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Performance of 5kwp grid-Connected Solar PV System in the Coastal, Tropical Forest and Northern Climatic Zones of Ghana

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Abstract

The performance of 5kWp grid-connected solar PV system in Takoradi, Sunyani and wa selected from coastal, tropical forest and northern climatic zones of Ghana respectively have been analyzed. The performance parameters considered based on IEC standard 61724 are the final PVsystem yield (Y_f), reference yield (Y_r) and Performance Ratio (PR). We recorded the best monthly final PV system yield throughout the year with peaking value of 146.73kWh/kW in the month of March when the highest solar irradiance was recorded while Sunyani had the lowest final PV system yield of 90.50kWh/kW in August when the lowest irradiance was recorded. Solar PV system reference yield was realized to have varied similarly as the final PV system yield. With respect to Performance Ratio,Sunyani was the best throughout the year with the peak performance ratio of 0.791 inAugust when the ambient temperature was lowest while the least was recorded in Wa to be 0.770 in March when the ambient temperature was highest. It is therefore realized that final PV system yield and reference yield greatly depended on the irradiance of the location considered while the performance ratio greatly depended on the temperature of the location.

Keywords: *Final PV system yield, Reference yield, Performance Ratio, Solar PV System, grid connected systems.*

1. INTRODUCTION

Accurate and consistent evaluations of photovoltaic systems performance are critical for the continuing development of the solar PV industry [1]. These performance parameters allow the detection of operational problems; facilitate the comparison of systems that may differ with respect to design, technology, or geographic location and validate models for system performance estimation during the design phase and use of solar PV technologies. Standard methods of evaluation and rating also help to set appropriate expectations for performance, ultimately leading to increased credibility for the PV industry and positioning it for further growth [1] [2].

Three of the IEC standard 61724[3] performance parameters may be used to define the overall system performance with respect to the energy production, solar resource, and overall effect of system losses. These parameters are the final PV system yield, reference yield, and performance ratio[1]. They are the most appropriate performance indicators of grid-connected PV systems [4]

Final PV system yield (Y_f)

The amount of energy delivered by solar PV system depends on a number of factors which mainly includes; size of the solar PV array, amount of irradiation and the total efficiency of the system which takes into consideration the power produced after considering all the losses of the solar PV system. The losses include soil age, shading, manufacturer's tolerance, temperature, voltage drop, inverter efficiency orientation and tilt angle of the module. Sometimes these losses are broadly categorized into de-rating of the solar PV array and sub-system losses. The derating of the PV array includes losses due to temperature, soil age, shading and manufacturers tolerance while sub-system losses includes losses due to voltage drop, inverter efficiency etc[5]

The final PV system yield (Y_f) is the net energy output (E) divided by the nameplate d.c.power rating (P_o)of the installed PV array. It represents the number of hours that the PV array would need to operate at its rated power to provide the same energy. The units are hours or kWh/kW. [1] The expression for Final PV System yield (Y_f) is given in equation (1) below

$$Y_f = \frac{E}{P_o}(\text{kWh/kW}) \text{ or } (\text{hours}) \quad (1)$$

Where *E* is the net energy output of the installed solar PV array
$P_o$is the nameplate d.c power rating of the installed solar PV array.

Reference yield (Y_r)

The reference yield (Y_r)is the total in-plane irradiance (*H*) divided by the solar PV's reference irradiance G. It represents an equivalent number of hours at the reference irradiance. If G equals 1 kW/m^2, then (Y_r)is the number of peak sun-hours (PSH) or the solar radiation in units of kWh/m^2. It defines the solar radiation resource for the PV system and is a function of the location, orientation of the PV array, and month-to-month and year-to-year weather variability: [2][6].The expression for Reference Yield (Y_r) is given in equation (2) below

$$Y_r = \frac{H}{G} \text{ (hrs)} \qquad (2)$$

Reference yield(Y_r) and final yield (Y_f) are the most important parameters for PV system analysis for grid-connected PV plants [7]

Performance ratio (PR)

The performance ratio PR is the ratio of the final PV system yield (Y_f) to reference yield (Y_r) as shown in equation (3) below. By normalizing with respect to irradiance, it quantifies the overall effect of losses on the rated output [6][1]

