中国航天

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MSDG

MSDG Green Energy

Solar Thermal Power Plant System Design Scheme

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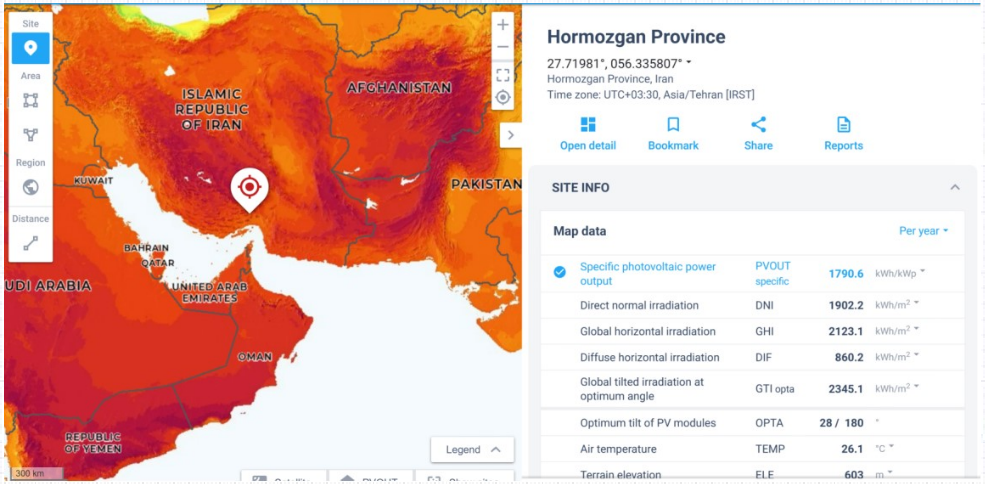
1、 Meteorological Data of the Project Site

Example: Hormozgan Province, Iran

- **Location**: Hormozgan Province, southern Iran (27.72° N, 56.34° E), near the Strait of Hormuz. Hot, arid climate with very high summer temperatures and mild winters.
- Solar Resource: Situated in Iran's Solar Belt with excellent DNI, ideal for CSP and hybrid solar projects.
- Solar Radiation:
  - Apr-Sep (High): ~16.8-29.6 MJ/m²·day
  - Oct-Mar (Moderate): ~11.6-14.7 MJ/m²·day
- Sunshine Duration:
  - Longest: May, up to ~13.5 hours/day
  - Shortest: December, ~10 hours/day
- Conclusion: Strong, stable solar conditions support high-efficiency, year-round solar power generation.



1、 Monthly Solar Energy Data (2024)

Monthly Average Solar Radiation (MJ/㎡·d)	Monthly Average Peak Sunshine Hours	Month
12011008.0	133.55	202401
13807616.0	144.65	202402
14743186.0	178.61	202403
17661440.0	198.84	202404
21692928.0	237.42	202405
19932160.0	223.53	202406
18236928.0	216.41	202407
16803840.0	200.72	202408
17132902.0	187.73	202409
14740992.0	163.46	202410
13263360.0	137.43	202411
11575296.0	126.75	202412

2、Project Planning

The project plans to construct a solar thermal power station with 8 hours of molten salt thermal storage.

Two schemes are proposed:

Scheme 1

Adopt a CSP trough solar thermal system as the heat source, with 8 hours of molten salt thermal storage.

