Implementation of the Movable Photovoltaic Array to Increase Output Power of the Solar Cells

Hassan Moghbelli*, Robert Vartanian**

*** Texas A&M University, Dept. of Mathematics**
****Iranian Solar Energy Society**
***Isfahan University of Technology, Dept. of ECE**
moghbeli@math.tamu.edu , vartanian@irses.org

Abstract

Photovoltaic converters are important converters for the application of renewable energy sources because of the direct conversion of solar energy to electric energy. They have some advantages such as low weight and feasibility of small scales, but they are more expensive compared to other types of energy converters. Therefore, it is important to absorb the maximum solar energy in order to increase the efficiency of the energy converter.

Because of the daytime motion of the sun, sunlight always radiates indirectly on solar arrays and some part of the light is reflected from the surface of the solar cells where incomplete absorption of the solar energy occurs. Using the movable solar array or solar tracker is one method to increase the output electric energy of photovoltaic converters. This can be done in such a way that the photovoltaic arrays follow the sun continuously in daytime and sunlight can be radiated to solar cells directly where maximum electric energy can be generated.

This paper discusses the implementation of the movable array in photovoltaic converter and its effect on increasing the output power characteristics compared to the fixed array with the same nominal power. Finally the test results are shown and discussed in the paper.

Key words: Solar Energy, Solar Cell, Photovoltaic, Tracker, Movable Array

1- Introduction

Solar energy is one type of the renewable energy sources which can be converted easily and directly to the electric energy by Photovoltaic converters. The process of no movable mechanisms to convert solar energy to electric energy is called photovoltaic phenomena whereas the conversion device is called solar cell [1].

Solar cells convert the energy of light's photons to electric energy with efficiency between 5 to 25 percent without using thermodynamic cycle or active fluid. Solar cells can be light collector directly or can use light concentrators like mirror or convex lens.

This photovoltaic converter is a developed energy converter with the advantages such as: relevant design and installation, silent energy conversion, long life time with less maintenance requirement, easy transportation and light weight. But in compare with other types of energy converters like diesel generator it is more expensive. Therefore, the optimum operation and the maximum energy absorption from solar cells are important factors [1,2].

Due to the high cost of the solar array, the angle between solar radiation and collector surface affects on the energy absorption, it is important to provide some conditions to absorb the maximum solar energy and then convert it to electric energy for optimum converter operation. Because of the low efficiency of the solar cells (less than 12%) and due to the high price of them in compare with other energy converters, it is important to convert and absorb the maximum electric energy from the PV-array.

Using movable photovoltaic array to follow the sun during the day and providing a condition in that the solar light directly radiates on the solar cells will optimize energy conversion. In this paper, the power-voltage characteristics of a movable photovoltaic array are compared with a fixed one during a summer day.

2- Effect of Light Radiation Angle on Photovoltaic Output Power

In a photovoltaic converter, the energy of absorbed photons is converted to electric energy by the solar cell. Therefore, the output electric power depends on the radiation angle of the sun light. The electric characteristics of the solar cells change due to the variation of the generated electrons with light intensity. Fig.1 shows the current-voltage characteristic of a sample solar cell [3]. The generated current by the solar cell has a large variation from light intensity changes. As a result, the output power of the solar cell can changes and the photovoltaic array can generates electric power less than its nominal power.

Due to the motion of the sun, the sun light always radiates on the surface with different angel during the day and it is not perpendicular for a fixed PV-array whereas it can be designed to be always perpendicular for a movable array with full degree of motion.

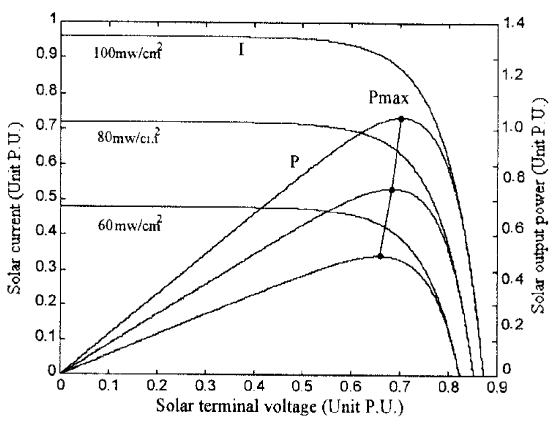

Fig.1: Variation of sample solar cell output characteristics with light intensity changes [3]

