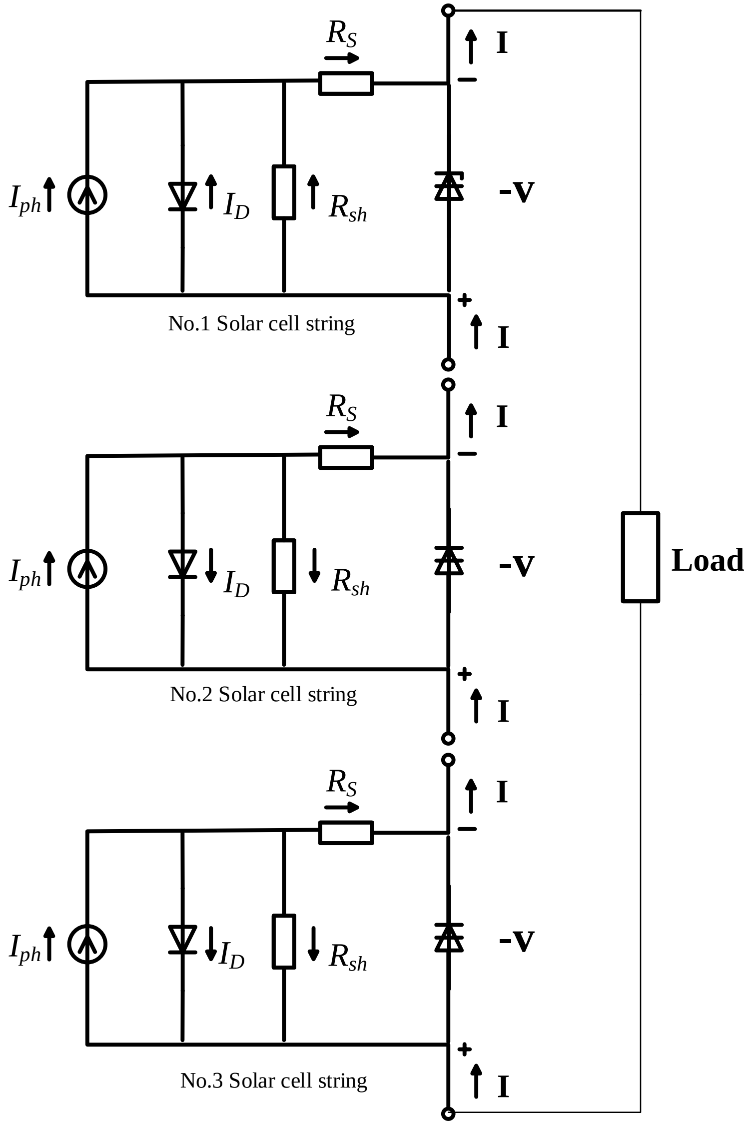


Diagram of a reverse biased solar cell

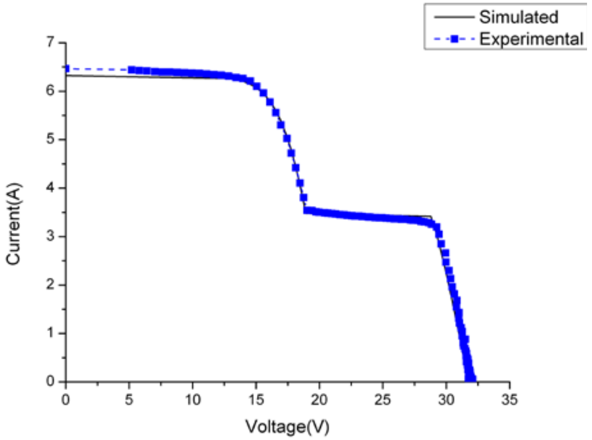


Internal structure of a PV module

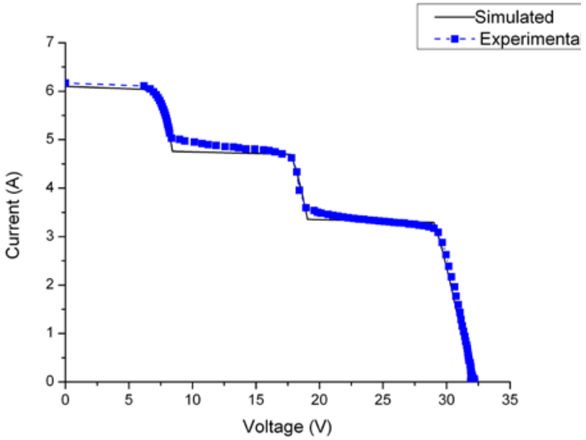


Internal structure of a PV array

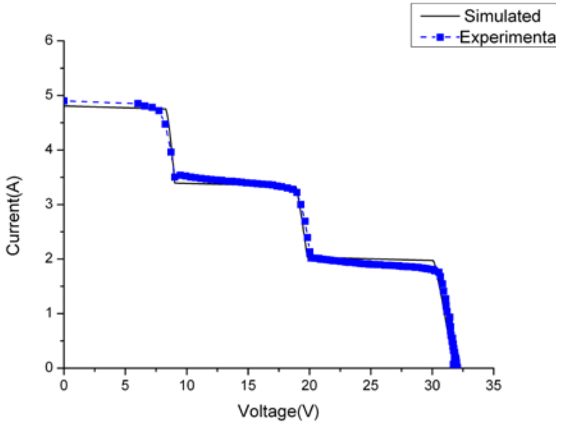