Scheme 2

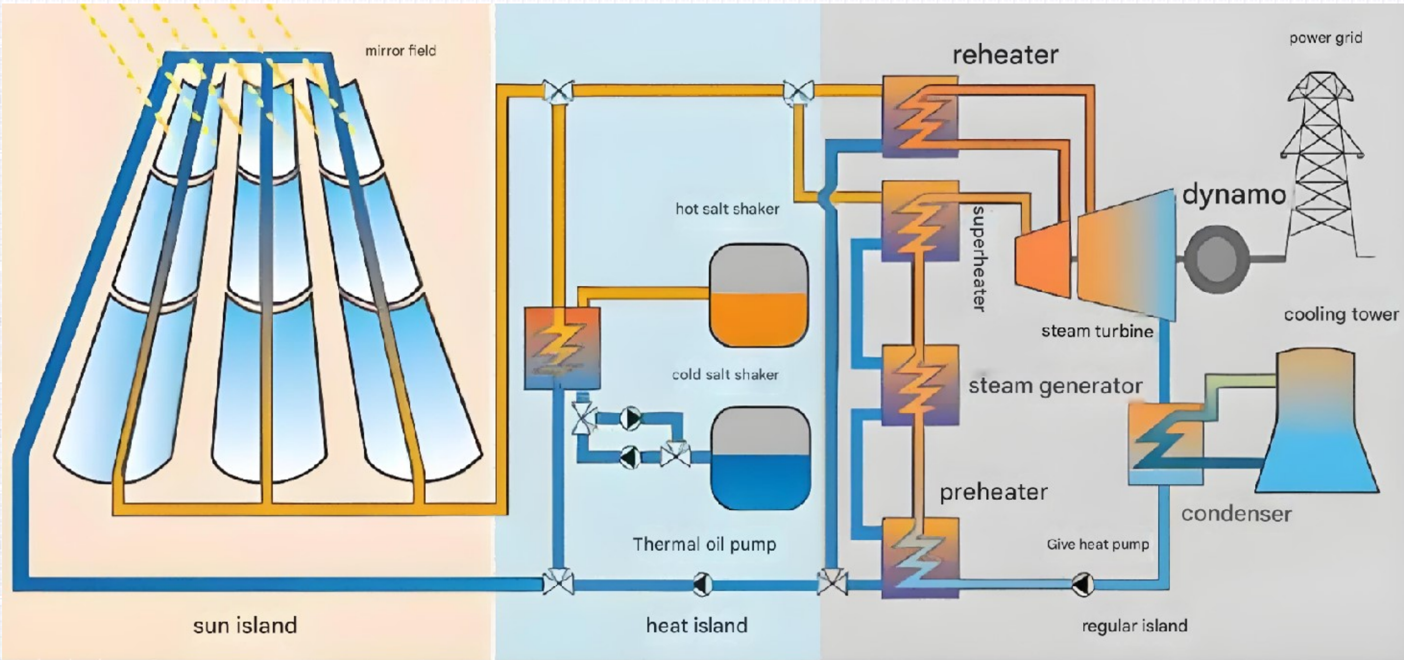
Adopt a Hybrid system, combination of CSP trough solar thermal system + 8 hours of molten salt thermal storage + PV (photovoltaic) power generation system.

3、Scheme 1 / Schematic Diagram and System Composition

CSP Trough Solar Thermal Plant

The system consists of:

1. Solar Mirror Field,
2. Heat Transfer Oil Circulation System,
3. Molten Salt Thermal Storage System,
4. Oil-Salt Heat Exchanger,
5. Steam Generation System,
6. Steam Turbine Generator Unit, Condensing System,
7. Auxiliary Energy System, and
8. Monitoring & Control System.



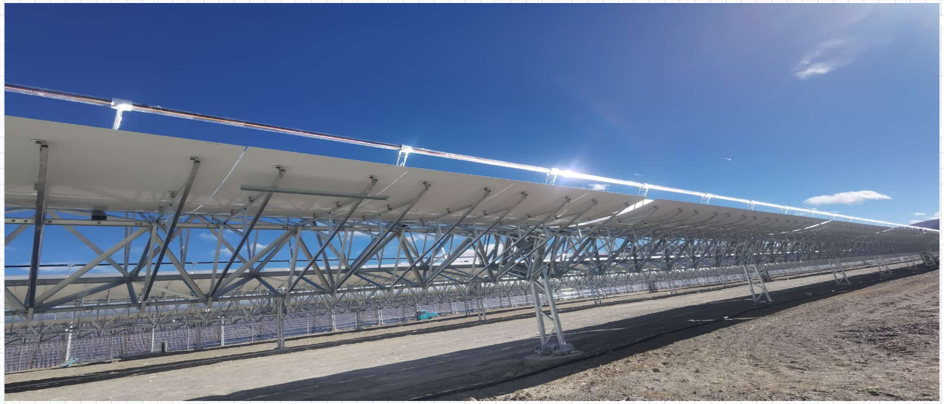
3.1 Solar Mirror Field

Composition

1. **Parabolic Trough Reflectors:** Rows of silver-coated glass mirrors shaped into parabolic troughs. Using single-axis tracking, they concentrate direct sunlight about 70-80× onto a focal line.

