

# STIRLING MODULE DEVELOPMENT OVERVIEW

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## I. Summary

The Solar Parabolic Dish-Stirling Engine Electricity generating module development has been pursued by the Department of Energy with Government laboratories and industrial participants since FY 1978. The solar parabolic dish-Stirling engine electricity generating module consists of a solar collector coupled to a Stirling-engine powered electrical generator. The module has been designed to convert solar power to electrical power in parallel with numerous identical units coupled to an electrical utility power grid.

Presently, the solar parabolic dish-Stirling engine electricity generating module exists as a commercial prototype erected by the Advanco Corporation at the Southern California Edison Company's Santa Rosa Substation located in the city of Rancho Mirage, California. If the commercial prototype, named Vanguard, tests prove the equipment to be effective and reliable, then the participants have planned to construct an electricity generating plant.

In order to prepare for the Vanguard module erection, Advanco Corporation has worked with their subcontractors to design, fabricate, assemble and test the many components and subsystems over the past year. The Stirling engine/generator consists of an United Stirling Model 4-95 solar engine and a Reliance Model XE286T induction generator. The power conversion assembly generates up to 25 kilowatts at 480 volts potential/3 phase/alternating current. The module electrical power system has been constructed by the Onan Corporation to be fully self-controlled.

The United Stirling/JPL have tested two test bed modules at the Parabolic Dish Test Site, Edwards AFB, California during the past year. Improvements in the reliability and performance of the USAB Model 4-95 solar engine results from knowledge gained in these tests, as well as from the DOE/NASA sponsored Automotive Stirling Engine tests at USAB and MTI, and from the private laboratory tests at USAB Malmo, Sweden. The joint USAB/JPL solar tests of the two Model 4-95 engines provide the only actual environment for function, performance and endurance measurements needed to improve the hardware and software, and to project the commercial value.

The testing has been very successful during the FY 1983 period. Piston rings and seals with gas leakage have not occurred, however, operator failures resulted in two burnt out receivers, while material fatigue resulted in a broken piston rod between the piston rod seal and cap seal.

## II. Commercial Prototype - Vanguard

The prototype 20-kWe Solar Parabolic Dish-Stirling Engine System Module (Vanguard) in Rancho Mirage, California, is the world's most effective solar-electric generating station. Design, fabrication, assembly and testing of the prototype Vanguard module represents a cooperative effort between government and private industry to commercialize the advanced technology developed over the past several years by the Solar Thermal Power Technology Division, United States Department of Energy. The solar-electric generating station is located in the northern Imperial Valley on the Southern California Edison Company's (SCE) Santa Rosa Substation. The Vanguard module can generate up to 25 kWe net electrical power at 480 V/3 /60Hz, however, the module is rated at a net electrical power of 20 kWe with direct insolation of 850 watts per square meter. All of the above module net power will be divided between supplying the station parasitic power requirement and power to the utility grid. As an estimate of the module effectiveness when operated continuously for one year in the Mojave desert, the module is estimated by the author to generate 60,000 kWh while converting an average of 27 percent of all direct insolation on the mirror surfaces to net electrical energy. The Prototype Solar Parabolic Dish-Stirling Engine System Module is a joint project of the Department of Energy, and the Advanco Corporation. Principal organization working with Advanco in addition to SCE are United Stirling, Inc., KB. United Stirling (Sweden) AB and Company, Onan Corporation, Rockwell International - Energy Systems Group, Electrospace Systems Inc., Modern Alloys Inc., Winsmith, and the Georgia Tech Research Institute. The Jet Propulsion Laboratory assists the Department of Energy in its Cooperative Agreement participation by providing technical consultants since prior development at JPL resulted in a test bed Solar Parabolic Dish Stirling Engine System Module.

