Levelized Cost Analysis for Desalination using Renewable Energy in GCC

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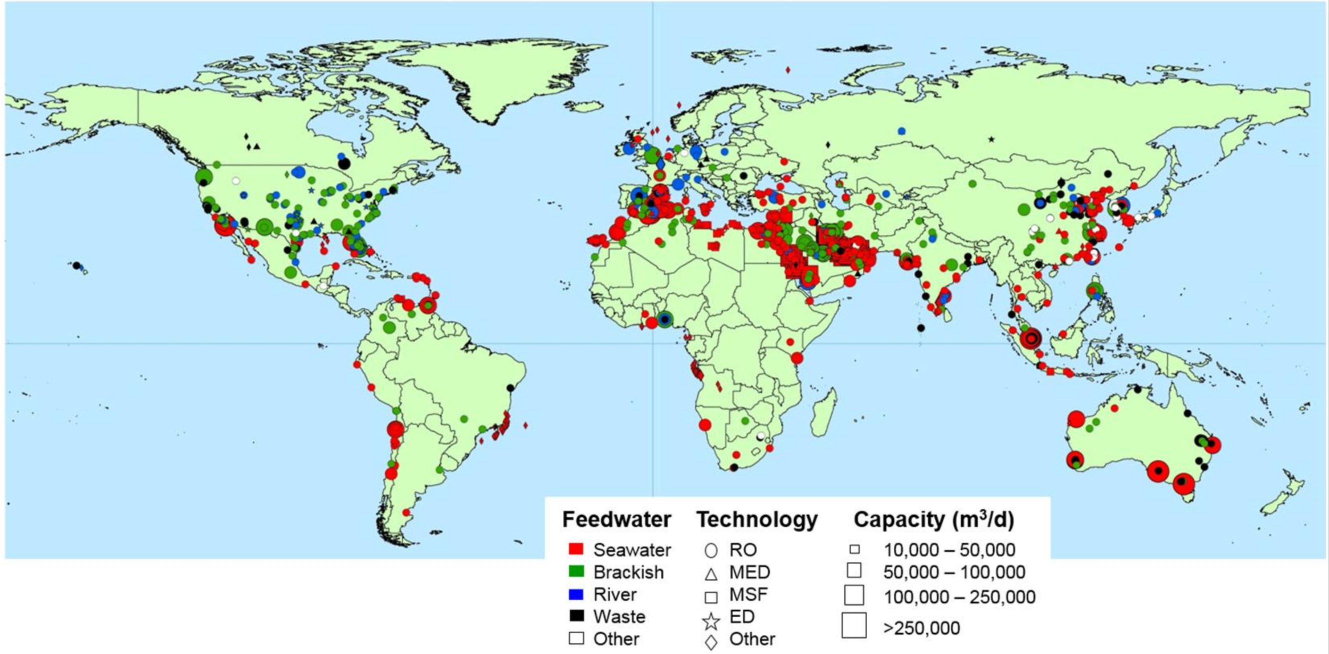
Overview

- Introduction
- Methodology
- Results
- Conclusions and Recommendations

Introduction

- Desalination is the only source for freshwater production in the GCC countries, except for Oman who have a considerable amount of groundwater.
- Because of its lower energy use and water production cost, seawater reverse osmosis (SWRO), the most common membrane-based technology, has become the method of choice for desalination worldwide over the last decade.
- Even most Middle Eastern countries halted or significantly restricted the development of new thermal desalination plants after 2015. As a result, the focus of this research will be on SWRO desalination plants.