2. **Evacuated Collector Tubes:** Located at the focal line. A metal absorber tube inside a vacuum-sealed glass envelope minimizes heat loss, like a thermos. A selective coating maximizes solar absorption and reduces heat radiation.

3. **Collector Array (Solar Field):** Individual trough units form collector loops connected in series; multiple loops are linked in parallel to create a large-scale solar thermal field that supplies heat to the power block.



3.1 Solar Mirror Field - Area

Mirror Field Area Calculation

- Rated Electrical Power: P
- Overall System Photoelectric Conversion Efficiency: %
- Solar Radiation Intensity: DNI (W/m^2) (December monthly average)
- Effective Sunshine Duration: E hours
- Thermal Storage Duration: T hours
- Daily Power Generation Duration: D hours (daytime power generation + nighttime thermal storage power generation)

Mirror Field Area Formula:

A = P × D hours ÷ % ÷ DNI W/m^2 ÷ E hours

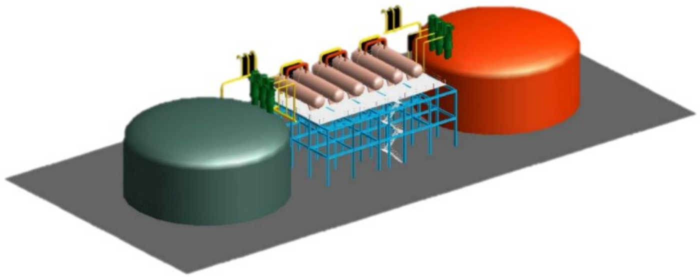
≈ A m^2

3.2 Heat Transfer Oil Circulation System

1. **Heat Transfer Fluid:** Currently, synthetic heat transfer oil is most commonly used (maximum operating temperature around 400°C).
2. **Piping and Circulation System:** Including circulation pipelines in the collector field, heat transfer oil circulation pumps, expansion tanks, overflow tanks, etc.
3. **Working Principle:** Heat transfer oil is pumped from the cold tank into the collector field, heated to become a high-temperature fluid, and directly sent to the oil-salt heat exchanger to heat the molten salt.

3.3 Molten Salt Thermal Storage System

- **Core Advantage:** Molten salt storage enables large-scale, long-duration, low-cost energy storage, giving CSP plants a major advantage over PV and wind by providing stable, dispatchable power.
- **Storage Medium (Solar Salt):** Binary nitrate molten salt (60% $NaNO_3$ + 40% KNO_3), operating reliably in liquid form between ~290° C and 565° C.
- **Storage Tanks:**
  - Cold Salt Tank: Stores lower-temperature salt (~290° C).
  - Hot Salt Tank: Stores high-temperature salt (~385° C) heated by the solar field.
- **Pumps & Heat Tracing:**
  - Molten Salt Pumps move hot and cold salt through the system.
  - Electric Heat Tracing keeps all pipes and tanks above the freezing point, preventing solidification and ensuring safe operation.



3.4 Oil-Salt Heat Exchanger

It is the "heat exchange hub" connecting the thermal storage system and the power generation system (or collector system).

Working Principle in Trough Power Stations (Using Heat Transfer Oil)

- **Heat Storage Stage:** High-temperature heat transfer oil (~395°C) flows through the oil-salt heat exchanger, transferring heat to the cold molten salt, which is then heated and stored in the hot salt tank.
- **Heat Release Stage:** Hot molten salt flows through the salt-water/steam heat exchanger (i.e., steam generator), heating water into superheated steam to drive the steam turbine for power generation.

3.5 Steam Generation System

1. **Core Function:** Converts heat from high-temperature molten salt into high-pressure, high-temperature steam that drives the turbine.

Role in Energy Chain:

Molten salt → Steam generator → Steam → Turbine → Generator → Electricity

1. **Design Concept:** Built as multiple modular heat exchangers rather than one large unit, improving safety, control, and efficiency.

