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G.A. PILAWJIAN

LENS REFRACTING COST EFFECTIVE PHOTOVOLTAIC SOLAR ENERGY CONCENTRATING SYSTEMS

The overall cost reduction task is studied for photovoltaic (PV) solar energy systems. For that purpose, a new, cost effective lens refracting system is developed. The concentrating system consists of Fresnel lenses placed under different facet angles refracting the sun light onto the solar cells placed along a line. The developed photovoltaic concentrating system uses the mathematical model of Fresnel lens concentrating optics for photovoltaic systems used to optimize the system by cost. A computer program FLCPVSys2.1 for the new concentrating system is developed allowing to design a photovoltaic system of the required power with the minimum cost. The program can be used for designing a cost effective photovoltaic solar concentrating system.

Keywords**:** Photovoltaic; Concentrator; Lens; Refraction; Cost; Effective.

Introduction. The high cost of photovoltaic (PV) modules makes the use of concentrators desirable and very demanded, because concentrators decrease the total cost of PV modules. Optical concentration offers an excellent and effective approach to the reduction of the PV system's high cost by substituting the solar cells by concentrator area. At present, different types of sun concentration systems are used to reduce the high cost of flat PV modules. For concentration, solar energy designers can use either light refraction (using Fresnel Lens) or light reflection (using mirrors). The Fresnel lens can either be circular lens to focus the sun light on a single cell, or linear lens to focus sun light on a row of cells. Amonix (US, California) uses an array of point-focus Fresnel lens [1, 2], Fraunhofer ISE (Freiburg, Germany) and Loffe institute (St. Petersburg, Russia) also use point-focus Fresnel lens in the concentrator PV syste-ms' design [3]. The US company ENTECH has developed line-focus Fresnel lens modules [4]. Each module uses rows of silicon cells operating at 20-suns concentration.

Besides the use of lenses, it is also possible to use mirrors to concentrate the sun light. Solar systems in Australia have developed a dish concentrating PV systems [5]. The EUCLIDES concentrating array consists of a mirror reflecting parabolic trough tracking the sun around the horizontal axis [6].

All the previously mentioned designs are different having various structures, concentrating optics, concentrating ratio, tracking system, solar cells' cooling designs and also they have a wide variety of designs. It is worth to mention that the cost reduction of PV concentrating systems is a must because most existing PV concentrating systems are still expensive, moreover concentrating systems are very clean, noiseless and belong to Green technology.

Structure of Photovoltaic Concentrating Systems. The basic disadvantage while dealing with solar energy is to efficiently collect this energy and cost effectively convert it into electricity. The existing solar generating systems are still too expensive. Electricity from solar electric systems is more expensive than that produced by conventional electric generation systems. For this reason and not only, it is extremely important to develop cost-effective solar electric systems. The structure of the new cost effective photovoltaic (PV) concentrating system is a lens refracting linear focus type. The concentrating system consists of Fresnel lens placed under different Fresnel facet angles which are refracting the sun light onto the solar cells mounted along a line. The Fresnel lens is placed at a specific distance from the cell called focus distance. To design the new Fresnel lens refracting cost effective photovoltaic system with different powers, a special computer program is developed. The program allows to optimize the concentration ratio and to design a cost effective photovoltaic system having an optimized cost.

Computer program for optimization and a cost effective PV system design. In order to develop a computer program capable of designing an optimized and cost effective PV concentrated system, we need to develop a mathematical model competent of giving the computer program the ability to calculate the Fresnel lens facet angles based on the given parameters [7].

In addition to the mathematical model, and in order to determine the optimal concentration rate of Fresnel lens refracting linear focus PV concentration system, a cost optimized algorithm is also developed. The algorithm is based on optimal concentration rate needed in order to get most effective and minimal cost. The algorithm passes through many calculation iterations to determine the cost of the concentration system by increasing the concentration by 2 facets per iteration, starting from one sun.

By increasing the number of facets by 2, we are increasing the concentration rate, and, at the same time, the cost of the concentration system starts decreasing, and after some iterations, the cost starts to increase due to the ineffective addition of the facets due to the total internal reflection which will not be able to refract the sun light effectively to reach the solar cell, this causes an increase in the concentration system cost, without being effective. Realizing the fact of the cost change from a low cost to a higher one will help to determine which cost to select, which is the main goal of this article. The effective cost of Fresnel lens linear focus PV concentrating system picks up one iteration before the cost starts increasing. To realize this optimization and the automated design of PV system, the computer program FLCPVSys2.1 is developed. The home page of the computer program is presented in Fig. 1.

