Investigation on the Behaviour of Photovoltaic Solar Panel under Different Configurations and Irradiation

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Abstract

The paper is aimed at the performance analysis and examination of the behavior of photovoltaic module based on the mode of configuration and the effect of changes in irradiance on the module. The connections studied are single, series and parallel. Different irradiations were used for the experiments. The analysis of these connection were done through the careful examinations of the electrical parameters such as the maximum operating voltage (V_{MPP}), maximum operating current (I_{MPP}), maximum operating power on the characteristic curves that is, the I- V and P –V curves. The electrical parameters, V_{MPP} and I_{MPP} were used to analyze the maximum operating power (P_{MPP}) of each connection. The report showed that the manner in which modules were connected to form strings affects electricity generation and the strength of the light incident on a photovoltaic module influences electricity generation.

Keywords: photovoltaic cell; Photovoltaic module; Maximum power point; Irradiation; Photovoltaic data

1.0 Introduction:

A photovoltaic cell is a device that is capable of converting photons of light into an electrical voltage and current. A photon with short enough wavelength and high enough energy can cause an electron in a photovoltaic device or material to break free of the atom that holds it. If a nearby electric field is provided, these electrons can be swept towards a metallic contact where they can emerge as an electric current (Masters, 2004; Togola, 2005). Photovoltaic cells represent the basic fundamental power conversion unit of photovoltaic system. These cells are made from semiconductors and like any other solid-state electronic devices such as diode, transistors and integrated circuit, and they have similar behavior. Photovoltaic cells are usually arranged into modules and array when applied practically (Markvart, 2001; Dike et al., 2011; Olesen, 2004). There are different types of photovoltaic cells available in the market and yet different other types of cells are under development, for example cells like dye-sensitized Nand-crystalline. The reason for different types of photovoltaic cell, materials and structure is to extract maximum power from the cell and to maintain cost to a minimum. According to Tomas Markvart (Markart, 2001) efficiency above 30%

have been achieved in laboratory and efficiency of practical application is usually less than half of this value. Crystalline silicon technology is well established and its cell is more expensive but still controls a major part of the photovoltaic market with efficiency approaching 18%. Other types of photovoltaic cells like amorphous thin films are less expensive but with disadvantage of poor efficiency. The modules are largely connected in series and parallel to create a higher voltage and current respectively (Masters, 2004; Sambo, 2006; Togola, 2005). An essential element in the photovoltaic analysis and design is deciding how many modules should be configured in series and how many should be in parallel to deliver the required energy needed. Such types of combination of panel are referred to as arrays (Sonnenenergie, 2006; Dike et al., 2011; Olesen, 2004).

This paper is aimed at the investigation of the behavior of photovoltaic modules and the examination of the performance of the module on the manner in which they are connected or configured. It will also give us an insight in the following areas such as the manner in which modules are connected together to form strings, affects electricity generation and how the strength of the incident on a photovoltaic panel influences electricity generation.

The area (A) of the photovoltaic module to be measured is $4.5 * 10^{-2} m^2$ and the power generated by the module is measured by equation 1

$$W = V.I \qquad (1)$$

While the efficiency of the panel is measured as;

$$\eta = W/A.Ir \times 100 \qquad (2)$$

The equation to predict the maximum power generated for any given level of irradiance is

$$\text{Maximum Power point (MPP)} = 2.2732 x I^{0.9281} \qquad (3)$$

2.0 Method of Analysis:

The experiment consists of two identical (36 cell Monocrystalline) photovoltaic modules/panels; screen to control the light level, ammeter, voltmeter, rheostat (load), tungsten halogen light and a pyrometer. The pyrometer calibration factor is $12.3 * 10^{-6} V/ m-^{2}W$ to produce a value for irradiance (Ir) in W/m^2. The experiment was done in the laboratory with the tungsten lamp used as the intensity of sunlight and the pyrometer to measure the irradiation.

The experiment setup is shown in figure 1.

