Reflectors and Concentrators for Solar Panels

J. Rizk, A. Hellany and M. Nagrial

Abstract**—**the paper discusses the potential economic benefits of a simple combined solar tracker/concentrator system based on tilting flat-plane mirrors. The system is aimed at simple roof-mounted situations, where the construction of full two-axis type solar trackers would be inappropriate and expensive. The paper also aims to show that implementing different types of reflectors in solar energy systems, will dramatically improve energy production by means of concentrating and intensifying more sunlight onto a solar cell. The Solar Intensifier unit is designed to increase efficiency and performance of a set of solar panels. The unit was fabricated and tested.

Keywords**—** Renewable Energy, Solar reflectors, Solar generation

I. Introduction

Extracting useable electricity from the sun was made possible by the discovery of the photoelectric mechanism and subsequent development of the solar cell – a semiconductive material that converts visible light into a direct current. By using solar arrays, a series of solar cells electrically connected, a DC voltage is generated which can be physically used on a load. Solar arrays or panels are being used increasingly as efficiencies reach higher levels, and are especially popular in remote areas where placement of electricity lines is not economically viable.

This alternative power source is continuously achieving greater popularity especially since the realisation of fossil fuels shortcomings. Renewable energy in the form of electricity has been in use to some degree as long as 75 or 100 years ago. Sources such as Solar, Wind, Hydro and Geo-thermal have all been utilised with varying levels of success. The most widely used are hydro and wind power, with solar power being moderately used worldwide. This can be attributed to the relatively high cost of solar cells and their low conversion efficiency. Solar power is being heavily researched, and solar energy costs have now reached within a few cents per kW/h of other forms of electricity generation, and will drop further with new technologies such as titanium-oxide cells. With a peak laboratory efficiency of 32% and average efficiency of 15-20% [1-7], it is necessary to recover as much energy as possible from a solar power system.

The great promise of solar photovoltaic (solar-PV) systems is of course their potential use as building-mounted units in everyday suburban applications. To achieve this further falls in the price of solar cells must occur and of course, major research programs, both here in Australia and overseas, are being pursued with this goal in mind [11].

J. Rizk, A. Hellany and M. Nagrial are with the University of Western Sydney, Australia. Locked Bag 1797 Penrith NSW 2751.

Concentrators and trackers offer opportunities to increase solar panel output in a cost-effective manner and a number of concentrator solar-PV systems are starting to appear. Most of these use high-cost pure mono-crystalline silicon and high concentrations. In this paper, we discuss the development of a low-cost tracker/concentrator system that is suitable for simple flush mounting on a roof or building, and uses conventional panels and reflector material.

In the past 30 years till present, solar energy has increased in efficiency and its price levels have improved dramatically. The price of photovoltaic solar cells has decreased from around $25 to a current price of $5 per peak watt. Today the theoretical efficiency of a solar PV cell is said to be around the 25% to 30% mark and a practical efficiency around the 17% mark [9]. The improvement in efficiency production of solar energy system will make big difference in the use of solar panels [6-8].

A flat panel solar module is a practical way in which common households and business can produce electrical or mechanical energy from solar energy conversion. The solar energy is still more expensive then the classical fossil burned electricity [6-11]. However, by implementing a reflector system for these flat panel modules, a theory that has been tested and developed that overall output and efficiency can be improved.
Renewable energy systems especially solar energy systems over the past 20 years has became one of the main focal points in developing new technologies were energy can be produced with efficient results. However with new technologies comes the fact that they will not be cheap to purchase and run. The main aim of this paper is to see what means of solar concentration can produce efficient power for homes and other environments.

II. Solar Intensifier Unit

An alternative approach was adopted, wherein commercial cells and simple cheap reflector systems used with low concentrations. This approach was also prompted by the fact that many pars of Australia have partly cloudy days, whereas high concentration systems are only effective on bright sunny conditions with high levels of beam radiation. A simple system with hinged tracker/reflectors shown in figure 1 was developed and tested.

The concept of using flat plate reflectors in conjunction with flat plate panels was first documented in 1984 [12]. Peak power outputs of 140 W per metre were obtained with mono-crystalline cells with high packing density and a concentration of 2.2 times. Experiments were also done with higher magnifications, which suggested higher levels of output were possible. The impact of increased cell temperature in decreasing cell efficiency, in particular reducing the cell “fill

ISBN: 978-1-61804-012-1

factor", was noted, but the increase in output was still positive. The authors' conclusions were that there was considerable scope for more development of cost-effective solar-PV devices using conventional commercial modules and low concentration factors.

