SMALL-SCALE CSP PLANT COUPLED WITH AN ORC SYSTEM FOR PROVIDING DISPATCHABLE POWER: THE OTTANA SOLAR FACILITY

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THE OTTANA SOLAR FACILITY

Location: Ottana (Italy)

Geographic coordinates:
40° 14.25 N - 8° 59.63 E

Available solar energy:
1800 kWh/(m²·yr).

Funder: Regional Government of Sardinia

Customer: ENAS (Sardinia Water Authority)

CSP section:
- Solar Field - linear Fresnel collectors
- TES section - two-tank direct system
- Power block - ORC unit

CPV section:
- CPV panels with biaxial solar trackers
- Battery bank - Sodium-Nickel batteries
**THE OTTANA SOLAR FACILITY**

**Solar Field:**
- number of loops: 6
- total collecting area: 8592 m²
- reference thermal output: 4690 kW_{th}
- HTF inlet temperature: 165 °C
- HTF outlet temperature 275 °C

**TES system:**
- Two-tank direct TES system
- HTF: Therminol SP mineral oil
- Mass of stored oil: 190 t
- storage capacity: 15.2 MWh

**CPV system:**
- Nominal Power: 430 kW_p (under CSTC)
- Nominal efficiency: 29.8%
- Number of trackers: 36
- Number of Panels per tracker: 6
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**Battery bank:**
- Battery type: NaNiCl₂
- Numbers of batteries: 24
- Battery bank capacity: 430 kWh
- DC/DC efficiency: 94%

**ORC unit:**
- ORC type: Turboden 6HR Special
- Input thermal power: 3100 kWt
- Gross/net power output: 664/629 kWe
- Gross/net efficiency %: 21.4/20.3
- Turbine inlet/outlet temperature: 275/165°C
- Electric generator: 50Hz/400 V
THE ORC UNIT

Schematic view of the ORC unit:

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**Main goal:** ability of the overall CSP+CPV system to deliver **scheduled profiles** in accordance with the **weather forecasting**

**Control logic:** combination of a **one-day ahead scheduling procedure**, which defines the set-point of the CSP+CPV power production for the following day, and a **real-time control algorithm** for the power profile tracking according to actual meteorological data.

**Determination of the daily ORC profile:**
Trade-off between two conflicting goals:
- The maximization of the **ORC performance**, achieved by operating it as close as possible to nominal conditions for high duration periods and with a low number of ORC start-up.
- The maximization of the **matching** between CPV and ORC power delivery periods, exploiting the storage capacity of the CSP section to minimize the fluctuations in the CPV power production.
Determination of the Daily Profile

**Main Input:**
- Weather forecast data \((\text{DNI}, \text{T}_{\text{AMB}}, \text{Wind speed})\) for the calculation of the expected solar field energy production \((E_{\text{SF}})\)
- **Stored energy** in the hot tank at the end of the previous day \((E_{\text{TES}})\)
- Expected thermal energy availability \((E_{\text{IN}} = E_{\text{SF}} + E_{\text{TES}})\)
- Clearness index \(K\): ratio between the expected \(E_{\text{SF}}\) and the corresponding \(E_{\text{SF}}\) in clear-sky conditions

**Main Output:**
- The ORC on/off state
- The net electrical power output \(P_{\text{EL}}\)
- The corresponding duration period \(\tau_{\text{ORC}}\)
- The start-up time \(t_{\text{ON}}\)

**Control parameters:**
1. Two clearness index threshold values \((K_{\text{HIGH}}\text{ and } K_{\text{LOW}})\)
2. Minimum number of operating hours \(\tau_{\text{ORC,min}}\) at nominal conditions
Determination of the Daily Profile

Logic block diagram:

STATE ON-FULL
\[ P_{EL} = P_{EL,\text{nom}} \]
\[ \tau_{ORC} = f(E_{IN}, P_{EL}) \]

STATE OFF
\[ K < K_{LOW} \]

Calculation of the \( E_{IN} \) and \( K \)

STATE OFF
\[ P_{EL} < P_{EL,\text{min}} \]

STATE ON-MIN
\[ P_{EL} = P_{EL,\text{min}} \]
\[ \tau_{ORC} = f(E_{IN}, P_{EL,\text{min}}) \]

STATE ON-PART
\[ \tau_{ORC} = \tau_{CPV} \]
\[ P_{EL} = f(E_{IN}, \tau_{ORC}) \]
**Daily Performance**

Forecast and measured DNI and energy flows during commissioning test:

![Graph showing DNI and energy flows](image)

**Expected annual performance:**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar energy availability [MWh]</td>
<td>14650</td>
</tr>
<tr>
<td>Solar field energy output [MWh]</td>
<td>5076</td>
</tr>
<tr>
<td>Defocusing energy losses [MWh]</td>
<td>160</td>
</tr>
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<td>ORC power production [MWh]</td>
<td>941</td>
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<tr>
<td>Mean ORC efficiency [%]</td>
<td>19.1%</td>
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<tr>
<td>Mean ORC power level [kW]</td>
<td>430</td>
</tr>
<tr>
<td>ORC running time [h/year]</td>
<td>2188</td>
</tr>
<tr>
<td>Number of ORC start/stop</td>
<td>217</td>
</tr>
</tbody>
</table>

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* K_{LOW}=0.1  
K_{HIGH}=0.8  
τ_{ORC,min}=2h
Influence of the $K_{\text{LOW}}$, $K_{\text{HIGH}}$ and $\tau_{\text{ORC,min}}$ on the ORC state, ORC efficiency and CSP capacity factor
This paper was focused on the ongoing studies at the Ottana Solar Facility, a new experimental power plant located in Sardinia (Italy). The innovative configuration of the solar facility, with the integration of a CSP plant with a CPV system, demands the development of a novel control strategy for the achievement of a semi-dispatchability of the plant. The expected performance are then presented highlighting:

1) the fundamental role of the thermal energy storage
2) the frequent operation of the ORC turbogenerator at part load and with variable input conditions.
3) The importance of three control parameters on the ORC power profile, which affects the plant capacity factor and the turbogenerator efficiency.
THANK YOU FOR YOUR ATTENTION

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