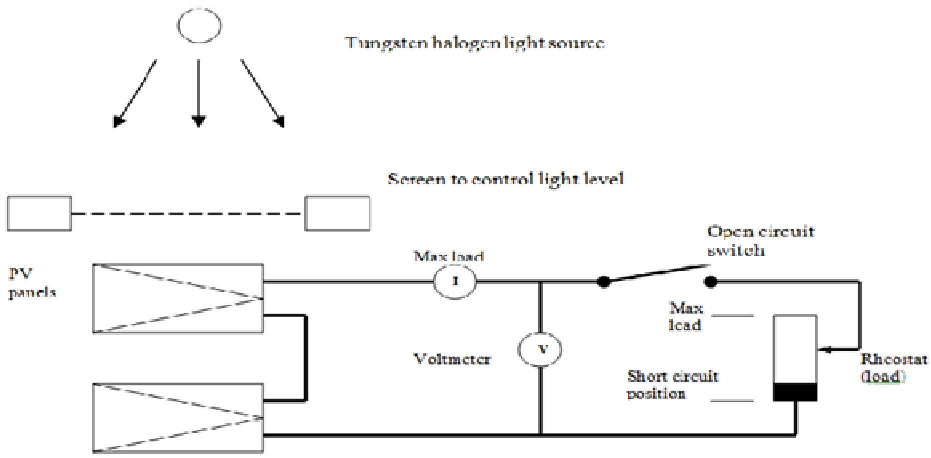

Fig. 1: Experimental setup

The experiment adopts the following procedures:

- The rheostat was move to the short circuit position and the current generated was measured with the voltage at zero. This is the maximum current the panel can generate.
- Also the open circuit switch was opened and the voltage and current recorded. This is the maximum voltage that the panel will generate.

The short circuit current and open circuit voltage were measured at different irradiance and connections.

Several measurements were carried out from the set up of fig.1 to determine the open circuit voltage and short circuit current on different connection of photovoltaic modules. That is, single panel connection, panels connected in series and parallel. The configuration for single, parallel and series are shown in fig. 2.

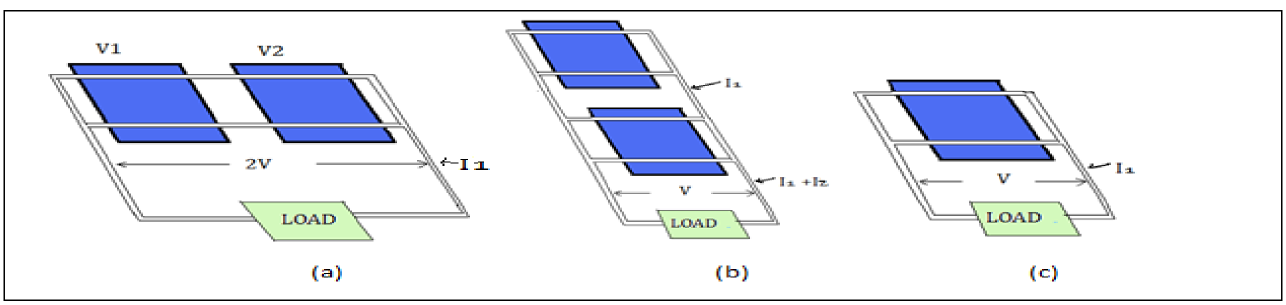

Fig. 2: Single, series and parallel connection/configuration of the photovoltaic modules.

These measurements were done at different irradiance and were made possible by adjusting the screen to control the light level. The irradiance was measured at

100%, 70%, 50% and 10% for the single photovoltaic panel as indicated in equation 4. The different irradiation level and pyrometer reading are shown in Table 1.

Irradiation = pyrometer (Milli-volt)/pyrometer calibration factor ($V/m^{-2}W$)… (4)

Table 1: Irradiation at different level

Pyrometer Reading (mV)	8.21 mV @ 100%	5.8 mV @ 70%	3.9 mV @ 50%	0.69 mV @ 10%
Irradiation (W/m^2)	667.5	471.5	317.1	56.1

3.0 Experimental result:

From the experiment the following data were recorded on the photovoltaic data sheet shown in Table 2.

Table 2: Experimental reading of Photovoltaic module on different configuration and irradiation