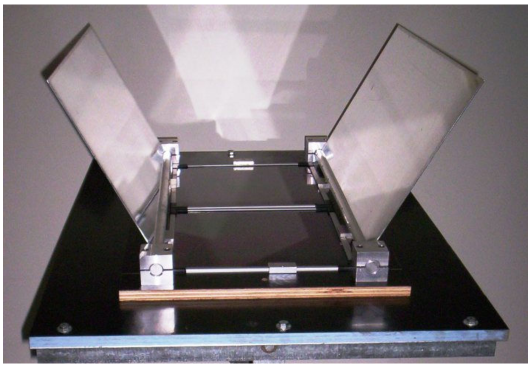

Fig 1 – Tested Unit

A four-reflector module using shiny aluminum, built around a single 1-Watt polycrystalline panel, was built and tested at UWS in September 2000. This produced peak outputs of about 3 times (out of a theoretical gain of about 4 times) near the middle of the day when pointed directly at the sun, but cell temperature rose excessively and caused fracture of the glass covering. A four-reflector panel would also require full two-axis tracking to be effective.

It was decided to construct a two-reflector model. Although outputs would be les, this would allow free flow of air across the panel surface and would also allow the reflectors to be tracked, avoiding the cost and complexity of a two-axis tracking mechanism and pedestal for the panel. That in turn would allow flush mounting of the panel, on a simple fixed frame or roof. Controlling the reflectors would also allow some control over the level of concentration and heat, according to day-to-day weather conditions and/or load requirements.

The panel is designed to be tilted at an appropriate angle and to track the sun from east to west. The geometry is shown in figure 2.

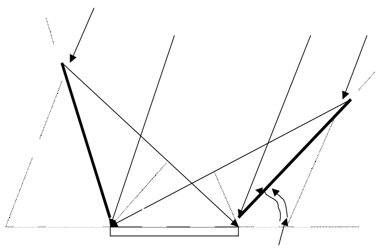

Fig 2 – Geometry of Panel Reflectors

From the angles of incident light, it an be shown that -

$$W\sin(\phi-2\alpha)=R\sin\alpha \quad \ldots(1)$$

W is the panel width, R the reflector size ϕ and α the angles of the sunlight and the reflector to panel surface. The gain, assuming perfect mirrors, is –

$G = 1 + \cos 2\alpha$ for one reflector, where $R=W\cos 2\alpha/\sin\alpha$.

Similar reasoning will apply to the second reflector, though in the general case the second values of α will be different. In the case where the sun is overhead, ϕ is 90 degrees and total gain is $1 + 2\cos 2\alpha$. For a reflector of size R = 1.84 times the panel width, this gives the angle α to be 22.5 degrees and a total gain of 2 times.

A set of graphs was drawn for a panel oriented at true north at local Sydney latitude with east west tracking on the reflectors. Perfect reflection was assumed. The results were compared to a panel with no reflection plus a panel with full two-axis tracking. The results apply to full sun in mid summer. The normal factors for solar intensity and air-mass ratio were assumed. The results are shown in figure 3.

It can be seen that the two-axis tracker performs better near sunrise and sunset, as it can point better toward the sun, but the tilting reflectors give better output (x 2.25) around noon. This gives overall advantage, as the vast majority of the energy from fixed solar panels occurs in the one or two hours either side of solar noon (two-axis tracking increases the output closer to sunrise and sunset).

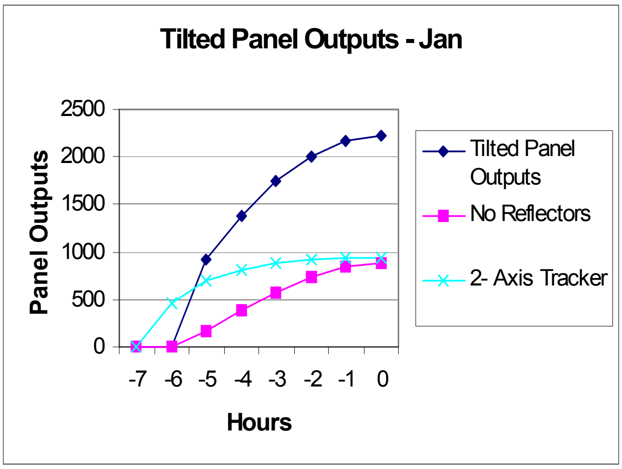

Fig 3 – Simulated Output

Actual performance tests were run on several days at different times of the year. The results from one test are shown in figure 4. The reflectors were metal coated with aluminised foil and taken on a fine hazy day in February 2002.