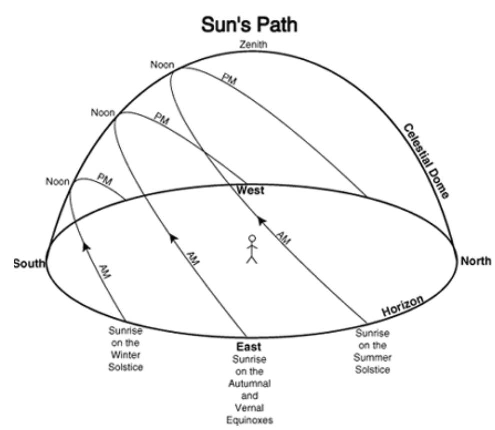

Fig.2: Variation of sun motion path during the year [4]

The sun light always radiates on the surface of the fixed collector with various angles during the day and because of the light reflection form the surface of the collector, fully absorption is not possible and this problem becomes important in the photovoltaic converters due to the expensive solar modules.

There is a traditional method to install the fixed PV-arrays where usually they are installed with a tilt of the 90 to 100 percent of the installation place latitude directed to the south (in north hemisphere). This type of installation causes loss of significant part of solar radiation energy because of the permanent reflection. The angle between light and the collector surface, and also the time length of the solar day, sun appearance time on the top of the solar collector, is shorter than duration of normal day especially in the summer. Fig.3 shows the effect of the light angle on the generated current on a sample solar cell. Conversion of the energy always remains under the full capacity and the efficiency of the converter comes lower.

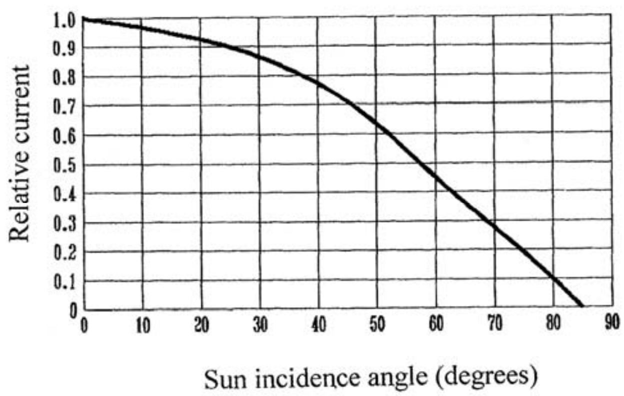

Fig.3: Solar cell current variation due to variation of the sun light radiation angel on the surface of the solar cell [2]

In contrast with the fixed PV-array, the solar collector (or PV-array) which follows the sun motion, can receive the maximum radiation and generates optimum energy because the sun light radiates perpendicular on the surface of the solar cells. A movable PV-array, as shown in Fig.4, is designed with two-degree of freedom, can follow the sun motion during the day by using the control light sensors that are designed to lock on the sun radiation and also to direct the structure to follow the sun. Each axis of the designed structure has its own sensors and mechanical drive systems since the motion of the systems is not continuous, the total energy consumption to control and drive the structure is small (Fig.4).

3- Standard Characteristics of the Movable PV-Array

The movable PV-array consists of four photovoltaic modules as shown in Fig.4 (type MA36/45 with specification shown in Table 1). The array consists of two parallel branches in which there are two modules that are connected in series. The electric equivalent circuit of the two modules is shown in Fig.5.

Table 1: Photovoltaic Module Electrical Characteristics (MA 36/45) [5]

Maximum Power	45 watts
No Load Voltage	20.5 (V)
Voltage in Maximum Power Point	16.7 (V)
Short Circuit Current	2.96 (A)
Current at Maximum Power Point	2.74 (A)

Fig.6 and Fig.7 show the electrical characteristics of the photovoltaic array in the standard condition (1kw/m^2 radiation & 25°C temperature). The maximum power of the PV-array reaches to 180 watts in the standard condition because the maximum power of each PV-module is 45 watts. Because of the lower sun radiation, cable losses, and temperature effect, it is usually less than 180 watts.