Series (100%)		Parallel (100%)		Single (100%)		Single (70%)		Single (50%)		Single (10%)		
Irradiation W/m^2		Irradiation W/m^2		Irradiation W/m^2		Irradiation W/m^2		Irradiation W/m^2		Irradiation W/m^2		
V	I(mA)	V	I(mA)	V	I(mA)	V	I(mA)	V	I(mA)	V	I(mA)	
0.03	97.4	0.04	195	0.4	98.4	0.2	67.5	0.1	48.1	0.1	10.4	Short circuit
25.0	44.7	16.7	91.4	16.5	44.7	13.4	61.1	11.7	45.2	2.6	10.1	
33.0	23.7	17.2	43.8	17.1	21.4	16.5	22.3	15.9	21.2	7.1	9.6	
34.1	14.6	17.3	27.9	17.2	14.0	16.7	13.7	16.3	13.8	10.7	8.5	
34.3	9.9	17.3	19.4	17.3	9.8	16.9	9.6	16.5	9.6	12.1	7.0	
34.4	7.6	17.4	15.1	17.3	7.3	16.9	7.5	16.6	7.4	12.9	5.7	
34.5	6.2	17.4	12.2	17.3	6.1	17.0	6.2	16.7	5.9	13.4	4.7	
34.5	5.2	17.4	10.3	17.3	5.2	17.0	5.1	16.7	4.9	13.6	4.1	
34.5	4.5	17.4	8.9	17.3	4.4	17.0	4.5	16.7	4.3	13.8	3.5	
34.5	4.0	17.4	7.9	17.3	4.0	17.0	3.9	16.8	3.8	13.9	3.2	
34.6	3.7	17.4	7.4	17.3	3.7	17.0	3.6	16.8	3.6	14.0	3.0	
34.8	0.0	17.4	0.0	17.4	0.0	17.1	0.0	16.9	0.0	14.7	0.0	Open circuit

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With this information, the performance of the photovoltaic panel was analyzed from the I-V and P-V characteristic curves plotted from the photovoltaic data sheet. The figures 3 to figure 8 were used to determine the behavior of the photovoltaic modules/panel in the manner in which they are connected.

The experimental calculations for power and efficiency curves were estimated using equations 1 and 2 and are shown in tables 3, 4, and 5.

Table 3: power generated by photovoltaic panel under different irradiance

Series	Parallel	Single (100%)	Single (70%)	Single (50%)	Single (10%)	
Irradiation W/m^2	Irradiation W/m^2	Irradiation W/m^2	Irradiation W/m^2	Irradiation W/m^2	Irradiation W/m^2	
Power (mW)	Power (mW)	Power (mW)	Power (mW)	Power (mW)	Power (mW)	
2.9	7.8	39.4	13.5	4.8	1.04	Short Circuit
1117.5	1526.4	737.5	818.7	528.8	26.3	
782.1	753.4	365.9	367.9	337.1	68.3	
497.9	482.7	240.8	228.8	224.9	90.9	
339.6	335.6	169.5	162.2	158.4	84.7	
261.4	262.74	126.3	126.8	122.8	73.5	
213.9	212.3	105.5	105.4	98.5	62.9	
179.4	179.2	89.6	86.7	81.8	55.8	
155.3	154.9	76.1	76.5	71.8	48.3	
138.0	137.5	69.2	66.3	63.8	44.5	
128.0	128.7	64.0	61.2	60.5	42.0	
0.0	0.0	0.0	0.0	0.0	0.0	Open Circuit

Table 4: single panel under full irradiance

SINGLE MODULE	
EFFICIENCY (η)	VOLTAGE (V)
0.1	0.4
2.5	16.5
1.2	17.1
0.8	17.2
0.6	17.3
0.4	17.3
0.4	17.3
0.3	17.3
0.3	17.3
0.2	17.3
0.2	17.3
0	17.4

Table 5: MPP and irradiance for single panel

SINGLE MODULE	
MMP (mW)	IRRADIATION (Ir)
765	667.5
800	471.5
540	317.1
90	56.1

From the experimental values the graphs of figure 3 to figure 8 were drawn. .