World Online Capacity Percentage by Technology in 2021



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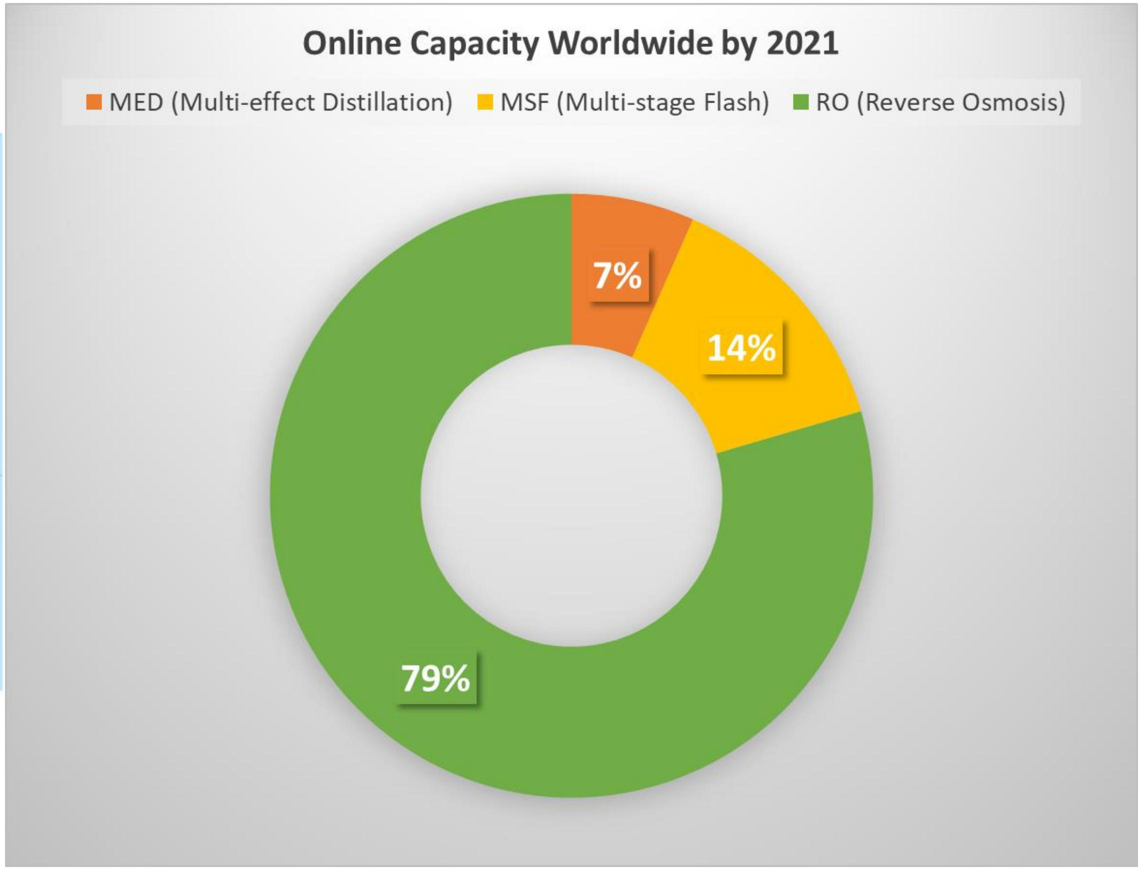
