Luter System a new approach to CSP energy diversification.

Key Words: Concentrated Solar Power (CSP), SME, Luter technology, Fresnel Dish concentrator, Stirling engine, Distributed power generation, performance analysis.

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Abstract: Luter system is a new concept of CSP. Luter system is a Dish-Stirling concept but trying to solve some of the typical problems in this CSP systems. This research was done in VICNI ENERGIA. As a result of the previous studies a Patent was fill in. The new CSP Dish-Stirling concept was supported by CDTI (Spanish development agency) in IDI20100067. Part of the development was done by AIDO, R+D institute specialized in Optics and photonics.

1.- Introduction.

Most of the Dish-Stirling often fail because of the Stirling engine. The environment in the housing causes a high temperature. This working environment is too extreme for lubrication and heat exchange. Additionally, extra heat exchange is not possible to install, due to the shadows causes by them. Moreover, the housing receives the solar beam and all the power concentrated by the parabolic surface. In these conditions Stirling engines often fail.

The Luter concept tries to avoid all those problems. So the concept consists on upside down of the

oncentrating must manage the light in different way. The light is refracted in place of reflected. This process implies some energy losses but other benefits. The hot focus of Stirling engine is the only parte exposed to solar power. Cold focus and engine housing is shadowed by the concentrator. Thus engine environment is suitable for engine and the time to failure grows up.

By other hand a plane concentrator surface in place of parabolic have advantages like: manufacturing accuracy, dust rejection, mounting precision and shape of structure, they are easier to carry out.

2.- Materials and Methods.

Optics, materials, structure design, control engineering, mechanical engineering, thermodynamics and solar science were applied to reach the results. The paper is organized in a transversal way. Thus the main topics to describe the system are: Stirling Engine topic, Concentrator aspects and tracking system issues. The main target of the R+D project, exposed in this paper, was to made a demonstrative prototype what shows how feasible will be the technology. So the prototype developed is not a commercial system.

Optical design was entrusted to AIDO, it is a R+D optical institute placed in Valencia. They studied different possibilities for designing taking into account the restraints of this demonstrator.

2.1.- Stirling Engine topics.

This section describes the subsystem that converts concentrated solar energy into AC three-phase power. Furthermore, adaptations have been made thereto and finally have developed elements which together form the sub-system.

2.1.1- Adaptations. The engine used for the demonstrator is a model Cleanergy V161. This engine was designed specifically for solar motor in Parabolic dish. Luter system has some peculiarities compared to Dish Stirling. Therefore, we have made some modifications to work in the LUTER System. The engine works in an inverted position in the Luter System. For this reason, the inlet of oil in the crankcase is in the opposite position. Due to the form of concentrate Luter system, it is possible to use a secondary optical system to reconcentrate rays. The cavity is the housing containing the receiver. The receiver is the element that transfers heat to the fluid. Both were adapted.

2.1.2.-General characteristics of the engine. CLEANERGY V161 Stirling engine. Engine with two cylinders in V-type alpha. Displacement of 160 cm3 with a Carrera, 44 mm and the diameter of the piston, 68 mm. The Stirling cycle is carried out at constant temperatures. The load is controlled depending on the gas mass flow. This is achieved by loading or unloading of the engine, using a specific system. All this to maintain constant engine speed and thus adapt the speed to the power grid. The motor rotates at 1500 rpm, and converts electrical energy through an asynchronous generator with 4 pairs of poles. This asynchronous generator acts as a starter motor and electric generator. Stirling cycle efficiency under these conditions is 30%. The three-phase AC electric power is obtained with a power factor of 0.85.

Stirling engine efficiency remains constant from 25% to 110% load. This is because the temperature difference remains constant throughout the load range. The Load in the range from 0% load to 25%, efficiency has an upward progression until it reaches its stable value. The main reason for this behavior is the importance of mechanical losses at low levels of production.

2.2.- Concentrator aspects.