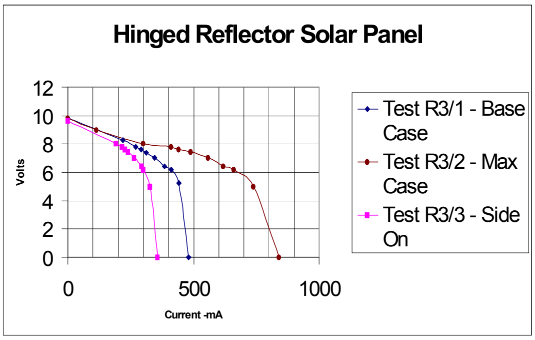

Fig 4 – Actual Performance

Test R3/1 was the base case, with the panel pointed directly at the sun with no concentration. The maximum power point was 2.54 W. Interestingly, this was slightly lower than the base case taken two months later, in April.

Test R3/2 was with the panel pointing directly at the sun (obliquity of zero degrees) with the reflectors arranged for maximum concentration. In this case, the maximum power point was 4.09 W, a ratio of about 1.6 times the base case. Test R3/3 was with the panel at about 90 degrees in azimuth to the sun, i.e. edge on. Without concentration, the beam component would be zero under these conditions. The reflectors were turned to give maximum concentration at that angle. Maximum power point was 1.88 W, about 0.75 times the output for the base case. The theoretical maximum would be about 1.0, but again the actual reflector material used explains the lower results. This was in line with expectations, and shows the benefit of the reflector system at a time when output from a fixed panel would be very low (about 15%).

The clear energy gains over a fixed panel and even a two-axis tracker are evident and would be improved with better reflector material.

The final solar panel and stand was built at the University of Western Sydney. It will consist of two 4-Watt amorphous solar panels connected in series to obtain output voltage and output current readings of each result with respect to the tests. Amorphous solar cells might don't produce as much power as mono and poly-crystalline cells, have better heat tolerances and don't not degrade in performance with excess heat radiated onto the solar cell. Although the temperature range of both mono and poly-crystalline solar cells is better than the amorphous type, amorphous solar cells don't drop in performance from excess heat radiation.

This solar intensifier unit will be used to show that for ordinary households, producing energy using solar power can not only save electricity usage and create a clean energy source but also save money. These solar energy systems will highlight savings in both average power produced and cost per kilowatt-hour. Initial costs of each solar energy system will be taken into account when determining overall money savings.

The dimensions of the solar reflector panels are 63cm by 31.5cm. The widths of the reflectors were chosen so that they were the same dimensions as of the two solar cells side by side. This allows that any sunlight hitting the top, bottom or centre of the reflector at an optimum angle, will reflect onto the solar cell at the opposite point that it hit the reflector (angle of incidence equals the angle of reflectance).

III. Type of Reflectors Panel

The type of reflector panel is used in a concentrating solar panel can influence the output power. This test will incorporate aluminum; stainless steel and chrome film reflectors to determine which type of reflector will be both efficient, practical and do not produce excess heat.

An overwhelming increase in power output when chrome film is used on the reflector plate came be seen from Figure 3. An average power output of 25.94W was recorded for chrome reflectors. These chrome reflectors produce a 27.65% increase in power output against aluminum foil and a 34.05% increase in power output against stainless steel. This is a substantial amount against the two other reflectors and even thou the chrome film cost overall $50 for both reflectors, the increase in power output large enough to warrant using this expensive reflective film.

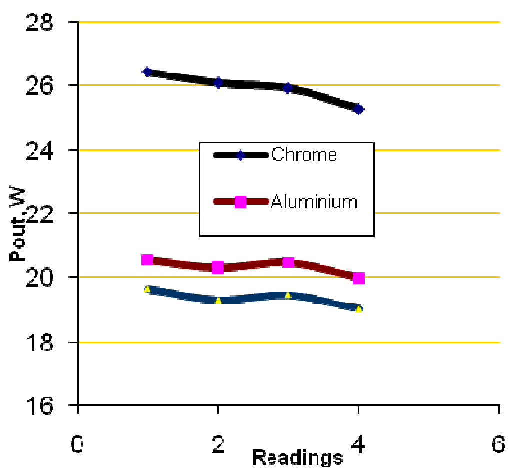

Figure 3: Power outputs of various reflector panels

These results were all conducted using a single-axis tracker adjusting the suns latitude angle and the longitude angle was set to 70˚. (Approximately longitude angle in October when results were taken). The stand was fixed to face due north.

