Comparative Performance Analysis Of Off-Grid Solar Power System Using Free Mounted Modules With Air Circulator And Integrated With Fully Insulated Back

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***Abstract*— The focus in this work is to compare the performance of solar power system using free standing solar panels with enough air circulation and another solar power system using solar panels that are integrated on rooftops or has the solar panel back insulated which prevent adequate air circulation. The essence of the study is to study the effect of cell temperature on the performance of the solar panel. The annual mean of the daily solar radiation on the case study site is 4.4138 kWh/m^2 and the mean of the ambient temperature is 26.201 °C. The case study daily load demand of 304 kWh/day. PVSyst software was used to determine the required number of PV modules and battery units for a 2 days of power autonomy and maximum of 3 % loss of load probability. In addition, the thermal loss factor (U) settings are U = 20 W/m^2K for the free standing PV modules and U = 15 W/m^2K for the insulated PV modules. The results show that the mean PR of 0.590416667 is obtained for insulated PV modules and mean PR of 0.60175 is obtained for free standing PV module and these two values give 1.883396 % increase or improvement in performance ratio of the free standing PV over that of the insulated PV modules. Again, there is -73.55704698% reduction or improvement in thermal loss performance of the free standing PV over that of the insulated PV modules; 1.605624024 % increase or improvement in solar fraction of the free standing PV over that of the insulated PV modules and -38.47591362 % reduction or improvement in loss of load probability performance of the free standing PV over that of the insulated PV modules. In all, the results show that adequate air circulation around the PV module can significantly improve the performance of the PV power system.**

Keywords*— *Off-Grid, Loss Of Load Probability, Solar Power System, Free Mounted Modules, Thermal Loss, Fully Insulated PV Module

1. INTRODUCTION

Across Nigeria, solar power system is popular installed as alternative energy source [1,2,3] since the national grid cannot guarantee adequate power supply to the entire population [4,5]. Increasingly, solar power systems are installed on roof tops, open spaces and at different corners of building [6,7].

Notably, studies have shown that the cell temperature significantly affect the performance of the PV modules [8,9]. As such, the nature of the PV module package and the nature of the installation site can affect the cell temperature and hence the system performance [10,11]. Accordingly, in this work, the performance of off-grid PV installation with insulated PV module, PV modules integrated tightly on rooftops or installed with restricted air circulation is studied and compared with the case of free standing PV module with adequate air circulation around the PV array. The study seeks to evaluate the differences in performance of PV system with the two different installation environment. PVSyst software is used to simulate the two PV systems and their compare their performances [12,13].

2. METHODOLOGY

The focus in this work is to compare the performance of solar power system using free standing solar panels with enough air circulation and another solar power system using solar panels that are integrated on rooftops or has the solar panel back insulated which prevent adequate air circulation. The essence of the study is to study the effect of cell temperature on the performance of the solar panel. The annual mean of the daily solar radiation on the case study site is 4.4138 kWh/m^2 (as shown in Figure 1)and the mean of the ambient temperature is 26.201 °C, (as shown in Figure 2). The case study daily load demand of 304 kWh/day is shown in Figure 3.

Based on the given daily energy demand in Figure 3 and the meteorological dataset in Figure 1 and Figure 2 the PVSyst software was used to determine the required number of PV modules and battery units for a 2 days of power autonomy and maximum of 3 % loss of load probability, as shown in Figure 4. Notably, battery capacity of 7050 Ah and PV array power capacity of 112 kWp are selected for the given solar power system. In addition, the thermal loss factor settings for the free standing PV modules and for the insulated PV modules are shown in Figure 5; the thermal loss parameter U = 20 W/m^2K for the free standing PV modules and U = 15 W/m^2K for the insulated PV modules.

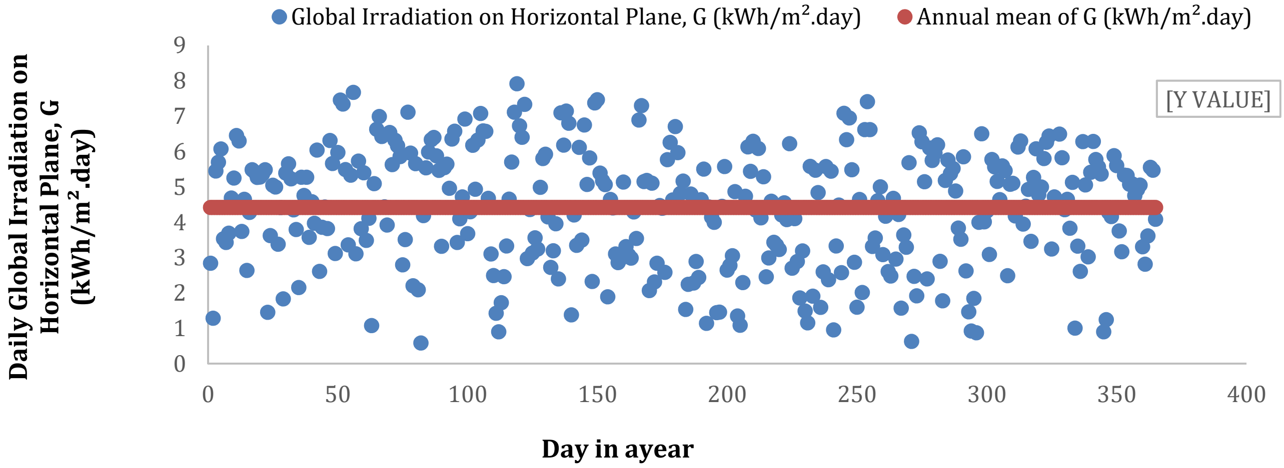

Figure 1 The scatter plot of the daily global irradiation on horizontal plane, G (kWh/m².day)

