Dish Stirling Reliability Improvement and Commercialization

Charles Andraka
Sandia National Laboratories, Albuquerque, NM, ceandra@sandia.gov

ABSTRACT

Stirling Energy Systems (SES) is pursuing an aggressive deployment of 25kW dish-Stirling systems for bulk power generation. Their hardware is based on the McDonnell Douglas (MDAC) design, with refinements for reducing manufacturing costs. SES is working under a CRADA[1] with Sandia National Laboratories' engineering team in order to maximize the possibility of success. This relationship leverages DOE money at least 3:1.

Sandia and SES have deployed 6 dish systems at Sandia in a Model Power Plant (MPP). Sandia has led an effort to improve the reliability of these systems, providing technical basis for systems improvement. Sandia has also supported design and testing of system improvements, both for reliability and cost reduction. Finally, Sandia has been intimately involved in the design process for the next-generation systems, particularly in the areas of optics, structure reduction, and controls.

The success of the MPP has, in part, led to SES signing agreements with Southern California Edison for up to 850MW of power and San Diego Gas and Electric for up to 900MW of Power. SES will begin deploying the first 1MW portion of the SCE plant in the next year. Operation and improvement of the MPP is critical in the design process for these deployments.

1. Objectives

Sandia is working closely with SES to improve system performance and reliability and to support deployment by industry in the near term, both explicit goals of the Multi-Year Program Plan section 4.2.5.3. This year, our primary goal has been to test the MPP systems, cataloging and characterizing system issues, and providing lead support of the problem resolution and testing process. In addition, using lessons learned on the MPP as well as significant experience with other systems, Sandia directly impacted the design process and tools for the next-generation pre-production systems. SES's objective is to put this system into production within a few years, with a target market of bulk power production in the southwest United States. This corporate goal drives the DOE goal of reliability improvement of the system.

2. Technical Approach

SES plans to achieve cost reduction by rapidly moving to high production rates in support of bulk power production. This has the advantage of lower cost through production automation early in the product design cycle, and lower O&M cost through consolidation of O&M resources, when compared to smaller prototype installations spread out at many locations.

SES has co-located its engineering team at Sandia's National Solar Thermal Test Facility. This provides direct access to technology transfer and expertise and allows the SES engineers daily hands-on access to the dish systems. This is critical to accelerating the development and deployment path, as well as rapidly training new solar engineers.

Sandia led the effort to develop a database of operational information, including faults and performance. Together with SES, we have prioritized the top priority development areas, and begun root cause analysis, design improvement, and field testing of potential solutions. Sandia consistently takes a systems view of problem areas, both in evaluation of the problem and proposing solutions. This is critical to improving reliability as well as reducing cost. To effect this, we have been directly involved in the next-generation design phase.

All of the dish system hardware is funded through SES investor financing while Sandia participation through the DOE CSP program provides in-kind engineering support, technology transfer, training, and facilities. While Sandia's primary goal is reliability improvement, the operation of the systems has also been driven by the need to demonstrate system operation to stakeholders.

3. Results and Accomplishments

3.1 Reliability Improvement

Sandia has helped SES formalize the process of reliability improvement through the implementation of a Failure Reporting Analysis and Corrective Action System (FRACAS), using commercial software. FRACAS ensures cataloging of incidents, ownership of each problem area, and a clear path to problem resolution and testing. The tool consolidates various databases of incident information across the technology departments at SES and Sandia. Once issues are prioritized in the system, we develop tiger teams of experts at Sandia and SES to attack each problem, identifying known information, drilling to a root cause, and proposing and testing solutions. While many detail areas have been addressed, only a few can be mentioned in this short paper.

The Gas Management System (GMS) was the highest priority focus of reliability improvement. The valves in the system are a 20-year-old design with significant leak-thorough and other reliability issues. We first continued testing of a replacement valve on the compressor short circuit location. We determined the original valve could be replaced by a substantially smaller valve, eliminating frequent problems and reducing cost by over a factor of 10. We performed extensive field testing of the replacement valve, and identified alternative vendors. We have down-selected to one US vendor, and are currently testing their valves, and working with the vendor to maximize performance of this valve in each location. The vendor has provided design services to fabricate an integrated valve block assembly. This will reduce leak paths as well as manufacturing costs. The components proposed for this block are currently under test as discrete items, including solenoid valves, check valves, and filters. Initial results are very promising, as is the responsiveness of this US company. We expect integrated block testing this spring. The implementation of the integrated system will have a dramatic impact on reliability as well as cost.

We noted a number of issues in controls hardware, including wiring and sensors. Much of the wiring is 20 years old, with untraceable heritage. We evaluated the electrical equipment, and supported re-work of the boxes to eliminate repeating issues such as improper terminations, loose connections, and cold solder joints. The vintage electronics have a large number of discrete components. We are assisting SES in the planning and design of a modern controller with improved functionality that will reduce parts (and joint) counts by a factor of 20 or more. We also determined that some digital switch signals were insufficiently filtered, and

developed analog filters as stop-gap measures to improve control data reliability. We also developed procedures to consistently install thermocouples, avoiding false readings that caused tripouts. We also identified some areas with custom circuits and sensors that could be easily replaced with commercial items, including drive motor position sensors, reducing cost and failures. These electrical improvements have been instrumental in improving reliability. The lessons learned will strongly drive the design process for next-generation controls, sensors, and wiring.

