A cost effective and efficient approach for a new generation of solar dish-Stirling plants based on storage and hybridization

Call FP7-ENERGY-2012-1
Grant Agreement nº 309028
Berlin, Germany, 23rd Oct 2017
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   - Partners involved:
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2. Objectives

• B4SKA is a Power Plant based on a Hybrid Stirling Dish (HSD) with experimental exploitation, under contract signed with the European Commission for the Seventh Framework Program (7FP), being the main aim to provide electric power for a set of demonstration astronomical SKA antennas to be mounted in Contenda, Portugal.

• The objective of the demonstration B4SKA Plant is the generation of clean electric power simultaneously using solar power and biomass energy in the form of biogas, and serve as a scalable example of power supply for future developments of applications to larger scientific infrastructures like the SKA, a radio-telescope to be built in South Africa or Australia (www.skatelescope.org).
2. Objectives

- Innovations in BIO STIRLING-4SKA project focus on:
  
  **Cost**
  - New designs for mass manufacturing.
  - New manufacturing and O&M Strategies.
  - Structures with less weight.
  - Easy commissioning and maintenance.

  **Efficiency**
  - Improved Stirling
  - New designs with reduction the reflectivity loss.
  - New reflective materials.

  **Dispatchability**
  - Biomass / solar hybrid receiver.
  - Storage systems

  **Life-time**
  - Glass coatings.
  - Improvement of steel resistance and stiffness.
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3. System Overview

Hybrid System: solar receiver, which absorbs the solar heat energy; combustor, where syngas is burned to produce heat, with syngas control system; and the hybridization system which makes it possible to seamlessly use heat from two sources, solar and gas burner.

Basic Stirling Engine: core engine with crank drive, engine block and the Stirling specific heat exchangers; working gas control system which regulates working gas pressure and fills new gas if working gas is lost, cooling system consisting of a fan, radiators, and circulation pump, generator and the Engine Control Unit (ECU).

Main features:

- Power Output: $13\text{kW}_e$ in gas mode / $10\text{kW}_e$ in solar mode
- Dimensions: $1358 \times 860 \times 980$ (mm)
- Weight: 481 kg
3. System Overview

• **BIO STIRLING-4SKA needs:**
  The B4SKA plant will feed the power need from the SKA demonstrator receivers and computing equipment with a 400 VAC 3 phase bus.
  The electric interface between the SKA demonstrator and the B4SKA will be a switch with power supply at 400 VAC.

Power required by the SKA Demonstrator Plant in Moura (Portugal):
- 20 kWe for the receivers (24/7)
- 20 kWe for the computing (24/7)
- 10 kWe air conditioning (on/off)

Power required by the BioStirling Plant:
- Stirling Engines: 0.2 kW\textsubscript{e} per engine
- Control System: 0.1 kW\textsubscript{e}
- Tracking System: 0.6 kW\textsubscript{e} per tracker
3. **System Overview**

**LayOut**

- **Hybrid Stirling Dish (HSD)**
- **Hybrid Stirling Sub-System**
- **SynGas Storage**
- **SynGas Sub-System**
- **Engine**
- **HSD**
- **Tracking**
- **Storage**
- **Public Grid**
- **Battery Bank**
- **Electrical Storage Sub-System**
- **400 V 3 phase AC-Bus**
- **ModBus TCP/IP Interface / Gateway**
- **Power Measurement**
- **AC-Bus / Electrical energy**
- **Hydrogen**
- **SynGas**
- **Biomass**
- **Sun rays**
- **Internal Communication**
- **ModBus Communication**

- **Load / Antennas**
  - **A/C**
  - **SKA/ DUMP LOAD**

**Status**
08/08/16
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4. Tasks

Concentrator Shape
GMSC, CTAER, ALN, MTAG/TT

Mirrors
MTAG/TT

Hybrid Engine, Burner and Receiver
CLEANERGY, TUT

Control System
FRAUNHOFER, GMSC, TUT

Documentary
IAA-CSIC

SKA Demo
ASTRON, IAA-CSIC, IT, MPG

O&M
LOGICA, ALN, IAA-CSIC, GMSC

Storage System
US, ALN
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5. Prototype

- **Dish and tracking system – Conceptual Final Design**
5. Prototype

- Dish and tracking system – Validation
5. Prototype

- Dish and tracking system – Stirling Engine Testing
5. Prototype

- **Mirrors – Steel Adapter for Mirrors**

Steel adapter unit description

- 10 x Omega Profile
- 2 x Rectangular Profile
- 3 x Mounting Pins
- Mounting Holes for Mirror Facets

Dish structure ready for mirror installation

Positioning and mounting of adapter unit
5. Prototype

- **Mirrors – QA test of Installed Dish Mirrors**

**Prototype setup:**
- Total aperture / mirror area: $A_{disk} = 50m^2$
  (44 mirror, 11 adapter segments)
- Focal length: $f_L = 5.600$ mm