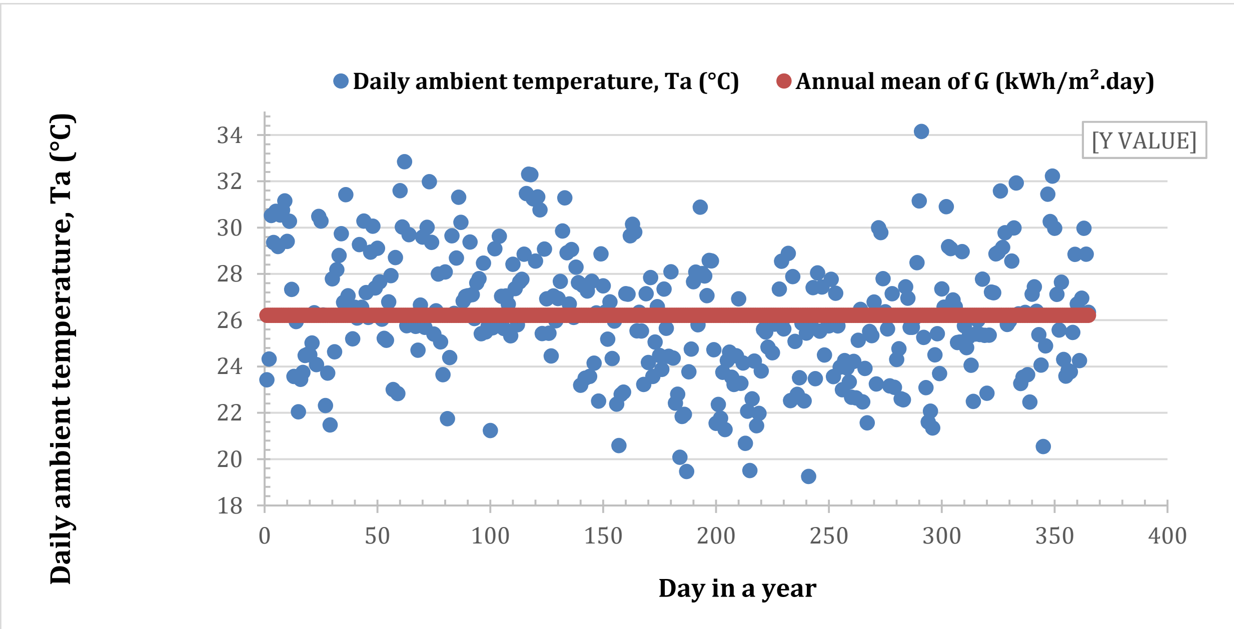

Figure 2 The scatter plot of the daily ambient temperature, Ta (°C)