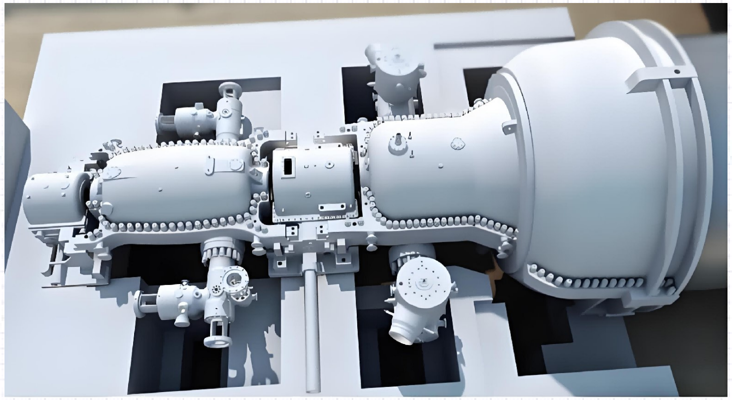
Typical Configuration: A six-module series:

Low-pressure preheater → High-pressure preheater → Evaporator → First superheater → Reheater → Second superheater.

3.6 Steam Turbine Generator Unit

The steam turbine generator unit is the core equipment that ultimately converts thermal energy into electrical energy in the entire thermal

Parameter Item	Typical Range / Configuration	Description and Correlation with Trough Type
Rated Power (Net Output)	105 MWe	Considering the auxiliary power consumption of the air cooling system, high-power molten salt pumps, etc., the steam turbine output is usually around 115-120MW.
Main Steam Parameters	~380℃ - 395℃ , 100 - 120 bar	Determined by the maximum temperature of the heat transfer oil (~395° C), which is a typical parameter of trough technology.
Reheated Steam Parameters	~380℃ - 395℃	Also limited by the oil temperature. The adoption of reheating is a key means to improve the efficiency of trough power stations.
Steam Turbine Type	Single-shaft, multi-cylinder condensing type	Standard configuration: 1 high-pressure cylinder + 1 intermediate-pressure cylinder + 1 double-flow low-pressure cylinder. Due to the relatively low steam temperature, the requirements for material thermal stress are relatively loose, which is conducive to rapid startup and shutdown.
Exhaust Pressure/Cooling	Approximately 0.05 - 0.07 bar, air-cooled	Approximately 0.05 - 0.07 bar, air-cooled
Feedwater Heating System	Multi-stage regenerative extraction	Extracting steam from the intermediate-pressure cylinder and low-pressure cylinder of the steam turbine to heat the feedwater is a standard configuration to improve cycle efficiency.



3.7 Monitoring and Control System

It usually adopts a hierarchical distributed control architecture, divided into three layers:

First Layer: Local Control Layer

- **Function:** Execute the lowest-level fast and localized control and protection.
- **Main Equipment:** PLC, intelligent instruments, frequency converters, drive motors, protective relays.
- **Typical Tasks:**
  - Solar tracking control of a single collector (receiving upper-level angle commands and driving hydraulic or motor actuators).
  - Start-stop and speed control of a single molten salt pump/heat transfer oil pump.
  - Switching and regulation of key valves.
  - Local sa fety interlock protection (such as pipeline overtemperature, overpressure, leakage).

3.7 Monitoring and Control System

Second Layer: Centralized Monitoring Layer - Core

- **Function:** Coordinate various subsystems of the entire plant to achieve process automation and optimized operation.
- **Core System:** Distributed Control System (DCS) or Programmable Automation Controller (PAC).

Typical Control Loops and Subsystems:

- **Collector Field Control System:**
  - Solar radiation monitoring: Conduct cloud prediction and short-term irradiation forecasting based on all-sky imagers and DNI measurement stations.
  - Whole-plant dispatching: Calculate and issue the target oil temperature/salt temperature at the outlet of the collector field according to the sun position, DNI intensity, thermal storage status, and power generation demand.
  - Flow distribution and temperature balance: Adjust the fluid flow of each collector loop to ensure uniform and stable outlet temperature of the whole field.