IV. Number of Reflectors

The solar panel has been built with only two reflectors running along. Figure 4 has optional reflectors 1 and 2. Both will be added on and a value of the output power will be recorded and compared to the result when using only 2 reflectors. This is merely a control test to see what effect the extra reflectors to the solar panel design would achieve. The final design will only incorporate 2 side reflectors regardless of the outcome of using 4 reflectors.

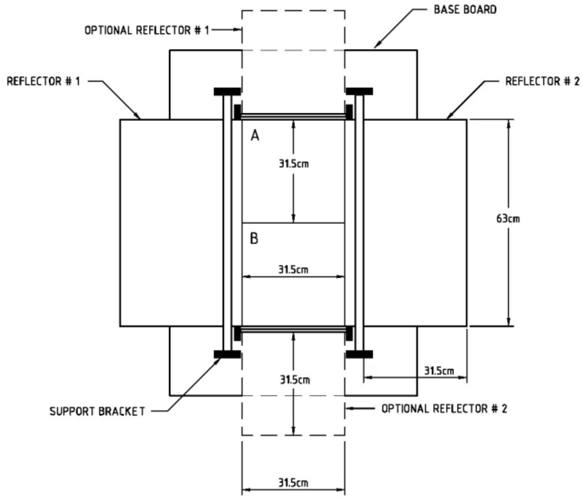

Figure 4: Solar Intensifier Unit with 4 reflectors

On a mass scale using four reflectors on a solar intensifier unit, could produce an extra 1.44% on top of the power output. For example if a 1000W output was produced by using 2 reflectors on an array of solar cells, an extra 144W could be produced from this output by implementing and extra 2 reflectors onto the system. By adding to more reflectors to the system we also create a more expensive and complex design structure to the unit. Using 2 reflectors can still provide a sufficient and efficient output from a solar cell or cells. Figure 5 shows the experimental results of a solar energy system with different number of reflectors.

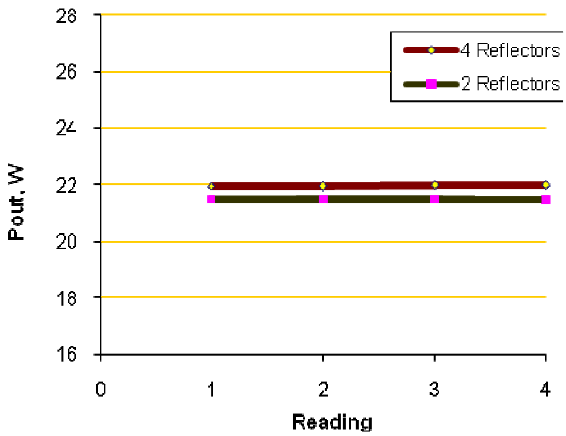

Figure 5: Power outputs from the number of reflectors used

V. Roof Mounted Solar Panels

This test was conducted with the solar panels stand set to a fixed longitude angle of 70° as this is the common roof angle discussed previously.

The reflectors were fixed to optimal angle of 22.5˚ (see section 3.2.1) throughout the recordings. Note that the recordings for 6:00 AM and 6:30 AM outputs were estimated by the curve characteristics.

The reflectors tracked the suns lateral movements (see table 3.2) throughout the recordings. Note that the recordings for 6:00 AM and 6:30 AM outputs were estimated by the curve characteristics.

The results indicate that having tracking reflectors results in higher power output than that of stationary reflectors. Both seem to peak at the same time of 11AM, however the tracking reflectors give the output power of the reflectors a constant and spread out curve characteristic but with added complexity to the solar energy system. The curves are not symmetrical for this system as both curves start to taper off after midday. This system does not provided a constant and predicable out put and that can be crucial when incorporating this energy into a system that needs constant and predicable power.

The output voltages for both systems were relatively the same throughout and the output current varied depending on the amount and intensity of light that was applied to the solar cells.