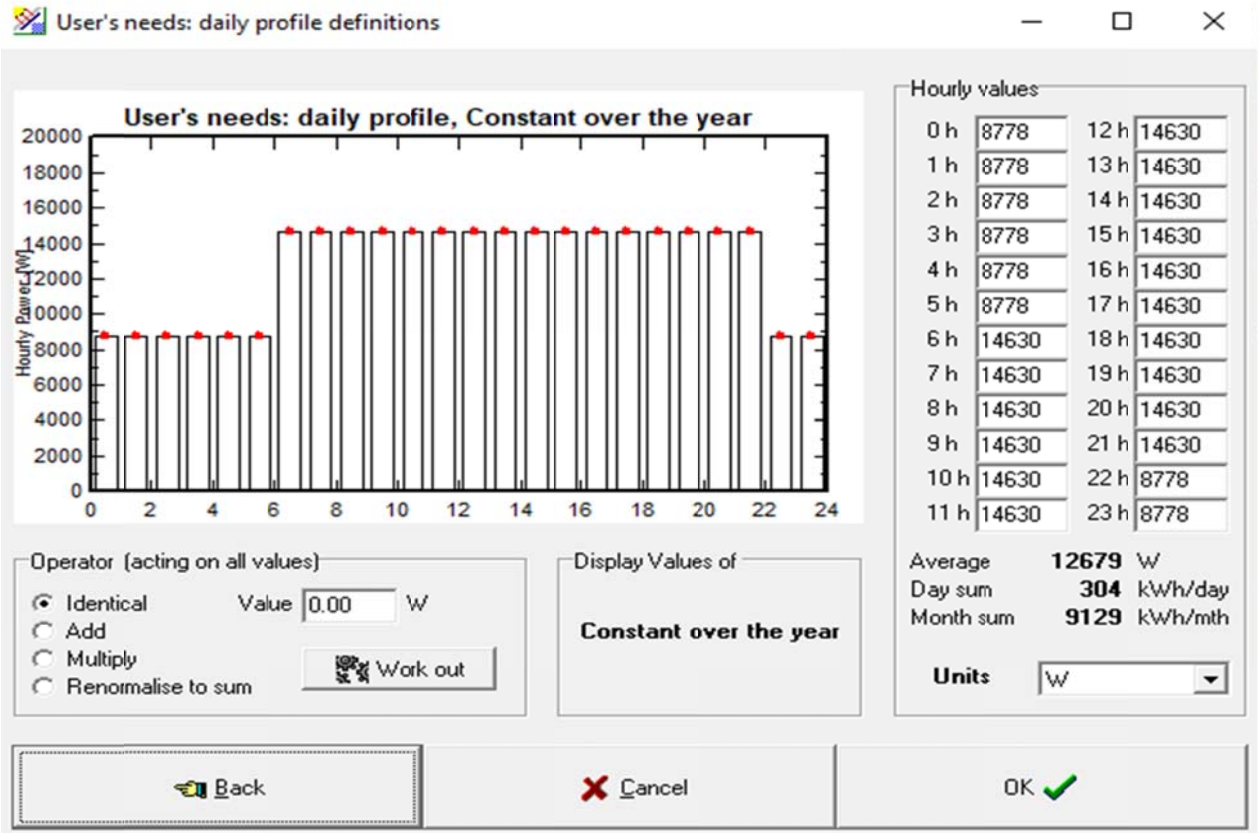

Figure 3 The case study daily load demand

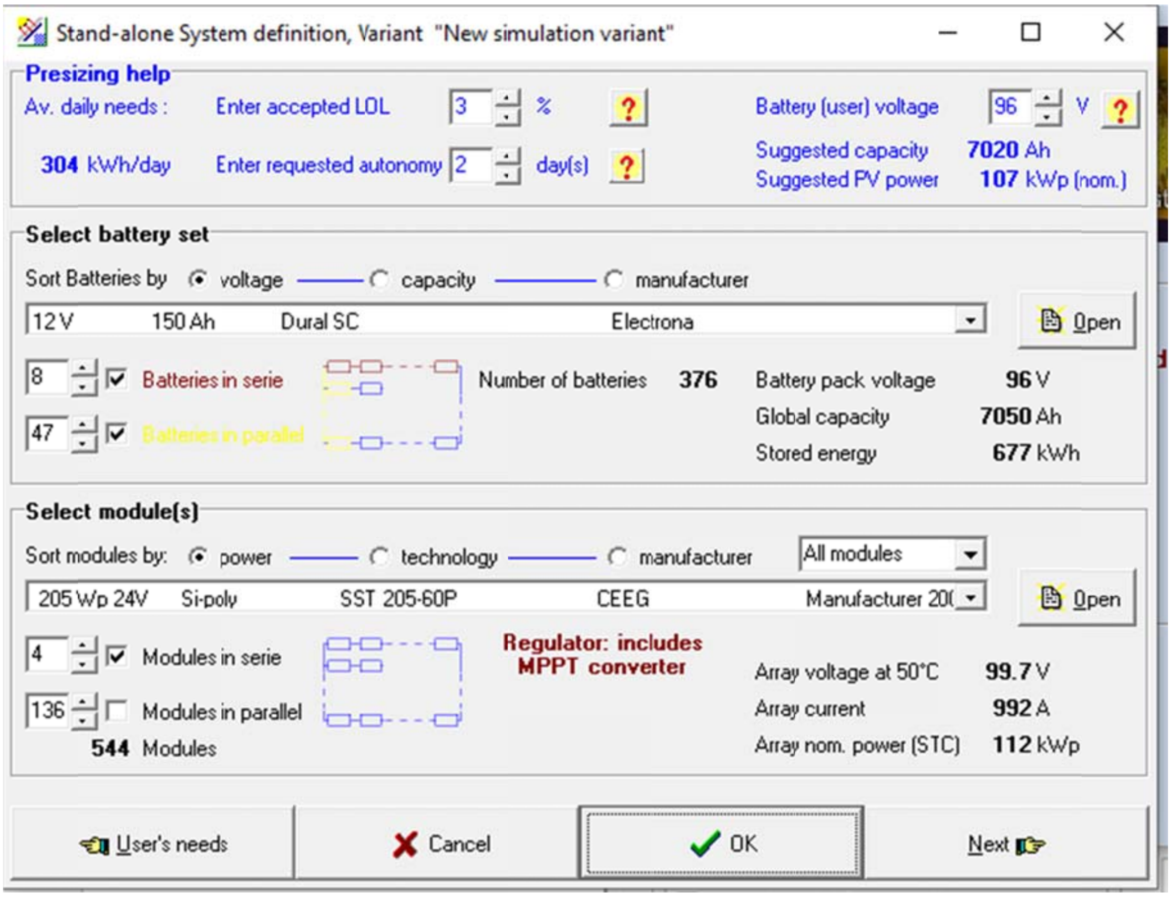

Figure 4 The battery and PV array sizing in PVSyst software

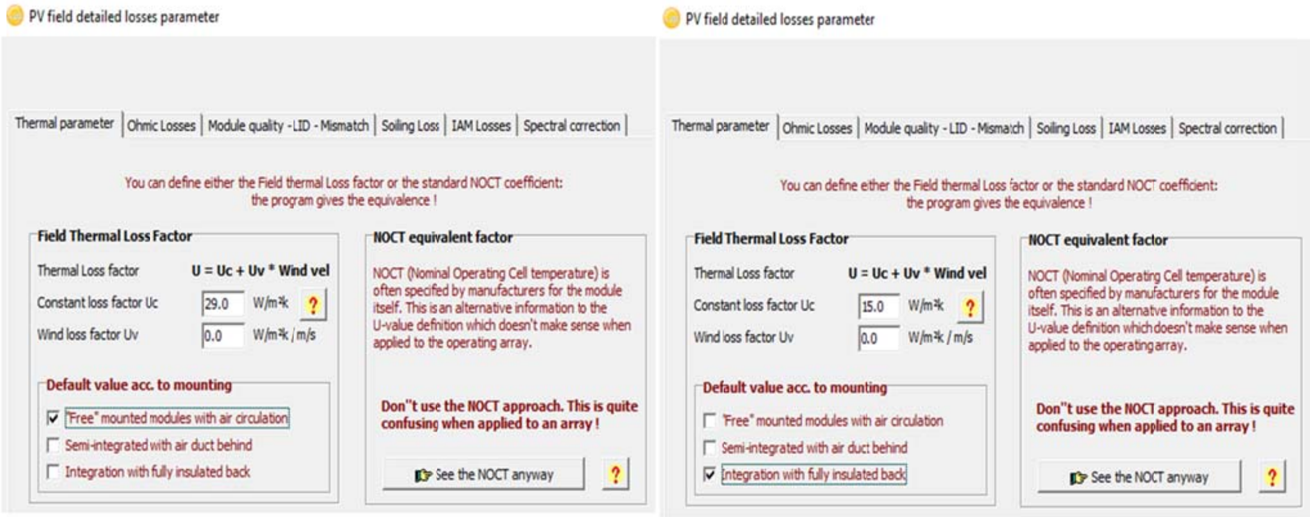

Figure 5 The thermal loss factor settings for the free standing PV modules and for the insulated PV modules

3. RESULTS AND DISCUSSIONS

3.1 THE RESULTS FOR THE FREE STANDING PV MODULES

The results of the energy balance for the free standing PV modules are shown in Figure 6. The results show that about 96% of the energy demand is supplied from the PV power while 4 % of the energy needed are not supplied. This resulted in about 4.04 % of loss of load with about 354 hours of loss of load duration per year, as shown in Figure 6.

The result on the energy balance in Figure 7 for the free standing PV modules shows performance ratio (Pr of 0.594), system production (Yf of 2.62 kWh/kWp/day), system losses (Ls of 0.355), array production (Ya of 0.04 kWh/kWp/day), array losses (Lc of 1.434), potential production (Yu of 4.41 kWh/kWp/day), unused energy losses (Lu of 0.555) and energy yield (Yr of 1608.79 kWh/m^2/day). The total annual thermal loss due to cell temperature is 15,645 kWh, as shown in Figure 8 and this is about 9.3 % of the energy yield, as shown in the loss diagram of Figure 9.

