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Analysis of the impact of PVSyst thermal loss factor setting on the performance of off-grid photovoltaic power system

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***Abstract*—In this paper, analysis of the impact of PVSyst thermal loss factor setting on the performance of two off-grid PV power systems using free-standing photovoltaic (PV) modules and close roof-mounted PV modules is presented. The thermal loss factor is used to determine the cell temperature of the PV modules and in turn the thermal loss that will occur due to the difference between the cell temperature and the ambient temperature of the PV modules. The study was conducted based on the solar radiation data obtained from NASA portal for a location inside the AkwaIbom state University at MkpaEnin, AkwaIbom State, Nigeria. The PVSyst default thermal loss factor setting are such that for the constant loss factor is set to 29 and 15 for the free-standing PV modules and the close roof-mounted PV modules respectively. Furthermore, apart from the thermal loss factor, the same set of simulation input parameters are used in the simulation of the off-grid solar power for the case of free-standing photovoltaic PV modules and also for the case of close roof-mounted PV modules. The system with free-standing PV modules produced 416 kWh per year with 100% solar fraction and no missing energy which is equivalent to the 0 % loss of load probability. On the other hand, the system with close roof-mounted PV modules produced 350 kWh per year 94.3 % solar fraction and missing energy of 20.7 kWh which is equivalent to the 5.7 % loss of load probability. Also, in all cases, the system with the roof-mounted PV array has higher cell temperature which resulted in higher energy loss in the PV array due to high cell temperature. In all, the rooftop solar PV power is significantly affected by the PV module mounting approach and approaches that will reduce the cell temperature is required for more efficient PV energy yield for roof-mounted PV modules.**

***Keywords*—Thermal Loss, Thermal Loss Factor, Cell Temperature, Missing Energy, Loss Of Load Probability, Free-Standing PV, Roof-Mounted PV, Solar Energy**

I. INTRODUCTION

Nowadays, solar power systems are increasingly used to power several electrical applinaces across the globe, especially at those remote locations that do not have access to the national power grid [1,2,3,4,5,6]. In addition, in a bid to conserve space, in some cases, the photovoltaic (PV) modules are installed on the rooftop [7,8,9,10,11]. However, in hot wheather, the roof casues increase in the cell temperature of the PV modules which leads to increase the thermal loss of the PV modules and also reduces the PV modules operating efficiency [12,13,14,15].

In this paper, two different off-grid solar PV power systems are studies, one with free-standing PV array and the other one with a close roof-mounted PV array. The perfromance of the off-grid PV power systems are sudied using PVSyst simulation software [17]. In PVSyst, the thermal loss due to the PV module mounting approach is captured in terms of the thermal loss factor settings in th software [18,19]. The selected thermal loss factor is then used to compute the PV cell temperature and eventually the PV array thermal loss and the PV module operating efficency. In this paper, sample numerical examples are used to compare the performance of the free-standing PV module and the close roof-mounted PV module. The motivation for this study is to demonstrate that the performance of the roof-mounted PV modules are significally effected by the roof. As such, a more appropriate PV mounting approach for rooftop solar power system is required.

II. METHODOLOGY

A. *The cell temperature and the thermal loss factor setting in PVSyst software*

The cell temperature of PV modules affect its operating efficiency and the thermal loss in the PV array due to the difference between the cell temperature and the ambient temperature of the PV array. According to the models used in PVsyst for the thermal behavior of PV modules the thermal loss factor (U) is related to the cell temperature (T_{cell}) and the ambient temperature (T_a) as follows [20] ;

$$U = \left(\frac{\alpha(G)\,(1 - \eta_{PVSTC}))}{T_{cell} - T_a}\right)$$

Where α the absorption coefficient of solar irradiation is, η_{PV} is the PV module efficiency at standard test condition and G in W/m^2 is the solar radiance incident on the tilted plane of the module. Again, the thermal factor U consist of the constant loss factor (U_0) and the wind loss factor (Uv) [20] ;

$$U = U_0 + U_v(V_w) \tag{2}$$

In the PVSyst, Uv is set to zero (Uv =0) hence $U = U_0$ and the PV cell temperature becomes;

$$T_{cell} = T_a + \left(\frac{\alpha(G)(1-\eta_{PVSTC})}{U}\right) = T_a + \left(\frac{\alpha(G)(1-\eta_{PVSTC})}{U_0}\right) \quad (3)$$

Particularly, the PVSystthermal loss factor settings for Uoand U1 are Uo =15, U1= 0 for close roof mount PV modules and Uo =29, U1 = 0 for free-standing array PV modules [21].