**Test 1:** March 10th, 2017, 10:30am (PT)
- Plate no: 1 (20mm steel plate)
- Dish pos.: Azi.: 138 deg / Ele.: 38 deg
- Burn time: approx. 60 sec
- Result/spot: Diameter - 150mm

Burning marks on „fake“ receiver

Test setup for QA test and evaluation of TT Dish mirror
5. **Prototype**

- **EMS**

### Updated Data Loads and Subsystems

<table>
<thead>
<tr>
<th>Load SKA Demo</th>
<th>Power Consumpt.</th>
<th>Variability</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>20kW</td>
<td>0.1%</td>
<td>Controllable</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biostirling</th>
<th>Power Production</th>
<th>Variability/Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stirling Engine</td>
<td>9kW (rated 10kW)</td>
<td>3kW +/- per min</td>
<td>Grid connected</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bidirectional Inv.</th>
<th>Power Production</th>
<th>Variability/Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter</td>
<td>20 kVA</td>
<td></td>
<td>UPS functionality</td>
</tr>
<tr>
<td>Battery</td>
<td>?</td>
<td>instantaneous</td>
<td></td>
</tr>
</tbody>
</table>
5. Prototype

- **EMS**

   Installed EMS and Monitoring Hardware. Overview

   - EMS and measurement boxes
   - Current transformers
   - Connecting switch for data communication
5. Prototype

- **EMS**

**EMS and Data Collection Box**

- Embedded system with OpenMUC data collector
- Power measurement
- Programmable Logic Controller (PLC)
- ModBus TCP/IP communication (via switch)
5. Prototype

- EMS

**Hardware Details**

Power meter with ModBus TCP/IP communication

Current transformers
5. Prototype

- **EMS**

**OpenMUC Data Acquisition Framework**

A customized OpenMUC data management framework is used as a monitoring, logging, and controlling system.
ENERGY STORAGE SYSTEM (WP4)

PRINCIPAL OBJECTIVE: Designing and sizing the Power Conversion Unit (Secondary Energy Storage System) for BIOSTIRLING-4SKA Platform.

TECHNICAL OBJECTIVES:
1) To assure electric energy supply to SKA Demonstrator (24/7).
2) If the grid is isolated the PCU acts as a grid stabilizer. Variations of frequency and grid voltage will occur.
## ENERGY STORAGE SYSTEM

### UNIT COST COMPARISON

**H₂ Technology**

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell</td>
<td>4 k€/kWe</td>
</tr>
<tr>
<td>Hydrogen Storage system (pressurized @ 30 bar)</td>
<td>1 k€/Nm³ H₂</td>
</tr>
<tr>
<td>Electrolyzer (alkaline technology)</td>
<td>2 k€/kWe</td>
</tr>
<tr>
<td>DC/AC inverter</td>
<td>600 €/kWe</td>
</tr>
<tr>
<td>AC/DC converter</td>
<td>600 €/KWe</td>
</tr>
<tr>
<td>Batteries set (Li-ion technology)</td>
<td>5 k€/KWe</td>
</tr>
<tr>
<td>Engineering and control system</td>
<td>100 k€</td>
</tr>
<tr>
<td>Auxiliaries</td>
<td>10 k€</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries set (Li-ion technology)</td>
<td>5 k€/KWe</td>
</tr>
<tr>
<td>DC/AC converter</td>
<td>1 k€/kWe</td>
</tr>
<tr>
<td>Engineering and control system</td>
<td>60 k€</td>
</tr>
</tbody>
</table>

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**BIOSTIRLING-4SKA**
5. Prototype

- **Stirling Engine. Design**

The final design consists of 48 wickless thermosyphons oriented in two concentric circles, enabling both a tubular sun receiver and a radial gas flow through the pipes. The design included the development of a high temperature thermosyphon capable of using two different heat sources. The geometrical and thermal challenges are mainly linked to the small heat transfer contact area between the thermosyphons condenser and the attached working gas channels.
5. Prototype

- Stirling Engine: Built
5. Prototype

• Stirling Engine. Test Results
  - The first hybrid receiver prototype was tested successfully on Cleanergy’s SunBox engine in combustion only mode, generating a maximum electrical power output of 7.7 kW with an electrical efficiency of 17% in January 2016.
  - Different heating powers were evaluated at an inclination of 15° and all results indicated that the developed receiver will also perform well when heated only from the sun or from both sun and gas simultaneously.
  - At the first test run of the unit in hybrid mode in Moura April 25th, the output power increased from combustion mode at 1,5 kW to hybrid mode producing 3 kW proving that the concept is working.
5. Prototype