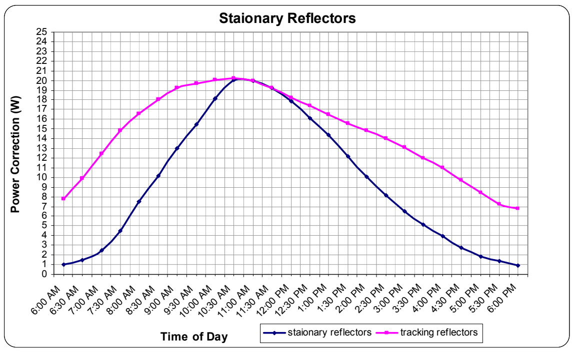

Figure 6: Power outputs of the roof-mounted solar energy system

A. Single Axis Tracking Panel

The single axis tracking panel test scenario was conducted by having the solar panel tracking the sun lateral movements (see φ in table 3.2) and the longitude angle set to approximately 70˚, (Approximately longitude angle in October when results were taken). The stand was fixed to face due north. The reflectors were set to an optimum angle of 22.5˚ along the side.

B. Two-axis Tracking Panel

The two-axis tracking panel test scenario was conducted by having the solar panel tracking the sun lateral and the longitude angle was tracked Results were taken in October with the solar energy system having a longitude angle of approximately 70˚ with the solar panel facing due north. The reflectors were set to an optimum angle of 22.5° along the side.

Both the single-axis and two-axis trackers gave the solar intensifier unit the most consist and produced the highest power readings. The resulting curve characteristics of both systems were as expected being both that they gave a close to symmetrical shape and that the two-axis tracker gave the highest power readings. The peak readings for both systems occurred between the hours of 11:00AM and 1:00 PM were the sun was at its highest point in the sky and most intense. The peak reading for the single-axis tracker was 23.35W and 24.07W for the two-axis tracker. Both systems require complex and detailed automated systems but the power output is much larger than the other system scenarios and will compensate for this added complexity. Figure 7 shows the output power for both tracking systems.

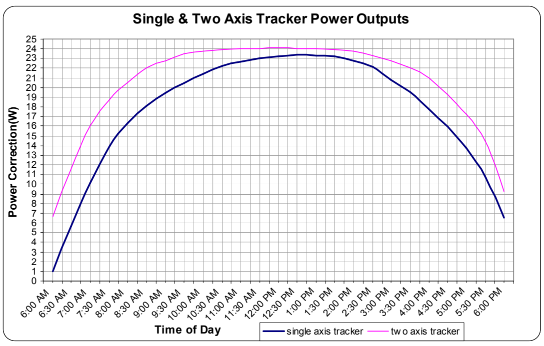

Figure 7: Power outputs of axis tracking solar energy systems

VI. Power Analysis

After looking at all the results from the solar panel tests, Figure 8 shows an overall comparison of the outputs.
The graph clearly shows the axis tracking panels to be far superior to the rest. The two-axis tracker generates more power than the single-axis tracker due to the fact the two-axis tracking panel was facing directly at the sun at all times. The single-axis tracker however creates a lot more than the rest of the solar energy systems with minimal complexity compared with the two-axis tracker.

The resulting power produced by all six solar energy systems shows the impact of tracking panels or reflectors has onto solar cells. The roof-mounted system with tracking reflectors gave more power output than that of the stationary stand. This is due to the fact that the roof was set to a longitude angle of 70˚. This angle is closer to the sun's longitude angle during testing. The tests were conducted in October, which has a longitude angle of around 70˚ to 75˚. The stationary stand however was sitting at an angle of 60˚. This angle was chosen as mentioned before to be half way in between the peak summer and winter angles. The roof-mounted system with tracking reflectors would be one of the least complex systems to setup at home and would provide sufficient power output. If the power out for the stationary stand was tested for every day the results would indicate a more stable and constant power output.

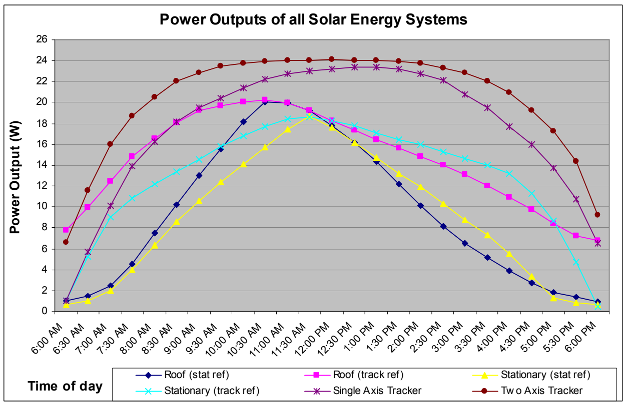

Figure 8: Power outputs of all solar energy systems

The solar panel converts sunlight into DC electricity. This DC voltage charges the battery and is then fed to the battery via a solar regulator which ensures the battery is charged properly and not damaged. DC appliances can be powered directly from the battery, but AC appliances require an inverter to convert the DC electricity into 240 Volt AC power. A regulated DC voltage can then be fed into the axis and reflector tracking system to provide movement for the solar panel stand and reflectors.