	EArray kWh	E Load kWh	E User kWh	SolFrac	T LOL Hour	Pr LOL %
January	10950	9433	9433	1.000	0	0.00
February	9702	8521	8521	1.000	0	0.00
March	10697	9433	9433	1.000	0	0.00
April	9390	9129	8120	0.889	80	11.18
May	10600	9433	9433	1.000	0	0.00
June	10190	9129	9129	1.000	0	0.00
July	9292	9433	8250	0.875	95	12.74
August	9269	9433	8667	0.919	60	8.11
September	9744	9129	8573	0.939	42	5.86
October	10061	9433	8489	0.900	76	10.27
November	10152	9129	9129	1.000	0	0.00
December	10872	9433	9433	1.000	0	0.00
Year	120919	111071	106611	0.960	354	4.04

Figure 6 The results of the energy balance for the free standing PV modules

	Yr kWh/m².day	Lu	Yu kWh/kWp/d	Lc	Ya kWh/kWp/d	Ls	Yf kWh/kWp/d	PR
January	147.40	0.614	4.75	1.582	0.04	0.444	2.73	0.574
February	138.75	0.801	4.96	1.846	0.04	0.381	2.73	0.551
March	150.81	0.766	4.86	1.769	0.04	0.367	2.73	0.561
April	140.18	0.904	4.67	1.859	0.04	0.380	2.43	0.521
May	138.88	0.516	4.48	1.414	0.04	0.337	2.73	0.609
June	120.11	0.186	4.00	0.954	0.04	0.321	2.73	0.682
July	107.55	0.215	3.47	0.872	0.03	0.314	2.28	0.658
August	105.99	0.046	3.42	0.691	0.03	0.200	2.53	0.739
September	117.58	0.244	3.92	1.000	0.04	0.279	2.64	0.674
October	137.22	0.606	4.43	1.470	0.04	0.507	2.45	0.553
November	155.00	1.093	5.17	2.130	0.05	0.308	2.73	0.528
December	149.32	0.706	4.82	1.670	0.04	0.418	2.73	0.567
Year	1608.79	0.555	4.41	1.434	0.04	0.355	2.62	0.594

Figure 7 The results of the system performance for the free standing PV modules

	PR	TempLss kWh
January	0.574	1609
February	0.551	1634
March	0.561	1679
April	0.519	1460
May	0.609	1299
June	0.682	929
July	0.688	701
August	0.733	702
September	0.654	973
October	0.555	1325
November	0.528	1723
December	0.567	1611
Year	0.594	15645

Figure 8 The results of the performance ratio and thermal loss for the free standing PV modules

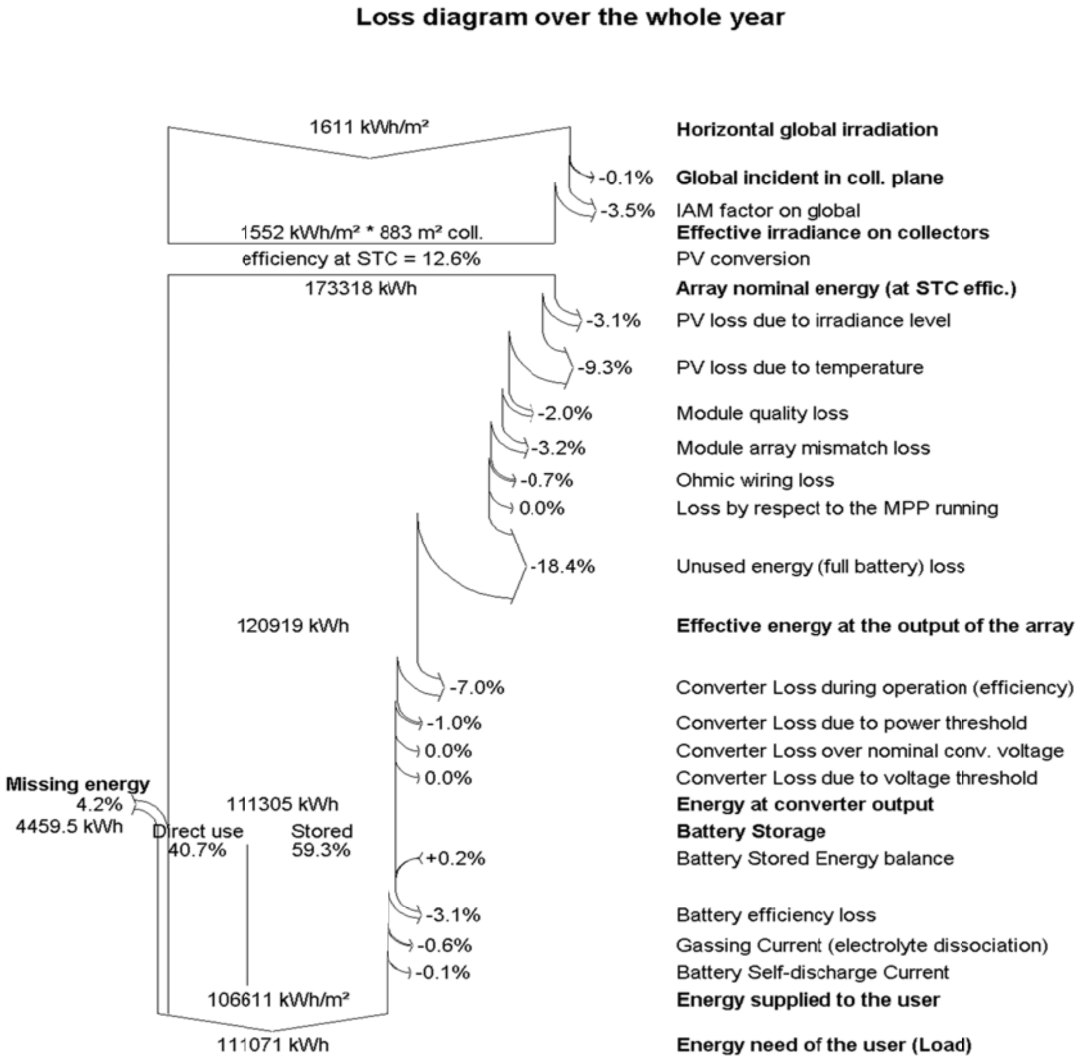

Figure 9 The loss diagram for the free standing PV modules

3.2 THE RESULTS FOR THE INSULATED PV MODULES

The results of the energy balance for the insulated PV modules are shown in Figure 10. The results show that about 94.4% of the energy demand is supplied from the PV power while 5.6 % of the energy needed are not supplied. This resulted in about 5.59 % of loss of load with about 490 hours of loss of load duration per year, as shown in Figure 10.

The result on the energy balance in Figure 11 for the insulated PV modules shows performance ratio (Pr of 0.585), system production (Yf of 2.58 kWh/kWp/day), system losses (Ls of 0.342), array production (Ya of 0.04 kWh/kWp/day), array losses (Lc of 1.489), potential production (Yu of 4.41 kWh/kWp/day), unused energy losses (Lu of 0.346) and energy yield (Yr of 1608.79 kWh/m^2/day). The total annual thermal loss due to cell temperature is 15,645 kWh, as shown in Figure 12 and this is about 9.3 % of the energy yield, as shown in loss diagram of Figure 13.