- Stirling Engine Test Results
5. **Prototype**

- **Stirling Engine. Hybrid engine on dish**
5. Prototype

- **Stirling Engine. Engine test run in hybrid mode, April 25th**
5. And SKA is:

<table>
<thead>
<tr>
<th></th>
<th>SKA1_LOW (Australia)</th>
<th>SKA1_MID (South Africa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors type</td>
<td>130 000 dipoles</td>
<td>197 Dishes (including 64 MeerKAT)</td>
</tr>
<tr>
<td>Frequency range</td>
<td>50-350 MHz</td>
<td>0.45-15 GHz (B1,2, B5)</td>
</tr>
<tr>
<td>Collecting Area</td>
<td>0.4 Km²</td>
<td>32 000m²</td>
</tr>
<tr>
<td>Max baseline</td>
<td>65 Km (between stations)</td>
<td>150 Km</td>
</tr>
<tr>
<td>Raw Data Output</td>
<td>157 Terabyte/sec</td>
<td>3.9 Terabyte/sec</td>
</tr>
<tr>
<td></td>
<td>0.49 Zettabyte/year</td>
<td>122 Exabyte/year</td>
</tr>
<tr>
<td>Science Archive</td>
<td>0.4 Petabyte/day (128 Petabyte/year)</td>
<td>3 Petabyte /day (1.1 Exabyte/year)</td>
</tr>
</tbody>
</table>
5. Prototype

- **SKA**

The SKA1: 3 sites

South Africa

Australia

SKA HQ
5. **Prototype**

- **SKA Power Estimates – General Analysis**

<table>
<thead>
<tr>
<th>SKA Phase 1&amp;2</th>
<th>South Africa</th>
<th>Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sparse Arrays</td>
<td>3.36 MW</td>
<td></td>
</tr>
<tr>
<td>Mid Dishes</td>
<td>2.5MW</td>
<td></td>
</tr>
<tr>
<td>On-site Computing</td>
<td>4.7MW</td>
<td>1.32MW</td>
</tr>
<tr>
<td>Totals/site</td>
<td>5.7MW</td>
<td>4.8MW</td>
</tr>
<tr>
<td>SKA Phase2 incl. Dense Arrays</td>
<td>&gt;40MW (SKA Phase 2 configuration not known yet)</td>
<td></td>
</tr>
<tr>
<td>Off-site Computing</td>
<td>~20-40MW (SKA Phase 2 configuration not known yet)</td>
<td></td>
</tr>
</tbody>
</table>
A Big Thank to: Nuno Pereira, IPB
Enabling RFI Testing
5. Prototype

Leader: CSIC
5. Prototype

- SKA Integration
5. Prototype

- AAs EMC/RFI testing:

A Big Thank to: Nuno Pereira, Enabling RFI Testing
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### 6. Results

**KPIs**

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<th>KPI</th>
<th>Target Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPI-1</td>
<td>Reduce the total mirror facet slope deviation</td>
</tr>
<tr>
<td>KPI-2</td>
<td>Reduce the total system deviation, including also the environmental impact</td>
</tr>
<tr>
<td>KPI-3</td>
<td>Increase the reflectivity of the mirrors</td>
</tr>
<tr>
<td>KPI-4</td>
<td>Increase the availability of the syngas burner</td>
</tr>
<tr>
<td>KPI-5</td>
<td>Decrease the reduction in the efficiency of the fuel cell after 500 hours of continuous operation.</td>
</tr>
</tbody>
</table>

**KPIs (2016)**

<table>
<thead>
<tr>
<th>KPI</th>
<th>Target Values (2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPI-1</td>
<td>General (quasi static operation) frequency stability within a defined tolerance range</td>
</tr>
<tr>
<td>KPI-2</td>
<td>General (quasi static operation) voltage stability within a defined tolerance range</td>
</tr>
<tr>
<td>KPI-3</td>
<td>Dynamic voltage and frequency drop relative to the reference value (50 Hz and 400 V)</td>
</tr>
<tr>
<td>KPI-4</td>
<td>Grid efficiency (total energy output ↔ total energy input)</td>
</tr>
</tbody>
</table>
5. **Prototype**

- **A 52’ TV documentary production**

**Credits:**
- CSIC – Direction/Script/Editing
- LANIAKEA M&C – Production/Script/Editing
- LIPSSYNC FILM (filming/editing)
- & VTH Producciones (filming Moura)

11 partners, 5 countries, 15 experts, 10 days

Energy + Astronomy + Technology

Six chapters:
- The energy problem
- The Sun energy
- Concentrating the Sun
- Biostirling: A new dish engine generation
- Energy for SKA Demonstrator
- The end

Mixing interviews, animations, resources, etc.

Distribution – TV & digital platforms
Thank you all for your attention