A microcontroller acts is the central controller of the unit and controls and regulates all the feedback coming from the motors and sensors. Temperature sensors can be setup to monitor the heat radiating off the solar panels and if the rated heat is exceed than it can be programmed to close the reflectors till its cools down to a safe level. Steppers motors move the stands longitude and latitude angles and the tracking reflectors as well. The Stepper motor driver and controller move these motors and can be programmed to track to suns movement during the day. Figure 9 shows such a system

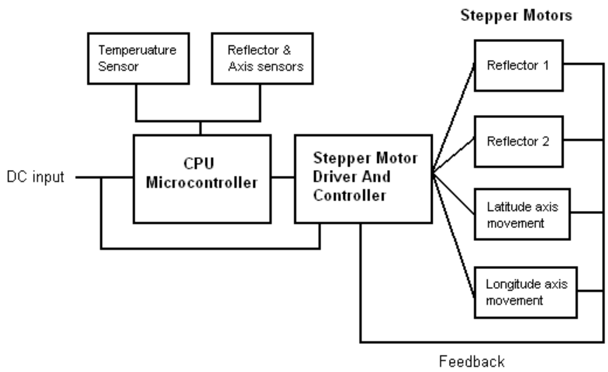

Figure 9: Components of an automated solar panel

VII. Conclusion

The first analysis was to see how this concentration can be achieved and what type of setup would prove to produce good power outages. By implementing reflector panels with a reflective finish on it, the rated output of a solar cell can be increased and surpassed. The affect found that an increase of around 40% can be achieved by using this method of concentration. Another factor that also improved the output of

ISBN: 978-1-61804-012-1

the solar cell was to add a chrome finish to the reflector panels. This alone created an increase in output power by a further 34%. These simple but effective measures are beneficial to the energy production of a solar energy system.

Solar energy systems can come in various designs, shapes, looks and structures. The four solar panel scenarios tested were a roof-mounted, stationary stand, single-axis tracker and two-axis tracker solar panels. All have pros and cons when in various aspects and areas of power and complexity.

REFERENCES

[1] Fahrenburch, A. and Bube, R. 1983, Fundamentals of solar cells, Academic Press, New York.

[2] Partain, L.D. 1995, Sollar Cells and their applications, John Wiley & Sons. New York.

[3] E Weise, R Klockner, R Kniel, Ma Sheng Hong, Qin Jian Ping, *"Remote Power Supply Using Wind and Solar energy – a Sino-German Technical Cooperation Project",* Beijing International Conference on Wind Energy, Beijing, 1995

[4] Wichert B, Lawrance W, Friese T, *First Experiences with a Novel Predictive Control Strategy for PV-Diesel Hybrid Energy Systems*, Solar'99

[5] Mitchell K, Rizk J, Nagrial M, 2006, Development of planning procedures with embedded solar systems, *Australian Journal of Electrical & Electronics Engineering*, vol 3, no. 1, pp 57-64, [ORS ID: 203802]

[6] K. Mitchell; M. Nagrial and J. Rizk - Simulation and Optimisation of Renewable Energy Systems" International Journal of Power & Energy Systems, Vol 27, pp 177-188, 2005.

[7] J. Rizk, K. Mitchell and M. Nagrial - Modelling and Simulation of Renewable Energy Systems" Proc. International Conference on Modeling & Simulation, pp. 261-265, Melbourne, Vic. Nov - 11-13, 2002.

[8] Jiménez V. 2004 [online]. *World Sales of Solar Cells Jump 32 Percent*. Earth Policy Institute. Retrieved: August 7, 2005

[9] Bernt Lorentz , *Basics about Solar Tracking and ETATRACK*, 2004, Germany

[10] National Renewable Energy , *Clean Energy Basics*, Laboratory , 2005. USA

[11] Mitchell K, Rizk J, Nagrial M, 2006, Development of planning procedures with embedded solar systems, *Australian Journal of Electrical & Electronics Engineering*, vol 3, no. 1, pp 57-64, [ORS ID: 203802]

[12] Stacey R W., McCormick P G., Effect of Concentration on the Performance of Flat Plate Modules, Solar Energy Vol 33, No 6, pp 565-569, 1984

ISBN: 978-1-61804-012-1