Modeling PV output under partial shading conditions （II）



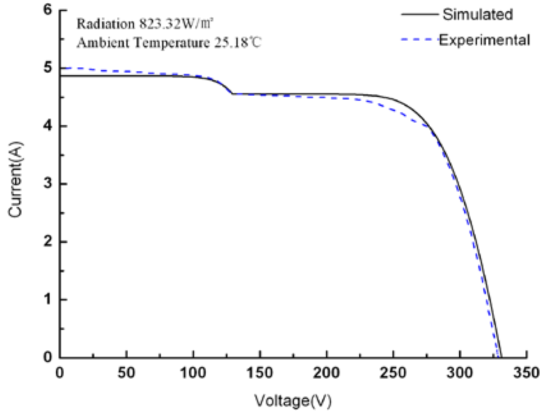
I-V curves under shading testing scheme 1



I-V curves under shading testing scheme 2



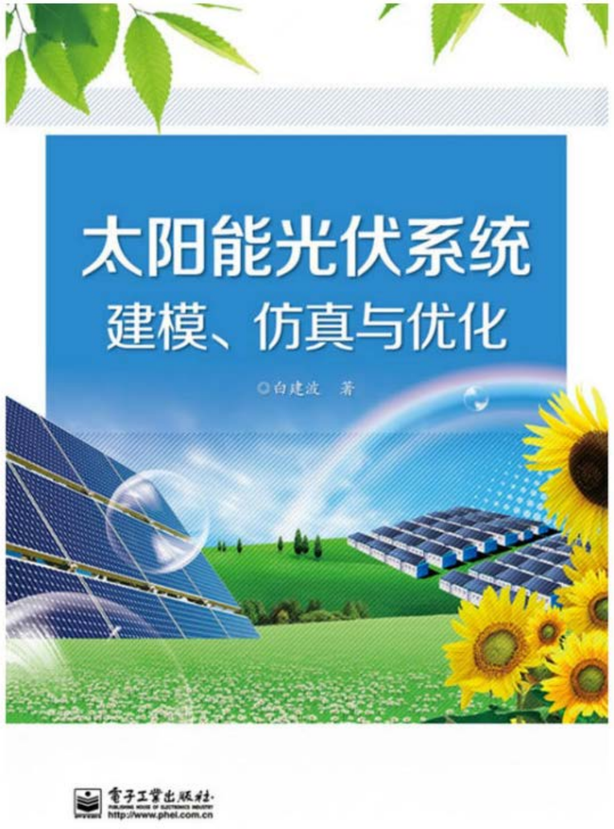
I-V curves under shading testing scheme 2



