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Güneş Takip Sistemi ile Çanak-Stirling Sistemi Tasarımı ve Testleri

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ÖZET

Enerji, hayatımızda kullandığımız evrenin önemli unsurlarından birisidir. Yaptığımız herhangi bir işte mutlaka enerji kavramı ile karşılaşırız. Enerjiyi hem üretip hem de tüketiriz ve bunun için hem fiziksel hem de kimyasal reaksiyonlar gerçekleşir. Hayatımızın en küçük noktasından itibaren sürekli enerji üretmeye ve bu enerjiyi en verimli şekilde kullanmaya çalışırız. Dünyamızda da enerji üretimi ve enerjiyi kullanmak adına çok çeşitli alanlarda çok farklı metotlar kullanılıyor. Birincil enerji kaynağı olan "Güneş" dünyanın temel enerji kaynağıdır. Güneş dünyayı aydınlatmayı, ısıtmayı, canlıların yaşamasını ve ikincil enerji kaynaklarının ortaya çıkmasını sağlar. Günümüzde enerji ihtiyacının büyük kısmını fosil kaynaklar karşılanmaktadır. Teknolojinin Yenilenebilir enerji kaynaklarının kullanılması yavaş gelişimile den fosil yakıtlar ön plana çıkarmıştır. Ancak fosil kaynakların çevreyi kirletmesi, enerji üreten tesislerin işletilmesinin pahalı olması ve kaynakların sınırlı olması daha farklı enerji üretim yollarına başvurmayı zorunlu kılmıştır. Bunlardan birisi de güneş enerjisi sistemleridir. Güneş enerjisi sistemleri doğa dostu özellikleriyle enerji üretiminde ön plana çıkmıştır. Gün geçtikçe güneş enerjisi Ar-Ge çalışmalarına artan ilgi, üretimde artmaya ve işletim maliyetlerinde azalmaya olanak sağlamıştır. Yapılan tez çalışmasında amaç yenilenebilir enerji kaynağı olan güneş enerjisinden faydalanmaktır. Bu çalışmanın hedefi, güneş enerjisi orta sıcaklık uygulamalarında kullanılan, teknolojisi hızla gelişen ve yoğunlaştırıcı kolektör tiplerinden biri olan "güneş takip sistemi ile kontrol edilen stirling motorlu jeneratör" sistemini incelemek, tasarımını yapmak, kolektör üretiminde kullanılan malzemelerin özelliklerini araştırmak ve temin etmek, deney düzeneği kurmak, kolektör performansını incelemek ve bilgisayar ortamında simülasyonunu gerçekleştirmektir. Son olarak çıkan deney, teorik ve simülasyon sonuçları karşılaştırılarak sistemin doğruluğu hakkında bilgiler elde etmektir.

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Design and Testing of Solar Dish-Stirling System with Solar Tracking System

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ABSTRACT

This article provides a review on design and testing solar dish-Stirling system. In this type of systems, Stirling engine is depending on sun radiation as source of heat to providing the input energy. This project presents design calculations of different components of solar dish-Stirling system like received terminal energy from sun, solar collector dimensions, Stirling engine parameters, generator selection and calculations for solar tracking system. This paper addresses issues we are seeing 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. The 3D

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model of system is prepared in solid work program to enable us starting the manufacturing and calculations. 3D model is showing the different components of solar Stirling system like the parabolic collector, receiver, Stirling engine, generator, and double axes Mechanism for solar tracking system. 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). The solar collector is fabricated by using communication satellite fitted with polished sheets of Aluminum as a reflection material. Overall efficiency of designed solar Stirling system is between (17 – 20) percentages.

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1. 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.

2. 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. The designed system is shown in figure 1.

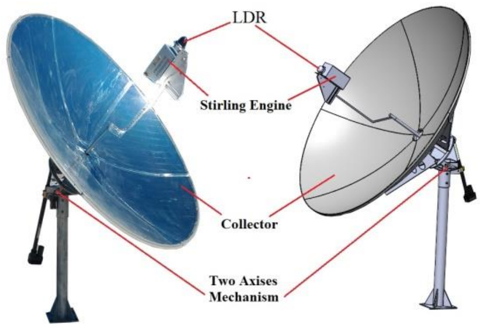

Figure 1. Solar Stirling System Components

2.1 Collector Calculation

2.1.1 Geometrical considerations

The concentration ratio is defined as the ratio of the radiant flux density in the focal spot 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, is the ratio of the radiant flux density at the focal spot to the direct normal irradiance. The concentration ratio C can be determined as follows [2]:

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

In present study the concentration ratio is 96 time. Because of the collector area C_{ap} is 4.9 m^2 and the receiver area C_{im} is 0.05 m^2. The concentration ratio C is shown in figure 2.