For the given values of generated electric power, temperature (ambient and permissible working temperature of the solar cell), solar radiation (based on the location of the solar concentrating system's manufacturing), parameters of the solar cell, focus distance, constructive material; transportation; solar array installation; heat sink; Fresnel lens manufacturing prices in addition to many other parameters, the computer program calculates the costs of the concentrating system by changing the concentration rate and shows the value of concentration rate when the minimum cost is obtained.

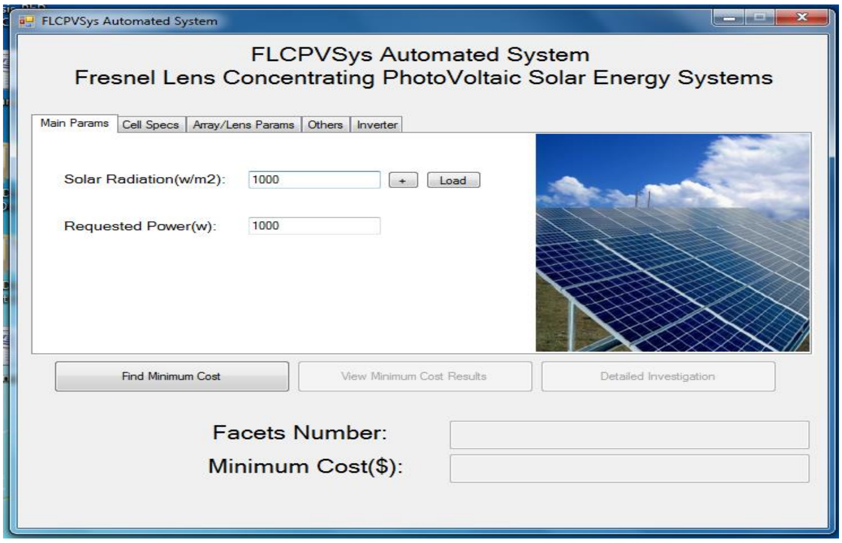

Fig. 1. Computer program home page

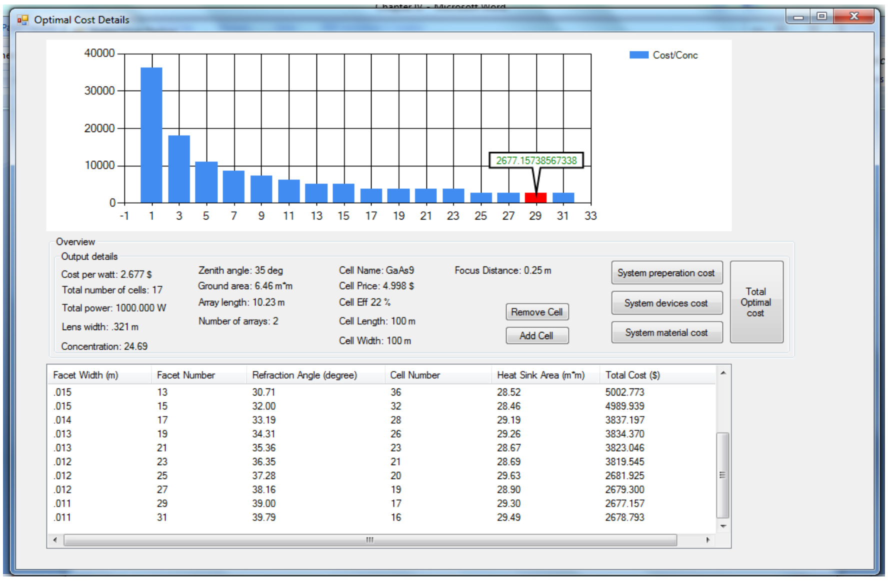

Fig. 2. Dependence of the PV concentrator system cost on the concentration rate and all the required data (Current option)

As an example, the concentration rate optimization curve obtained for the 1 *kW* photovoltaic system in addition to all details needed for manufacturing the Lens (Facets number, Facet width, Refraction angles), the number of cells needed to generate the required power, cost per watt, and heat sink temperature change are presented in Fig. 2.

For solar array manufacturing, installing and transporting convenience the solar cells implanted per solar array does not cause the array to be very long so that it should be used for both small (home) and large (company) efficiently. Based on these facts each solar array will consist of 20 solar cells only. The developed program is not cost affected while determining the optimal facet refraction angles of the Fresnel lens (based on the focus distance) by the critical angle of the Fresnel lens because the program finds the critical angle of incidence which causes total internal reflection causing no more concentration but cost. Therefore finding the critical angle helps to determine the cost effective photovoltaic system.

The computer program does not only calculate Fresnel lens refracting PV solar energy concentrating system optimized cost based on the required power, but also gives the designer an opportunity to get a more optimized cost per watt based on implanting the missing solar cells in the last solar array. This technique will reduce the c ost per watt generated as shown in Fig. 3 and Tables 1, 2.