It is used to assess the installation quality and provides standardized basis for comparison of different types and sizes of PV systems. It can also be used for comparing different system types for the same location as well as identical systems installed in different locations.[5]

$$PR= \frac{Y_f}{Y_r}\text{(dimensionless)} \qquad (3)$$

Performance Ratio (PR) values of solar PV systems is typically reported on a monthly or yearly basis and indicates the overall effect of losses on the rated output. It is independent of the plant's location with respect to irradiation, but is affected by the module temperature and thus by the ambient temperature of the system's site [7]. It does not represent the amount of energy produced, because a system with low performance ratio in a high solar resource location might produce more energy than a system with a high performance ratio in a low solar resource location. However, for any given system, location and time if a change in component or design increase the performance ratio, the final PV system yield (Y_f) increaseaccordingly [2]. Because of losses due to PV module temperature, performance ratio values greatly fall within the range of 0.6 to 0.8. Decreasing yearly values may indicate a permanent loss in performance.[1]To compare mounted grid connected solar PV systems on different locations, the performance ratio is a decisive value [8]. It is the most important quantity to be measured for evaluating the overall behavior of a PV plant [9]

2. MATERIALS AND METHODOLOGY

The performance of grid-connected solar PV system in the three major climatic zones of Ghana, which are; Coastal, Tropical forest and Northern climatic zones have been analyzed i. The analysis has been carried out based on performance of 5kWp grid-connected solar PV system in Takoradi, Sunyani and Wa which were respectively selected from each of the climatic zones of the country.Temperature and irradiance used in analysis have been obtained fromNational Aeronautics and Space Administration (NASA) which is available in the database of RETScreen. The long term measured data was used to ensure accuracy of climatic conditions of the selected regions. The Honey module 250W (TSM 250 PC/PAO5A) byTrinasolar PVmodule was considered in sizing and analyzing the annual performance of the 5kWp solar PV system. To enable comparison and analysis of performance of identical grid-connected solar PV systems in the three locations, factors such as manufacturers tolerance, voltage drop and inverter efficiency were considered equal for the 5kWp grid connected solar PV system inall the three locations.

SPECIFICATIONS OF SOLAR PV MODULE

The Honey module by Trinasolar (TSM 250; PC/PAO5A) has been considered in sizing the 5kWp grid connected solar PV system. The specification of the solar panel is provided in table 1 and table 2 below

Table 1: Electric Specifications of TSM 250 at Standard Test Condition (STC).

Electric data at STC	**Value**
Peak Power watts-$P_{max}(W_p)$	250
Power output tolerance- P_{max}(%)	0/+3
Maximum power voltage-V_{MP} (V)	30.5
Maximum power current -I_{MPP} (A)	8.20
Open Circuit VoltageV_{oc} (V)	37.8
Short Circuit Current$-I_{sc}$ (A)	8.83
Module Efficiencyn_m (%)	15.3

Table 2: Temperature ratings of TSM 250.

Temperature ratings	**Value**
Nominal Operating Cell Temperature (NOCT)	46°C ($\pm$2°C)
Temperature Coefficient of P_{max}	-0.41%/°C
Temperature coefficient of V_{oc}	-0.32%/°C
Temperature coefficient of I_{sc}	0.053%/°C

DESIGN CONSIDERATIONS OF SYSTEM COMPONENTS

Table 3 shows the specifications and losses of solar PV system components considered

Table 3: Solar PV System Component Specifications.

Component	**Value**
Inverter efficiency	94%
Voltage drop between arrays and inverter	3%
Dirt tolerance	4%

CLIMATIC CONDITIONS OF TAKORADI, SUNYANI AND WA

Ambient temperature and irradiance of Takoradi, Sunyani and Wa has been showed in Table 4 and Table 5 respectively

Table 4: Ambient temperature of Takoradi, Sunyani and Wa

	Takoradi(°C)	**Sunyani** (°C)	**Wa** (°C)
January	26.7	25.6	26.8
February	27.8	25.8	28.4
March	28.3	25.8	29.5
April	27.8	25.8	28.4
May	27.2	25.5	27.1
June	26.1	24.6	25.6
July	25.0	23.7	24.6
August	25.0	23.5	24.4
September	25.0	24.0	25.2
October	26.1	24.6	26.8
November	27.2	24.9	28.1
December	26.7	25.0	27.1

Source: www.RETScreen.net

Table 5: Average daily solar irradiation of Takoradi, Sunyani and Wa

	Takoradi ($kWh/m^2/d$)	**Sunyani ($kWh/m^2/d$)**	**Wa ($kWh/m^2/d$)**
January	4.45	5.49	5.73
February	5.15	5.67	6.02
March	5.55	5.63	6.15
April	5.42	5.45	6.10
May	5.08	5.14	5.96
June	4.29	4.49	5.46
July	4.15	3.97	4.92
August	4.00	3.69	4.67
September	4.63	3.83	5.01
October	5.44	4.40	5.60
November	5.69	4.82	5.59
December	4.78	5.08	5.63