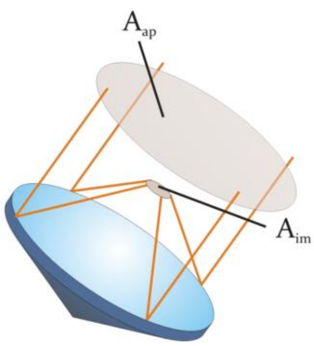

Figure 2. The concentration ratio

2.1.2 Choosing reflection material

One of below mentioned reflectors can be chose and it is important to choose the ideal one taking all factors into consideration as it will define the light intensity and system output power. This study, 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]. Reflecting surfaces and reflection ratios are shown is table 1.

Table 1. Reflecting surfaces and reflection ratios [3]

Reflector Surface Material	Reflection Ratio
Silver	0,94 ± 0,02
Silver Rear Coated Mirror	0,88

AL Foil Band	0,88
Acrylics Coated AL	0,86
AL	0,82 ± 0,05

2.1.3 Calculation of Collector dimension

The dimension of the collector depends basically on the desired electrical output of system, the available radiation and the total efficiency of the conversion of radiation to electrical energy. 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. In present study the desired electrical output is 250 w. System efficiency between (17-20) %, where the different came from different working times and other factors like weather, pollution..etc. The direct normal irradiance in Kilis City is more than 1360 kWh/m2 a year, this area also receives nearly 1400 hours of solar irradiation in a year [5].

2.2 Double Axis Mechanism Design

In this project we designed double axis mechanism to get max thermal energy from sun radiation. The mechanism with solar tracking control are always direct the collector toward the sun. Z-Y axis mechanism (Horizontal, Vertical) and X-Y axis's mechanism (Left-Right) movement is being carried out with 2 DC motors and their gears [5]. The designed double Axis's mechanism shown in the figure 2.

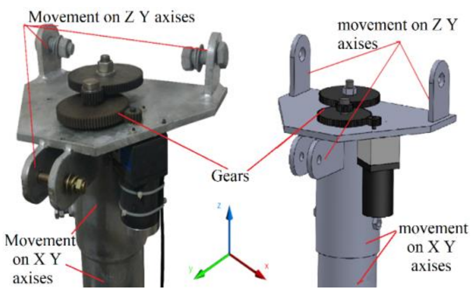

Figure 3. Double Axis's Mechanism Design

2.3 Solar Tracking System

Proteus Simulate

In this project, we used Arduino as processor which received the sun location information from four LDER fixed on the collector axis. After processing received information the Arduino send the control signal to double axis mechanism which moves toward the sun. The system simulation in Proteus was done before purchasing any control items. The Proteus simulations help us to be sure if our program will work correctly or not. The Proteus simulation is shown in Figure 4.

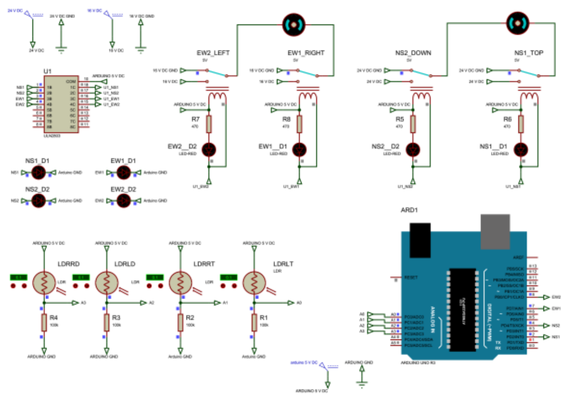

Figure 4. The Proteus simulation

The used solar tracking block diagram is shown in figure 5.