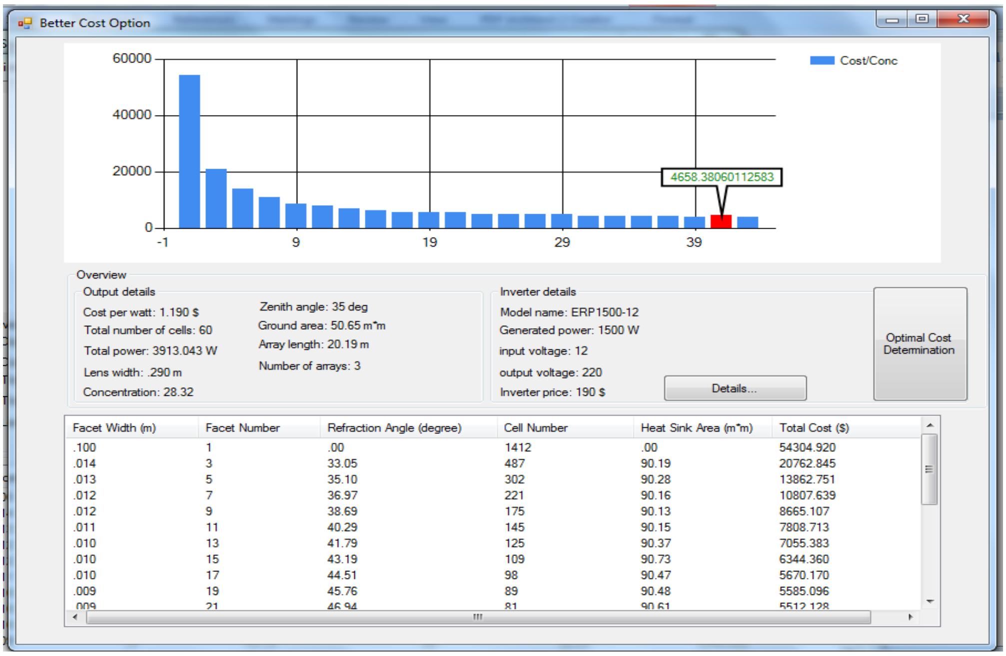

Fig. 3. Better dependence of the PV concentrator system cost on the concentration rate and all the required data (Better option)

Table 1

Dependence of the required and generated powers on the cost per watt when the last solar array misses solar cells

Required Power (*KW*)	Solar cells required	Lens Width (*m*)	Cost per watt (*$/w*)	Power Generated (*KW*)
1	25	0.226	1.649	1
2	35	0.271	1.249	2
10	97	0.379	0.971	10
12	111	0.391	0.962	12
15	128	0.412	0.939	15

Table 2

Dependence of the required and generated powers on the cost per watt when the last solar array is saturated

Required Power (*kW*)	Solar cells required	Lens Width (*m*)	Cost per watt (*$/w*)	Power Generated (*kW*)
1	40	0.226	1.168	1.6
2	40	0.271	1.125	2.28
10	100	0.379	0.946	10.31
12	120	0.391	0.9	12.97
15	140	0.412	0.869	16.41

The program allows to determine the optimal concentration rate which provides the minimum cost of Fresnel lens refraction linear focus PV concentration system.

It is obvious from tables 1, 2 that the Fresnel lens refraction linear focus PV concentration system cost per watt decreases with increasing the required power of the system, and that the cost per watt calculated by FLCPVSys2.1 program is competitive in comparison with other well known PV concentration systems as shown in Table 4.

All input parameters and some results obtained from the computer program are presented in Table 3.

Table 3

Input Parameters and obtained results

Required Power (*kW*)	**1**	**10**	**100**
Solar Radiation (*W/m*^{2})	850	850	850
Solar cell efficiency (%)	25	25	25
Max. Allowable solar cell temp. (*Cent.*)	60	60	60
Ambient solar cell temp. (*Cent.*)	40	40	40
Cell Price (*$*)	15	15	15
Lens Price (*$*)	20	20	20

Table 3(continued)

Array Installation (*$*)	25	25	25
Array Transportation (*$*)	20	20	20
Array Fabrication (*$*)	25	25	25
Constructive Material (*$*)	100	100	100
Inverter Price (*$*)	50	50	50
Convertor Price ($)	150	150	150
RESULTS OBTAINED			
Cost/watt ($/W)	1.168	0.946	0.866
Power Produced (KW)	1.604	10.31	100.74
Array Width (m)	0.226	0.379	0.477
Concentration rate	23	77	155
Cells required	40	100	680
Arrays required	2	5	34

The program allows not only to determine the optimal concentration rate, but also determine the heat sink area needed to keep the solar cells per array in their best efficiency, moreover, the program determines all the necessary parameters to manufacture the Fresnel lens per solar array. In addition, the program gives the designer all details per one solar array (solar cells cost, Fresnel lens area and cost, the power produced and the total array cost).

