INTERNATIONAL JOURNAL of ENGINEERING SCIENCE AND APPLICATION
Toygar et al., Vol.2, No.1, March, 2018

New Design of Solarux CSP Greenhouse, Produces And Dries Agricultural Products In Addition To Electricity Generation

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Received: xx.xx.xxxx Accepted:xx.xx.xxxx

Abstract- As we all know, world population is growing rapidly in recent decades. That comes with a significant increase in energy demand, and most used energy resources are harmful to the environment. Aim of this paper is to design and develop a Greenhouse system that generates the electricity by CSP dish mirrors which are on the roof of greenhouse, produces agricultural products and dries agricultural products with the remaining energy from the electricity generation. CSP dish mirror design has the features of parabolic mirror system but Solarux system has flat mirrors instead of high cost parabolic mirrors, so it is much cheaper. Also Solarux system follows the sun in two axis, which increases its efficiency. Agricultural production and product drying in greenhouse provides extra incomes to the system, so cost effectiveness of the project increases. It will be possible to grow agricultural products, dry agricultural products and generate electricity for 12 months in the greenhouse with this presented project. Solidworks 2016 program package has been used for the designing the parts of the greenhouse.

Keywords Greenhouse, two axis tracking, CSP, agricultural production, electricity generation

1. Introduction

Familiar energy resources like fossil fuels and natural gas, which are harmful to the environment, have been using to satisfy the growing energy demand but it can no longer meet the need. The new energy resources are required and one of the most effective and environmental friendly technology is the concentrated solar power, which uses the mirrors to concentrate the sun's rays. In sunny developing countries such as Africa, Asia and South America, CSP is the promising technology for the future, and designing such a system has low cost and effective is challenging [1]. In spain there are several large CSP plants planned [2]. Within the United States, CSP plants have been operating more than 15 years and CSP Technologies offer a great opportunity for local manufacturing. Therefore, the economic development and job creation can occur. Four type of CSP system that exist in the World, are Parabolic Through Systems, Dish Stirling Systems, Linear Fresnal Systems and Parabolic Dish Systems [3-5].

CSP technologies collect solar energy and convert it to thermal energy, which can be stored and can be used as a flexible provider of electricity, such as a natural gas plant. Parabolic through system is the line focus system that use curved mirrors to focus sunlight on a receiver; but have only one axis tracking system [6]. Linear Fresnel System is the line focus system that use flat mirrors arranged to focus sunlight on a receiver. During process, water is boiled and turns into saturated vapor to convey heat energy for industrial usage [7]. Dish Stirling system tracks the sun and focuses solar energy into a cavity receiver where it is absorbed and transferred to a heat engine/generator. Stirling motors, which have the capacity between 2 to 50 kW per one system, are used in Dish Stirling systems[8]. When the Dish Stirling system is compared with parabolic through system, it has low efficiency then parabolic through systems. Parabolic Dish Stirling system is one type of concentrating solar power technology and can use only the direct component of incoming solar diffuse and direct solar radiation (beam radiation).

In December 2014, Aalborg CSP was selected to design and deliver the world's first integrated system based on the concentrated solar power (CSP) technology for the sustainable operation of sun drop farm's new greenhouse facilities. In the Sahara Forest Project seawater-cooled greenhouses and CSP technology are linked together. Therefore, water cooling towers of a CSP plant are replaced with a seawater cooling system that utilizes the greenhouse roofs to dissipate the waste heat from the CSP process.

There are several arrangements of mirrors that can be utilized to focus the energy to achieve the high temperatures required. Tower systems are a field of mirrors that can be stored in two dimensions to focus the sunlight onto a receiver on top of a tower. Through systems used curved mirrors into parabolas to focus the sun onto a pipe receiver mounted at the focal point. Fresnel systems use an array of long flat mirrors mounted horizontally that rotate to focus onto a pipe suspended above the mirrors. For some industrial and residential energy needs, new approach such as Solarux CSP system has been designed [9-12].