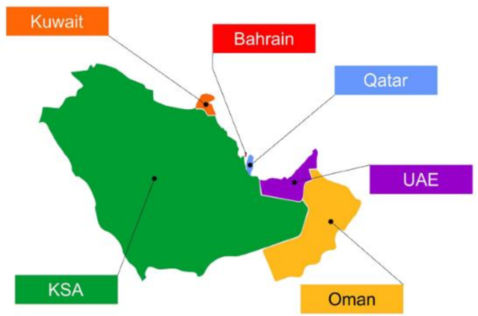
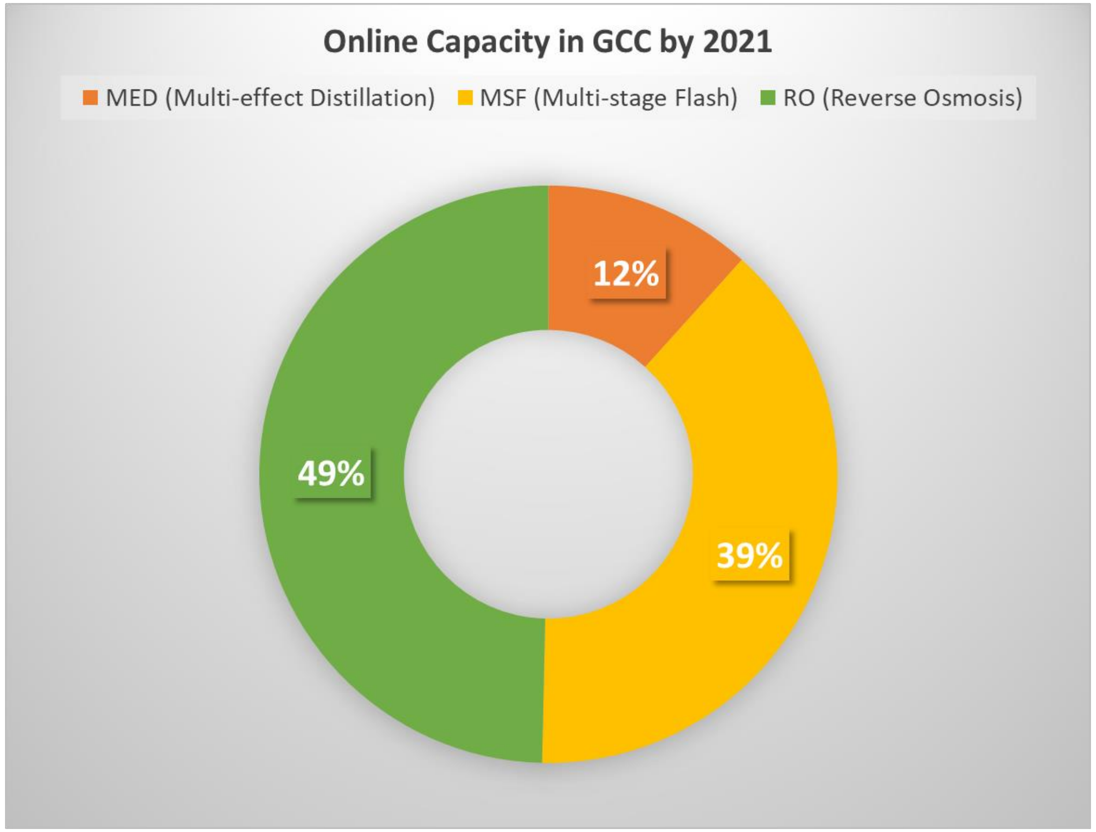
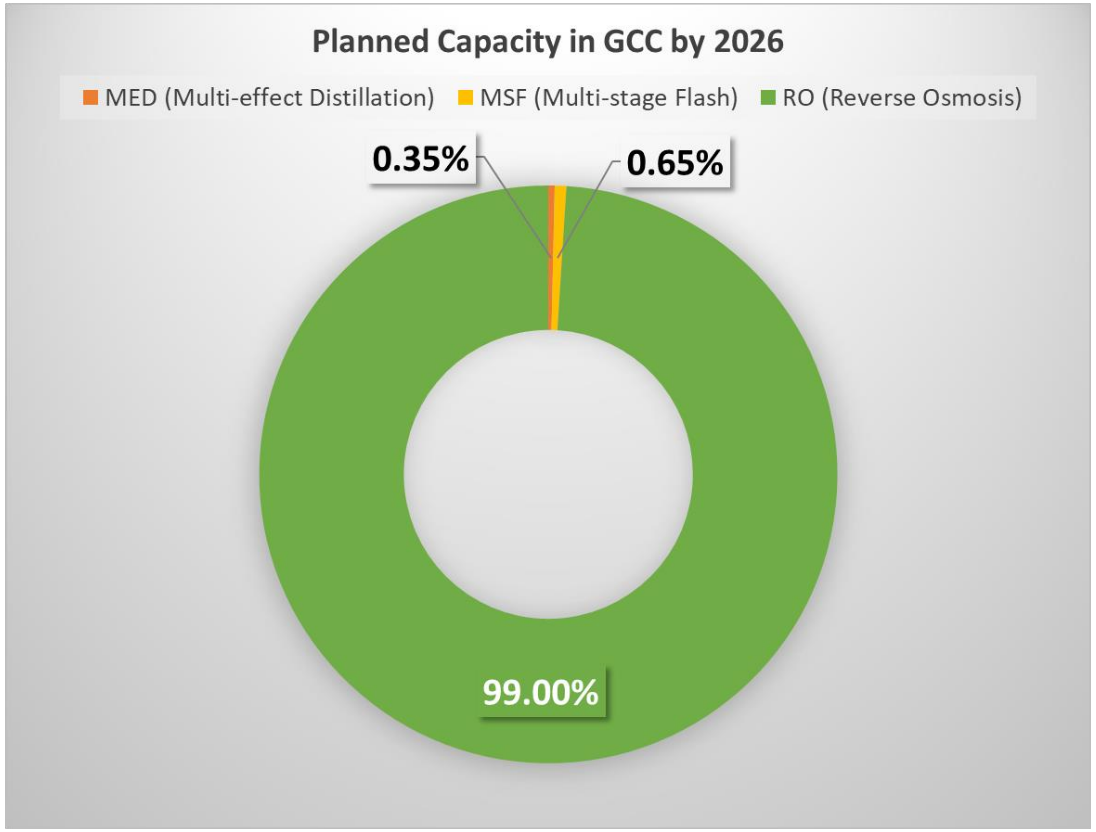