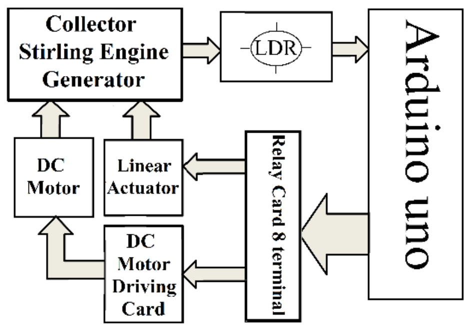

Figure 5. Solar Tracking Block Diagram

In designed solar tracking system there five different statuses depending on sun location which we can explain them as below:

Status 1: All LDRs' have equal light intensity with good/high evaluation:
If LDR**LD** = LDR**LT** = LDR**RD** = LDR**RT**
LDR output is 0.1V and the Motors EW&NS will be stable (Where **LD**: is left down LDR, **LT**: is left right LDR, **RD**: is right down, and **RT**: is right top LDR).
The other Statuses: LDRX > LDR: If LDRL > the others, so LDRL output has (0.1-3.91)V, our aim is to reach status 1 with mechanism motors which is

move according to received control signal from Arduino. (**X**: LT, LD, RT or RD). The bile of material (BOM) which used in solar tracking system control panel in this project is shown in Table 2.

Table 2. Solar Tracking Driving Panel BOM

Elements	Q.ty	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

2.4 Stirling Engine and Generator

2.4.1 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.

Assumptions:

1. The expansion and compression process is adiabatic
2. The temperature of hot end heat exchanger, cold end heat exchanger and regenerator is constant.
3. The working fluid obeys ideal gas law.
4. The specific heats for the working fluid (Helium) are constant.
5. The pressure is uniform throughout the engine at all instants.
6. The volume inside the engine varies in a sinusoidal manner.
7. There is no leakage of working fluid from the engine.
8. Perfect regeneration occurs in the regenerator volume.
9. The heat transfer in the hot end heat exchanger and cold end heat exchanger occurs at constant temperature.
10. The initial pressure is known
11. 0-degree crank angle corresponds to topmost position of displacer [6].

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.

1. Assume known hot end and cold end temperatures.
2. Select instantaneous crank angle increment in degrees.
3. Calculate initial engine volume by assuming that crank angle is 0 when displacer is at topmost position.
4. 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.
5. Now calculate instantaneous volume inside engine for assumed instantaneous crank angle increment.
6. Since T and M are constant, calculate new instantaneous pressure P(N) for newly calculated instantaneous volume.
7. Next calculate the differential work dW=PdV,

$$dV = V_{new} - V_{previous} \quad (5)$$

8. Now repeat all above steps by incrementing crank angle for every iteration and take cumulative sum of work dW after every iteration [7].
9. Once the crank angle reaches 360, stop the iterations. We now have our work output W from the cycle in J/cycle.

The formula to calculate the terms involved in above steps, are given as follows,
Regenerator temperature

$$TR = \frac{TH-TC}{\ln(\frac{TH}{TC})} \quad (6)$$

Moles of working gas inside engine

$$\mathrm{M} = \frac{\mathrm{P(1)(Vc)\ln\left(\frac{TH}{TC}\right)}}{\mathrm{R(TH-TC)}} \quad (7)$$

Maximum hot end live volume

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

Maximum cold end live volume associated with displacer:

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

Maximum cold end volume associated with power piston:

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

Regenerator volume:

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

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. The hot end live volume is given by:

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

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

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

The total volume at any instant N is then given by:

$$V(N) = H(N) + C(N) + RD \quad (14)$$

Now the pressure at any instant can be given by:

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

The change in volume will simply be:

$$dV = V(N) - V(N - 1) \quad (16)$$

And total work will be:

$$dW(N) = P(N)dV \quad (17)$$

The instantaneous work will now be;

$$W(N) = W(N) + dW(N) \quad (18)$$

Nomenclature and symbols are shown in table 3.

To get the work output per cycle we just repeat above calculations by differentially incrementing F from 0 to 360. 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 analysis numerous times and then optimizing them for the targeted power output [8]. Choosing Stirling engine parameters are as below:

Table 3. Nomenclature and symbols

Symbol	Nomenclature
TR	regenerator temperature
Tc	compression space temperature
Th	hot end heat exchanger temperature
Vc	Cold end volume
M	total mass of working gas present in the engine, in gram mole
R	universal gas constant= 8.314 J/gmol-K
R2	stroke of power piston, in cm
RC	stroke of displacer, in cm
AL	phase lag
DB	displacer diameter, in cm
DC	diameter inside engine cylinder, in cm
Dp	change in pressure, in MPa
f	crank angle