In general, solar thermal technologies are based on the concept of concentrating solar radiation to produce steam or hot air, which can then be used for electricity generation using conventional power cycles. Collecting the solar energy, which has relatively low density, is one of the main engineering tasks. In this study, it has been focused on CSP technologies, and to design and develop CSP greenhouse system that generates the electricity, produces and dries agricultural products, and it has flat mirrors to concentrate the sun rays, which has the features of parabolic mirror system that follows the sun in two axes. The main idea of the design is that the low cost and high performance than parabolic mirrors.

2. Description of the Greenhouse System

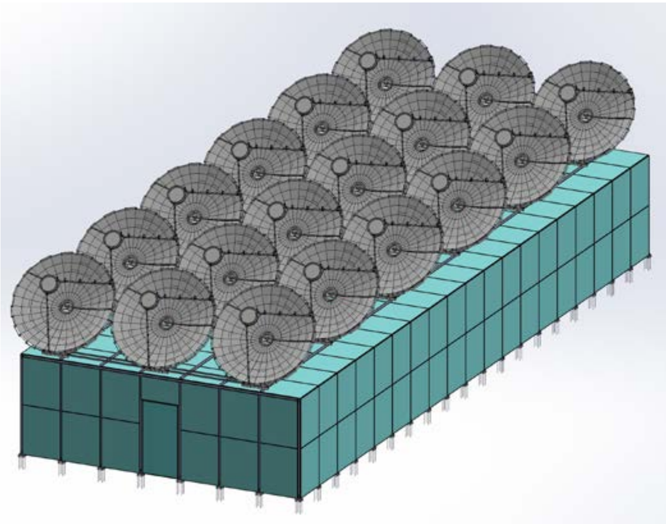

Figure 1. Outside view of the Solarux CSP Greenhouse

In this study, greenhouse with concentrated solar power (CSP) dish mirrors, which uses flat mirrors to focus the sun's rays is designed and developed to generate heat and electricity and also to produce agricultural products and dry them with the remaining energy (see Figure 1). St37 materials have been used as main profiles in the greenhouse. The glass greenhouse consists of tempered glasses that pass into the aluminum profiles. Tempered glasses provide high protection of products grow inside the greenhouse. Agricultural products are dried in the Agricultural Product Dryer, so value of the products increases. 12 months of the year, agricultural production and product drying can be done. During the cold weather, the heating of greenhouse is accomplished by hot water pipes passing through the heating pipes located on the sides. The temperature and humidity of the greenhouse is quantified and reported to the center, and automated irrigation and ventilation are performed. During the hot weather, to remain cool inside of the greenhouse, the mirrors are revealed to the needed angle so that the incoming sun rays are reflected out.

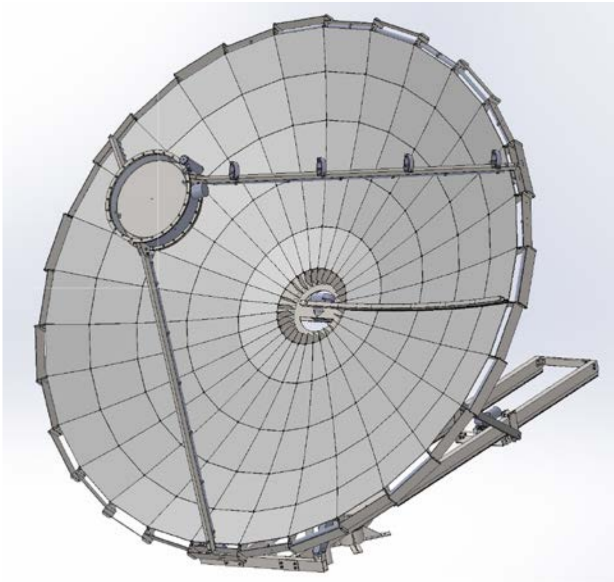

Figure 2. Dish Mirror Design

As it is seen from Figure 2, the mirror system of Greenhouse has flat mirrors, which focus the sun ray's and have also properties of parabolic mirror system. It follows the sun perpendicularly through the two axes via the computer to get high temperatures on the concentration surface. Then, CSP greenhouse system has higher performance and lower cost with respect to parabolic mirror system. During the data collection it is seen that, the CSP Greenhouse system has 30% more energy than European-based system, which has one tracking axes. In Solarux CSP system, dish mirror follows the sun with 0.1 degree precision. Since the each piece used in modular and can be altered when worn. The lifetime of the CSP dish mirror system is unlimited.

