Energy Analysis of a 20W Solar Photovoltaic Module: A Review

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ABSTRACT

The solar photovoltaic (PV) system generates both electrical and thermal energy from solar radiation. In this paper, an attempt has been made for evaluating electrical output of solar PV panel installed at Ajat Instruments Nigeria Limited, Mokola, Ibadan, Nigeria. Using the first law of thermodynamics, energy/power analysis was performed. The operating and electrical parameters of a PV array include PV module temperature, open-circuit voltage, short-circuit current, fill factor, etc. were used. The reviewed formulas were used for the calculation of the energy/power efficiency of the PV system. Energy/power efficiency was calculated to be approximately 18%. Future studies should focus on modelling the efficiency of the solar panel. More investigation is required to define the optimum efficiency of the solar panel.

Keywords: solar PV; electrical energy; thermal energy; power; energy and exergy efficiency

INTRODUCTION

The amount of solar energy striking the earth's surface depends on the season, local weather conditions, location and orientation of the surface, but it averages about 1000 W/m^2 if the absorbing surface is perpendicular to the sun's rays and the sky is clear. Fortunately, Nigeria is blessed with abundant solar radiation and has a coordinate of 9.0820° N, 8.6753° E in the sunny belt of the world. Nigeria has an average annual solar incident of about 1,831.06 kWh with a total land area of 923,768 km^2. Evaluation of the technical potential of solar energy in Nigeria shows that a useful annual energy of 15 x10^{14} kJ can be obtained with 5 % device efficiency. This translates to about 258.62 million barrels of oil corresponding to 4.2 x10^5 GWh of electricity production annually [1]. The country has an annual average sunshine of about 6.25 h, ranging from 3.5 h at the coastal regions to 9.0 h at the north [2, 3]. Similarly, the mean daily solar radiation is about 5.25 kWh/m^2/day, ranging from 3.5 kW/m^2/day at coastal zones to 7.0 kWh/m^2/day at the north [4 – 6].

In spite of this high potential, solar energy technologies are not now widely used. There are favorable climatic conditions in Nigeria to harness enormous energy for solar applications. Solar cell or photovoltaic (PV) cells convert light, i.e., both direct and indirect sunlight, into direct current electricity in a solid-state semiconductor device. Solar irradiance consists of direct beam irradiance and diffuse irradiance. The latter is created by scattering processes in the atmosphere. The beam radiation is contained within the solid angle subtended by the solar disk. Solar PV system uses only beam irradiance and very little diffuse component. But even on a clear day, the diffuse irradiance can represent 20% of the total irradiance [7]. The maximum amount of radiation is always received by a surface normal to its direction. Therefore, the design of a solar PV system needs information about the solar radiation being intercepted by the tilted surface and site meteorological data. As systems-tracking are expensive, a fixed system at a proper tilt angle (adjusted

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monthly, seasonally or yearly) will maximize the solar radiation being collected.

Incoming sunlight 'pushes' electrons into the p-layer and leaves holes in the n-layer. This will generate an electric power to be extracted through an electric circuit. The solar exergy is converted into electrical exergy. A typical electrical circuit of the solar PV system is schematically illustrated in Figure 1.

The energy efficiency of a solar panel, the ratio of the power output to the energy originally delivered to the solar panel, conventionally is used to measure solar PV efficiency. Energy analysis is based primarily on the first law of thermodynamics, Energy analysis is concerned only with the quantity of energy use and efficiency of energy processes. Energy analysis thus ignores reductions of energy potential, which could be used productively in other physical and/or chemical process. Energy analysis can provide sound management guidance in those applications in which usage effectiveness depends solely on energy quantities [8].

A typical electrical circuit of the solar PV cell [8].

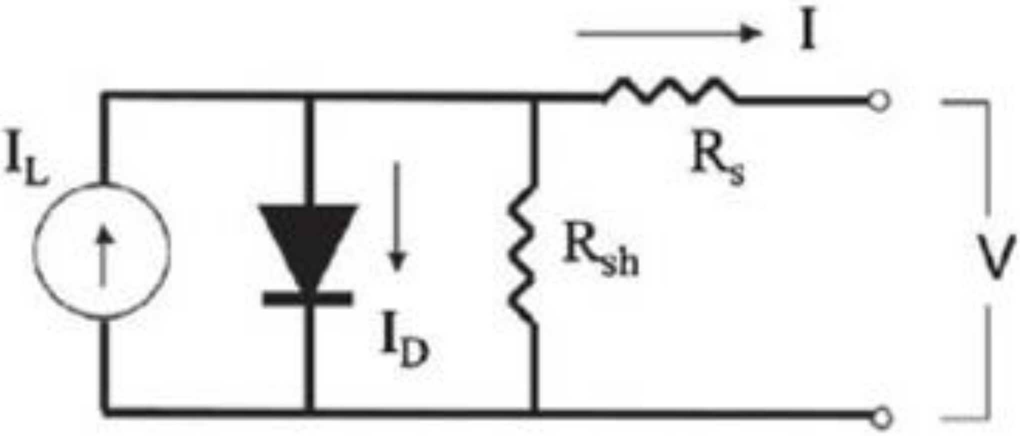

Figure 1: A typical electrical circuit of the solar PV cell [8].

The main purposes of this work was to apply an energy analyses for the solar PV,

METHODOLOGY

Energy efficiency of the solar panel

The most general formulation of the energy equation for an open system under steady-state assumption, using the first law of thermodynamics can be written as

$$E_{in} = E_{out} \quad (1)$$

$$E_{in} - E_{out} = E_{loss} \quad (2)$$

Equation (2) is a general equation for the energy balance: E_{out} is the maximum amount of energy that can be obtained from a system whose supplying energy is E_{in}: the smaller the energy consumed, the smaller the energy loss. A solar cell's *energy conversion efficiency* is the percentage of power converted (from absorbed light to electrical energy) and collected, when a solar cell is connected to an electrical circuit. Energy efficiency of the solar PV can be defined as the ratio of power output to energy input of the solar PV. The output power and energy efficiency of the PV system, however, fluctuate depending on solar insolation and surface temperature.