Source of data: GWI DesalData, updated 30/09/2021

Desalination Capacity in GCC







Source of data: GWI DesalData, updated 30/09/2021

Cont., Introduction

- Desalination is an energy-intensive process, where energy price represents more than 44% of the cost of the desalinated water. Most of the desalination plants depends on the fossil fuel for securing the required energy for desalination.
- GCC countries are gifted with consistent and predictable solar energy that can be used to power the desalination processes to improve their sustainability and to reduce their environmental impacts.
- However, solar desalination is expected to become economically attractive as the renewable technologies' costs continue to decline, and the prices of fossil fuels continue to increase.

Cont., Introduction

- In this paper, the energy cost in the form of Levelized Cost of Energy (LCOE) was calculated for a PV solar power generation plant and hence, the Levelized Cost of Water (LCOW) for a SWRO desalination plant in the six GCC countries had been estimated and compared.
- This paper proposes a simplified platform using well-known and freely available software to estimate the LCOE of Renewable Energy Power Plant (REPP) and LCOW of SWRO desalination plant based on the REPP power generation.

Methodology

- The key factor for utilizing renewable energy sources in desalination is the overall cost of freshwater production.
- The Levelized Cost of Water (LCOW) represents the average cost for water production over the project life, it is the total value of energy costs divided by the total energy generated.
- The energy cost is presented by the Levelized Cost of Energy (LCOE) and is used in the calculation of the energy cost in water.
- In this work, a reference SWRO desalination plant was selected for this investigation. This plant was mainly operated using a Combined Cycle Power Plants (CCPP).

Cont., Methodology

- The power needed for this desalination plant was estimated using **WAVE®** design software by **DuPont**.
- The Desalination Economic Evaluation Program, **DEEP®** software by **IAEA** was used to estimate the LCOW based on the CCPP.
- System Advisor Model, **SAM®** software by **NREL** was used to evaluate the LCOE of the Renewable Energy Power Plant (REPP).
- The LCOE using REPP is calculated and plugged into DEEP to evaluate the LCOW using renewable energy.
- SAM uses design DNI value from the weather data file along with other design parameter values to determine the nominal capacities of the solar field.
- For the reference SWRO desalination plant, the average required electric power is 76 MW. A PV power plant (PVPP) of capacity 76 MW was designed, and the LCOE is evaluated using SAM software.