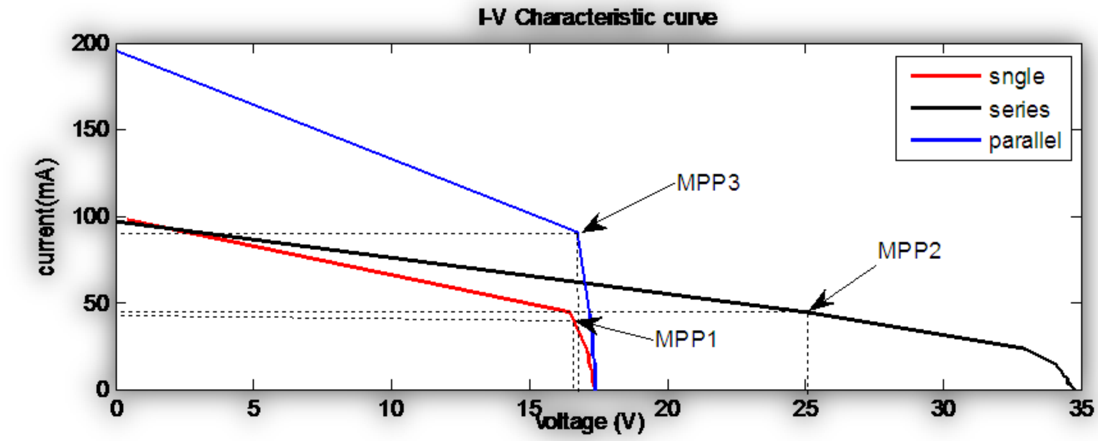

Fig. 3: The current voltage curves for single, series and parallel connection of the photovoltaic modules.

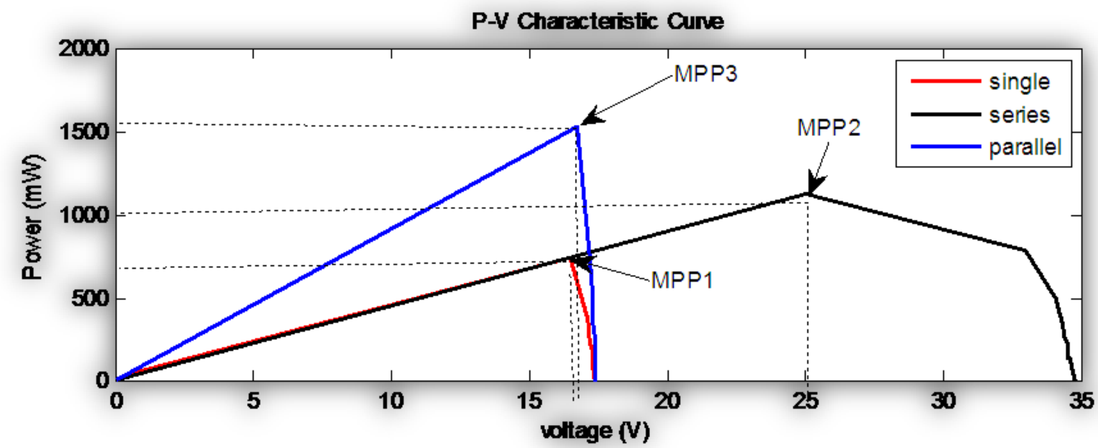

Fig. 4: The power voltage curves for single, series and parallel connected modules

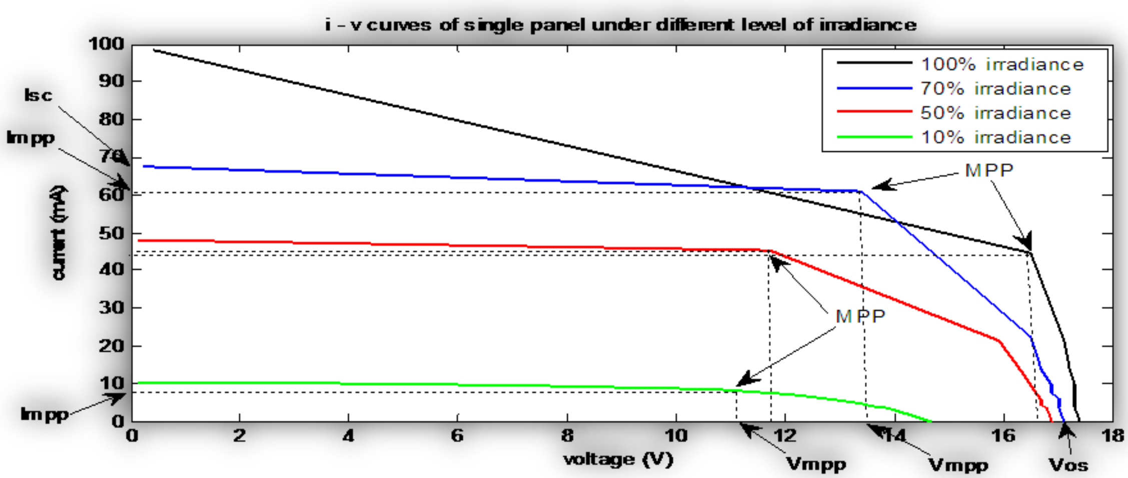

Fig. 5: current voltage curves for single module at different irradiance.