Source: www.RETScreen.net

ESTIMATION OF THE DERATED OUTPUT OF THE SOLAR ARRAY

The derated output of the grid connected solar PV array (P_{array}) is calculated by the equation

$$P_{array} = P_{stc} \times f_{mm} \times f_{temp} \times f_{dirt} \quad (4)$$

Where (P_{stc}) is the output power rating of the solar PV system at Standard Test Conditions
(f_{mm})Considers the losses due to manufacturer's tolerance and is given by the equation;

$$f_{mm} = 1 - l_{mm} \text{ manufacturers tolerance} \quad (5)$$

Where (l_{mm}) is manufacturers tolerance
(f_{temp})Considers the losses due to temperature of the project site and is given by the equation;

$$f_{temp} = 1 - [Y_{temp} \, (T_{cell} \; - 25°C) \;\;] \quad (6)$$

(Y_{temp}) Is the temperature coefficient of panel considered and (T_{cell}) is the cell temperature given by equation (7) below

$$T_{cell} = T_{amb} + 25°C \quad (7)$$

Where (T_{amb}) is the ambient temperature
(f_{dirt})Considers the soil age losses given by the equation;

$$f_{dirt} = 1 - (l_s) \quad (8)$$

Where (l_s) is the soilage losses

From equations (6) and (7) the estimated (f_{temp})of Takoradi, Sunyani and Wa is shown in Table 6 below

Table 6:f_{temp} of solar PV array estimated for Takoradi, Sunyani and Wa

	Takoradi	**Sunyani**	**Wa**
January	0.891	0.895	0.890
February	0.886	0.894	0.884
March	0.884	0.894	0.879
April	0.886	0.894	0.884
May	0.888	0.895	0889
June	0.893	0.899	0.895
July	0.898	0.903	0.899
August	0.898	0.904	0.900
September	0.898	0.902	0.897
October	0.893	0.899	0.890
November	0.888	0.898	0.885
December	0.891	0.898	0.889

From equation (4) and Table 6, the estimated dailyderatedoutputs of solar PV array (P_{array})is given in Table 7 below

Table 7: Dailyderated outputs of solar PV array

	Takoradi (Wp)	**Sunyani (Wp)**	**Wa (Wp)**
January	4274.5	4296.2	4272.6
February	4252.9	4292.3	4241.1
March	4243.1	4292.3	4219.4
April	4252.9	4292.3	4241.1
May	4264.7	4298.2	4266.7
June	4286.4	4315.9	4296.2
July	4308.0	4333.6	4315.9
August	4308.0	4337.5	4319.8
September	4308.0	4327.7	4304.1
October	4286.4	4315.9	4272.6
November	4264.7	4310.0	4247.0
December	4274.5	4308.0	4266.7

Average monthly energy output of the PV array(E_{month}) of the solar PV system is given by the equation below

$$E_{month}=P_{array} \times H_i \times D_{month} \qquad (9)$$

Where (H_i) is the daily solar irradiance of project installation site and D_{months} are the days in the month.

From equation (9), table 3 and table 7 the estimated average monthly energy output of the PV array of the solar PV systemE_{month} is given in table 8.

Table 8: Average Monthly Energy Output of the Solar PV Array

	Takoradi (kWh)	**Sunyani (kWh)**	**Wa (kWh)**
January	589.67	731.17	758.94
February	613.27	681.44	714.88
March	730.02	749.13	804.44
April	691.52	701.78	776.12
May	671.61	684.87	788.31
June	551.65	581.35	703.72
July	554.22	533.33	658.26
August	534.19	496.17	625.38
September	598.38	497.25	646.90
October	722.85	588.68	741.72
November	727.98	623.22	712.22
December	633.40	678.42	744.66

SUBSYSTEM EFFICIENCY

The equation to determine monthly output energy (E_o) to the grid considering subsystem losses is given by equation 10 below

$$E_o = E_{month} \times n_{inv} \times n_{sub} \qquad (10)$$

Where(n_{inv}) is the inverter efficiency
$n_{sub}$is a factor that considers the voltage drop between the solar PV array and the inverter given by the equation;

$$n_{sub}= 1 - V_{drop} \qquad (11)$$

Where (V_{drop}) is the percentage voltage drop between solar PV array and the inverter