Results

- SWRO plant specifications

Technology	RO
No. of Passes	Two-Pass
Pretreatment	Dual Media Filtration
Feedwater type	Seawater
Capacity	400,000 m^3/d

- The PVPP Specifications

Nameplate DC capacity	91,198 kW_{dc}
Total AC capacity	76,050 kW_{ac}
Total inverter DC capacity	78,826 kW_{dc}
Number of modules	294,048
Number of strings	24,504
Total module area	479,592 m^2
String V_{oc} at reference conditions (V)	772.8
String V_{mp} at reference conditions (V)	656.4

LCOE of REPP at the six GCC countries

Country	BHR	KWT	OMN	QAT	SAU	ARE
Location	Bahrain Intl Ap	Kuwait Intl Ap	Muscat Intl Ap	Doha Intl Ap	King Khalid Intl Ap	Abu Dhabi Intl Ap
Annual energy, GWh/year	173.040	169.449	170.985	175.046	173.154	176.449
Annual energy yield, kwh/kw	1897.401	1858.018	1874.861	1919.395	1898.641	1934.775
Capacity factor	21.660	21.210	21.403	21.911	21.674	22.086
Performance ratio, %	0.781	0.770	0.769	0.770	0.765	0.769
No of modules	294,048	294,048	294,048	294,048	294,048	294,048
No of inverters	169	169	169	169	169	169
Installation cost, $	103,343,968	103,342,432	103,346,832	103,345,840	103,343,800	103,345,784
Installation cost, $/kW	1,133	1,133	1,133	1,133	1,133	1,133
Size of debt, $	79,833,544	79,833,256	79,833,752	79,833,696	79,833,536	79,833,672
Size of equity, $	23,510,428	23,509,178	23,513,082	23,512,144	23,510,264	23,512,112
PPA price (year 1), cent/kWh	8.354	8.529	8.459	8.261	8.348	8.195
PPA price (nominal), cent/kWh	**8.915**	**9.102**	**9.027**	**8.816**	**8.909**	**8.746**
PPA price (real), cent/kWh	7.353	7.507	7.445	7.271	7.348	7.213
LCOE (nominal), cent/kWh	**8.860**	**9.045**	**8.971**	**8.762**	**8.854**	**8.692**
LCOE (real), cent/kWh	7.307	7.460	7.399	7.226	7.302	7.169
Project NPV, $	690,553	691,413	689,471	689,799	690,597	689,875
NPV for PPA revenue, $	111,404,128	111,401,488	111,408,680	111,407,336	111,403,976	111,407,200
IRR target year	20	20	20	20	20	20
IRR in target year, %	11.00	11.00	11.00	11.00	11.00	11.00
IRR at end of Project, %	13.07	13.07	13.07	13.07	13.07	13.07

The nominal LCOE is a current dollar value, while real LCOE is a constant dollar, inflation-adjusted value.

LCOW produced in different GCC countries

Country	BHR	KWT	OMN	QAT	SAU	ARE
Location	Bahrain Intl Ap	Kuwait Intl Ap	Muscat Intl Ap	Doha Intl Ap	Khalid Intl Ap	Abu Dhabi Intl Ap
PPA nom, ¢/kWh	8.915	9.102	9.027	8.816	8.909	8.746
LCOW, ¢/m^3	**104.27**	**104.88**	**104.63**	**103.95**	**104.27**	**103.73**