I-V curve under PV array mismatch condition

Book - Modeling, Simulation and Optimization for Photovoltaic systems

Directory



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Introduction of SolarPV

可设计光伏电厂及
屋顶工程

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

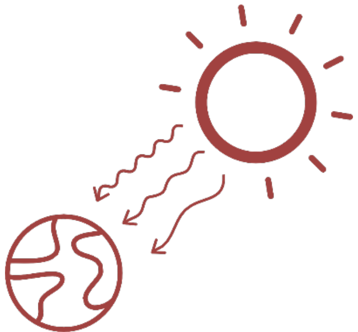
实时发电量计算及累积
年发电量、系统效率分析

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.



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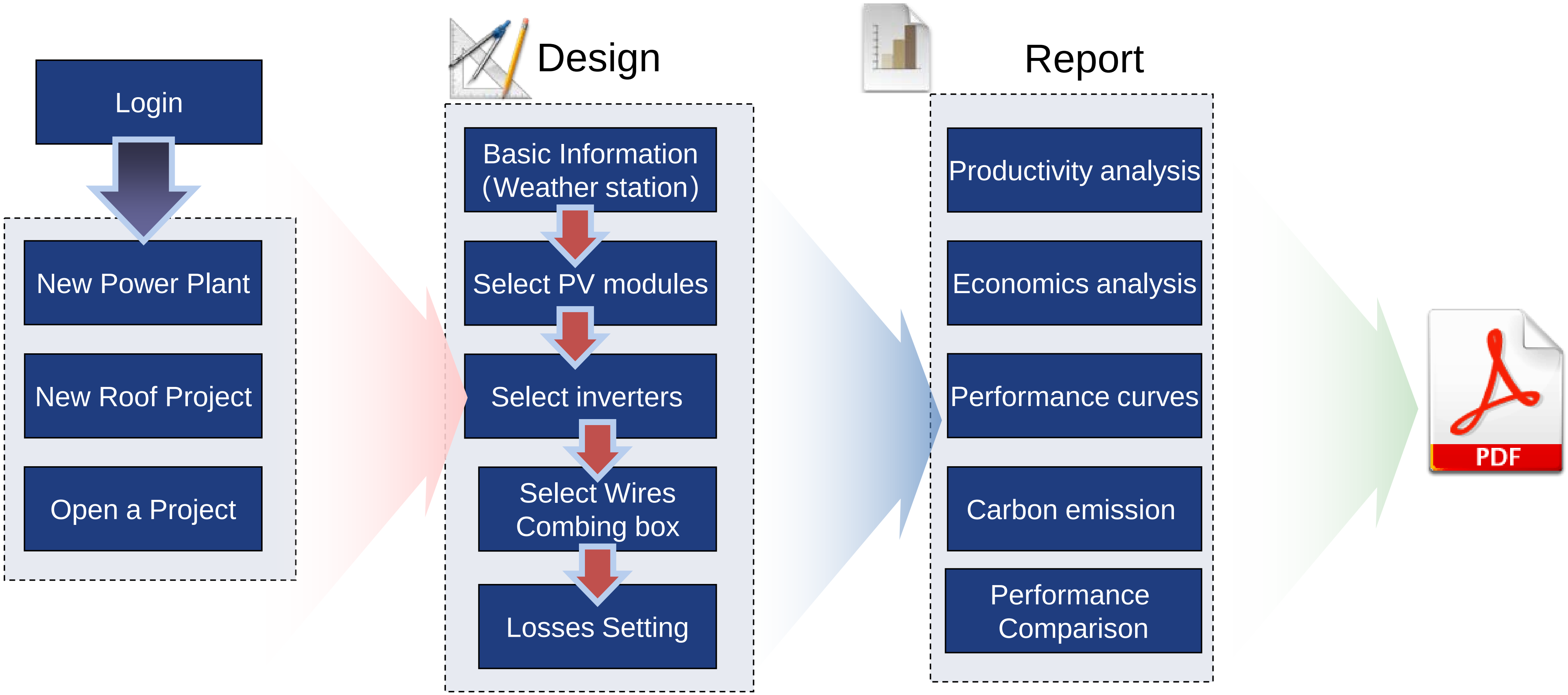
Procedures of using software