Each mirror autonomously operates by itself and due to this situation there is no need to shut down other valves in the system during the replacement. On the other hand, while the mirror system is being repaired, other mirrors can continue to produce electricity or process heat due to modular effect. The parts are mounted with bolts and nuts to prevent the decrease in strength during heat treatment in welding process. Laser cutting method is used in design.

Figure 3. Dish Mirror Design

There are 18 CSP dish mirrors on the roof of the greenhouse. (See Figure 3) Dish mirrors are attached to the St37 profiles on the roof by bolts and bolt nuts. Those profiles are supported by other St37 profiles as it seen from figure 3. With this new design of the greenhouse, almost every kind of fruit and vegetable can be grown inside of the greenhouse, so the depreciation period of the system lowers easily.

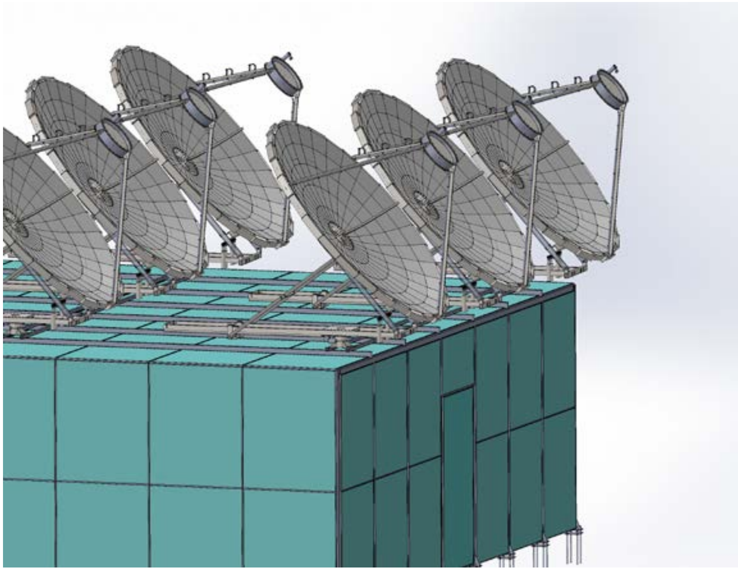

Figure 4. New Dish Mirror System

3. Background of CSP System

New Solarux CSP system on the roof of the Greenhouse (see Figure 4) has many advantages over the former system. In the developed project the absorber surface temperature at the dish will be increased by increasing the number of flat mirrors from 96 to 150. Therefore, the efficiency will be increased by increasing temperature of hot oil in the absorber. The components of the CSP system have been designed under the laser cutting method, and are connected with bolts and nuts. The cost will be reduced easily because of each dish mirrors will be controlled with a single automation system. Horizontal angle of mirrors is determined precisely by rack and pinion mechanism which is connected with new designed car system (see Figure 5). Car system prevents low efficiency due to the shadow on the mirrors created by rack.

In the previous one, each dish mirror had its own automation system and the angle of mirror was determined by screw thread mechanism. All the bearings of the dish mirrors inside the greenhouse are dry bearings and they are teflon materials. But in the previous project, all the bearings work with the oil system, which causes oil flow to the ground.

Figure 5. Car System of the Dish mirror

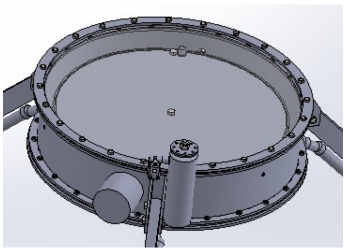

Figure 6. Heat Exchanger of the Dish System

Heat exchanger of the system (see Figure 6) is located at the focal point of the flat mirrors. Heat exchanger surface heats up to 500 ^{0}C because of the sun rays. Oil pumps with oil pump and heats up to 325 ^{0}C while passing through the heat exchanger, and pumps to the Heat Storage Battery (see Figure 7a) with another oil pump. In the developed system, solid mass is located in aluminum pipes and hot oil flows on the outer walls of the aluminum pipes (see Figure 7b). The hot oil comes from the absorber is delivered to the heat storage boiler cell and the energy is stored in the solid bars in the heat bath by the solid depolarization method. Aluminum pipes provide extra heat storage capacity and repairing capability in case of any fault in the heat storage battery. Therefore, faulty pipes can easily be removed from the battery and replaced. It is not needed to weld the pipes. Hot oil doesn't contact with solid masses, so no shortcoming take place in the solid mass. Heat Storage Battery is coated with special insulation materials to minimize the heat loss, and placed on a tray to provide extra security in case of failure.