For concentration element, some restrictions have been considered. First, the lens is manufactured. The manufacturing process for full scale production is provided by plastic injection. But the prototype the concentrator is machined. The concentrator has been based on the concept of Fresnel lens with some peculiarities. The optical design is based on maximum diameter 6.8 m (maximum diameter that can be machined by the provider), the focal length is 5.5 m. We analyzed large number of transparent plastic and the design has been based on the properties of PMMA [5].

The optical design is based on Fresnel lenses but including some peculiarities. Generally, Fresnel lenses has its toothed area on the face where the rays are parallel. In this case such a configuration causes excessive fouling and hence increase losses due to shading dirt. For the prototype has been used PMMA into sheets 30mm thick. Subsequently machined Fresnel profile. We analyzed the optical properties of absorption and chromatic aberration of the material to compensate for the optical design.

The optical design was commissioned to optical AIDO Institute of Technology. Furthermore, the study of the behavior of the concentrator was completed, taking experimental measurements on site. Computer modeling was compared (using the appropriate software Cmax) with the experimental measurements.

On the other hand, we have designed a cavity type element which serves to accommodate the solar receiver in an element that behaves like a black surface. To improve this behavior has included a secondary concentrator in the whole design. it can recover some rays that leave the target with the advantage that it does not generate shadow over the main concentrator. This type of secondary optics if implemented in other Dish- Stirling type systems generate shadow on the primary concentrator.

2.3.- Tracking system issues.

For the design of solar tracking system, it has been divided into several parts. On the one hand is determined the mechanical system that keeps track. On the other hand, it designed the tracking control system. And finally it has implemented a power system to move the tracker.

The follower system or solar tracker has built from purchasing a Commercial PV follower. To adapt it, a number of changes have been implemented. In the standard photovoltaic (not CPV) orientation to the sun is not a very critical parameter. For solar thermal, orientation to the sun is a critical parameter. CSP requires an orientation to the sun of maximum 0,12º (see section 3.1), For a parabolic dish focal length of 5.5 m. We assume that the tangent of that angle by the focal length (for small angles), is equal to the displacement of the focus. 0,12º angle that equals a displacement of 2 cm. This difference in the receiver represents the maximum displacement of the spot on the receiver. However, Luter in technology, that angle of deflection of the surface of the lens, a focal displacement is 0.5 cm for the same focal length. Therefore, we are far from the maximum permissible error.

The control system is composed of various control strategies at different levels. At one level or high level, it has scheduled an automaton that determines the state control at all times. The control states are:

a) Initial state. It is a state in which the system is whenever the control system is started. It is a state where nothing is done, it just is awaiting the following instruction.
b) Manual state. The Tracker obeys the instructions indicating by the user. Defined two sub-modes: manual from console and remote manual.
c) Automatic closed loop. We have implemented a model based predictive control algorithm. A modified GPC with measurable disturbances is programmed [9]& [10]. In this state we have three sub-states: Cloudy mode, sunny mode and night mode.
d) Emergency state.

The remaining lower levels are not considered particularly relevant to this paper and they will be developed in a specific publication of mechatronics. Simply it says that the closed loop control has two sub-states: Sunny mode and cloudy mode. For this, the system is equipped with two sensor systems of different nature. On the one hand they are installed tracker position sensors that determine the azimuthal position and the zenith position of the system.On the other hand, it has installed a solar sensor that gives us two facts: pointing error with respect to the sun and luminosity. When the brightness is high you have a sunny day and therefore the Tracker is controlled by the pointing error. When the brightness falls below a threshold it has cloudy day, and then the tracker is controlled by the position sensors. In the latter case the reference to follow is the astronomical position of the sun relative to the position on earth and considering the GMT time in that location. For this astronomical tracking, we are using a model developed by the PSA (Almeria Solar Platform) and published in [ref PSA].

3.- Theory and calculations.

To carry out this project, we have developed a series of theoretical works. These works have served to know the order of magnitude of the variables we were going to handle. The most notable activities have been conducted in the fields of: follower alignment with the sun, materials used in the system of concentration and calculations in the production of power and energy.

3.1.- Align error.