Project design

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

Basic Information

PV modules selection

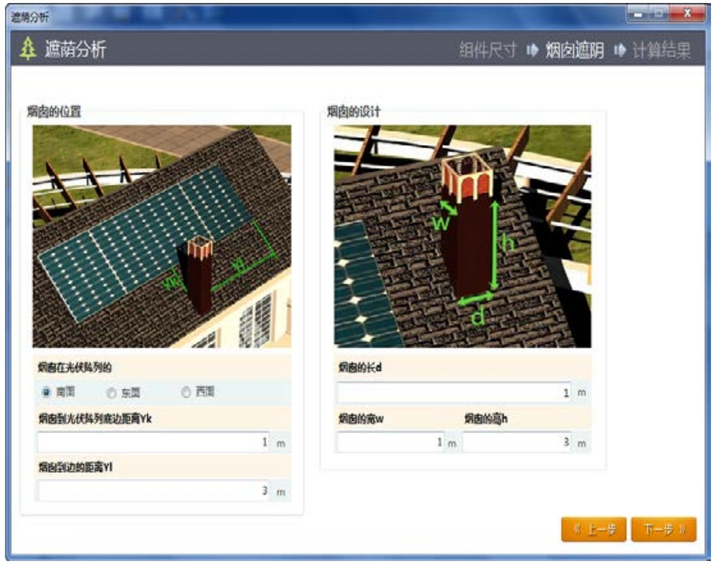
Inverters selection

Wires and Combiner boxes selection

Losses Setting

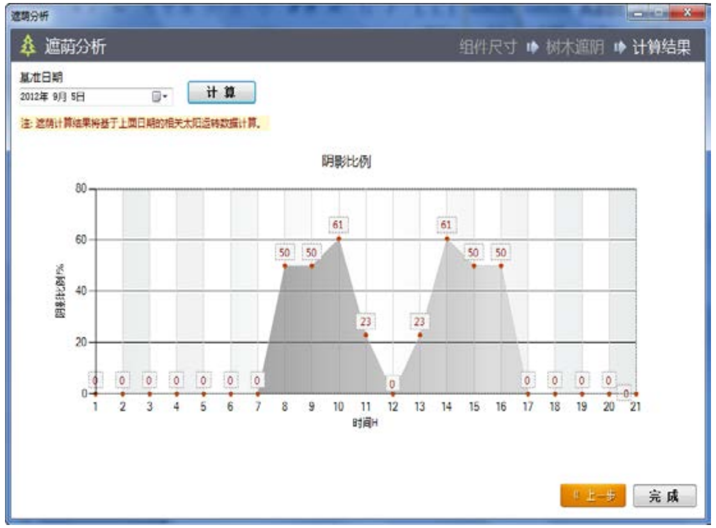
Shading simulation

Simulated pitched roof



Shading configuration(chimney)

Simulated flat roof



Simulation shading data

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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

➡ 逐时水平面辐射量 ➡ 逐时阵列面辐射量
➡ 逐时阵列发电量 ➡ 未来25年发电量预测

产能分析报告

月份	月水平面接收辐照量 (kWh/m2)	斜面接收总辐照量 (kWh/m2)	斜面接收直射辐照量 (kWh/m2)	斜面接收散射辐照量 (kWh/m2)	斜面接收反射辐照量 (kWh/m2)	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
运行及维护	6,111.0
债务偿还(元/年)	337,435.8
总计	343,546.8