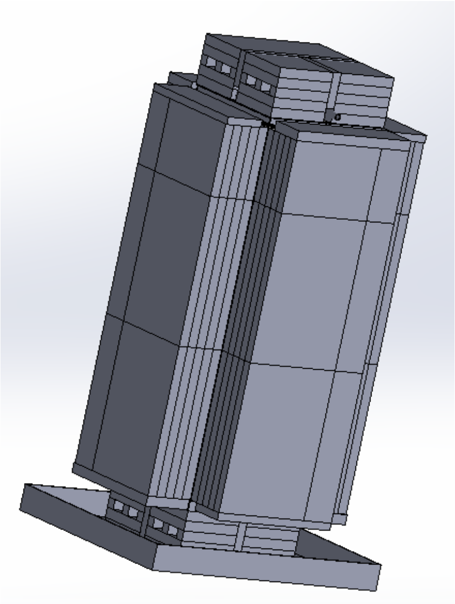

Figure 7a. Dish Mirror Design

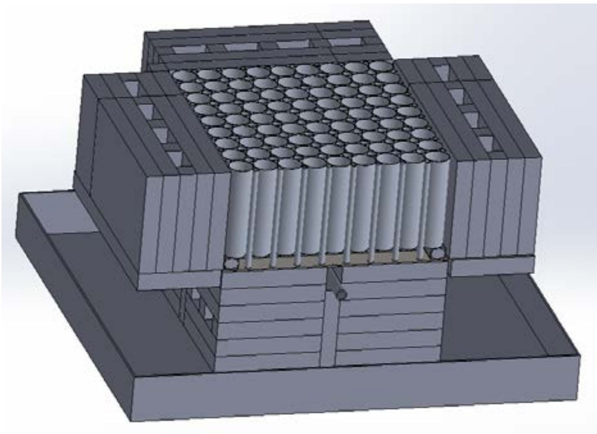

Figure 7b. Dish Mirror Design

The greenhouse can be heated by the hot water obtained by the energy stored in the Heat Storage Battery. Water heated by the energy stored in the solid masses of Heat Storage Battery circulates in the hot water pipes, which are passing around the greenhouse. To produce electricity, the steam generated by the energy from the Heat Storage Battery is sent to reciprocating steam motor and electricity is produced by the AC Generator. Waste steam from the electricity generation is sent with pipes to the Agricultural Product Dryer (see Figure 8) to deplete agricultural products without any consumption of electricity. The energy is obtained from the waste steam is transmitted through the fans of the dryer to deplete the agricultural products with this heated air.

Assistant fasteners such as gaskets and washers that is used in oil pump system exposed to high temperatures approximately 300-350 ^{0}C. Then, the oil pump connected to the motor shaft is removed from the motor by an assistant shaft attachment for the cooling process, and the cooler is located beside the oil pump.

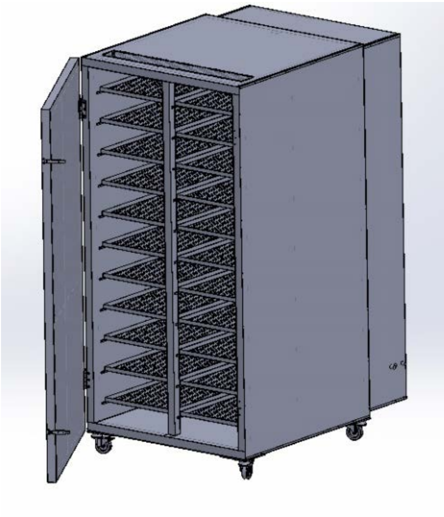

Figure 8. Agricultural Product Dryer

The important point of dryer in our Project is that the heat energy is supplied by waste steam, while it is provided by electricity in the other projects. The air, which is heated by this energy, is transmitted through the fans by special cannels to the salver to be dehydrated. In the agricultural product dryer, the temperature level can be adjusted to the desired value with the speed control of the fans.

