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Comprehensive Design of Stirling Engine Based Solar Dish Power Plant with Solar Tracking System

Omer Faruk Farsakoglu and Adil Alahmad*

Department of Electrical and Electronics Engineering, Kilis 7 Aralık University, Turkey

Abstract

As solar energy is an important source of renewable energy resource. Sun radiation is being used as renewable energy, a combination of solar collector dish type and a Stirling engine is generally referred to the solar power. In this type, Stirling engine is depending on sunlight as source of heat to providing the input energy. This project presents different components and various configurations alongside with the feasibility of using solar energy as a source of heat for a Stirling engine. In addition to this, calculation of different components of Stirling engine and parabolic dish like sun heat calculations, Stirling torque calculations, generator calculations, and calculations for following and tracking the light intensity to get maximum solar power. This paper addresses issues which we saw during design and development of solar Stirling engine with generator to be sufficient acceptable for experimental and small wattage applications. This makes the energy usable in homes as a supplemental source of power or as an independent power source. 3D model is showing that is consisting of the parabolic collector, receiver, Stirling engine, and generator. The 3D model is prepared in solid work to enable us starting the manufacturing and calculations. The design is implemented to include location and depends on properties that affect the performance based on the sun elevation angle, ambient temperature, the wind speed, and density of air (altitude). Here experimental study is conducted on small-scale solar parabolic Stirling engine with generator. The solar collector is fabricated using satellite dish antenna fitted with polished sheets of aluminum. Low power is consumed to find the maximum power and highest light intensity. The applications of solar Stirling have green and clean energy generation from sun energy. Overall efficiency of solar Stirling power of system is expected to be around (36-24) percentage.

Keywords: Solar Stirling system; Stirling engine; Stirling dish system; Solar tracking; Solar plant; Renewable energy

Introduction

Solar energy is one of the famous renewable energy sources that can be used as an input energy source for Stirling engine. Solar Stirling systems convert the thermal energy in solar radiation to mechanical energy and then to electrical energy. Solar Stirling systems have demonstrated the highest efficiency of any solar power generation system by converting nearly 30% of direct-normal incident solar radiation into electricity after accounting for parasitic power losses [1]. Solar Stirling system produces electricity by using parabolic collector and Stirling engine. Dish/Stirling concentrating solar power (CSP) converts solar heat into electricity by focusing solar radiation onto a receiver containing a heat-engine known as a Stirling engine (Figure 1).

History of Solar Stirling System

In 1872 John Ericsson built the solar Stirling device and developed Stirling engine to work with a parabolic reflector to be as a solar powered machine, but his business backers persuaded him to patent the design as an engine, heated by coal wood or gas.

In 1986 the project involved the construction of two 50 kW dish/Stirling systems close to Riyadh in Saudi Arabia. It has the below properties collector diameter 17 m, Power 25 kW, reflector material glass/silver mirrors on membrane reflector and maximal system efficiency 23%.

In 1997 three dish/Stirling-systems were built in the PLATAFORMA Solar de ALMERÍA Spanish. It has the below properties collector diameter 8.5 m, reflector material steel membrane with silver coated glass mirrors, power 10 Kw and maximal system efficiency 21%.

In 2007 The INFINIA Corporation built in Kennewick, WA, US. It has the below properties collector diameter 4.6 m, reflector material glass fiber reinforced plastic with silver coated glass mirrors, power 3 kW and maximal system efficiency 24%.

In 2010 the proposed Imperial Valley Solar/SES Solar built in Imperial County, California, USA. It has the below properties collector diameter 11.6 m, reflector material curved glass mirror facets, the station produced about 750 kW and maximal system efficiency 31.25%.

In 2016 RIPASSO parabolic dish collectors in South Africa. It has the below properties collector diameter 14.5 m, reflector material curved glass mirror facets, the station produced about 60 MW and maximal system efficiency 32%.

Solar Stirling System Components

The main components of a solar Stirling engine Systems are the solar collector (dish-satellite) with the sun-tracking system, the solar receiver and the Stirling motor with the electric generator.

Collector

Geometrical considerations: The concentration ratio C is defined as the ratio of the radiant flux density in the focal spot, or, what is the

***Corresponding author:** Adil Alahmad, Department of Electrical and Electronics Engineering, Kilis 7 Aralık University, Turkey, Tel: +903488142666; E-mail: adel.alahmad90@gmail.com

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same, in the Sun image, C_{im} to the direct irradiance on the aperture of the collector $C_{b,ap}$.