Fig.4: The two-axis Photovoltaic tracker implemented for the survey

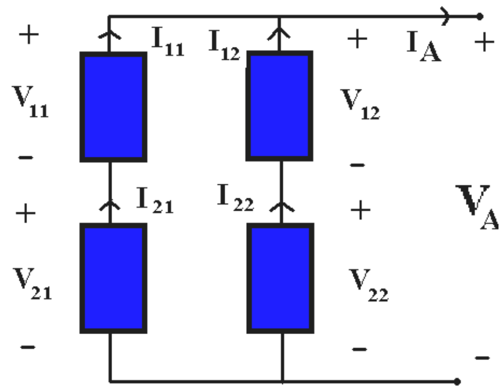

Fig.5: The photovoltaic array configuration mounted on the tracker

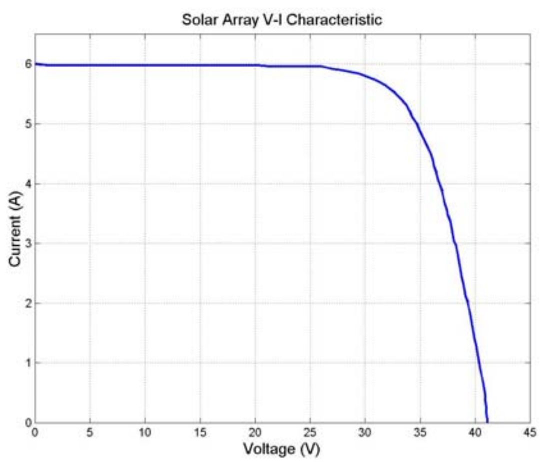

Fig.6: The output current curve of the PV-array at the standard condition

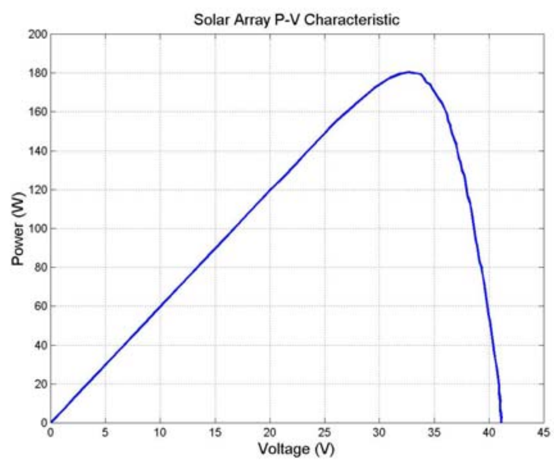

Fig.7: The output power curve of the PV-array at the standard condition

4- Comparison Characteristics of Movable and Fixed Arrays during the Day

The experiment was performed in July and the first comparison curve was available at 9:00 AM because of the installation situation of the movable array and the fixed array. The output power characteristics of these arrays are shown in Fig.8. Because the movable array is directly faced to the sun, it generated more electric power and its peak power is higher than fixed array. In this study we assumed that the maximum power can be obtained by a maximum power point tracker (MPPT). The corresponding measured data are shown in the Table 2 which shows the 55.2 percent increasing in the power at 9:00 AM.
The obtained power curves at 10:00 AM are shown in Fig.9. It shows the increasing of the

fixed array power in compare to 9:00 AM whereas the movable array has a little change in its generating power and still it is greater than fixed array by 19.5 percent increment in power. From 11:00 AM to 14:00 (Fig.10 to Fig 13), the power curves of the fixed array become closer to the movable array. Because of the sun motion close to south, both movable array and fixed array are faced to the south where the movable array still generates more power (4 to 13 percent higher).

Because the sun height starts to decrease after 14:00, the generated power by the fixed array starts to decrease. The generated power in both PV-arrays decrease but in the movable array, the slow rate of decreasing is observed. As the Fig.14 and Fig.15 show, by the sun motion to the sunset, the generated power reduces in both PV-arrays but the movable PV-array still generates more power than the fixed one. Fig.16 shows the power characteristics of the arrays to compare the maximum available power at 17:00. This curves show 2.4 times greater power in movable PV-array than fixed array and this ratio is about 6.1 as in the Fig.17 at 18:00. This comparison illustrate that the movable photovoltaic array with sun tracking capability can significantly increase the absorbed energy that increases the generated electric power. Fig.18 and Fig.19 show the power curves of both movable and fixed PV-arrays and it shows that the generated power by the movable array has less variation in compare with fixed array during the day. It can be concluded that in terms of electric power supply, by using the movable photovoltaic array the power quality will be higher and by using the fixed array, the large power variation should be dumped due to a larger energy storage unit.