LCOE and LCOW at different location in Kuwait

Country	KWT	KWT	KWT
Location	Kuwait Intl Ap	Failakah Island	Salmy
Annual energy, GWh/year	169.449	176.081	182.421
Annual energy yield, kwh/kw	1858.018	1930.740	2000.264
Capacity factor	21.210	22.040	22.834
Performance ratio, %	0.770	0.778	0.779
No of modules	294,048	294,048	294,048
No of inverters	169	169	169
Installation cost, $	103,342,432	103,342,944	103,341,784
Installation cost, $/kW	1,133	1,133	1,133
Size of debt, $	79,833,256	79,833,456	79,833,280
Size of equity, $	23,509,178	23,509,488	23,508,502
PPA price (year 1), ¢/kWh	8.529	8.208	7.921
PPA price (nominal), ¢/kWh	**9.102**	**8.760**	**8.454**
PPA price (real), ¢/kWh	7.507	7.225	6.972
LCOE (nominal), ¢/kWh	**9.045**	**8.706**	**8.401**
LCOE (real), cent/kWh	7.460	7.180	6.929
Project NPV, $	691,413	690,915	691,561
NPV for PPA revenue, $	111,401,488	111,402,888	111,400,896
IRR target year	20	20	20
IRR in target year, %	11.00	11.00	11.00
IRR at end of Project, %	13.07	13.07	13.07
LCOW, ¢/m^3	**104.88**	**103.79**	**102.79**

Conclusion and Recommendations

- Like most renewable power generation technologies, PV systems are capital intensive but have no fuel costs.
- The LCOE for the studied locations ranged from 8.46 to 9.11 ¢/kWh, and the LCOW ranged from 103.0 to105.0 ¢/m^3, compared to 10.737 ¢/kWh and 110.1¢/m^3 for the conventional CCPP.
- The three key drivers of the LCOE of PVPP are:
  1. The capital and the installation costs of PV modules and BOS ($/W).
  2. The average annual electricity yield (kWh per kW); functions of the local solar radiation and the solar cells' technical performance.
  3. The finance cost of the PV system.

Conclusion and Recommendations

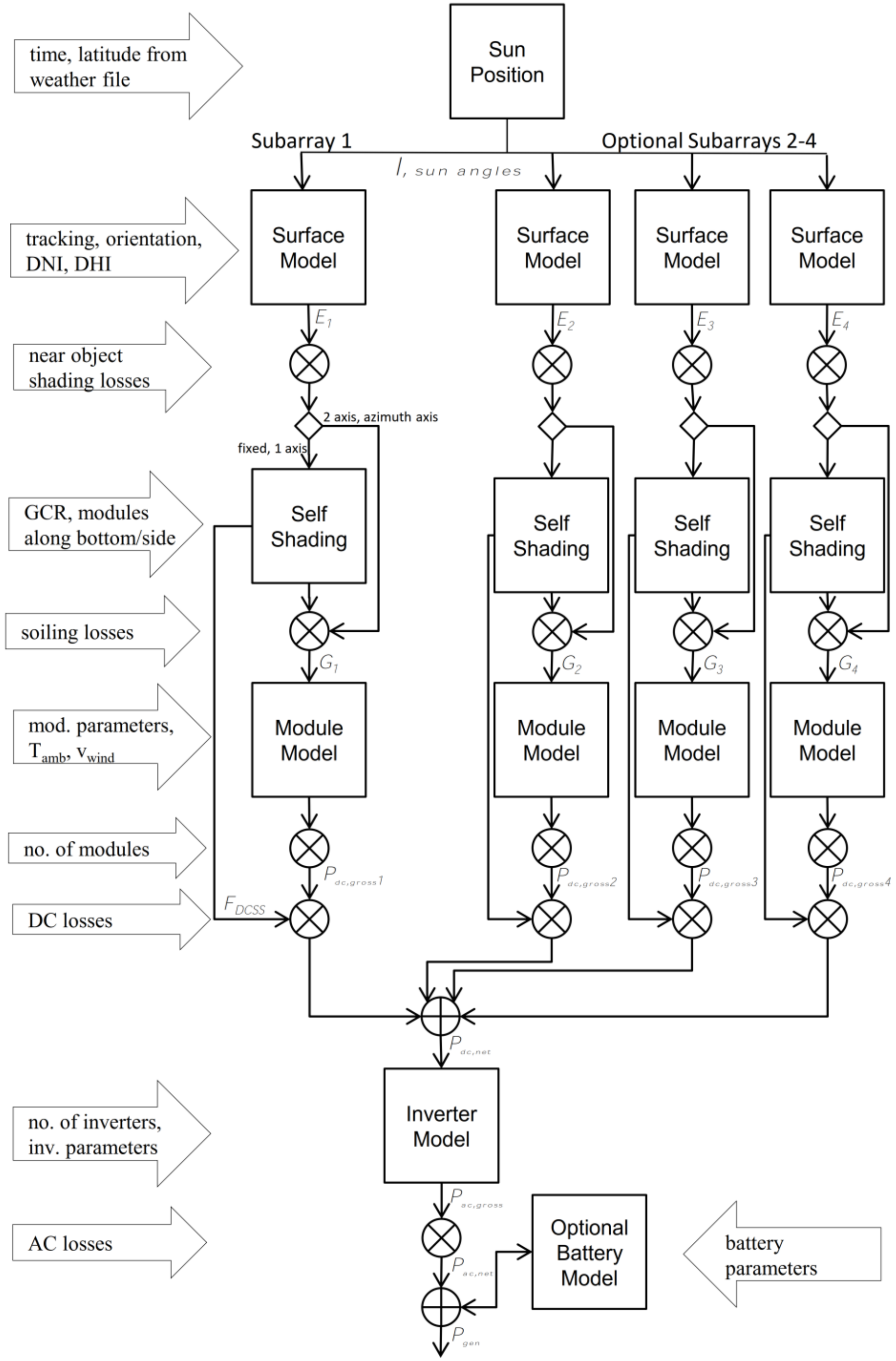
- While desalination processes are still costly, declining renewable energy technology deployment costs are expected to bring the desalination cost down in the coming years, which is of particular interest to remote regions and islands with small populations and for areas of inadequate infrastructure for freshwater and electricity transmission and distribution.