	EArray kWh	E Load kWh	E User kWh	SolFrac	T LOL Hour	Pr LOL %
January	10885	9433	9433	1.000	0	0.00
February	9679	8521	8521	1.000	0	0.00
March	10642	9433	9433	1.000	0	0.00
April	9359	9129	8114	0.889	81	11.26
May	10561	9433	9433	1.000	0	0.00
June	9818	9129	8782	0.962	27	3.75
July	8678	9433	7600	0.806	144	19.41
August	8936	9433	8459	0.897	76	10.25
September	9280	9129	8073	0.884	84	11.63
October	10017	9433	8476	0.899	77	10.39
November	10129	9129	9129	1.000	0	0.00
December	10824	9433	9433	1.000	0	0.00
Year	118808	111071	104887	0.944	490	5.59

Figure 10 The results of the energy balance for the insulated PV modules

	Yr kWh/m².day	Lu	Yu kWh/kWp/d.	Lc	Ya kWh/kWp/d.	Ls	Yf kWh/kWp/d.	PR
January	147.40	0.332	4.75	1.606	0.04	0.420	2.73	0.574
February	138.75	0.483	4.96	1.856	0.04	0.371	2.73	0.551
March	150.81	0.466	4.86	1.787	0.04	0.350	2.73	0.561
April	140.18	0.629	4.67	1.875	0.04	0.372	2.43	0.519
May	138.88	0.270	4.48	1.425	0.04	0.326	2.73	0.609
June	120.11	0.095	4.00	1.069	0.04	0.309	2.63	0.656
July	107.55	0.141	3.47	0.959	0.03	0.312	2.20	0.634
August	105.99	0.028	3.42	0.834	0.03	0.138	2.45	0.716
September	117.58	0.168	3.92	1.145	0.04	0.361	2.41	0.616
October	137.22	0.389	4.43	1.529	0.04	0.446	2.45	0.554
November	155.00	0.759	5.17	2.139	0.05	0.299	2.73	0.528
December	149.32	0.410	4.82	1.686	0.04	0.402	2.73	0.567
Year	1608.79	0.346	4.41	1.489	0.04	0.342	2.58	0.585

Figure 11 The results of the system performance for the insulated PV modules

	PR	TempLss kWh
January	0.574	2737
February	0.551	2729
March	0.561	2852
April	0.519	2505
May	0.609	2246
June	0.656	1665
July	0.634	1298
August	0.716	1298
September	0.616	1764
October	0.554	2346
November	0.528	2950
December	0.567	2763
Year	0.585	27152

Figure 12 The results of the performance ratio and thermal loss for the insulated PV modules

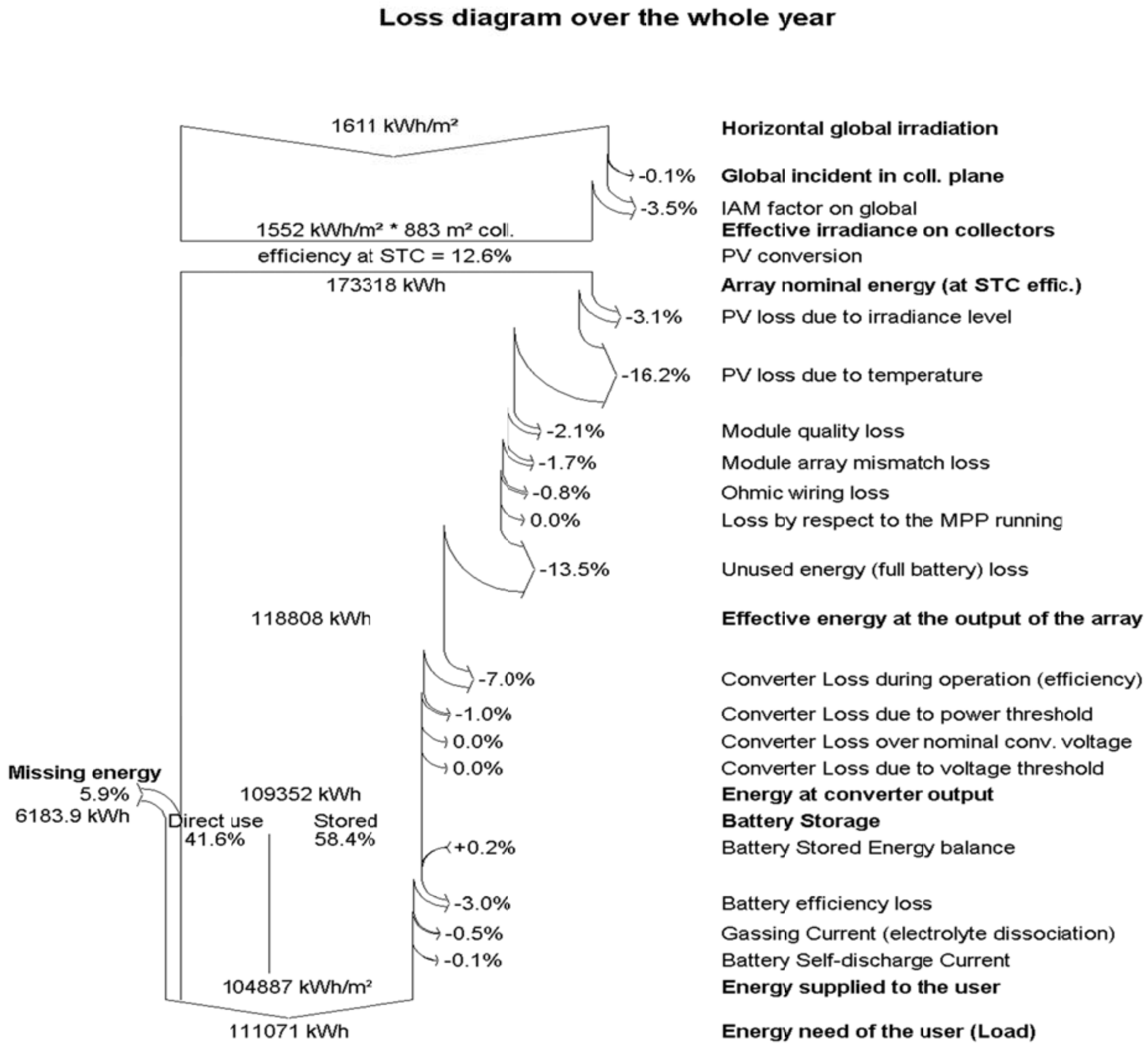

Figure 13 The loss diagram for the insulated PV modules

3.2 THE RESULTS FOR THE INSULATED PV MODULES

The results of the energy balance for the insulated PV modules are shown in Figure 14. The results show that about 94.4% of the energy demand is supplied from the PV power while 5.6 % of the energy needed are not supplied. This resulted in about 5.59 % of loss of load with about 490 hours of loss of load duration per year, as shown in Figure 14.