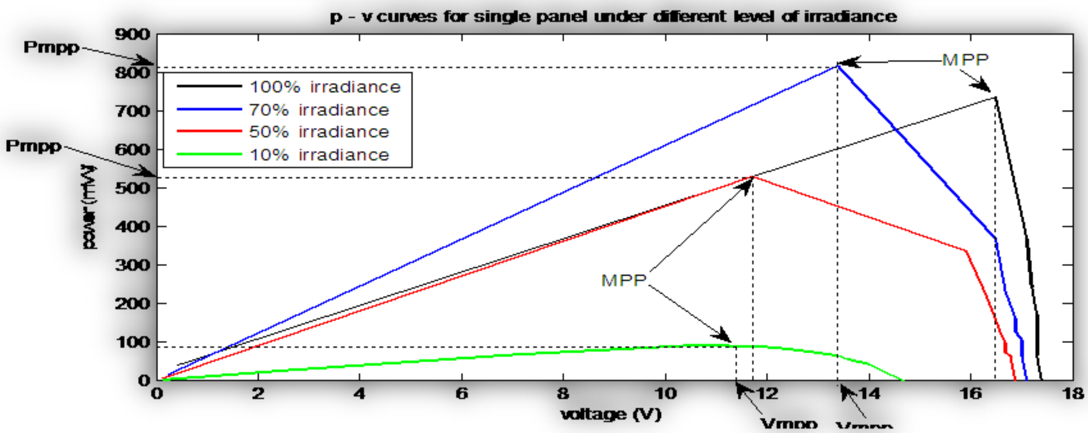

Fig. 6: Power voltage curves for single module at different irradiance.

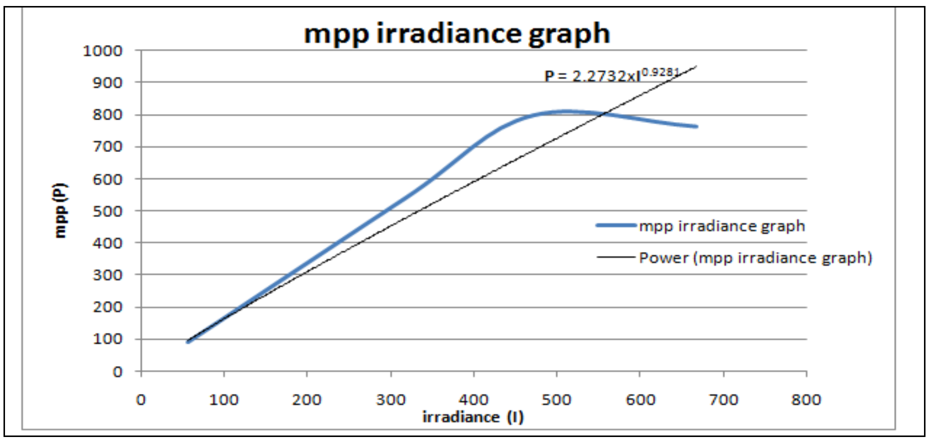

Fig. 7: MPP irradiation curve for single photovoltaic module.

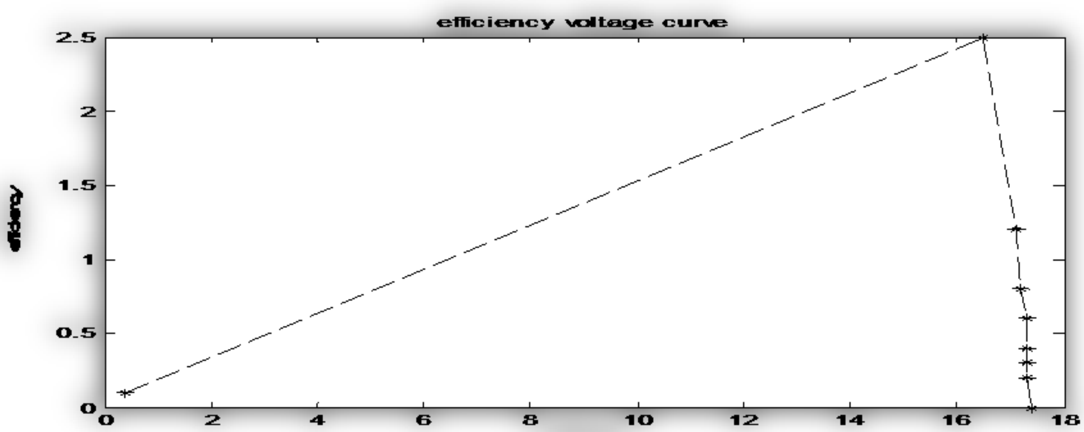

Fig. 8: efficiency voltage curve for single module tested under full irradiation.