With the assumption of using a maximum power point tracker (MPPT) to absorb the maximum power from both arrays, and using one hour as power sample time, the absorbed electric energy is calculated for both arrays and the results are shown in Table.1 the results show more than 36 percent increase in energy absorption from movable PV-array. Using the full sample time (from sunrise to sunset), this increase will be more than 40 percent as shown in Fig.20. Also Fig.21 shows the current-voltage characteristics of the movable PV-array during the day and current generated by this array has a small variation during the day (about 18%) where Fig.22 shows the same characteristics for the fixed PV-array and a large variation (more than 81%). In conclusion, the movable PV-array has an improved electrical characteristic and need a smaller energy storage unit [6]. Typical applications for trackers are for water–pumping photovoltaic systems. The benefits are the greatest in the summer when the sun makes its widest path across the sky. Under these conditions, a tracker can improve daily energy production significantly in compare with fixed array [7].

Table 2: Test results of measuring the output power

Sampling time	Array Type		Increment Rate (%)
	Movable	Fixed	
9:00	112.3	73	55.2
10:00	113.3	94	19.5
11:00	120.4	106.5	13.1
12:00	119.7	113	5.4
13:00	119.1	115.2	3.9
14:00	118.6	110.3	7.5
15:00	117.1	95.5	22.6
16:00	111.7	69.2	61.4
17:00	106.4	45	236
18:00	98	16.2	605
Absorbed Energy During the Test (Wh)	1136.5	837.9	35.6