The result on the energy balance in Figure 15 for the insulated PV modules shows performance ratio (Pr of 0.585), system production (Yf of 2.58 kWh/kWp/day), system losses (Ls of 0.342), array production (Ya of 0.04 kWh/kWp/day), array losses (Lc of 1.489), potential production (Yu of 4.41 kWh/kWp/day), unused energy losses (Lu of 0.346) and energy yield (Yr of 1608.79 kWh/m^2/day). The total annual thermal loss due to cell temperature is 15,645 kWh, as shown in Figure 16 and this is about 9.3 % of the energy yield, as shown in loss diagram of Figure 17.

	EArray kWh	E Load kWh	E User kWh	SolFrac	T LOL Hour	Pr LOL %
January	10885	9433	9433	1.000	0	0.00
February	9679	8521	8521	1.000	0	0.00
March	10642	9433	9433	1.000	0	0.00
April	9359	9129	8114	0.889	81	11.26
May	10561	9433	9433	1.000	0	0.00
June	9818	9129	8782	0.962	27	3.75
July	8678	9433	7600	0.806	144	19.41
August	8936	9433	8459	0.897	76	10.25
September	9280	9129	8073	0.884	84	11.63
October	10017	9433	8476	0.899	77	10.39
November	10129	9129	9129	1.000	0	0.00
December	10824	9433	9433	1.000	0	0.00
Year	118808	111071	104887	0.944	490	5.59

Figure 14 The results of the energy balance for the insulated PV modules

	Yr kWh/m².day	Lu	Yu kWh/kWp/d	Lc	Ya kWh/kWp/d	Ls	Yf kWh/kWp/d	PR
January	147.40	0.332	4.75	1.606	0.04	0.420	2.73	0.574
February	138.75	0.483	4.96	1.856	0.04	0.371	2.73	0.551
March	150.81	0.466	4.86	1.787	0.04	0.350	2.73	0.561
April	140.18	0.629	4.67	1.875	0.04	0.372	2.43	0.519
May	138.88	0.270	4.48	1.425	0.04	0.326	2.73	0.609
June	120.11	0.095	4.00	1.069	0.04	0.309	2.63	0.656
July	107.55	0.141	3.47	0.959	0.03	0.312	2.20	0.634
August	105.99	0.028	3.42	0.834	0.03	0.138	2.45	0.716
September	117.58	0.168	3.92	1.145	0.04	0.361	2.41	0.616
October	137.22	0.389	4.43	1.529	0.04	0.446	2.45	0.554
November	155.00	0.759	5.17	2.139	0.05	0.299	2.73	0.528
December	149.32	0.410	4.82	1.686	0.04	0.402	2.73	0.567
Year	1608.79	0.346	4.41	1.489	0.04	0.342	2.58	0.585

Figure 15 The results of the system performance for the insulated PV modules

	PR	TempLss kWh
January	0.574	2737
February	0.551	2729
March	0.561	2852
April	0.519	2505
May	0.609	2246
June	0.656	1665
July	0.634	1298
August	0.716	1298
September	0.616	1764
October	0.554	2346
November	0.528	2950
December	0.567	2763
Year	0.585	27152

Figure 16 The results of the performance ratio and thermal loss for the insulated PV modules