Figure 9. Dish Mirror Washing System

In the previous system there is no exchanger glass washing system. In the developed one, as seen from Figure 9, half of a V-type guide, a nozzle and a washing valve at the end of the washing pipe, the lower glass of the heat exchanger is cleaned with pressurized water. The water comes out of the heat exchanger and cleans the mirrors through the wiper (see Figure 10) due to dust collecting in the lower part. Therefore, the intensity of sunlight reflected by mirrors will increase.

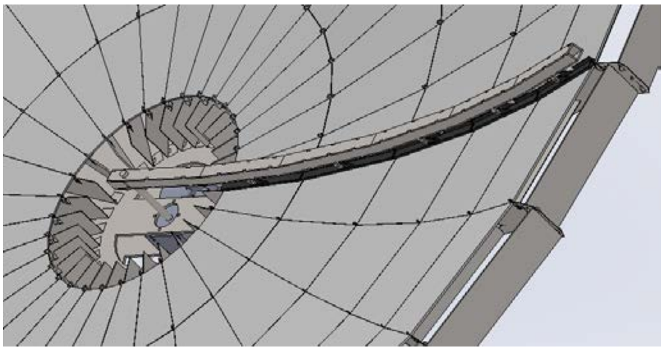

Figure 10. Dish Mirror Wiper

4. Comparision of Developed System With Other Available Systems

There are similar systems in CSP technology. However, as shown in Table 1, some fundamental differences have allowed the developed CSP technology to be separated from other systems. These differences are as follows: the mirrors that are used, the tracking system, the energy loss due to the sun, the absorber type, the heat transfer material, the maximum temperature that can be reached, the modular installation possibility, heat storage capability, production cost of electricity generation and the motors used in automation.

There are several advantages because of these differences. In the first developed system, instead of high cost parabolic mirrors, industrial low cost flat mirrors were used.

All other systems have disadvantages to the Solarux system in steering. The losses in the tower system are due to the fact that the mirrors in the system are far away from the tower (in some cases 500 m), although the two axes are directed.

In windy weather, a deviation of 0.5 degrees due to the shaking of the system at a distance of 500 meters corresponds to a deviation of 4.5 meters in the absorber at the head, which reduces the efficiency of the entire system. In windy weather, there are deviations but there is no loss in the Solarux system because the distance of the absorber is 4-5 meters and no loss at focal point of at absorber because it shakes with the system. The deviation of the sun rays in the absorber does not exceed 1-2 cm. Because the Paraboloid and Fresnel systems follow the sun in one axis, there is a natural loss of up to 30% in these systems compared to the double axis tracking. In the Solarux system and the Paraboloid system, the absorber is vacuumed, which prevents heat loss in a very large amount. There is no vacuum in Tower and Fresnel systems where the heat losses from free convection and heat communication are high.

In the Solarux system, air and oil are used for heat transfer. In tower systems, air or liquid salt is used and liquid salt causes big problems at high temperatures because of material types. Only oil is used in the paraboloid system. The temperature to be reached due to the pressure of the oil at high temperatures is limited. Water is used in the Fresnel system where the temperature does not exceed 3000 ^{0}C due to the high pressure that the water vapor creates in the pipes

The temperature that can be reached when using oil in the Solarux system is 3500 ^{0}C and the temperature that can be reached when the air is used is around 8000 ^{0}C. With the Solarux system, the temperature can rise to 30000 ^{0}C, if it designs to have 350 flat mirrors, but the material temperature tolerance is limited to 800 °C. The other systems do not reach these temperatures. The tower system can reach 8000 ^{0}C, but the temperature suddenly drops in the wind when the mirrors