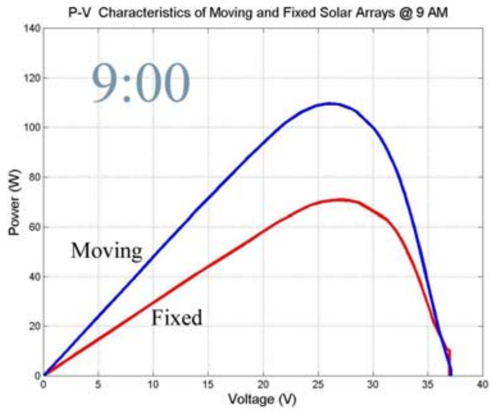

Fig.8: Power characteristics of movable and fixed PV-Arrays at 9:00

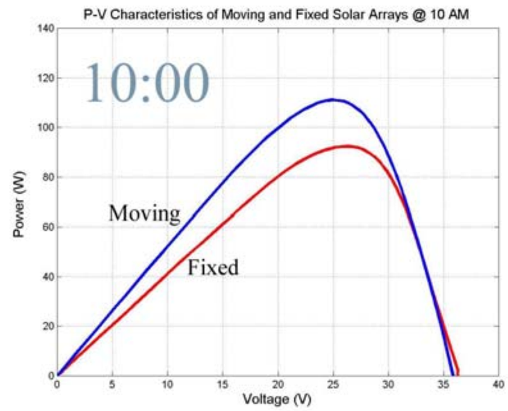

Fig.9: Power characteristics of movable and fixed PV-Arrays at 10:00

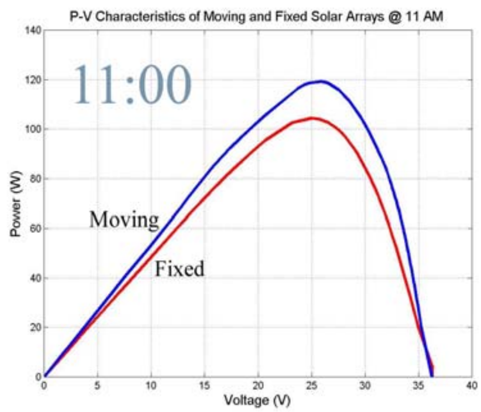

Fig.10: Power characteristics of movable and fixed PV-Arrays at 11:00

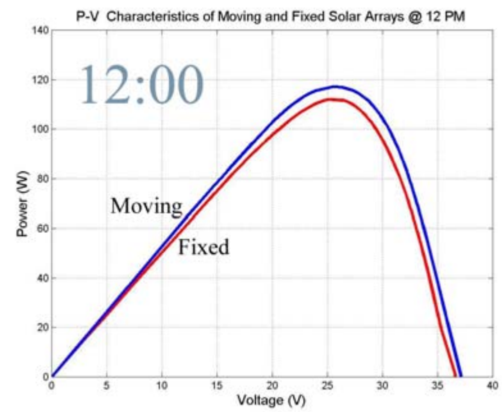

Fig.11: Power characteristics of movable and fixed PV-Arrays at 12:00

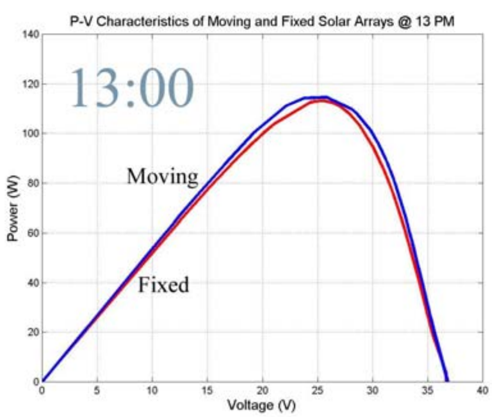

Fig.12: Power characteristics of movable and fixed PV-Arrays at 13:00

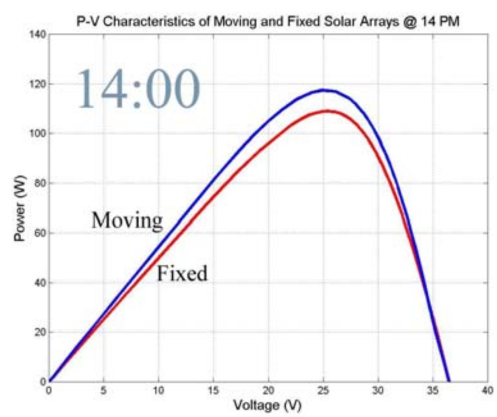

Fig.13: Power characteristics of movable and fixed PV-Arrays at 14:00

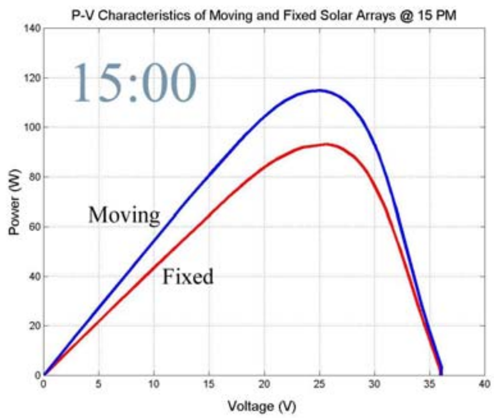

Fig.14: Power characteristics of movable and fixed PV-Arrays at 15:00

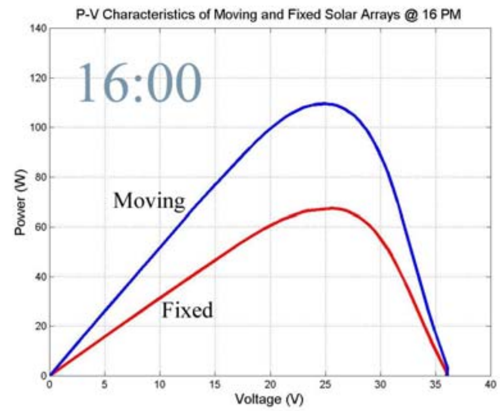

Fig.15: Power characteristics of movable and fixed PV-Arrays at 16:00

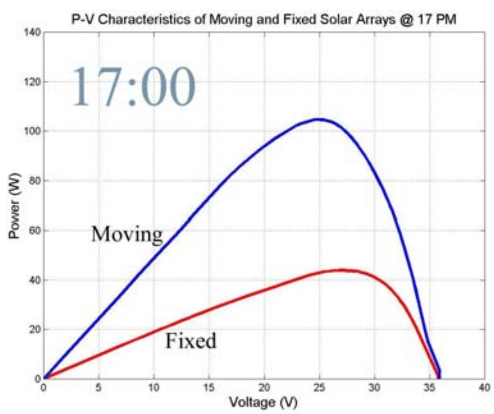

Fig.16: Power characteristics of movable and fixed PV-Arrays at 17:00

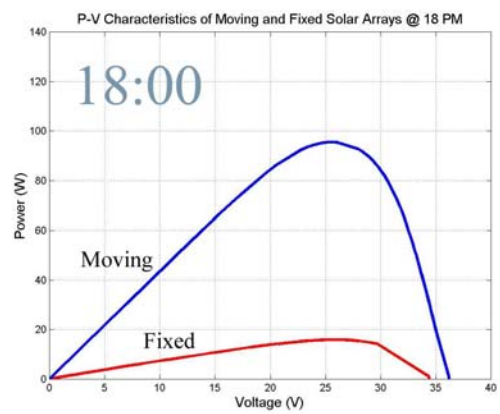

Fig.17: Power characteristics of movable and fixed PV-Arrays at 18:00