CSP Systems using Stirling engine, have been carried out by concentration by parabolic reflector. However, Luter system uses a refractor concentrator. The phenomena of reflection and refraction of light have different natures. Therefore, they are governed by different laws. When reflection is governed by two simple laws, refraction is governed by Snell's law and some restrictions (total internal reflection). In essence, the result of alignment error in the phenomenon of refraction and reflection, are not the same.

In the case of reflection: the alignment error causes a doubling of the error in focus. That is, an alignment error of one degree, represents two degrees in total. This error means that in focus, is about 17.5 cm out of range. If we consider that the solar receiver is about 22 cm in total, one can easily conclude that this error is unacceptable. In fact, the spot must be about 2 cm of the center of receiver. Under these conditions the maximum acceptable error for reflective concentrators alignment is in the + -0,12º.

The case of refraction, the analysis is more complex. Results from the application of Snell's law of refraction. For the present case, a material with a refractive index of 1.4906. Considering deviation angle of 1 degree. It must meet the limit of total internal reflection (in this case 38,43º). Misalignment in focus is a maximum 0,67º. At first glance, it shows that the total error is compensated and it is mitigated. In fact, the maximum misalignment error is admitted, it is 0,34º. In this extreme case, the displacement of the spot, at the receiver, would be correct.

3.2.- Material Components.

Different materials have been tested for composing the concentrator [5]. It had to meet different project requirements. Some as obvious as the optical properties of the components. Other various kinds such as aging of parts, its yellowness and mechanical strength against mechanical wear, corrosion, abrasion or hygroscopic properties.

3.3.- Power generation.

Theoretical studies have been conducted from direct normal irradiation (DNI) and its relationship with the generated electric power. Those measures were carried out in steady conditions, once temperatures are stables. In theoretical studies, efficiencies of components and losses are estimated and compare with previous papers, see Peter Heller and Wolfgang Reinalter [3].In addition, the paper published by D. Howard [2] provides the basis for the assumptions used in this section, to analyze the behavior of the power according to the DNI. A method of estimating the DNI direct normal irradiance developed into a dual-axis solar tracking precision, from the data of global radiation and normal in a horizontal surface. This method allows approximate energy production since it includes: position (latitude, longitude, altitude), solar position every moment.

Asynchronous motor speed remains approximately constant (slide = 1), then relation between torque and power is lineal. Hypothesis: engine efficiency 20 % at low load, electrical efficiency, Concentrator surface 30,19 sq. m and optical efficiency 60%. Table 1 contains the data summary. Maximum power in standard day and clear sky are included.

Month	MaximumThermalPower (kW)	PeakThermalPower (kW)	MaximumElectricalPower (kW)	PeakElectricalPower (kW)
Januari	8,12	11,80	1,38	2,01
Februari	7,97	12,08	1,35	2,05
March	9,62	13,41	1,64	2,28
April	8,46	12,68	1,44	2,15
May	9,62	13,17	1,64	2,24
Jun	10,47	13,26	1,78	2,25
July	11,27	13,68	1,92	2,33
August	10,87	13,20	1,85	2,24
September	10,43	13,14	1,77	2,23
October	9,04	12,32	1,54	2,09
November	7,52	11,18	1,28	1,90
December	7,16	10,85	1,22	1,84

Tabla 1.- resumen de cálculos de producción del prototipo Luter.

4.- Experimental results.

Finally, experimental tesst were done. Optical characterization was done by PSA (plataforma Solar de Almeria), R+D facilities depending on CIEMAT (Spain). These facilities are the most important laboratory in the world, for CSP technologies. These experimental result were financed by CDTI ina R+D project with the code IDI20100067.

High accurate tracking control system was designed. The control algorithm scheme and states automate is summarized in the figure 1.

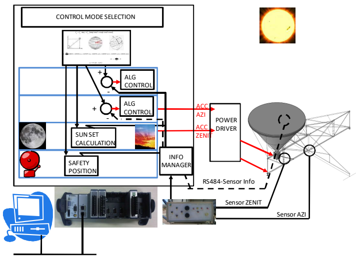


Figure 1.- Control Scheme.

The figure 2 Shows the experimental connections. The autonomous control algorithm is tracking the sun and supervising Stirling engine. A computer is downloading the data, while the experiment is running. Real time system is in the low level. RT acquisition is warranted by NI RT processor.

