A better steam engine: Designing a distributed concentrating solar combined heat and power system

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Research objective

It is my objective to advance the technical and socioenviroeconomic understanding of solar combined heat and power.

This work will investigate the potential of a small scale solar Rankine thermodynamic cycle.
- establish the economic and environmental parameters that will guide the design and analysis
- Determine value through water, energy, GHG and economic analysis
- simulate and test expanders for such a system

A small and efficient expander is key new enabling technology, yet as a single component collector costs dominate, therefore both are vitally important.
A few potential benefits of DCS-CHP

- Higher reliability of grids/microgrids esp. in developing world.
- Decreased transmission constraints
  - Quick permitting, less new transmission, etc.
- Decreased cost of heat and electricity compared to other distributed renewables (<$4/W electric, $0.40/W thermal)
- Large capital fundraising on a project by project basis not required
- Increased overall solar utilization with CHP
- Thermal storage is cheaper than electric
- Developed world: Mass production, like a refrigerator not a nuclear power plant
- Developing world: Local production, ease of manufacturing without specialized equipment and materials
- Water use greatly reduced compared to centralized generation
- More jobs for skilled technicians in repair and installation
- Distributed power is owned and operated locally vs. the centralized power paradigm of corporate and government control

Sources: Casten and Ayres (2007); Norwood et al. (2010); Concentrating solar power commercial application study: Reducing water consumption of concentrating solar power electricity generation, Tech. rep., United States Department of Energy.
Figure 1: Above, power tower pilot project, pioneered in the U.S. (Barstow, CA) and (left) commercial unit under development by Abengoa called PS10, an 11 MW plant in Sevilla Spain (photo credit: Abengoa Solar). Bottom left, Stirling Dish/Engine, Center SEGS trough plants, Right, Compact Linear Fresnel Reflector.

Distributed concentrating solar combined heat and power

Diagram:
- Solar collector
- Thermal buffer
- Expander
- Generator

State of working fluid:
- Point 1: High pressure liquid
- Point 2: High pressure vapor
- Point 3: Low pressure saturated vapor/liquid
- Point 4: Low pressure liquid

Flow:
1. Heat in
2. Expander
3. Generator
4. Condenser

Feedwater for purification and desalination or cooling water/air

To distillation process or other thermal storage/load

Electricity
Developing tools for design and optimization: Performance testing: Rotary lobe expander

- Testing at UCB with air
- Rotary lobe expander performance is expected to be better than:
  - Radial inflow turbine: bad performance at this power output
  - Screw: Volume (power) to surface area (losses) ratio low at this scale
  - Tesla turbine: further development possible, low pressure ratios (<2), low efficiency

Developing tools for design and optimization:
Performance testing: Rotary lobe expander

Source: Katrix, Inc. Australia
Developing tools for design and optimization: Performance testing: Rotary lobe expander
Test Procedure

1. First the VFD is turned on and the electric motor spins the expander up to the set frequency starting at 300 rpm (with no load).
2. Then the compressed air supply is turned on allowing the expander to begin providing power through the shaft to the electric motor where it is converted to AC, then dissipated in a resistor bank connected to the VFD.
3. After the system runs for 15 minutes to “warm up” (i.e. reach steady state) several data acquisition boards powered by LabView will begin recording the upstream and downstream pressure and temperature of the working. Torque, and differential pressure across the orifice plate flow meter are also recorded during the 10-20 minutes of data collection.
4. Data collection stops and the VFD frequency is adjusted up by 100 rpm.
5. Repeat steps 3 and 4 until the VFD frequency reaches the limit of the motor (1800 rpm) being sure to wait for steady state operation before doing data acquisition at each speed.
6. The apparatus is shut down by first shutting off the compressed air and then turning off the VFD.
7. Find 5 minutes of data with fairly steady characteristics of upstream pressure and temperature to calculate efficiency.
Developing tools for design and optimization: Performance testing: Rotary lobe expander

Results: 80-95% isentropic efficiency

400-600W mechanical power
Developing tools for design and optimization: Performance testing: Rotary lobe expander

Results: 6-11 Pressure Ratio
Developing tools for design and optimization: Performance testing: Rotary lobe expander

Results: Unexplained oscillating torque & mass flow rate
Developing tools for design and optimization: A near-optimal DCS-CHP system

Thermal Output (annual kWh/m^2 collector) $0.03 / kWh in Oakland

Electrical output (annual kWh/m^2 collector) $0.25 / kWh in Oakland
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