3.7 Monitoring and Control System

- **Thermal Storage and Heat Transfer System Control:**
  - Switching between heat storage and heat release modes: Automatically switch valves according to strategies to determine whether heat is used for heat storage, direct power generation, or a combination of both.
  - Level and temperature control of molten salt tanks: Precisely control the level and temperature of cold and hot salt tanks to prevent overflow or emptying and optimize thermal storage capacity.
  - Anti-solidification protection: Monitor and manage the electric tracing system of the entire molten salt loop (pipelines, valves, tanks).
- **Power Generation Island (Steam-Power Generation) Control System:**
  - Steam generator control: The core is to maintain stable steam pressure and temperature. This is achieved by adjusting the molten salt/heat transfer oil flow and feedwater flow (typical three-element control).
  - Steam turbine control: DEH controls the speed and load, cooperating with the steam generator.
  - Auxiliary boiler management: Automatically put the auxiliary boiler into operation during startup or insufficient irradiation to ensure steam parameters

3.7 Monitoring and Control System

Third Layer: Production Management and Optimization Layer

- **Function:** Conduct forward-looking dispatching and overall plant economic optimization based on weather forecasts, power grid electricity prices, and market signals.
- **Core System:** Plant-level Monitoring Information System (MIS), Production Management System (PMS), advanced application programs.
- **Typical Tasks:**
  - Formulation of power generation plans for the next 24-72 hours: Combine numerical weather forecasts to predict DNI, and formulate optimal power generation and energy storage plans considering thermal storage status, power grid dispatching instructions, and maintenance plans.
  - Cloud cover prediction and response: Use all-sky imagers to predict cloud cover 5-15 minutes in advance, and instruct the collector field and power generation island to adjust in advance to smooth power fluctuations.
  - Performance calculation and efficiency analysis: Real-time calculation of the efficiency of each subsystem and the whole plant, diagnosis of performance deviations, and guidance for operation and maintenance.

3.8 Condensing System

- **Role:**

  The cold-end of the thermal cycle, critical to overall plant efficiency and power output.

- **Core Functions:**
  - Condense turbine exhaust steam back into water, releasing waste heat.
  - Create and maintain high vacuum (≈ −95 kPa), reducing turbine back pressure and increasing power output (≈ 1-2% gain per 1 kPa reduction).
  - Recover condensate for reuse as boiler feedwater in a closed-loop cycle.

- **Key Benefit:**

  Acts like the plant's radiator, removing unused heat to keep the steam turbine operating efficiently.

3.9 Auxiliary Energy System

- **Purpose:**

  Compensates for the intermittency of solar energy, ensuring stable and reliable CSP plant operation.

- **Key Functions:**

  1. Startup & Stability: Provides heat for cold/warm startup and smooths output during short-term cloud cover.
  2. System Protection: Prevents solidification of molten salt/HTF and maintains thermal storage in hot standby.
  3. Grid Reliability: Supports committed power delivery when solar input or storage is insufficient.
  4. Economic Benefit: Increases annual operating hours and enables profitable generation during peak-price periods.