As the direct irradiance at the collector aperture is just the direct normal irradiance, C is the ratio of the radiant flux density at the focal spot to the direct normal irradiance [2]:

$$C = \frac{C_{im}}{C_{b,ap}} = \frac{C_{im}}{DNI} \quad (1)$$

Concerning the mean concentration ratio, contrary to the punctual one, there is an easy way to specify it without any measurement: The geometrical concentration ratio C_G is a useful approximation. C_G is the ratio of the (projected) collector aperture area A_{ap} to the focal spot area, i.e., to the area of the Sun image A_{im} or to the receiver aperture area (supposing that the receiver aperture has exactly the size of the Sun image) [3]:

$$C_G = \frac{A_{ap}}{A_{im}} \quad (2)$$

Collector materials: It is important to choose the ideal reflectors taking all factors into consideration as it will define the light intensity and system output power. Here AL Foil Band 45 mm × 0.06 mm × 40 M has been used. As it has 88% high reflection ratio beside of its low cost [3].

Collector size: The size of the collector depends basically on the desired electrical system power, the available radiation and the efficiency of the conversion of radiation to electrical energy. At known direct normal solar irradiance and system efficiency, the aperture area and the respective collector diameter can be determined as follows [4]:

$$A_{ap} = \frac{P_{el}}{\eta_{sys}.DNI} \quad (3)$$

$$d = 2\sqrt{\frac{P_{el}}{\pi.\eta_{sys}.DNI}} \quad (4)$$

Where P_{el} is the desired electrical system power, η_{sys} the solar-to-electric system efficiency and DNI the direct normal irradiance at the design point.

Two axises mechanism design

To get max solar power all the time from collector at point concentrating, we need a two-axises tracking system so that the collector is always directed toward the Sun and the direct solar radiation is always parallel to the optical axis of the system. Z-Y axises mechanism (Horizontal, Vertical) and X-Y axises mechanism (Left-Right) movement is being carried out with 2 DC motors and their gears [5-9]. Two axises mechanism design shown in Figure 2.

Solar tracking system

Proteus simulate: Arduino is used as processor, 2 DC motors for Left-Right and Up-Down movements (according to LDR), to make sure that our program will work correctly Proteus Simulator is used as shown in Figure 3.

Status 1: All LDRs' have equal light intensity with good/high evaluation: If LDRLD=LDRLT=LDRRD=LDRRT LDR output is 0.1 V and the Motors EW&NS will be stable [10-12].

Status 2: LDRX>LDR: If LDRL> the others, so LDRL output has (0.1-3.91) V, our aim is to reach status 1 with EW&NS motor suitable movements (X: LT, LD, RT or RD).

The BOM of used material in solar tracking system: Solar Tracking Driving Panel BOM (Table 1).

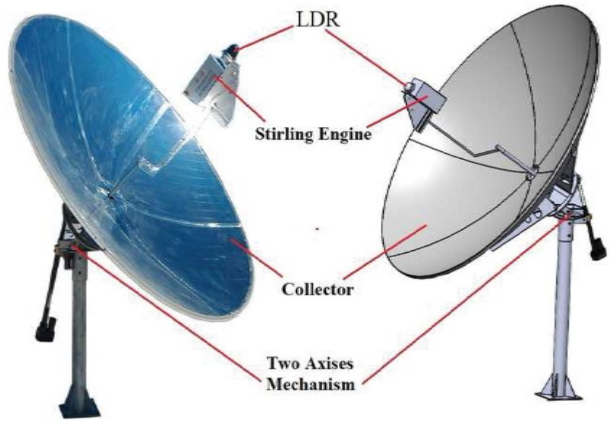

Figure 1: Solar Stirling system components.

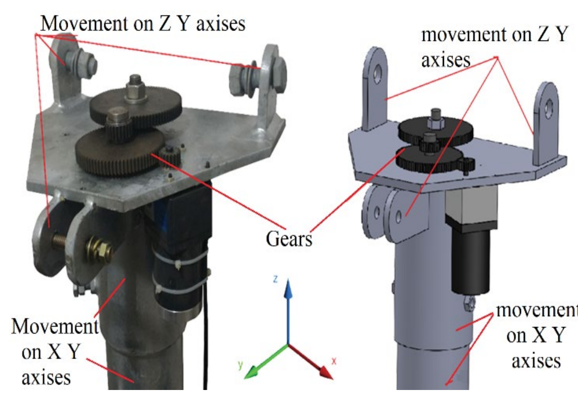

Figure 2: Two axises mechanism design.`

Elements	Quantity	Note
Arduino Uno	1	
Relay Card	1	8 terminal , 5 VDC
DC Motor Driving Card	1	
DC Motor	1	
Gearbox	1	
Linear Actuator	1	
Light Resistance	4	LDR
Resistance	4	47 KΩ

Table 1: Solar tracking driving panel BOM.