周期性成本

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

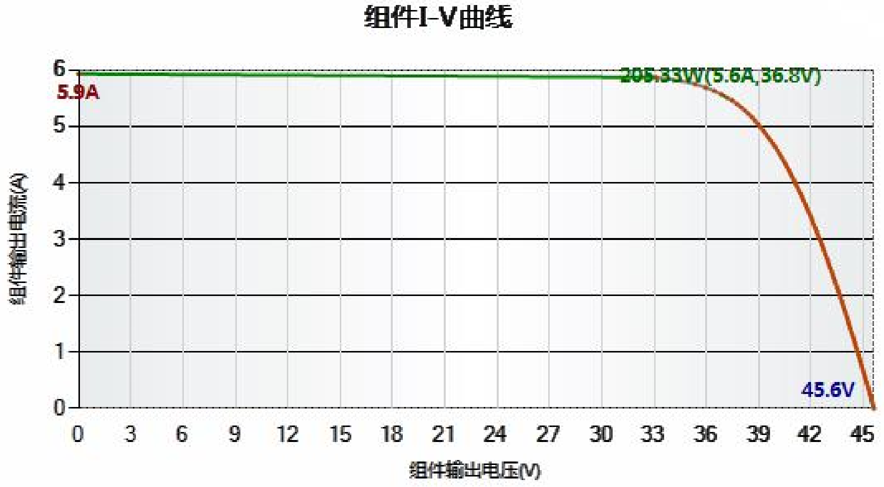
成本汇总

初始投资总计	5,755,638.0
年度成本和债务总计	343,546.8
周期性成本总计	690,234.0
合计	15,034,543.1

Economical report

温室气体年减排量 138.05t

Carbon emission report



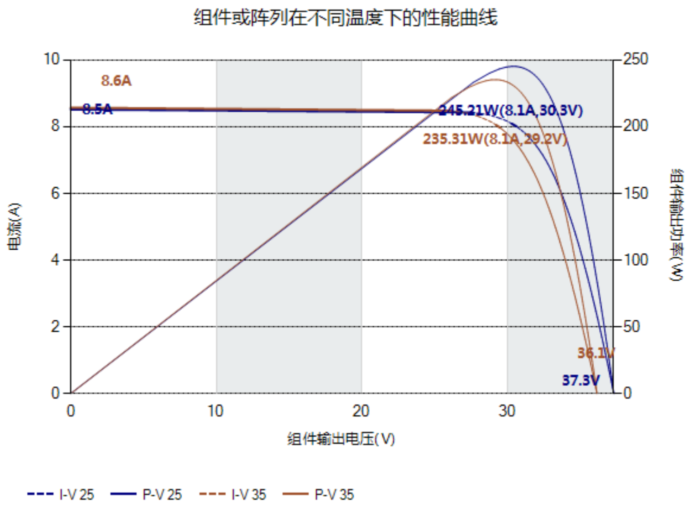
Equipment performance report

System performance comparison

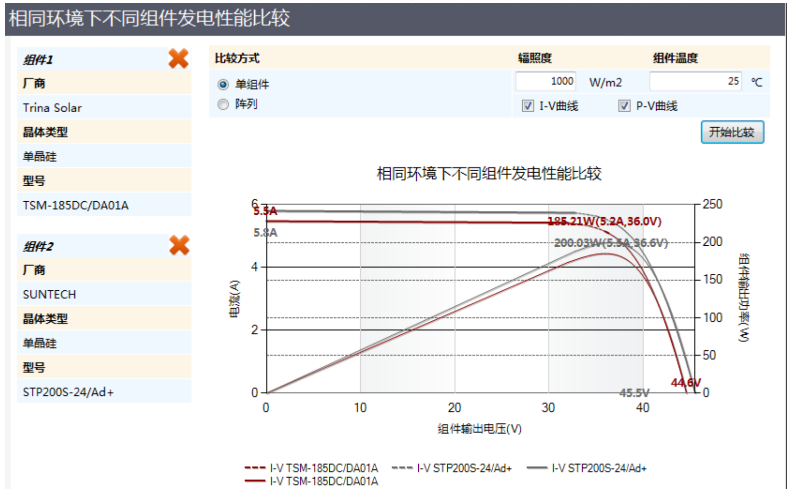
Project tools

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