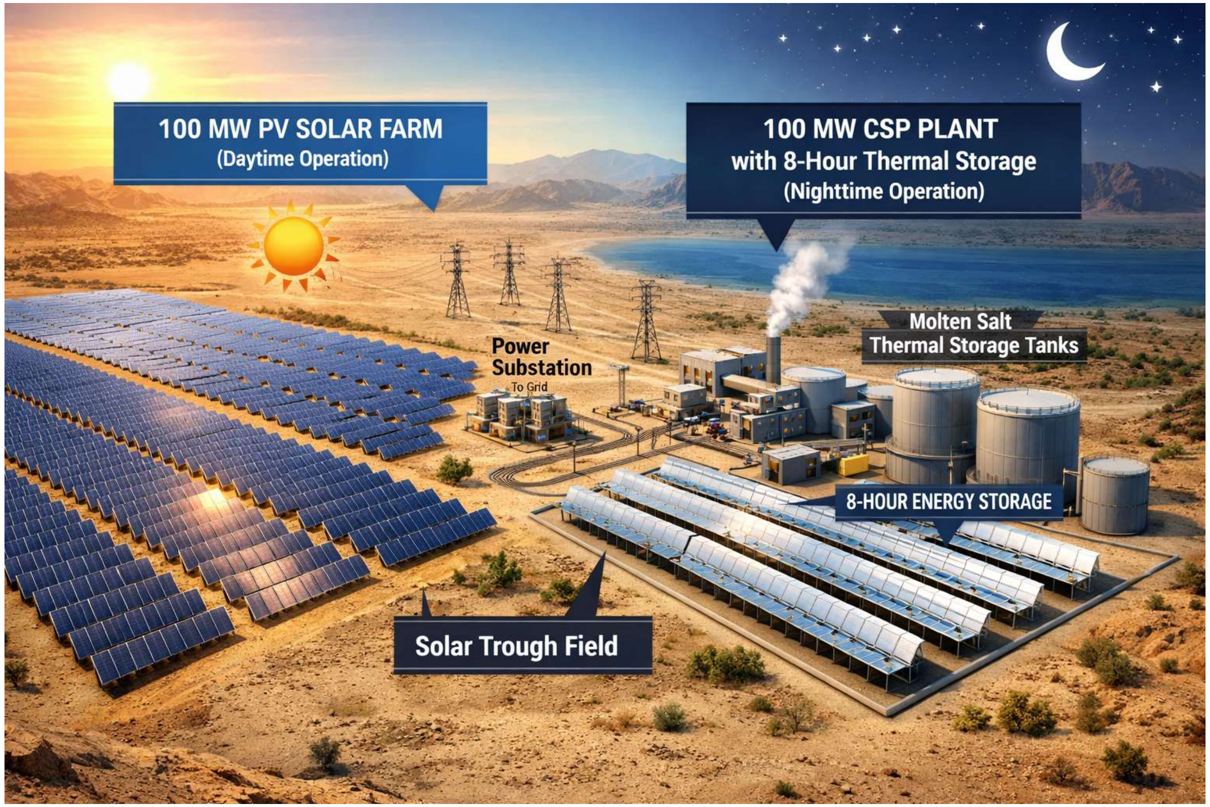
- **Overall Role:**

  Makes the CSP plant dispatchable, reliable, and more economically competitive.

4. Scheme 2 / Schematic Diagram and System Composition

Hybrid CSP Trough + PV Solar Plant

System	Main Components	Function
PV	PV modules, inverters, transformers, switchgear, transmission	Daytime electricity generation
CSP	Refer to Scheme 1,	Nighttime firm power delivery
Hybrid Integration	Control system, combined substation	Time-shifted, dispatchable energy delivery



4.1 Main Components: Photovoltaic (PV) System

1. **PV Arrays:**
   - Hundreds of rows of monocrystalline or polycrystalline solar modules arranged in a fixed-tilt or single-axis tracking configuration.
   - Optimized for high solar irradiance.
2. **Inverters:**
   - Convert DC output of PV modules into grid-compatible AC electricity.
   - Sized to match peak PV generation capacity.
3. **Transformers & Switchgear:**
   - Step-up voltage to match grid connection requirements.
   - Protect system and allow safe integration into the transmission network.
4. **Transmission Connection:**
   - Medium-voltage lines from PV field to main substation.
   - Integrated with CSP output at the plant substation for consolidated dispatch.

4.2 Hybrid Plant Integration

1. **Control & Dispatch System:**
   - Coordinates PV and CSP output to optimize grid delivery.
   - Prioritizes PV generation during the day, while CSP output is ramped up in the evening.
2. **Combined Substation:**
   - Merges PV and CSP AC outputs into a single high-voltage transmission connection.
   - Facilitates streamlined PPA reporting and revenue tracking.
3. **Energy Profile Optimization:**
   - Daytime: PV contributes most of the energy, reducing grid dependence.
   - Evening/Night: CSP with 8-hour TES ensures firm dispatchable renewable power.
   - Firm renewable generation during high-value demand periods

Time	Active Technology
07:00-17:00	PV dominant
17:00-23:00	CSP (storage discharge)
23:00-03:00	CSP (storage tail)
Night off-peak	Minimal

4.3 Cost Advantage

❑ Cost Advantage

Compared with full CSP solar thermal power generation, the combined use of photovoltaic and CSP solar thermal can save approximately 1/3 of the cost.

❑ Alternative Configuration

With the investment amount of pure CSP solar thermal power generation, the hybrid CSP + photovoltaic system can reach about 3 times power generation.

❑ Maximum flexibility for future market and policy evolution

- This configuration balances cost efficiency, dispatchability, and scalability, making it the most commercially competitive and strategically robust choice for large-scale solar deployment.

Thank You!!!

MSDG Pte. Ltd.