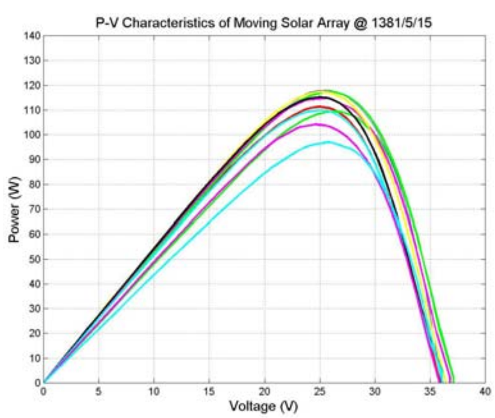

Fig.18: The output power curves of the movable PV-array between 9:00 & 18:00

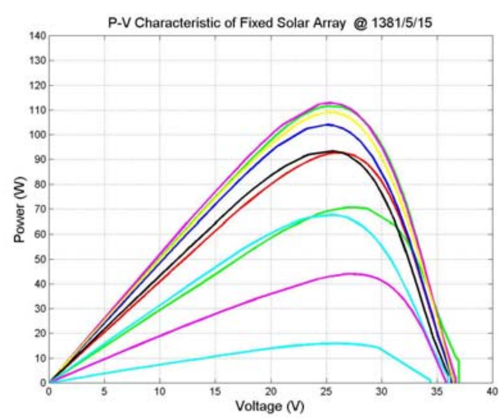

Fig.19: The output power curves of the fixed PV-array between 9:00 & 18:00

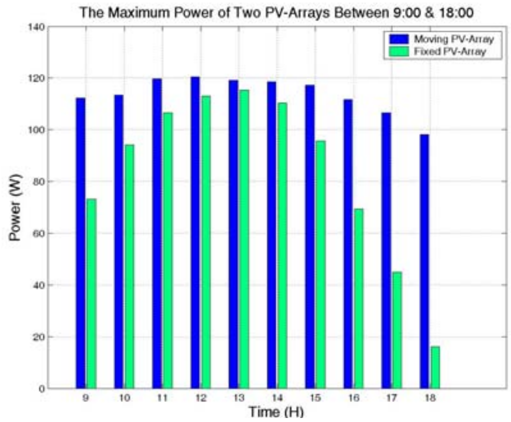

Fig.20: The maximum output power of two PV-arrays between 9:00 & 18:00

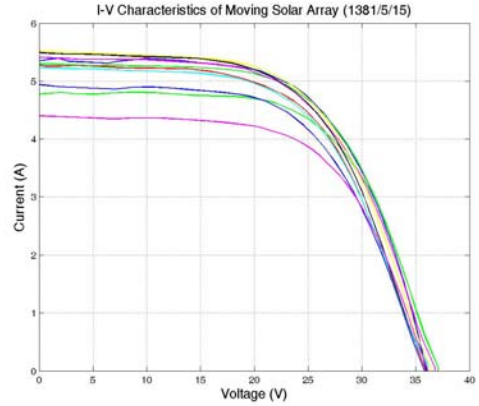

Fig.21: The output current curves of the movable PV-array between 9:00 & 18:00

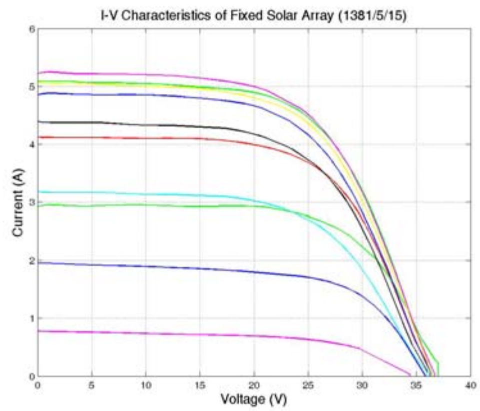

Fig.22: The output current curves of the fixed PV-array between 9:00 & 18:00

5- Conclusion

Photovoltaic arrays have several advantages such as silent energy conversion without any environmental effects, long life, and installation capability from small power (watt) to large power (Mega-watt) scales, and having light components. Because of these advantages, the photovoltaic converters are more interested among the other types of energy converters in solar energy. Due to the high cost of photovoltaic modules, it is necessary to absorb the maximum energy from the PV-array and reduce the cost of generated electric energy.