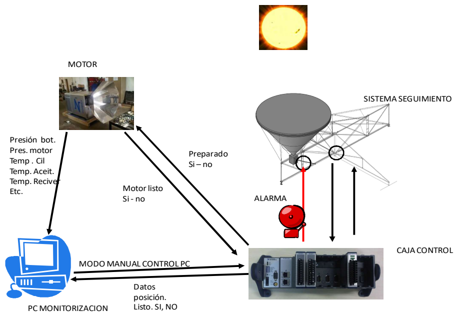


Figura 2.- Test connections during the experiments.

Experimental tests were performed where radiation ID compared compared to production of electricity. It has developed a graphical overview of all the experimental results. It is part of a drag situation. Under these conditions the engine consumes energy, radiation 0 W / m2. This situation occurs upon starting without charge.The engine will consume about 3.4 kW of power maintained, if the ambient temperature is constant. there is another reference point, It is the point of zero consumption. This point is about 550 W / m2 (DNI).Under these conditions the Stirling cycle generates net power to overcome mechanical losses. From this point to the radiation 950 W / m2 (maximum irradiance reached during the experiments), all experimental points have been approximated to a linear behavior, as shown in the graph. The linear regression obtained has a level of 99.6% correspondence with the experimental data.

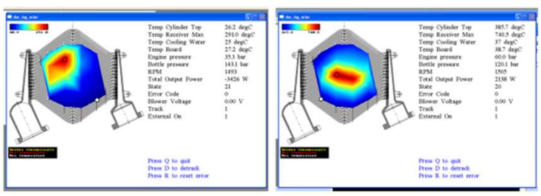
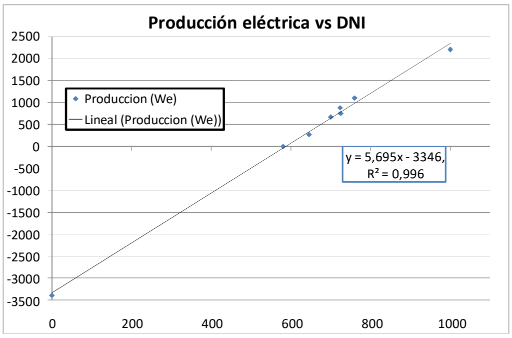


Image 1.- Starting engine behavior.

The left side of the picture 2 shows the monitoring screen engine during system startup. It can be observed power consumption 3.4 kW and in system temperatures early in the morning. The right side of the image 2 presents the motor generating the maximum power of concentration prototype surface (29 m2). The power exported to the grid is 2.1 kW electric.



Graphic 1.- Power versus DNI.

in Graphic 1 a good linear correspondence with experimental results is displayed. Importantly, in these operating conditions the Stirling cycle has a yield close to 20%. From 30% engine load up to full load, its thermal / electrical efficiency reaches 25%. In relative terms they may be obtained 20% more electrical power simply by having a larger concentrator.

5.- Discussion.

The developed and tested system presented in this article is a promising technology. One of the main advantages presented is the position where the Stirling engine is placed. The engine is placed in the shadow of concentrator, for this reason, the engine working environment is more appropriate. Both the working temperatures as ease to evacuate the heat in the cooling system are better than other types of dishes.

The demonstrator prototype has a good performance in energy generation versus DNI received. Considering the handcrafting of the concentrator with a measured efficiency of 66%. The surface finish is far from injected concentrator.

6.- Conclusion and future work.

a) A technology demonstrator has been designed and built up.

b) The prototype has shown the availability of this technology.

c) Net energy production is positive, even when the contractor is handcrafted and 3 times smaller than the commercial one.

d) Tracking control system is more accurate than needed, so system performance is good enough.

e) Experimental measures were taken and concentrator behavior is parametrized. Thus the theoretical models have been validated.

f) Some prizes were delivered as well as grant and financial support. The highlighted prizes are: Green Grant Engineering from National Instruments, “50 EmpresasInnovadoresen un Click” From Ministry of Science and Technology.

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