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Correlation ofPhotovoltaic Generated Voltage with Ambient and Cell Surface Temperatures

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ABSTRACT:*Energy usage is important in the economic development of any nation. The per capita energy consumption rate of any nation is a measure of its economic development. Because of the debilitating effects of conventional energy resources, there has been a focus on finding and developing non-polluting renewable energy alternatives. Solar voltaic is one of these renewables. The main drawback in the application of the photovoltaic (PV) is the high cost of storage in addition to the poor availability of design data. Two monocrystalline modules have been designed and built in-house. Experimental data has been obtained from both the cooled and uncooled modules and from these two equations have been obtained. The voltages generated by each of the modules have been expressed as a function of the ambient temperature and module surface temperature. Within the range of parameters investigated, there is a good agreement between the experimental and predicted data.*

KEYWORD: *Photovoltaic, monocrystalline, module, renewable, sustainable, carbon footprint*

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I. INTRODUCTION

Energy is a vital resource that significantly contributes in the classification and nation placement on the global development ladder. It is one of the yardsticks used to measure the economic wellbeing of the nation state. It is a known fact that any nation whose per capita energy consumption is high will simultaneously be associated with high per capita economic development. On the other hand, the reverse defines the so-called developing nations. The industrialised nations consume disproportionally high volumes of energy made up of significant conventional environmental polluting sources that are associated with high carbon footprint. It is therefore understandable why the developing nations argue, even though without success, that the industrialised nations are the polluters and should cater for attendant 'clean-up' inorderto slow global warming. While the politicians and their financial managers argue about carbon 'buy back' and who should pay for it, there is another group made up of scientists and engineers whose focus is on finding alternative and sustainable non-polluting energy resources with near zero carbon footprint. This group also accepts that economic growth and sustainable development of any nation depends largely on the long-term availability of energy from sources that are affordable, accessible, and environmentally friendly **[1]**. In a developing economy, energy is the life-wire that will accelerate the nations into fully developed and industrialised state. Most developing nations even those that situate near the equator where there is abundant sunshine, still rely on fossil fuel for both social and economy development. In many of these countries, population increase is astronomical and this can partly account for the enormous stress exerted on infrastructural facilities including energy supply. This has made it virtually impossible for energy supply to keep up with demand There is always a shortfall in the supply chain. Developmental efforts are adversely affected when in this way demand outstrips supply. In agreement with the group focussing on alternative renewable energy resources, this study has taken place. Solar energy is one form of renewable energy that has great potential in in many developing economies even though the cost of storage facilities such as batteries is high. Nigeria as an example is a country near the equator and is quoted to receive an average of 6,372,613 PJ/year of insolation which approximates to 1,770x10^3 TWh per year and at full exploitation will yield about 120,000 times the total grid electricity produced in the country [2]. Another study that considered the coastal south and the arid north of the country has validated the former study on the basis of the enormous amount of solar energy available in the country [3].