Because of the high dependency of the generated power of a PV-array to the sun light angle, one proper way for optimum operation of the photovoltaic converter is to use a movable PV-array. The test result shows that using a PV-array with sun tracking capability can increase the absorbed energy more than 36% in compare with the fixed PV-array. Also, this type of array can supply the electric energy with small variation and better power quality during the day. Moreover, the motion of the tracking structure for a small period of time (45 minutes in day) consumes a small amount of energy (less than 10 watt-hours) to follow the sun path in the sky where the total efficiency of the converter is high. Investigation of the cost of the movable array and its effect on the energy price can be analyzed in another research study.
This research study also shows that if the movable structures are used in a large scale in a

solar power plant, a significant amount of energy will convert to electric energy in compare to the fixed arrays. The increased investment due to the usage of movable PV-arrays and their maintenance will be justified due to increasing of the output power. Notice that manufacturing of the structure in large amount will reduce the cost. Therefore, this type of trackers can be manufactured, used, and serviced in solar power plants with lower cost.

References

[1]-L.D. Partain, *Solar Cells and Their Applications*, John Wiley & Sons, New York, 1995.

[2]-M.R. Patel, *Wind and Solar Power Systems,* CRC Press, 1995.

[3]- C. Hua and C. Shen ‘"Control of DC/DC Converter for Solar Energy System With Maximum Power Tracking " , *IECON 23rd International Conference on Industrial Electronics, Control and Instrumentation,* Vol.2, pp.827–832, 1997.

[4]- http://www.madison.k12.wi.us/planetarium/sunpath.gif

[5]-Technical Catalogue of Solar Module, MA36/45, Optical Fiber Fabrication Company, IRAN.

[6]- R. Vartanian, "Design & Implementation of Movable Photovoltaic Array with Two-degrees of freedom to Study of increment in Absorbed Solar Energy in Compare with Fixed one", M.Sc. Thesis, Isfahan University of Technology, 2001.

[7]-D. Prasad and M. Snow, *Designing with Solar Power: A Source Book for Building Integrated Photovoltaics*, Earthscan, Australia, 2005.

Authors' Biography

HASSAN MOGHBELI received his B.S. in electrical engineering from Iran University of Science and Technology (IUST) in 1973, his M.S. in electrical engineering from Oklahoma State University in 1978, and his Ph.D. in electrical engineering with specialization in electrical drives and power electronics from University of Missouri-Columbia (UMC)in 1989. Dr. Moghbelli was a lecturer at IUST from 1973-1976, an instructor at Isfahan University of Technology (IUT) from 1978-1984 and an assistant professor at Purdue University Calumet (PUC) from 1989-1993 and an associate professor in IUT and IUST from 1989-2002. He has done several projects in the area of electrical drives, power electronics, electric vehicles and hybrid electric vehicles. He was a consultant at Northern Indiana Commuter Transportation District from 1991-1993 and Isfahan Regional Metro Company from 1993-1998. He has directed several projects in the area of electric vehicles, hybrid electric vehicles and railway electrification. He was the Head of School of Railway Engineering at IUST from 2000-2002. He was a Research Associate in the Advanced Vehicle Systems Research Program in the department of Electrical Engineering at Texas A&M University from 2002 to 2004. His research interests are mainly the control, electric drive train, and power electronic design of electric vehicles, hybrid electric vehicles, fuel cell vehicles, and electrified railroads. He has published more than 70 papers in these areas. He is a member of SAE, ASME, and IEEE.

ROBERT VARTANIAN was born in 1976 in IRAN. He received the B.Sc. degree in 1999 and M.Sc. degree in 2001 in power engineering from the Isfahan University of Technology. He is with Power Research Center (Matn Co.) as a research engineer from since 2001. He has published more than 10 papers on renewable energy sources, fuel cells, and power system. His interests include power system simulation, renewable energy sources, fuel cell vehicles and photovoltaic converters. He is presently member of board of directors of the Iranian Solar Energy Society (IRSES).