TABLE 1: COMPARISON OF THE SOLARUX SYSTEM WITH OTHER SYSTEMS

	Mirrors	Tracking	Energy Loss %	Absorber type	Heat Transfer Material	Maximum Temp. reached	Modular installation possibility	Heat storage capability	Production cost of electricity generation	Motors used in Automation
Tower	Parabolic	Two axis	20-25%	Square shaped vacuum	Hot air, liquid salt	700-80^{0}C	None	Available	2.1 Euro/kWh	Servo, Step Linear
Paraboloid	Parabolic	Single axis	30%	Tube shaped vacuum	Oil	550-600^{0}C	None	Available	2.0 Euro/kWh	Servo, Step Linear
Fresnel	Flat	Single axis	30%	Tube shaped vacuum	Water, steam	250-300^{0}C	None	None	1.4 Euro/kWh	Servo, Step Linear
Solarux	Flat	Two axis	0	Circular absorber made of glass vacuum	Oil,water, steam	350-3000^{0}C	Available	Available	0.5 Euro/kWh	Asynchronous

are shaking, so Tower systems are not designed to work at these temperatures. Due to the oil pressure in the paraboloid system, maximum 5500 ^{0}C can be reached and in Fresnel systems, 3000 ^{0}C can be reached due to vapor pressure.

Solarux system is a system can be installed on all kinds of terrain. The tower, paraboloid and Fresnel systems must be installed on flat terrain because of their constructional properties. This means that the establishment of expensive lands such as plains or highlands.

Only the Solarux system can be installed modularly. If a part of the entire installed system fails, the remaining part may continue to operate. Paraboloid and Frensel systems should be deactivated if there is a problem in the absorber or on the line, or mechanical, or on the mirror. In the Solarux system, only the faulty mirror is deactivated, but the entire system continues to operate. On the contrary, if there is a fault in the absorber in the tower system, the entire installation must be shut down.

Solarux, Tower and Paraboloid systems have the possibility of storing heat but there is no such possibility in the Fresnel system because of the steam is used directly. This means that overall efficiency of the system will reduce because it cannot be used at night.

In Tower, Paraboloid and Fresnel systems, servo, step and linear motors are used. The cost of these motors and drivers is very high and they are not manufactured in many countries. Solarux system uses cheap asynchronous motor and drivers which are cheap and can be found easily.

Tower, Paraboloid and Fresnel systems are based on RS485 network system. Solarux system is based on the I2C based network system that Solarux Company has developed.

Solarux system is much cheaper than the Tower, Paraboloid and Fresnel systems, as indicated on the Table 2.

TABLE 2. COST COMPARISON OF SOLARUX SYSTEM WITH OTHER SYSTEMS IN THE WORLD

Tower system	Yearly production=110 GWh/a, Installation cost =230.000.000€
	Installation cost based on electricity generation yearly =2.1 €/kWha
Paraboloid system	Yearly production =160 GWh/a, Installation cost =320.000.000€
	Investment cost based on yearly production =2.0 €/kWha
Fresnel collector system	Yearly production =50 GWh/a, Installation cost =70.000.000€
	Investment cost based on yearly production =1.40 €/kWha
Solarux System	Yearly production =5.302.800 kWh/a, Installation cost =3.977.100 €
	Investment cost based on yearly production =0.75 €/kWha

5. Conclusion

In this presented project, it is aimed that to use CSP technology has high cost of investment with greenhouse to provide extra incomes in addition to electricity generation. With agricultural production and agricultural product drying with waste steam from the electricity generation, additional incomes provided and depreciation period of the investment shortened. The average duration of greenhouse usage, which is 7 months in Turkey, has been increased to 12 months in a year with the usage of the CSP mirrors in the greenhouse, so production has been increased and has become better quality. Thanks to CSP mirrors, agricultural production and agricultural product drying in the greenhouse are possible without using extra fuel and energy.

With the special aluminum profiles and tempered glasses used, the modular, quick and low cost installation of the greenhouse is possible. New Heat Storage Battery design provides higher energy storage capacity than other systems in the world, and can be repaired in case of failure. With the Agricultural Product Dryer runs with waste steam, agricultural products can be added to extra value by drying. Electricity generation, agricultural production and agricultural product drying can be done 12 months in the year.

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