From table 8, considering inverter efficiency of 94% and voltage drop of 3% between the array and the inverter the monthly output energy (E_o) to the grid is estimated in Table 9 below

Table 9: Monthly Output Energy of Solar PV system(E_o)

	Takoradi (kWh)	**Sunyani (kWh)**	**Wa(kWh)**
January	537.78	666.83	692.15
February	559.30	621.47	651.97
March	665.78	683.20	733.65
April	630.67	640.03	707.82
May	612.50	624.60	718.94
June	503.11	530.19	641.79
July	505.45	486.40	600.33
August	487.18	452.51	570.35
September	545.72	453.49	589.97
October	659.24	536.88	676.45
November	663.92	568.38	649.55
December	577.66	618.72	679.13

FINAL PV SYSTEM YIELD

From equation (1) and considering P_o of 5kWpthe monthly final PV systemyield(Y_f) is estimated in Table 10 below

Table10: Monthly Final PV System Yield of Solar PV System

	Takoradi (kWh/kW)	**Sunyani (kWh/kW)**	**Wa (kWh/kW)**
January	107.56	133.37	138.43
February	111.86	124.29	130.39
March	133.16	136.64	146.73
April	126.13	128.01	141.56
May	122.50	124.92	143.79
June	100.62	106.04	128.36
July	101.09	97.28	120.07
August	97.44	90.50	114.07
September	109.14	90.70	117.99
October	131.85	107.38	135.29
November	132.78	113.68	129.91
December	115.53	123.74	135.83

MonthlyReference Yield

From equation (2), the monthly reference yield(Y_r) of the solar PV system in Takoradi, Sunyani and Wa is given in table 11 below

Table 11: Monthly Reference Yield of Solar PV System

	Takoradi (hr)	Sunyani (hr)	Wa (hr)
January	137.95	170.19	177.63
February	144.20	158.76	168.56
March	172.05	174.53	190.65
April	162.60	163.50	183.00
May	157.48	159.34	184.76
June	128.70	134.70	163.80
July	128.65	123.07	152.52
August	124.00	114.39	144.77
September	138.90	114.90	150.30
October	168.64	136.40	173.60
November	170.70	144.60	167.70
December	148.18	157.48	174.53

PERFORMANCE RATIO

From equation (3), table 10 and table 11 the estimatedmonthly performance ratio (PR) of the solar PV system is shown in table 12 below

Table 12: Estimated Monthly Performance Ratio of Solar PV System

	Takoradi	Sunyani	Wa
January	0.780	0.784	0.779
February	0.776	0.783	0.774
March	0.774	0.783	0.770
April	0.776	0.783	0.774
May	0.778	0.784	0.778
June	0.782	0.787	0.784
July	0.786	0.790	0.787
August	0.786	0.791	0.788
September	0.786	0.789	0.785
October	0.782	0.787	0.779
November	0.778	0.786	0.775
December	0.780	0.786	0.778