3.2 System Operation

System operation has recently been extended to unattended weekend operation. Sandia engineers routinely connect remotely to the systems to monitor operation. As of January 31, 2007, we have accrued over 8500 hours of system operation. The systems are routinely operating at or above the system specification. Sandia-led improvements to the dish system have substantially increased the power delivered by the dish at little additional cost. In addition, the optical alignment improvements have increased the engine's ability to deliver output power, by balancing the cylinder-to-cylinder power. We are in the process of evaluating these improvements in order to more accurately size the next-generation dish reflective area.

3.3 Design Support

SES is in the process of designing next-generation systems for a 1-MW installation in California. This plant will demonstrate system improvements as SES moves toward highly automated production, but will still be high in labor content due to the small quantities. It is critical that SES incorporate the lessons learned through the collaboration with Sandia, to address reliability as well as cost issues. Thus, Sandia has been directly involved in the design and review processes for these next-generation systems. This is an integral part of the reliability improvement process.

Substantial structural modifications were proposed for the dish backup structure. This, in part, was based on the experiences with field erection of the 6 dishes at Sandia National Laboratories. The deployment model for SES is substantially different than that of MDAC with some design constraints removed. No comprehensive design tool existed for the dish structure, resulting in over-designed (more costly) structures on most dish systems. Sandia proposed combining the SES structural Finite Element modeling (FEA) with Sandia's CIRCE2[2] optical model, and an SES Computational Fluid Dynamics (CFD) wind loading model, so that design changes could be evaluated for their impact on the stability of the flux pattern on the engine, under gravity and wind loading. The tools were calibrated against measurements on the MPP dish systems, including mechanical, optical, and thermal data.

The end results has been a design reduction of nearly 4000 pounds of rotating steel structure, while providing a stiffer, more stable structure. This will improve system reliability by preventing flux hotspots on the receiver tubes while dramatically reducing the cost. In addition, the discrete joints were reduced in number and simplified, further improving reliability. Prototype systems will be fabricated this next year.

Sandia developed a field systems model including an accurate dish-to-dish shading model, as well as many features[3]. Combined with field data, this model accurately models the loss in operation and revenue due to shading. In particular, it was used to help determine minimum dish-to-dish spacing to avoid mid-day tripouts on shading, while optimizing the revenue stream compared to land capital costs. This model was used to design the 1MW field layout, and will improve reliability during potentially shaded periods.

Sandia has teamed with SES suppliers to develop alignment tools to reliably align the facets in the assembly plant without highly skilled labor. We have worked with SES suppliers to ensure the tools proposed would be compatible with high rate production. These tools will be fabricated and demonstrated in the next year.

Sandia has helped SES to characterize and understand existing vintage controls hardware and software, in preparation for design of the next-generation system. Since the controls function as a systems integrator, they have a direct impact on the system reliability. The clear documentation of the existing and future controls is critical to the implementation of a reliable future low-cost system.

4. Conclusions

Reliability improvement processes impact every facet of dish system operation, maintenance, redesign, and deployment. Sandia National Laboratories has unique experience and skills used to support SES in their development, improvement, and deployment plan. A number of key reliability areas have been characterized in detail, and field testing of simpler, more robust solutions is in progress. These improvements and lessons learned are being actively incorporated into next-generation planning and design efforts to ensure success of the SES deployments. Some vintage hardware at Sandia will simply be patched to test and demonstrate improved components. Pre-prototype improved systems will be installed at Sandia to prove out integrated reliable systems prior to initial deployments in California. The current systems are performing at expected efficiency and power production levels, which helps firm up predictions for large plant production.

SES has developed agreements with California utilities for up to nearly 2GW of installed capacity. These systems have brought unprecedented publicity to the CSP program in general and SES in particular. SES is continuing an aggressive schedule for product improvement and deployment. They will next install a 1MW (40-dish) system, followed by high rate production. The involvement of high production suppliers and Sandia National Laboratories in the deployment of the MPP and the 1MW plant is key to transitioning to production.

The partnership between Sandia and SES is a new way of doing business that maximizes the benefit to SES while continuing to leverage the expertise developed at the Laboratories.

ACKNOWLEDGEMENTS

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

REFERENCES

[1]"*Dish Stirling System Development",* Cooperative Research and Development Agreement SC06/01728 between Sandia National Laboratories and Stirling Energy Systems, Oct. 24, 2006.

[2]Romero V.J., "*CIRCE2/DEKGEN2: A Software Package for Facilitated Optical Analysis of 3-D Distributed Solar Energy Concentrators – Theory and User Manual",* SAND91-2238, 1994

[3]Igo, J.R., Andraka, C.E., "*Solar Dish Field System Model for Spacing Optimization*", Proposed for ASME Solar Energy Division Conference, Long Beach, California, June 26-30, 2007.