### A. Collector System

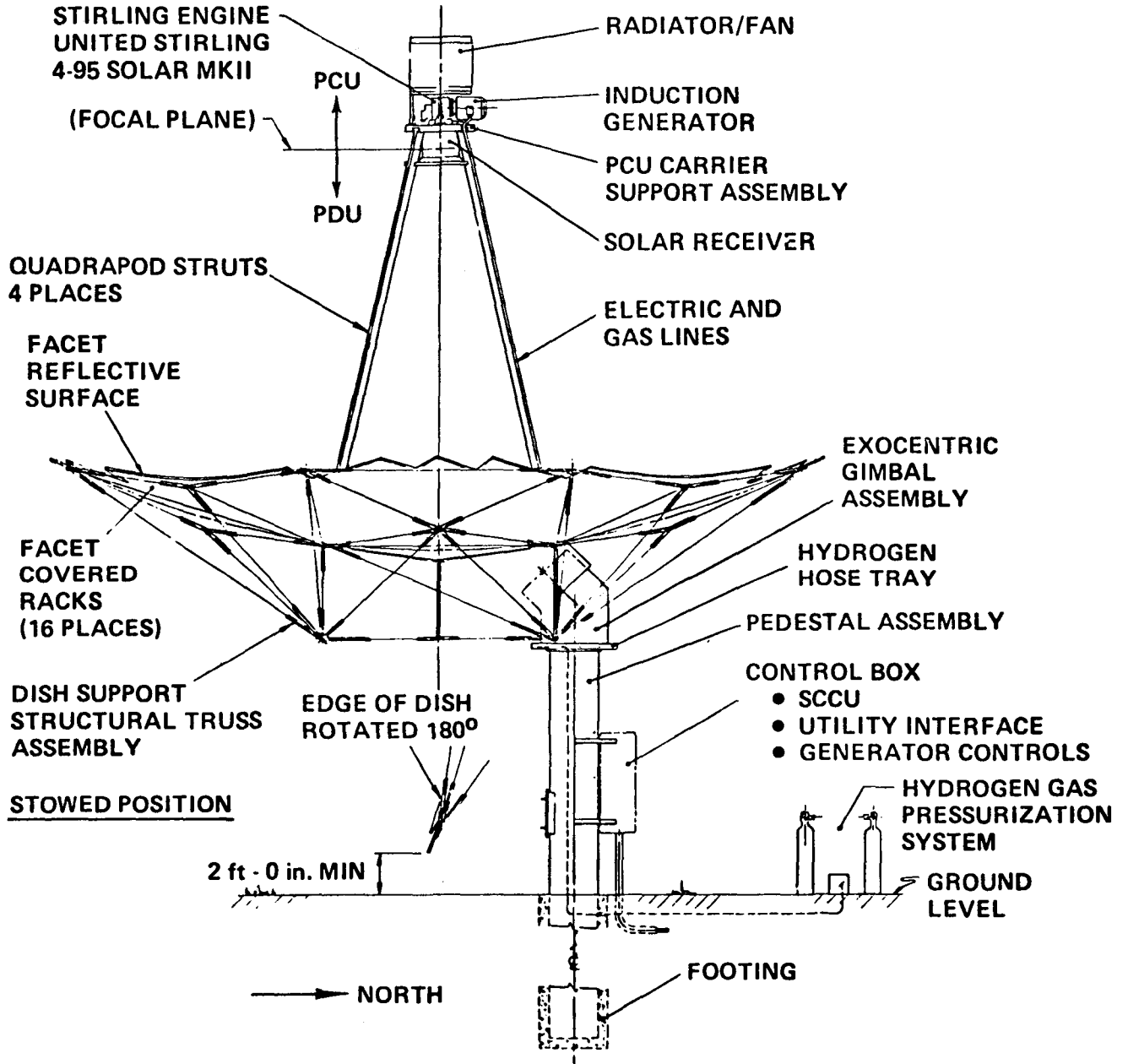
A collector system consists of 32 solar parabolic dish concentrators. Each collector is a solar parabolic dish concentrator with a reflective net area of 83 square meters (893 square feet) consisting of 328 back-silvered fusion glass mirrors cold saggged and bonded to a spherically ground foam-glass substrate. These 5-cm (2-in.) thick, (46-cm) (18 in.) by 61-cm (24 in.) mirror facets have been individually mounted on 16 steel rack assemblies. Of ten mirror facets tested, all survived accelerated environmental tests at JPL and SNLA with no trace of failure. The 16 mirror rack assemblies are mounted on a geared drive unit for azimuth and elevation control. With the skewed elevation axis passing through the center of gimbaled mass, the elevation drive has demonstrated very small torque requirements.

The collector control system consists of individual microprocessor concentrator controllers and a central controller for groups of up to 32 concentrators. Each concentrator can be controlled individually or in groups in either the manual or automatic modes through the central controller in the plant control room. Also,

# VANGUARD DISH - STIRLING MODULE

## OVERALL MODULE FEATURES

DIAMETER: 11 m (36 ft - 1 in.)  
 HEIGHT: 12 m (39 ft - 4 in.)  
 WEIGHT: 7980 kg (17,560 lb)  
 SYSTEM EFFICIENCY: 25.4%  
 ELECTRICAL POWER: 20.8 kWe



each concentrator can be controlled at the individual concentrator controller. The concentrators have been designed to operate in steady winds of 13 m/sec (30 mi/h) with 2 sec gusts up to 22 m/sec (50 mi/h). In the stowed position, the concentrator has been designed to survive 40 m/s (90 mi/h) short duration gusts. Soon after the prototype concentrator was erected, it withstood up to reportedly 17 m/s (40 mi/h) gusts with no noticeable ill effect.

Of those JPL technical consultants engaged in the Cooperative Agreement activity, all agree the reflective facets, the rack assemblies, the geared drive units, the remaining structure and foundation, the individual concentrator microprocessor control, and the group microprocessor controller have been expertly designed, fabricated, tested, installed and operated by the Advanco Corporation with their several subcontractors.