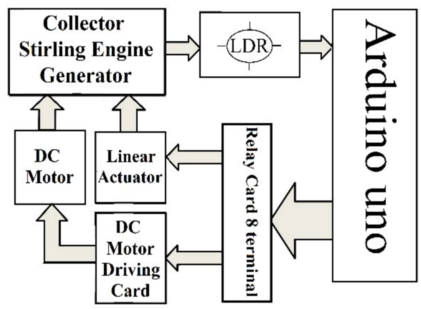

Figure 3: Solar tracking block diagram.

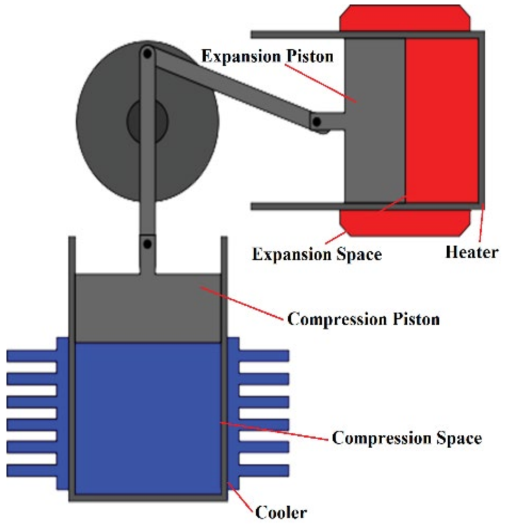

Figure 4: The alpha configuration Stirling engine.

Stirling engine and generator

Thermodynamics analysis of the Stirling cycle using MATLAB: The engine is divided into 5 control volumes for this analysis, and it is assumed that the expansion and compression processes follow the adiabatic law (Figure 4).

***Calculations for work and efficiency*:** We will perform the analysis in the following steps. These steps will also help in coding the analysis in MATLAB.

Assume known hot end and cold end temperatures.

- Select instantaneous crank angle increment in degrees.
- Calculate initial engine volume by assuming that crank angle is 0 when displacer is at topmost position.
- Assume that initial pressure is known, by measurement, and calculate moles M of gas present in engine. This value (M) will be constant throughout the cycle.
- Now calculate instantaneous volume inside engine for assumed instantaneous crank angle increment.
- Since T and M are constant, calculate new instantaneous pressure P(N) for newly calculated instantaneous volume.
- Next calculate the differential work $dW=PdV$,

$$dV=V_{new}-V_{previous} \tag{5}$$

- Now repeat all above steps by incrementing crank angle for every iteration and take cumulative sum of work dW after every iteration.
- Once the crank angle reaches 360, stop the iterations. We now have our work output W from the cycle in J/cycle.

The formulae to calculate the terms involved in above steps, are given as follows,

Regenerator temperature $$TR=\frac{TH-TC}{ln\left(\frac{TH}{TC}\right)} \tag{6}$$

Moles of working gas inside engine

$$VL=\frac{\pi}{4}(2)(RC)(DB)^2 \tag{7}$$

Maximum hot end live volume

$$VL=\frac{\pi}{4}(2)(RC)(DB)^2 \tag{8}$$

Maximum cold end live volume associated with displacer

$$VK=2(RC)[(DB)^2-(DD)^2]\left(\frac{\pi}{4}\right) \tag{9}$$

Maximum cold end volume associated with power piston

$$VP=2(R2)[(DC)^2-(DD)^2]\left(\frac{\pi}{4}\right) \tag{10}$$

Regenerator volume

$$RD=2(LR)[(DB)^2-(DD)^2]\left(\frac{\pi}{4}\right) \tag{11}$$

We now define 3 arrays to store 3 volumes, namely H(N) to store instantaneous hot end volume, C(N) to store instantaneous cold end volume and V(N) to store total instantaneous engine volume [13]. The hot end live volume is given by

$$H(N)=\frac{VL}{2}[1-cos(F)]+HD \tag{12}$$

The cold end live volume at any instant N is given by

$$C(N)=\frac{VK}{2}[1+cos(F)]+CD+\frac{VP}{2}[1-cos(F-AL)] \tag{13}$$

The total volume at any instant N is then given by

$$V(N)=H(N)+C(N)+RD \tag{14}$$

Now the pressure at any instant can be given by

$$P(N)=\frac{(M)(R)}{\frac{H(N)}{TH}+\frac{C(N)}{TC}+\frac{RD}{TR}} \tag{15}$$

The change in volume will simply be

$$dV=V(N)-V(N-1) \tag{16}$$

And total work will be

$$dW(N)=P(N)dV \tag{17}$$

The instantaneous work will now be

$$W(N)=W(N)+dW(N) \tag{18}$$

To get the work output per cycle we just repeat above calculations by differentially incrementing F from 0 to 360 [14,15].