4.0 Discussion and Conclusion:

From the characteristic I–V curve in figure 3, the photovoltaic module connected in series increases the voltage while the panel connected in parallel increases the current. This is demonstrated in the electrical parameters and characteristic curves. It was observed that the V_{MPP}, add up for series while the I_{MPP} add up for parallel connection (Table 2). The area under maximum point of the series is greater than that of the parallel which means that the series connection increases power. It was also observed that the open circuit voltage remain constant for parallel while short circuit current remain constant for series connection. Figure 4 demonstrates the power generated when photovoltaic panels are connected in series and parallel. The P-V curves and electrical parameters in figure 4, demonstrate the changes in power for the different panel connections. The area under the MPP of the series is greater and better than the parallel which shows that the P_{MPP} and the V_{MPP} add up for series connection while for parallel connection the I_{MPP} and P_{MPP} add up. The electrical parameter and characteristic curves of the photovoltaic single panel in figure 5 are dependent on the irradiance. The changes in irradiance affect the panel current and voltage. The current is directly dependent on the irradiance; when the irradiance reduces, the electricity generated also reduces. This is demonstrated in the electrical parameters and the I-V curves of figure 5. As the irradiance reduces from 471.5 W/m^2 to 317 W/m^2, the current also reduces while from 317 W/m^2 to 56.1 W/m^2 the current further reduces. The MPP voltage due to the change in irradiance is relatively constant because the change is about 3V from figure 5. Also in figure 6 the maximum power point MPP, is directly dependent on the irradiance. For installation driven by photovoltaic panel, at very low irradiation, the voltage reduces significantly which affects the load, and then the downstream inverter now operates in the fixed voltage area. This means that the operating point of the inverter at low irradiance is no longer the MPP. In figure 8, the maximum efficiency of the single panel photovoltaic cell is 2.5% which is less than the publish data for Monocrystalline photovoltaic module of 22%. In figure 7, it shows that the panel is sensitive to light. The maximum power point MPP is proportional to irradiation but for the case of 100% there is a short fall which is due to heat loss from the panel. This heat loss can be reduced by proper ventilation system.

Conclusion,

Basically the curves are characterized by the following three points,

I. MPP (maximum power point) is the point on I –V curve at which the solar panel operate at maximum power. For this point the power P_{MPP}, the current I_{MPP} and the voltage V_{MPP} are specified

II. The short circuit current (Isc) is approximately 5-15% greater than the MPP current. This current is linearly dependent upon the irradiance. i.e if the irradiance double, the current doubles.

III. The open circuit voltage (Vo) stays relatively constant as the irradiance changes.

From the work it was observed that the series connected panel increases voltage and the parallel connected panel increases current but multiple panels, are configured in series to increase voltage and in parallel to increase current, the product of which is power. It was seen that the area under maximum power point of the series connection is greater than that of the parallel connection, which indicates that the series connection increases power. But generally, the number of series and parallel connections depend on needs.

References:

[1] Masters, G.M. (2004). Renewable and efficient electric power systems, John Wiley and sons Inc, Hoboken, New Jersey, p.445.

[2] Markvart, T. (2001). Solar electricity, john Wiley & sons Baffin's lane, Chichester west Sussex PO19IUD, England, p.25.

[3] Deutsche Gesellschaft fur Sonnenenergie. (2006). Planning and installing photovoltaic systems, James and James Earthscan, 8-12 Camden high street London U.K, pp. 55-101.

[4] Barr, S. and Thomas, J.P. (2005). The role of renewable energy in the development of productive activities in rural West Africa: the case of Senegal.

[5] Dike, V.N., Chineke, T.C., Nwofor, O.K. and Okoro, U.K. (2011). Evaluation of horizontal surface solar radiation levels in southern Nigeria.

[6] Olesen, G.B. (2004). Inforse Vision: 100% renewable in 2050, Sustainable Energy News, 45

[7] Sambo, A.S. (2006). Renewable Energy Electricity in Nigeria the way forward: Renewable Electricity Policy Conference. Pp. 1 – 42.

[8] Togola, I. (2005). Renewable energy solution perspectives for Africa Mali – Folke Centre.

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