B. Engine/Generator System

Each individual United Stirling Model 4-95 Solar MK II engine with Reliance Model XE286 induction generator is rated at 25 kWe with a normalized direct insolation value of  $1000 \text{ W/M}^2$ . A group of 32 units would be rated at 800 kWe, electrical power less the power required for parasitic loads. Overall direct insolation to electricity conversion efficiency is estimated to be 27% for the solar year. From test results obtained by the Jet Propulsion Laboratory with the United Stirling Model 4-95 Solar MK I engine with the ASEA induction alternator these performance estimates have been essentially verified. The engine operates at a solar receiver temperature of  $700^\circ\text{C}$  ( $1290^\circ\text{F}$ ) with a coolant temperature of  $50^\circ\text{C}$  ( $122^\circ\text{F}$ ) with several grams of hydrogen as the working medium. The present commercial engine represents an improvement in 30% reduced production cost and increased reliability by a factor of at least 2 while maintaining the performance level of the prior test bed engine. Reduced production cost and increased reliability has yet to be verified by the U.S. Department of Energy. The electrical power system control uses a simple reliable design with all commercial components. Standard design practices have been used to satisfy electrical codes and utility requirements.

C. Group Control System

The group control system is one master microprocessor that controls the plant from a plant control room. The plant/group control is ultimately fully automatic with an operator override option. For individual system control to augment the group control, each individual system has its own distributed process controller. Two of these process controllers are digital, the concentrator controller and the engine controller, while one is hard-wired, the electrical power system controller. The process controllers are located near or within the respective system's hardware in the distributed systems. There is strong reason for

JPL to believe group control system and/or the process controllers will function properly because the simple and proven components and software have been integrated into prior and proven systems.

### III. Solar Engine Development

United Stirling funded the construction of an engine/generator with 5 experimental solar only receivers for evaluation at the Parabolic Dish Site in Edwards AFB, California. The test program was jointly funded by United Stirling and the DOE. The objectives of the test program are to gain practical fabrication and operating experience, and to establish the capability of building commercial solar receivers. Early results of tests performed between January and March 1982 may be found in Reference 1. Later results of tests performed during the period of May 1982 through July 1983 are published in Reference 2. Another current paper describing the solar engine development by United Stirling has been published in Reference 3. Also, previous proceedings of the Parabolic Dish Solar Thermal Power Program Review includes early progress reports of the present activity.

#### A. Experimental Solar Only Receivers

United Stirling has tested 5 different experimental solar only receivers (BSORs) on the two engine/generator units at Edwards Air Force Base. The principal difference between these receivers was in the tube-manifold construction of the heater. The different heaters were --

- ESOR I, the standard combustion system heater.
- ESOR IIA, a new designed solar only receiver, including a manifold.
- ESOR IIB, a new designed solar only receiver with only single tubes.
- ESOR III, a new designed solar only receiver with only single tubes but with increased diameter and specially designed tubes of "hair pin" type.
- ESOR IV, a new optimized receiver for solar application with production cost considered.

All of these receivers except the last have operated for many hours on the test bed concentrators at the Parabolic Dish Test Site, EAFB, California with no failures other than burnout of three receivers due to operator mistakes. Burnout of tubes was readily repaired by brazing in replacement tubes - usually one per quadrant.

- B. Model 4-95 engine and generator United Stirling provided one engine/generator especially configured for these tests. Through JPL, the Department of Energy provided another Model 4-95

engine/generator previously purchased from United Stirling.

The engine/generator furnished by United Stirling operated flawlessly through about 300 hours of solar testing. The government furnished engine/generator twice experienced the breakage of a piston rod in the same cylinder due to material fatigue. Mal-alignment of cylinder-seal-piston components may have subjected the rod to unusual stresses.

C. Engine Control System

United Stirling provided two digital electronic control units for the two test engines. The control system provided automatic totally remote, unattended operation of the engine/generator systems. Software provided with the digital electronic control units was modified and further developed as the tests progressed. There were no problems encountered with the engine control systems.

D. Radiator System

Early tests were conducted without an engine cooling system mounted on the engine.

Later the government provided engine was equipped with a complete radiator system furnished by United Stirling. The radiator has four heat exchange matrices built up in a square form with a radial fan in the center. A water pump circulates water from the engine through heat exchanger matrices. At full engine power a fan power of 790 W and water pump power of 200 W provides adequate cooling. A comparable ground mounted cooling system required a power of 4000-5000 W to operate a cooling fan and water pump.

References

1. Nelving, H-G, "Performance Test of 4-95 Solar Stirling Engine with Two Different Solar Only Receivers", United Stirling AB, Malmo, Sweden, September 7, 1982.
2. Nelving, H-G, "Testing of 4-95 Solar Stirling Engine in Concentrator at Edwards Air Force Base During Period May 1982 - July 1983", United Stirling AB, Malmo, Sweden, September 7, 1983.
3. Holgersson, Sten, and Worth H. Percival, "The 4-95 Solar Stirling-Engine - A Progress Report", Proceedings of the Twentieth Automotive Technology Development Contractor's Coordination Meeting, Society of Automotive Engineers, Inc., April 1983.