1. Hot end working volume in cm^3 = 18 cm^3
2. Cold end working volume in cm^3 = 18 cm^3
3. Working piston working volume in cm^3 = 18 cm^3
4. Hot end heat exchanger volume in cm^3 = 3 cm^3
5. Cold end heat exchanger volume in cm^3 = 3 cm^3
6. Regenerator volume in cm^3 = 1.75 cm^3
7. Hot end heat exchanger temperature in K = 800 K
8. Cold end heat exchanger temperature in K = 300 K
9. Effective regenerator temperature in K = 450 K
10. Phase angle between displacer and working piston = 90
11. Working gas is Helium
12. Mass of gas filled in engine = 0.1 moles
13. Specific heat ratio for Helium = 1.6667
14. Alfa type components are shown in figure 6.

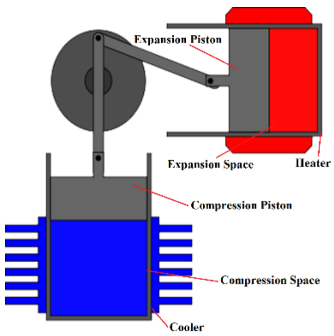

Figure 6. The Alpha configuration Stirling engine

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 [9]. Work per cycle in J by numerical integration: 2.5

2.4.2 The Used Stirling Engine:

Alfa type double cylinder Stirling motor-generator is used in this application. This engine achieves all simulation result parameters and has also below properties, Cylinders covers are made from Stainless steel. Cylinders are made from Copper. Flywheel and piston are made from Aluminum Double cylinder system provides stable performance and output power. The generator is connected to the motor with two belts. The technical specifications are dimension: L * W * H (205X150X111) mm, flywheel diameter is 64mm and wheels diameter is 29 mm.

3. Testing

The designed project was designed and set up in Kilis, Turkey, based on previous initial evaluations. The Experimental setup and testing were carried out on the roof of electrical and electronic engineering faculty of Kilis 7 December University, as shown is figure 7.

Figure 7. The designed project

3.1 Testing equipment

1- A pyrometer
2- A tachometer
3- A digital multimeter (DMM)
4- Wattmeter
5- 12 V DC motor 250 W

3.2 Experimental set-up

Using the solar tracking system, the solar intensity to engine speed and temperature can be determined. As follows set up the solar Stirling engine in concentrator focal point, allow 5 minutes warm up, start engine, and allow engine speed to settle down for 1 minute, Record engine speed, hot cylinder and cold cylinder temperature, temperature difference between hot and cold cylinders, Record experimental data and time. In first day of test, some problems were found in first assembly and test and the correction:

1. The receiver material should be change to another material to protect the engine from overheating (used receiver sheet metal material is Aluminum with 1 mm thickness), the material should change to HRP sheet metals with 3 mm thickness and send it to Stainless Steel plating, which gives a good reflection and protects from rusting).
2. The solar tracking system program needs more adjustments and LDERs signals is weak. For tracking system adjustment the control program should be update. The LDRs should be change to bigger LDERs and change the used cables to low resistance cables.
3. High temperature of LDRs cables due to heat of the sun. We should use high strength temperature resistant aramid fiber to covering LDRs cables.

In this situation, there is no ability to take any measurements, because the system is not ready for testing due to the previous problems. After solving the problems which face us in first test day, the testing repeated. The measurement results have a good agreement with simulation result. Regarding experimental result the motor speed and out power increase radically with the temperature differential. Same result was achieved in MATLAB program. Comparison the test result and MATLAB analysis is shown in Figure 8 and Figure 9.