Thank you

Ready for Questions

The simulation model performs the following calculations for each time step in one year:

1. For each of up to four subarrays:
    A. Calculate sun angles from date, time, and geographic position data from the weather file. (Section 4.2)
    B. Calculate the nominal beam and diffuse irradiance incident on the plane of array (POA irradiance). This depends on the solar irradiance data in the weather file, sun angle calculations, user-specified subarray parameters such as tracking and orientation parameters, and backtracking option for one-axis trackers. (Section 7.1)
    C. Apply the user-specified beam and diffuse nearby-object shading losses to the nominal beam and diffuse POA irradiance. (Section 7.2)
    D. For fixed subarrays and subarrays with one-axis tracking and self-shading enabled, calculate and apply the self-shading loss factors to the nominal beam and diffuse POA irradiance. (Section 7.4)
    E. Apply user-specified monthly soiling factors to calculate the effective POA irradiance on the subarray. (Section 7.5)
2. For subarrays with no tracking (fixed) and self-shading enabled, calculate the reduced diffuse POA irradiance and self-shading DC loss. (Section 9)



3. Determine subarray string voltage calculation method (Section 11.1).
4. For each of up to four subarrays, run the module model with the effective beam and diffuse POA irradiance and module parameters as input to calculate the DC output power, module efficiency, DC voltage, and cell temperature of a single module in the subarray.
5. Calculate the subarray string voltage using the method determined in Step 3.
6. For each subarray, calculate the array DC power (Section 11):
   A. Apply the fixed self-shading DC loss to the module DC power if it applies.
   B. Calculate the subarray gross DC power by multiplying the module DC power by the number of modules in the subarray.
   C. Calculate subarray DC power by multiplying the gross subarray power by the DC loss.
   D. Calculate the subarray string voltage by multiplying the module voltage by the number of modules per string.
   E. Calculate the array DC power by adding up the subarray values.
7. Run the inverter model to calculate the gross AC power and inverter conversion efficiency (Section 12).
8. Calculate the AC power by applying the AC loss to the gross AC power (Section 15).
9. For systems with batteries, calculate power to and from the battery (Section 14).