The performance of photovoltaic module (PV) in the conversion of solar energy into electricity is a function of time of the day and many meteorological factors. Weather pattern and seasonal variation in different regions all combine to regulate the amount of sunlight available to power the PV system. Research has shown that solar module works better in certain weather conditions. Therefore, the performance of the PV system depends on the cell characteristics as well as environmental factors **[4].** In a study it was concluded that ambient temperature is one of the factors that affect the PV conversion process as well as its performance [5]. The performance of the module varies with different geographical locations due to different environmental factors and atmospheric conditions relating to each of these locations [6]. Temperature variation across the regions is one of those vital parameters that affect the reliability of the PV performance. The performance of a solar module of a given cell type depends largely on ambient temperature and the cell surface temperature. These parameters are vital in evaluating the voltage generated by the module. The daily average ambient temperature in the tropics over the year could be as high as 30^o C and this correspondingly leads to increases on module cell surface temperature and reduction in module voltage generation **[7]**. It has further been shown that the relationship between the cell surface temperature and module efficiency is in inverse proportional [8]. Studies have shown that less than 20% of the irradiance falling on the module surface is converted to electricity and the balance is converted to heat accounting for the reason why the cell surface temperature is higher than the ambient [9, 10]. It is thought that as the module surface temperature increases, the degree of hotness of the of silicon solar cell increases and as such the usual orderly vibration of electrons is altered to become randomly chaotic with the net result of reduced voltage generation. This vibration obstructs the free movement of the electrons with the resultant effect of heat build-up in the cells and a decrease in cell efficiency. Another study not only correlated the finding of the others but also emphasized that it is the heat buildup on the module the leads to reduced efficiency [11]. Again, energy production of the solar cell depends on solar radiation intensity, a variable which is time of the day and weather condition dependent. In agreement with other workers, it was concluded that it is the rise in cell module temperature that causes the voltage as well as the power delivered and efficiency to drop **[12]**. This shows clearly that the solar radiation absorbed by the module is converted to electricity and thermal energy. The electrical efficiency of the system at different operating temperatures is based on the energy balance of the system and this gives an estimate of the performance of the electrical power output of the module. In a study in Kaduna, Nigeria to further validate the effect of temperature on the performance of the solar module [7], it was found that in a clear and cloud free day the solar module best performance occurs in the morning hours when the ambient temperature is not too high and the worst period is about 1400 hours when the solar intensity is highest. However, to determine the percentage improvement at reduced temperature requires careful research analysis in a real environment. Using both active and passive methods, several studies have been carried out to validate the degree of influence the module surface temperature exerts on performance. Different cooling techniques such as forced air, cooled air, silicon oil as well as water have been used by different authors under different weather and climatic conditions to study the performance of the PV system [13]. The results have shown that performance varies across between the studies but overall, the efficiency of the solar module increases as module surface temperature is reduced.

There is no doubt that the availability of solar energy is a function of time of the day and environmental factors. However, module temperature which is a function of meteorological factors is vital for assessing the long-term performance of the PV module system and its annual electric power production. Incessant increase in cell temperature during operation gradually decrease the performance of the PV module energy generation **[14]** and this together with the high cost of storage systems might affect its acceptability for part replacement of electric power from conventional sources. A key factor for the PV system designer, is ability to simply predict the voltage range that will match the intended usage. This will be an improvement to the practice of relying on data generated from practical measurements from site installations **[15]**. Therefore, the aim of this study is to obtain an expression relating module generated voltage to ambient and module surface temperatures.

II. DATA CAPTURE

This study was carried out in Kaduna, Nigeriawhere the maximum average monthly daylight hour and temperature range have been estimated to be 12.7h [16] and 13^0C to 42.9^0C **[17]** respectively.

Two monocrystalline modules each of 9V capacity were used in the investigation. These modules were built in-house and consist of solar cells with 4.5A and 2.25W specification. One of these modules surface temperature was controlled using an air-conditioning system and the other exposed to the ambient temperature. Data was acquired using these modules with thermocouples and digital read-out units attached. In each case the module surface temperature, ambient temperature and the generated voltage were recorded at equally spaced intervals. This process was repeated for weeks. It is noted that the longer the module is exposed to the sun the higher the surface temperature rise [18]. It is from the data generated that the curves were obtained by generating simultaneous equations of variable module surface temperatures with unknown coefficients and ambient temperature as a constant. The resulting matrices were solved for the unknown coefficients using Gauss Elimination and Gauss-Seidal methods.