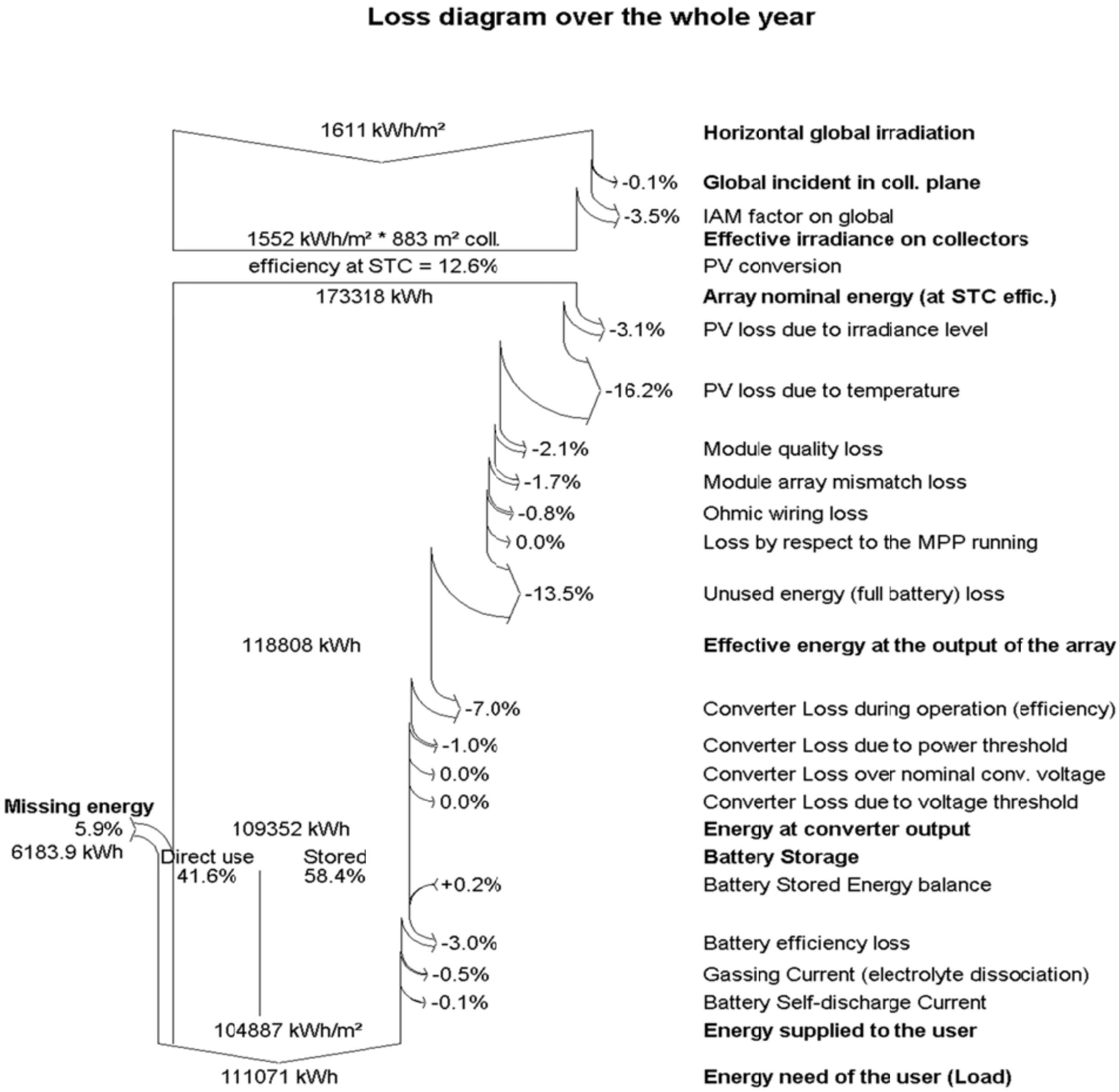

Figure 17 The loss diagram for the insulated PV modules

3.3 Comparison of the performance of the free standing PV module and the insulated PV module

Comparison of the performance ratio , PR of the free standing PV module and the insulated PV module is presented in Figure 14. The results show that the mean PR of 0.590416667 is obtained for insulated PV modules and mean PR of 0.60175 is obtained for free standing PV module and these two values give 1.883396 % increase or improvement in performance ratio of the free standing PV over that of the insulated PV modules.

Comparison of the thermal loss (kwh) of the free standing PV module and the insulated PV module is presented in Figure 15. The results show that the mean thermal loss of 2262.75kWh is obtained for insulated PV modules and mean thermal loss of 1303.75 kWh is obtained for free standing PV module and these two values give -73.55704698% reduction or improvement in thermal loss performance of the free standing PV over that of the insulated PV modules.

Comparison of the solar fraction of the free standing PV module and the insulated PV module is presented in Figure 16. The results show that the mean solar fraction of 0.94475 is obtained for insulated PV modules and mean solar fraction of 0.960166667 is obtained for free standing PV module and these two values give 1.605624024 % increase or improvement in solar fraction of the free standing PV over that of the insulated PV modules.

Comparison of the loss of load probability (%) of the free standing PV module and the insulated PV module is presented in Figure 17. The results show that the mean loss of load probability (%) of 5.5575 is obtained for insulated PV modules and mean loss of load probability of 4.013333333 kWh is obtained for free standing PV module and these two values give -38.47591362 % reduction or improvement in loss of load probability performance of the free standing PV over that of the insulated PV modules.

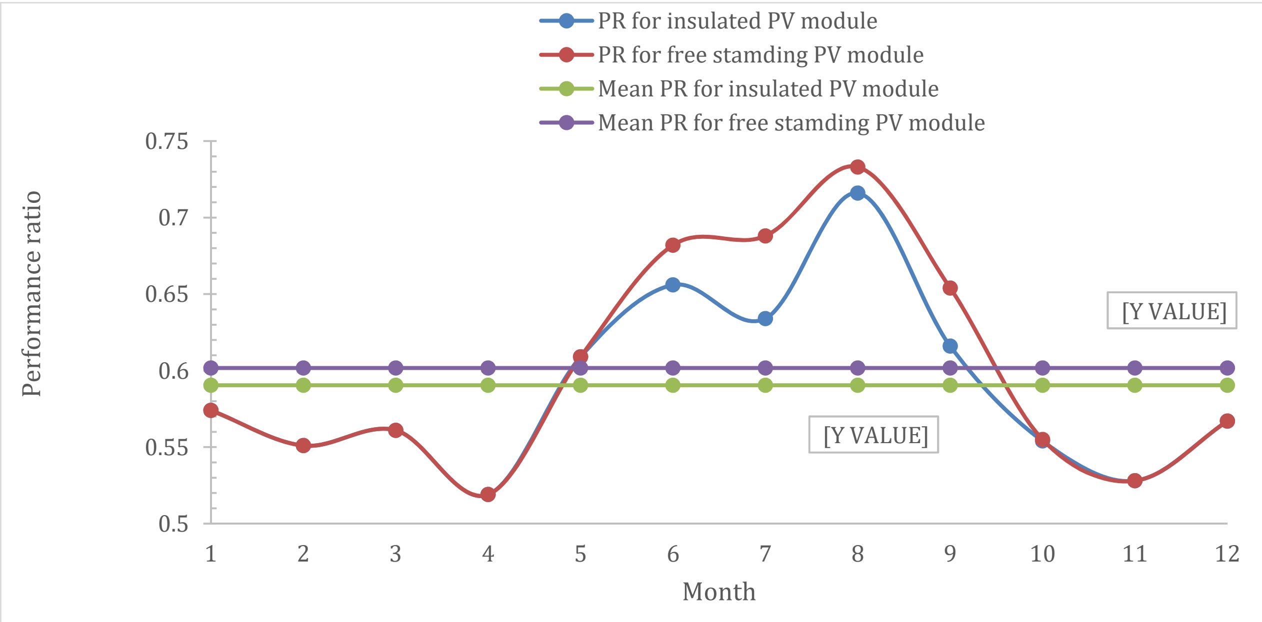

Figure 14 Comparison of the performance ratio , PR of the free standing PV module and the insulated PV module