Lifetime prediction for PV modules



PV modules performance under different conditions



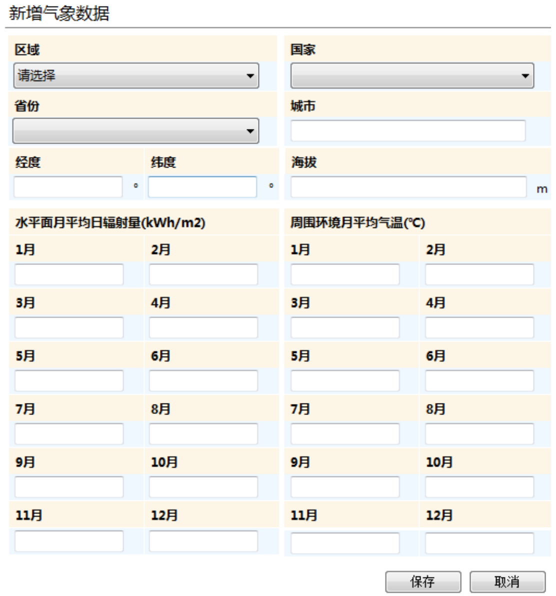
PV modules performance of different manufactures

I-V output under shading conditions

Series resistance influence on PV modules performance

Project setting

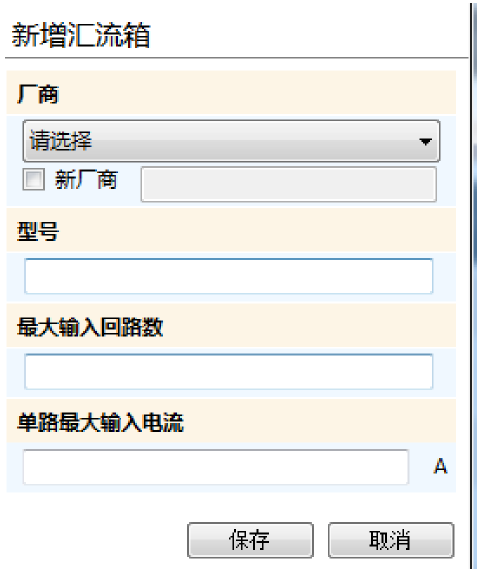
ID	Modules
1	Weather information setting
2	PV modules setting
3	Inverters setting
4	Combining boxes setting
5	Currency setting