Table 4

Results for cost per watt of FLCPVSys2.1 compared to well known PV concentrating systems

Software/Institute	Required Power (*W*)	Solar Radiation (*W/m*^{2})	Focus Distance (*m*)	Cost of watt (*$/W*)	FLCPVSys2.1 cost of watt (*$/W*)
CPVCAD/ SEUA [8]	500	1000	0.3	2.88	1.168
PVCsyst1.2/ SEUA [8]	1000	850	0.5	1.48	0.920
Germany Spain Project [9]	1000	850	0.5	2.02	0.920

The results obtained in Table 4 by the new cost effective Fresnel lens refraction type PV solar energy concentration system FLCPVSys2.1 (costs in red) under the same conditions of temperature, solar radiation, constructing materials cost, and focus distance are competitive compared to the projects mentioned.

Conclusion. At present, several companies have developed and installed reliable PV concentrating solar energy systems. The price of the existing PV concentrating systems is high. The developed new cost effective Fresnel lens refraction type PV solar energy concentration system has several advantages in comparison with the well known systems.

The developed optimized method, algorithm and computer program allow to design cost effective Fresnel lens refracting linear focus PV solar energy systems.

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Գ.Ա. ՓԻԼԱՎՋՅԱՆ

ԱՐԵՎԱՅԻՆ ԷՆԵՐԳԻԱՅԻ՝ ՈՍՊՆՅԱԿԱՅԻՆ ՏՆՏԵՍԱՊԵՍ ՇԱՀԱՎԵՏ ՖՈՏՈԷԼԵԿՏՐԱԿԱՆ ԿՈՆՑԵՆՏՐԱՏՈՐԱՅԻՆ ՀԱՄԱԿԱՐԳԵՐ

Ուսումնասիրված է արևային ֆոտոէլեկտրական էներգետիկ համակարգերի ընդհանուր ինքնարժեքի իջեցման խնդիրը: Մշակվել է նոր, արդյունավետ ոսպնյակային համակարգ: Ոսպնյակային կոնցենտրատորը կազմված է տարբեր անկյուններով տեղադրված ֆրենելյին ոսպնյակներից, որոնք բեկում են արևի ճառագայթները դեպի ուղիղ գծով տեղաբաշխված արևային մարտկոցները: Մշակված ֆոտոէլեկտրական կոնցենտրատորային համակարգի հիմքում ընկած է ֆրենելյին ոսպնյակների օպտիկական համակարգի մաթեմատիկական

մոդելը, որն օգտագործված է որպես ինքնարժեքի օպտիմալացմանն ուղղված հիմնական գործիքամիջոց: Կոնցենտրատորային նոր համակարգի համար մշակվել է քոմփյութերային ծրագիր, որը թույլ է տալիս նախագծել ֆոտոէլեկտրական արդյունավետ համակարգ՝ պահանջվող էլեկտրական հզորությամբ և նվազագույն ինքնարժեքով: Ծրագիրը կարող է օգտագործվել տնտեսապես շահավետ ֆոտոէլեկտրական արևային էներգիայի կոնցենտրատորային համակարգեր նախագծելու համար:

Առանցքային բառեր. ֆոտոէլեկտրական, կոնցենտրատոր, ոսպնյակ, բեկում, գին, արդյունավետ:

Г.А. ПИЛАВДЖЯН

ЛИНЗОВЫЕ ЭКОНОМИЧЕСКИ ЭФФЕКТИВНЫЕ ФОТОЭЛЕКТРИЧЕСКИЕ КОНЦЕНТРАТОРНЫЕ СИСТЕМЫ СОЛНЕЧНОЙ ЭНЕРГИИ

Исследована задача снижения общей себестоимости фотоэлектрических солнечных энергетических систем. С этой целью разработана новая, экономически эффективная линзовая система. Концентраторная система состоит из расположенных под различными углами линз Френеля, которые преломляют солнечный свет на солнечные батареи, расположенные вдоль линии. В разработанной фотоэлектрической концентраторной системе используется математическая модель френельной линзовой концентраторной оптики, которая позволяет оптимизировать систему по себестоимости. Разработана компьютерная программа для новой концентраторной системы, позволяющая спроектировать фотоэлектрическую систему данной требуемой мощности с минимальной стоимостью. Программа может быть использована для проектирования экономически эффективных фотоэлектрических солнечных концентраторных систем.

Ключевые слова: фотоэлектрический, концентратор, линза, преломление, цена, эффективный.