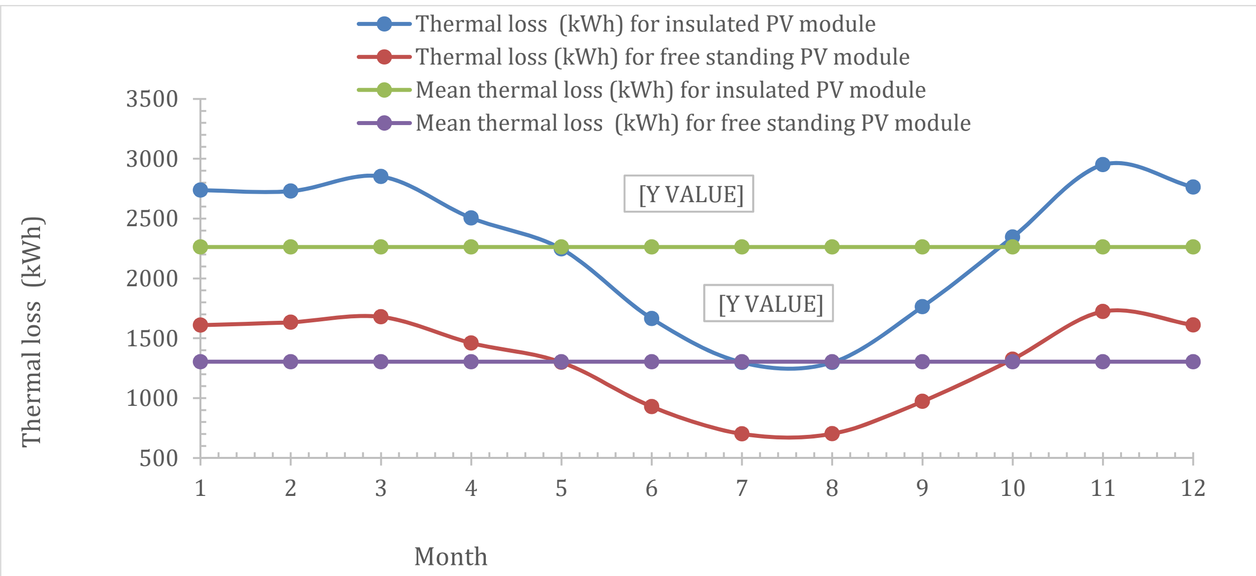

Figure 15 Comparison of the thermal loss (kwh) of the free standing PV module and the insulated PV module

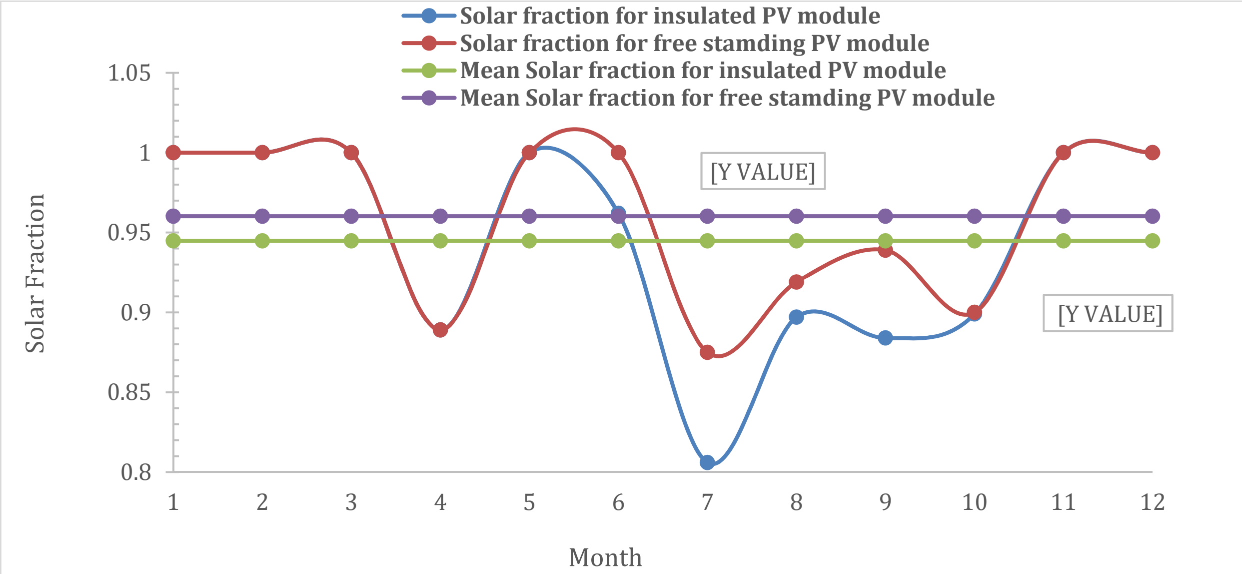

Figure 16 Comparison of the solar fraction of the free standing PV module and the insulated PV module

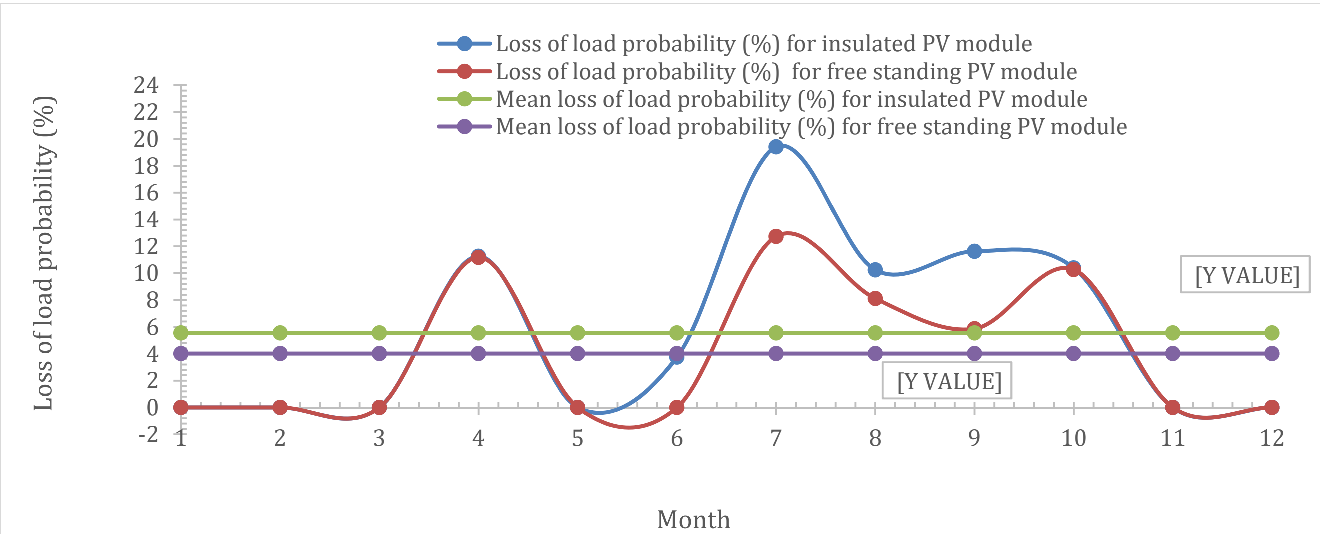

Figure 17 Comparison of the loss of load probability (%) of the free standing PV module and the insulated PV module

4 CONCLUSION

The effect of air circulation around the PV module and the attendant effect on thermal loss and other system performance is studied for an off-grid photovoltaic solar power system. The results show that adequate air circulation improves on the thermal loss performance, as well as other system performance of the PV power system. The study is essential for understanding the reason for poor performance of PV power systems in some installation sites. And especially on rooftops where much heat radiation from the roof do affect the cell temperature and the system performance. It also shows the need for adequate air circulation around the PV modules used in PV power supply system.

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