RESULTS AND DISCUSSION

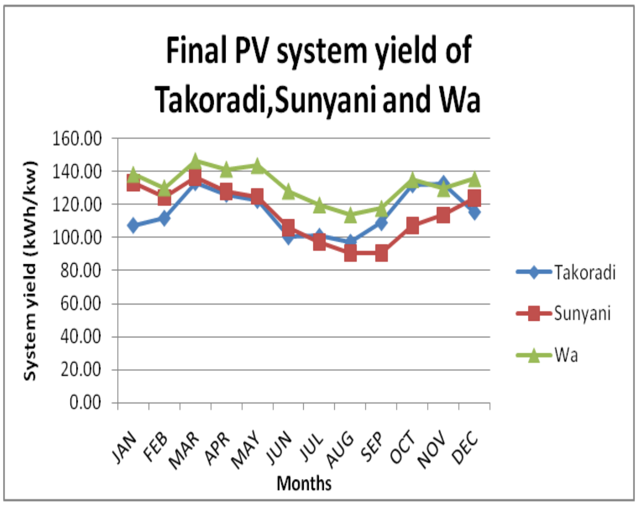

Figure 1: Monthly Final PV System Yield of Takoradi, Sunyani and Wa

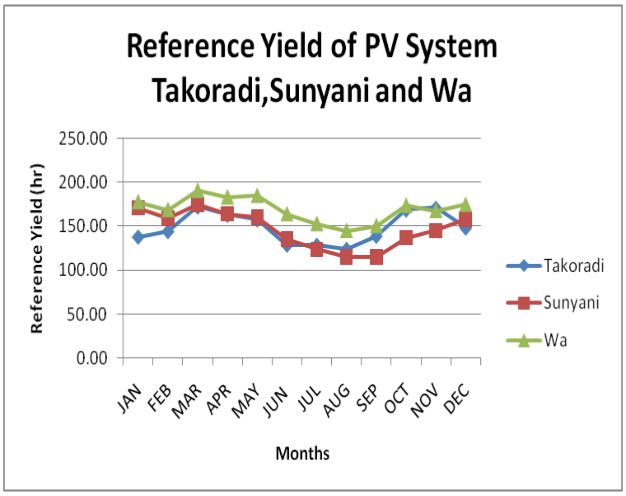

Figure 2: Monthly Reference Yield of Takoradi, Sunyani and Wa

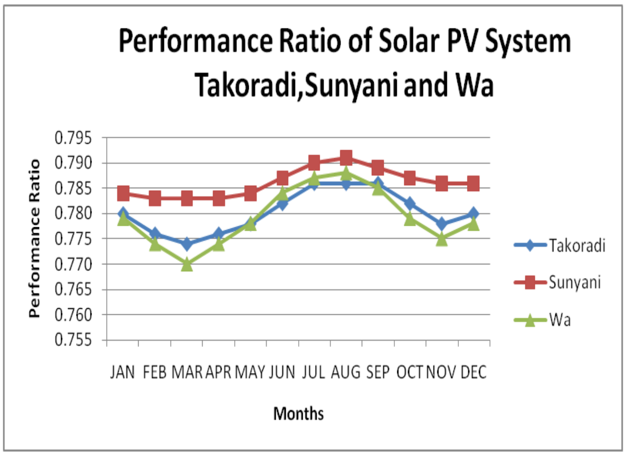

Figure3: Monthly Performance ratio of Takoradi, Sunyani and Wa

The final PV system yield of the Takoradi, Sunyani and Wa is shown in Fig 1. From the figure Wa has the best system yield for the various months of the year over which the system yield has been considered except in the month of November when it was exceeded by Takoradi. This can be attributed to the higher value of irradiance in Wa as compared to the Takoradi and Sunyani since system yield depends on the solar irradiation of the location considered From the same figure the highest final PV system yield of 146.73kWh/kW was recorded for Wa in the month of March when the highest solar irradiance of 6.15kW/m^2/d was recorded while the least final PV system yield of 90.50kWh/kW was recorded in Sunyaniin the month ofAugust when the lowest irradiance of 3.69 kW/m^2/d was recorded . The final PV system yield of Takoradi and Sunyani however depended on the part of the year being considered, at the early parts of the year, that is from January to February, Sunyani had higher final PV system yield as compared to Takoradi while final PV system yield was virtually the same for the months of March to June was virtually the same for the two locations. For the last half of the year, Takoradi had higher values of final PV system yield as compared to Sunyani except in the month of December. The highest system yield of Takoradi was recorded in the month of March 133.16kWh/kW while the lowest value was recorded in August to be 97.44 ofkWh/kW.The highest system yield of Sunyani was recorded in the month of March 133.16kWh/kW while the lowest value was recorded in August to be 90.50kWh/kW in the month of August. The reference yield(Y_r) displayed in Fig 2 is realized to be similar in variation as the system yield since they are dependent on solar irradiance.

Considering the general performance range of 0.6-0.8, it can be realized that all the three regions recorded high performance range of 0.770 -0.791. Sunyani had the highest performance ratio throughout the year which peaked at 0.791 in the month of August. This can be attributed to the lower ambient temperature Sunyani as compared to the Takoradi and Wa. The highest performance ratio of 0.791 was recorded in the month of August during which the temperature of Sunyani is lowest. Wa recorded the lowest performance ratio of 0.770 among the three locations in the month of March during which the highest ambient temperature of 29℃ was recorded.

CONCLUSION

Considering the performance of the 5kWp three locations analyzed in this paper, Wa recorded the best monthly final PV system yield throughout the year with the highest recorded to be 146.73kWh/kW in the month of Marchwhile Sunyani had the lowest final PV system yield of 90.50kWh/kW in the month of August. Solar PV system reference yield varied similarly as the final PV system yield. With respect to Performance Ratio, Sunyani was the best throughout the year which peaked at 0.791 in the month of August while the least was recorded in Wa to be 0.770 in March. It is therefore realized that final PV system yield and reference yield greatly depended on the irradiance of the location considered while the performance ratio greatly depended on the temperature of the location considered.

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