The following engine parameters are chosen to get the work output for the test case presented. These are not randomly chosen parameters, but have been decided after running the isothermal and adiabatic analysis numerous times and then optimizing them for the targeted power output.

- Hot end working volume in cm^3=18 cm^3
- Cold end working volume in cm^3=18 cm^3
- Working piston working volume in cm^3=18 cm^3
- Hot end heat exchanger volume in cm^3=3 cm^3
- Cold end heat exchanger volume in cm^3=3 cm^3
- Regenerator volume in cm^3=1.75 cm^3
- Hot end heat exchanger temperature in K=800 K

- Cold end heat exchanger temperature in K=300 K
- Effective regenerator temperature in K=450 K
- Phase angle between displacer and working piston=90
- Working gas is Helium
- Mass of gas filled in engine=0.1 moles
- Specific heat ratio for Helium=1.6667.

The hot end heat exchanger and hot end working volume are constant and equal as we are assuming the process to be isothermal. Similarly the cold end heat exchanger and cold end working volume are assumed to be at the same constant temperature.

The used Stirling engine: ALFA type double cylinder Stirling engine with generator set used in this application. Double cylinder system provides stable performance and output power, the generator is connected to the motor with two belt, the technical specification as follows:

- Heat transfer is very good, because the cylinders of Engine made from stainless steel.
- Friction is good, because ability to adding some grease at the moving parts and thus reduce friction.
- Balance isn't good, because material of movement wheels is Aluminum (is very light this led to fast movement but this need more time to balance).
- Expansion is good, because the used gas in cylinders is helium.
- Compression is good, because when the helium is squeezed in cylinders is converts power from heat to mechanical.
- Timing is very good, because the difference between fixing place of the hot and cold cylinder arms have a good timing to change the pressure between both of cold and hot cylinders.

Testing

The Experimental setup and testing, the testing of built system was carried out on the roof of electrical and electronic engineering college 7 December University.

Used equipment for test

- A pyrometer
- A tachometer
- A digital multimeter (DMM)
- Wattmeter
- 12 V DC motor 150 W.

Experimental set-up

Using the solar tracking system, the solar intensity to engine speed and temperature can be determined. Position Stirling engine in concentrator focal point, allow 5-minute warm up, start engine, and allow engine speed to settle down for 1 minute, Record engine speed, displacer hot and cold temperature, ambient temperature, Record experimental data.

Problems to solve (12.07.2017) at first testing day: The receving part need to change to cover the motor and prevent the cold cylinder from overheating.

- The solar traking systim need more ajusment and changing the LDER and cable of LDER to more bigger LDER and low resistanse cabel.
- Covering the cable which come from the engine and LDER cable to prevent them from heating.
- The data in the graphs of Figures 1 and 2 represent the measurements taken of the solar Stirling systim was completed, however, not yet ready for testing due to some adjustments in design that are to be made.

After solving the problems which face us at 23.07.2017, the testing repeated at 08.08.2017.

Comparison the test result and MATLAB analysis

Regarding experimental result the motor speed and out power increase radically with the temperature differential. Same result was achieved in MATLAB program as shown at Figure 5.

Total system output (genertator speed and output energy in watt) in august month shown in Figure 6.

Test conclusions

Results from this experimental testing indicates that the engine power, and speed all increase with increasing temperature differential. While the system was initially sized for 150 W, there are several factors that made this power output unattainable:

- The friction present in the engine (Friction is a large factor in the performance of a Stirling engine).
- The engine design hot and cold cylinder close to each other.

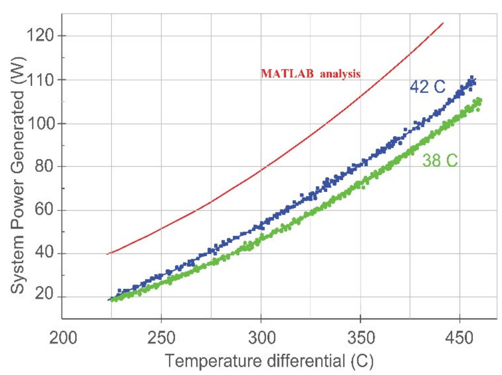

Figure 5: Temperature differential (°C) and energy (W).