The energy conversion efficiency of the solar PV (η_{energy}) is calculated from the following equation [9]:

$$\eta_{energy} = \frac{V_{OC} \times I_{SC} \times FF}{A \times G} \quad (3)$$

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The current–voltage characteristics of the electric circuit of solar cell can be described by the following simplified equation:

$$I = I_1 - I_0 \times \exp^{(q\times(V - IR_s))/(A\times K\times T)}. \quad (4)$$

The electric power output of PV is

$$P_{el} = I \times V. \quad (5)$$

Moreover, the maximum output power is given by

$$P_{max} = V_{OC} \times I_{SC} \times FF = V_{mp} \times I_{mp}. \quad (6)$$

Input parameter and specification of the module

Table 1. Input parameter used for analysis.

Input parameter	**Value**
Nominal operating cell temperature (NOCT)	41◦C
Stefan Boltzmann constant (σ))	5.67 × 10-8W/m2 K
Emissivity of the panel (ε)	0.9
Sun temperature	5780K

Table 2. Specification of the PV module.

Model	**SOLAR AP-PM-20**
Maximum Power (P_{max})	20W
Output Tolerance	±5%
Current at P_{max} (I_{mp})	1.14A
Voltage at P_{max} (V_{mp})	17.5V
Short-Circuit (I_{sc})	1.27A
Open-Circuit Voltage (V_{oc})	22.05V
AM	1.5
Fill Factor	0.85
E	1,000W/m^2
TC	25^{o}C

Table 3. Calculated Parameters.

Parameter	Value
Maximum Power ($P_{max} = V_{mp} X I_{mp}$)	19.95W
Electrical Power	24 VA
Area (A) (45cm X 30cm)	0.135m^2
$Power\ or\ Energy\ efficiency\ (\eta_{power})$	17.77%

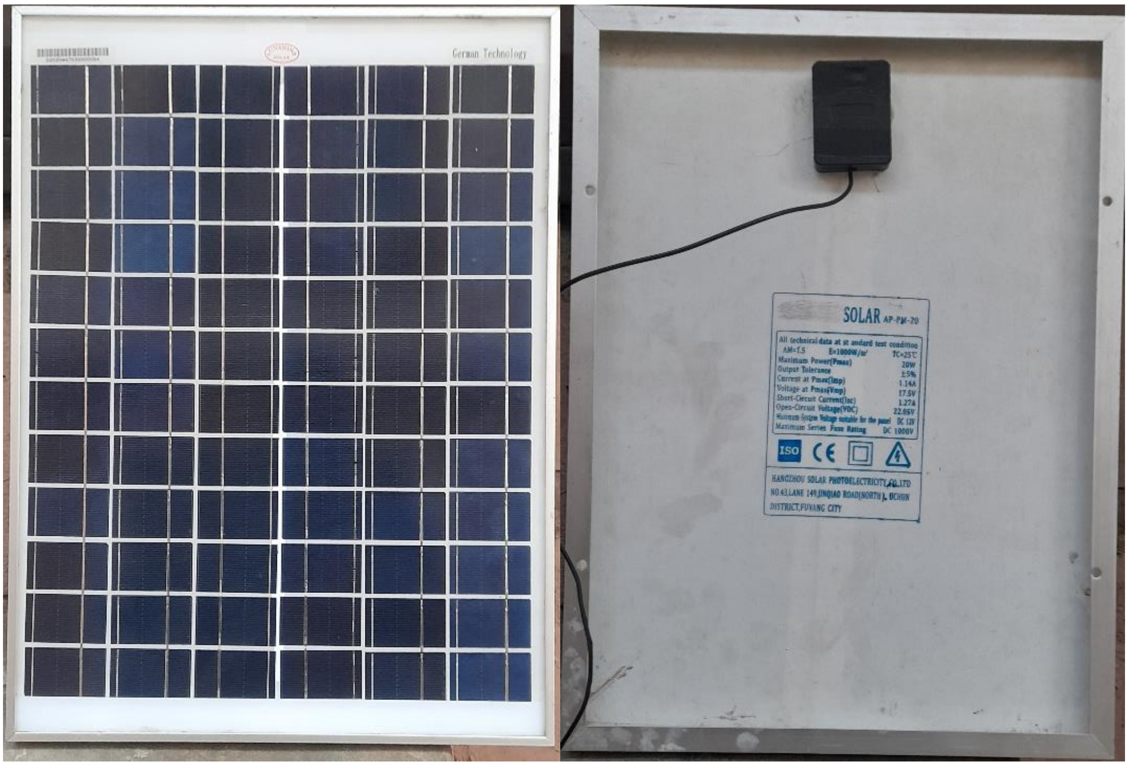

Figure 1 (a) **Figure 1 (b)**

Figure 1: (a) showing the front view of the used solar panel; (b) showing the back view of the solar panel with manufacturer's specification

CONCLUSION

In this review, energy analyses of the 20W solar PV were investigated using energy formula. A parametric study has been carried out to investigate the performance of a solar PV panel. The following are the conclusions drawn from the study:

1. The value of energy efficiency for the solar panel are found to be 17.77%.
2. Research directed towards improving the efficiency of the solar panel could be useful. Development and low-cost semiconductor material could significantly reduce the cost of electricity generation with solar energy.
3. Future studies should focus on modelling the efficiency of the solar panel. More investigation is required to define the optimum efficiency of the solar panel

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