Weather information setting

PV modules setting

Inverters setting



Combining boxes setting

Currency conversion setting

PDF document

SOLARPV™

设计类型	电厂工程
倾角/方位角模式	固定倾角/方位角 (28°/0°)
系统容量	100kWp
预测年发电量	129.02MWh

光伏组件

线缆（交流侧）	SUNTECH
晶体类型	单晶硅
型号	STP205S-24/Ad+
组件使用数量	488
组件最佳间距(竖排)	1.50m

逆变器

厂商	GSO NEW ENERGY
型号	GSG 1.5K(1650W)
逆变器使用数量	61
运行方式	MPPT

线缆（直流侧）

厂商	N/A
材料类型	Cu
线缆截面积	1.5mm2
单根线缆长度	10m
线缆数	62

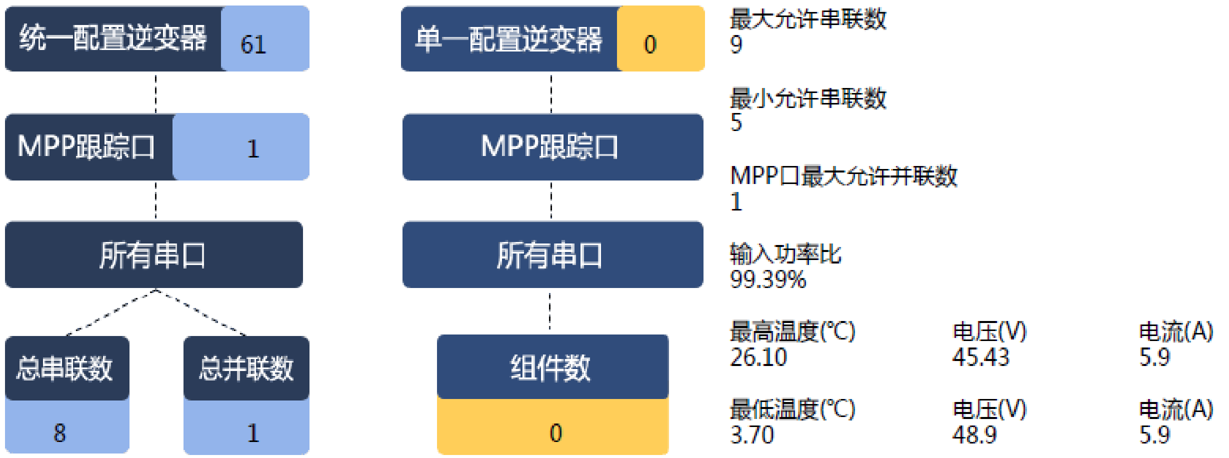
线缆（交流侧）

厂商	N/A
材料类型	Cu
线缆截面积	1.5mm2
单根线缆长度	10m
线缆数	61

汇流箱

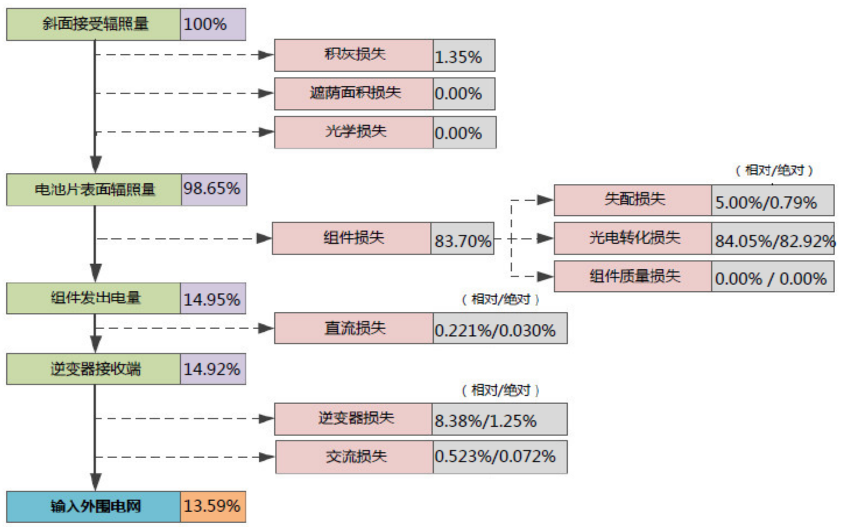
厂商	A
型号	AGF-M4R
单路最大输入电流	12A
直流实际输入路数	62
汇流箱数量	16

Design overview



Series-parallel optimization scheme for a PV array

损耗估算（*以光伏阵列面接收的太阳能为参考基准）



Detail loss analysis

月份	月水平面接收辐照量(kWh/m2)	斜面接收总辐照量(kWh/m2)	斜面接收直射辐照量(kWh/m2)	斜面接收散射辐照量(kWh/m2)	斜面接收反射辐照量(kWh/m2)	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

SOLARPV™

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