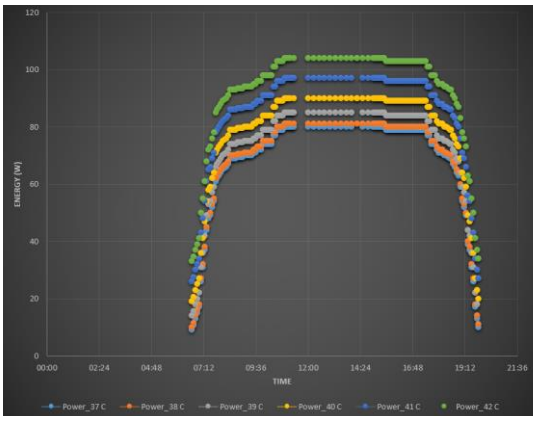

Figure 8. Temperature differential & Generator Speed

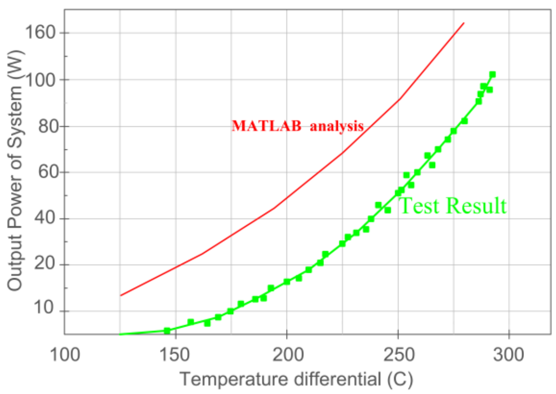

Figure 9. Temperature differential (C) and Energy (W)

Total system output energy in watt is shown in Figure 10.

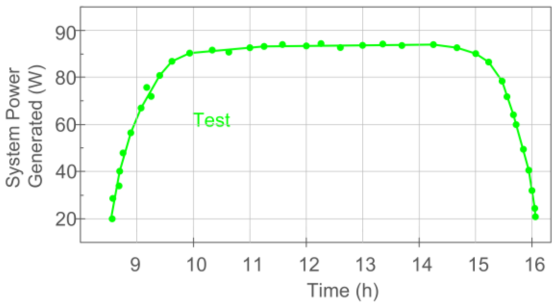

Figure 10. Time and Energy (W)

3.3 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:

1. The engine manufacturing quality is not perfect.
2. The friction present in the engine (Friction is a large decrease factor in the performance of a Stirling engine).
3. The engine design hot and cold cylinder close to each other which cause overheat.

4. Results and Recommendations

1. The high efficiency of solar Stirling engines makes them an attractive replacement for traditional stations. With their inherent high maintainability and reliability would be perfectly suited for supplementary or whole system power providers.
2. Most usual energy generation 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 the nature very bad as it may not recover again. To protect our world from alike situations and to get high quality energy with less efforts, less risk and higher productivity.
3. Using this method decrease using other methods which may cause risk and help us to protect our environment which gives this method high rank rating.
4. If we compare this method with other power generation systems we will find it is the best one because of its low cost and high reliability.
5. Making use of the solar energy as cheapest renewable energy and highest efficiency 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] M. Abbas, B. Boumeddane, N. Said, and A. Chikouche, ‘‘Dish Stirling technology: A 100 MW solar power plant using hydrogen for Algeria,’’ *Int. J. Hydrogen Energy*, vol. 36, no. 7, pp. 4305–4314, 2011.

[2] M. H. Ahmadi, H. Hosseinzade, H. Sayyaadi, A. H. Mohammadi, and F. Kimiaghalam, ‘‘Application of the multi-objective optimization method for designing a powered Stirling heat engine: Design with maximized power, thermal efficiency and minimized pressure loss,’’ Renewable Energy, vol. 60, pp. 313–322, Dec. 2013.

[3] E. Gholamalizadeh and S. H. Mansouri, ‘‘A comprehensive approach to design and improve a solar chimney power plant: A special case—Kerman project,’’ Applied Energy, vol. 102, pp. 975–982, Feb. 2013.

[4] E. Gholamalizadeh and J. D. Chung, ‘‘Design of the Collector of a Solar Dish-Stirling System: A Case Study,’’ *IEEE Access*, vol. 5, 2017, October 2, 2017.

[5] T.C. MINISTRY OF FORESTRY AND WATER WORK General Directorate of Meteorology https://mgm.gov.tr/veridegerlendirme/sicaklik-analizi.aspx

[6] S. Petrescu, M. Costea, C. Harman, and T. Florea, ‘‘Application of the direct method to irreversible Stirling cycles with finite speed,’’ Int. J. Energy Res., vol. 26, no. 7, pp. 589–609, 2002

[7] Jean-Pierre Van Dormael, ‘‘sothermic calculation of a Stirling engine: alpha, beta or gamma,’’ *Moteur Stirling*, 2002.

[8] W. B. Stine, and R. W. Harrigan, Solar Energy Fundamentals and Design: With Computer Applications. Hoboken, NJ, USA: Wiley, 1985.

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