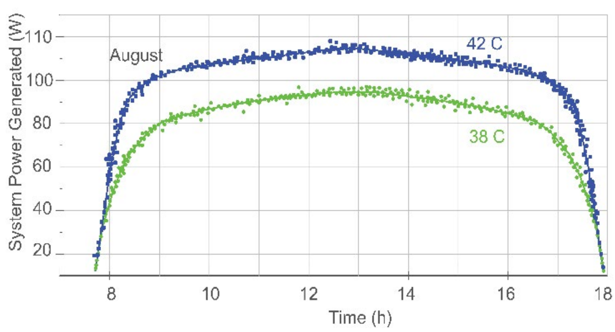

Figure 6: Time and energy (W) in August.

The higher efficiency of solar Stirling engines makes them an attractive replacement for traditional photovoltaic arrays. With their inherent high maintainability and reliability would be perfectly suited for supplementary or whole system power providers.

Conclusions

Most renewable energy methods have harmful effects on the environment which cause risk for all beings. Power Plant like Thermal, Nuclear and Hydro Electrical Power Plants, have high generation capacity but they destroy nature very bad as it may not recover again. To protect our world from alike situations and to get high quality energy with less effort, less risk and higher productivity we made our step into our project under clear energy roof. These methods may cause risk and help us to protect our environment which gives this method high rank rating.

If we compare this method with other photovoltaic systems we will find it the best one because of its low cost and high reliability. It works by concentrating sun solar in one point to heat the gas exists in the Stirling motor and rising the pressure inside which cause power on the shaft as there is cold gas with high pressure (relatively) both at the same time cause torque and that allows us generate electricity. Making use of the solar energy as cheapest renewable energy and highest efficiencies clear is the aim in this project. For our future finding clean new methods to generate power and support related researches had better be a goal.

References

1. Washom B (1984) Parabolic dish Stirling module development and test results. Proceedings of the 19th IECEC, San Francisco, CA.
2. John E (1876) Solar Power - Contributions to the Centennial exhibition. Royal Swedish Academy of Engineering Sciences, Stockholm.
3. Ziyad S (2014) Renewable Energy System Design. Academic Press, University of Massachusetts Lowell, United States.
4. Adkins RD, Andraka CE, Moss TA (1995) Development of a 75-kW Heat-Pipe Receiver for solar Heat-Engines. Sandia National Laboratories, Albuquerque, NM 87185 USA.
5. Mancini TR (1997) Solar-Electric dish Stirling system development. Sandia National Laboratories, Albuquerque, NM 87185 USA.
6. Michael G (1998) Plataforma Solar DE Almeria annual technical report 1997. Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas Instituto de Energías Renovables Plataforme Solar de Almería Apartado, Spain.
7. Thomas K, Wolfgang S (2003) Envirodish and Eurodish- system and status. Schlaich Bergermann und Partner (SBP GmbH), Stuttgart, Germany.
8. Peter B (2003) National Conference of state legislatures. VP Business Development & Government Relations, Infinia Corporation.
9. Utz JA, Braun RA (1960) Design and initial tests of a Stirling engine for solar energy applications (Master's thesis). Mechanical Engineering Department, University of Wisconsin.
10. Walker G, Kentfield J, Johnson E, Fauvel R, Srinivasen V (1983) Coal-fired Stirling engines for railway locomotive and stationary applications. Proc Inst Mech Eng 46: 197.
11. Baumüller A, Schiel W (1997) Single acting 10 kWel Stirling engine Application and results. Proceedings of the International Stirling Engine Conference, University of Ancona, Italy.
12. Keck T, Schiel W, Benz R (1990) An innovative dish/Stirling system. Proceedings of the 25th IECEC, Reno, Nevada.
13. Schiel W, Laing D (2001) Survey on solar-electric dish/Stirling technology. Proceedings of the VDI-GET 10th International Stirling Engine Conference.
14. Schweitzer A, Schiel W, Keck T, Kern J (1992) Third generation dish/Stirling technology-Testing in continuous operation-System description and initial results. Proceedings of the 6th International Symposium on Solar Thermal Concentrating Technologies, Mojacar, Spain, pp: 715-730.
15. Dunn PD, Rice G, Thring RH (1975) Hydraulic and rotary drive Stirling engines with fluidized bed combustion/heat pipe systems. Proc 10th Inter Soc Energy Conv Conf Newark Del, pp: 942-947.