III. RESULT and DISCUSSION

Equations (1) and (2) are the two expressions obtained for predicting the voltages for any given ambient and module surface temperatures. Equation (1) refers to the uncooled module whereas equation (2) is for the cooled module. T_u and $T_c$in the equations represent the uncooled and cooled module surface temperatures respectively and T_a is the ambient temperature.

$$V = -0.074T_0 + 0.723T_u - 0.0176T_u^2 + 1.83E\text{-}04T_u^3 - 6.83E\text{-}07T_u^4 \qquad (1)$$

$$V = -0.0161\,T_0 + 1.04\,T_c - 0.0342\,T_c^2 + 4.58E\text{-}04\,T_c^3 - 2.18E\text{-}06\,T_c^4 \qquad (2)$$

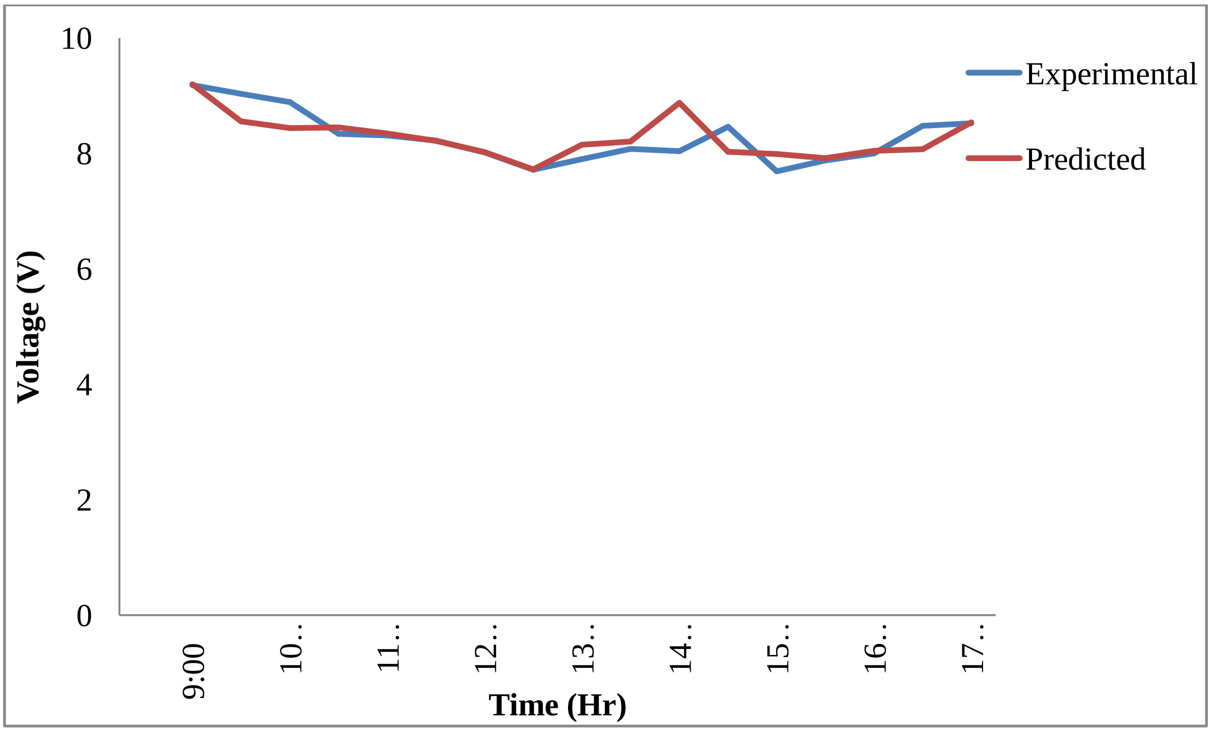

Fig. 1 Comparison of Experimental and Predicted Curvesfor the Ucooled Module

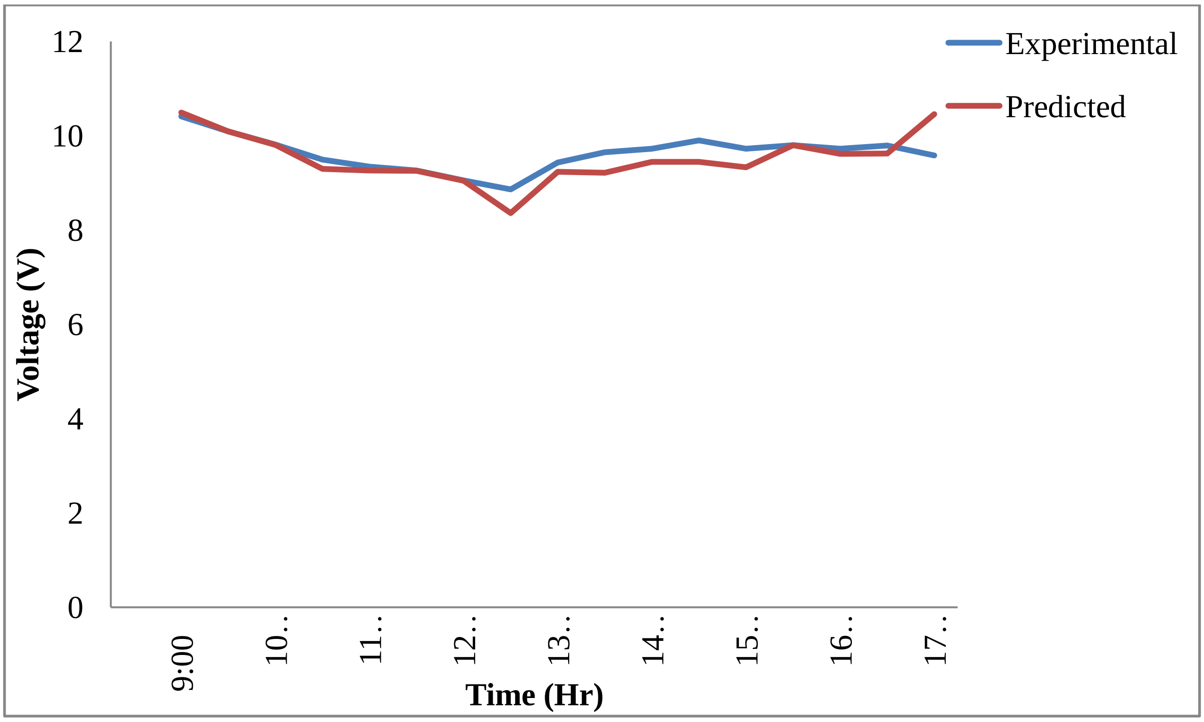

Fig.2 Comparison of Experimental and Predicted Curves for the Cooled Module

Originally the intention was to obtain a single expression that would cater for both cooled and uncooled modules but it was found that the margin of error was high as it was over predicting and under predicting the cooled and uncooled modules respectively. This is thought to be as a result of the uncontrolled air conditioning system power supply system with its tendency to fluctuate widely. The prediction follows the trend established by the experimental investigation. At moderate ambient temperatures 18 to 24^{o}C such as those experienced in the experimental location at around 8 to 10am, the voltage generation rate is at its pick. As the day advances, the ambient temperature and hence module surface temperature increase with consequent reduction in voltage generation rate. This sluggish behaviour in voltage generation rate reaches the worst level at about 2pm. At around 4pm, the ambient temperature begins to cool down but the module surface temperature cooling rate lags behind and this adversely affects the voltage generation rate. The overall result is that for a similar ambient temperature, the morning hours voltage generation rate of the PV module is better than that of the early evening rate and the inability of the module surface temperature to lose its excess heat fast enough can account for this. There is a fair agreement between the curves plotted using the experimental data and the predicted values as shown in figures 1 and 2. In the morning hours, it is difficult to distinguish between the experimental and predicted curves but from about 1300 hours, the differences between the curves are significant the unpredictable behaviour of the module with rising ambient temperature may account for this. No attempt has been made to extrapolate the curves outside the areas where experimental data is available.

IV. CONCLUSION

Data has been obtained for the voltage generated by cooled and uncooled photovoltaic modules and the data has been used to obtain expressions that could help PV system designers in estimating the voltage generated at each given ambient and solar panel surface temperatures. Acceptable agreement between the predicted and experimental data has been shown in the plots.

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