B. The site meteorological data and off-grid PV power system simulation parameters and procedure

The solar radiation of at the site of the off-grid solar power system is downloaded from the NASA portal into the PVSyst simulation software. The study site is located in Akwa Ibom State University(main campus) in Ikot Akpaden, Mkpat Enin with longitude, latitude and elevation of 4.621437, 7.763997 and 18 m respectively. The solar radiation and ambient temperature of the study site are downloaded from NASA portal into the PVSyst software and the screenshot of the metorological data in PVSyst is shown in Table 1.

Table 1: The solar radiation and ambient temperature of the study site

Months	Monthly Average Solar Irradiation on The Horizontal Plane (kWh/m²/mth)	Monthly Average Solar Irradiation on The Horizontal Plane (kWh/m².mth)	Ambient temperature (°C)
Jan	161.2	171.8	25.7
Feb	146.7	152.6	26
Mar	148.8	149.8	26.1
Apr	138	135.2	26.2
May	131.1	125.5	26
Jun	106.2	101.5	25.3
Jul	100.4	96.2	24.6
Aug	106	103.3	24.3
Sep	102.9	102	24.5
Oct	114.1	116.5	24.8
Nov	126.3	132.4	25.1
Dec	153.5	164.6	25.4
Year Average	1535.2	1551.4	25.33

The PVSyst software is used select theyearly fixed optimal tilt angle of 9° for the the PV modules. The daily energy demand is estimated at 1 kWh per day and as shown in Figure 1, four (4) days autonomy is adopted for the simulation. According to Figure 1, about 7 PV modules are used ,where each of the PV module is the A-50M monocrystalline silicon manufacturerd by Atersa, as shown in Figure 2. The norminal power of each of the PV module is 50 Wp with temperature coefficent of -0.50 %/°C and standard test condition (STC) eficency of 9.93 %. After the batery and PV modules are selected the thermal loss factor is set using the PVSyst detail loss parameter dialogue box in Figure 3. According to Figure 3, for the free-standing PV module, the constant loss factor, denoted as Uc is set to 29 while the wind loss factor, denoted as Uv is set at zero (0) [21]. On the other hand, for the close roof-mounted PV module, the constant loss factor (Uc) is set to 15 while the wind loss factor (Uv) is set at zero (0) [21]. The off-grid solar power with the free-standing PV modules is simulated in PVSyst using the parameters shown in Figure 4. Apart from the thermal loss factor setting, the rest of the simulation input parameters in Figure 4 are also used to run the simulation for system with close roof-mounted PV modules.

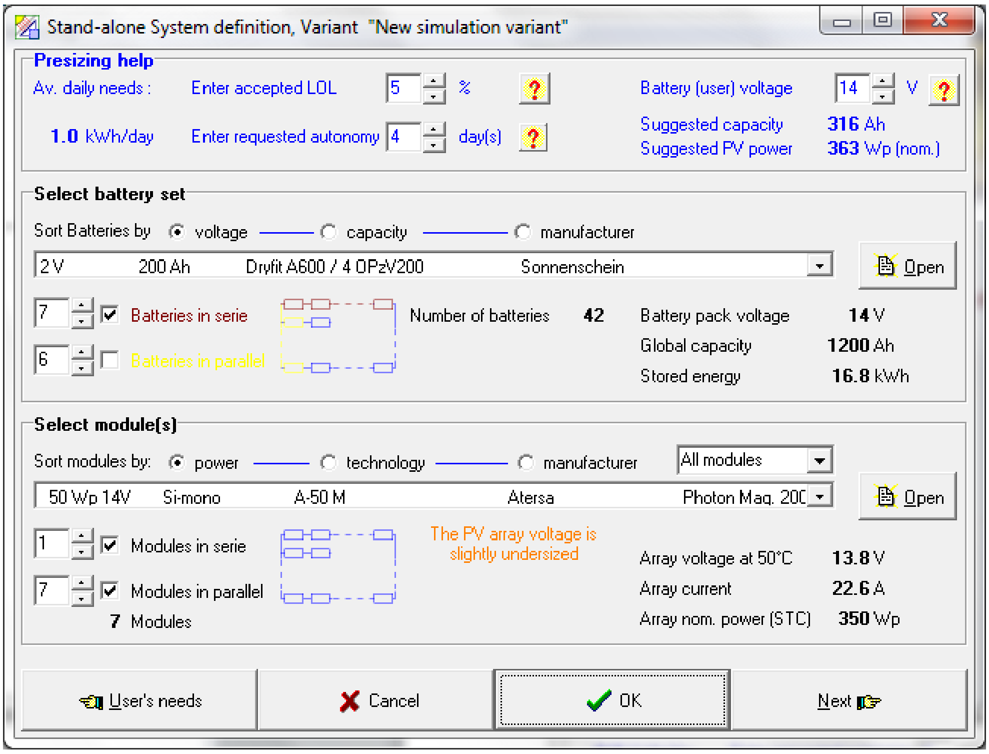

Figure 1: The selected battery bank and PV array for the off-grid solar power system.

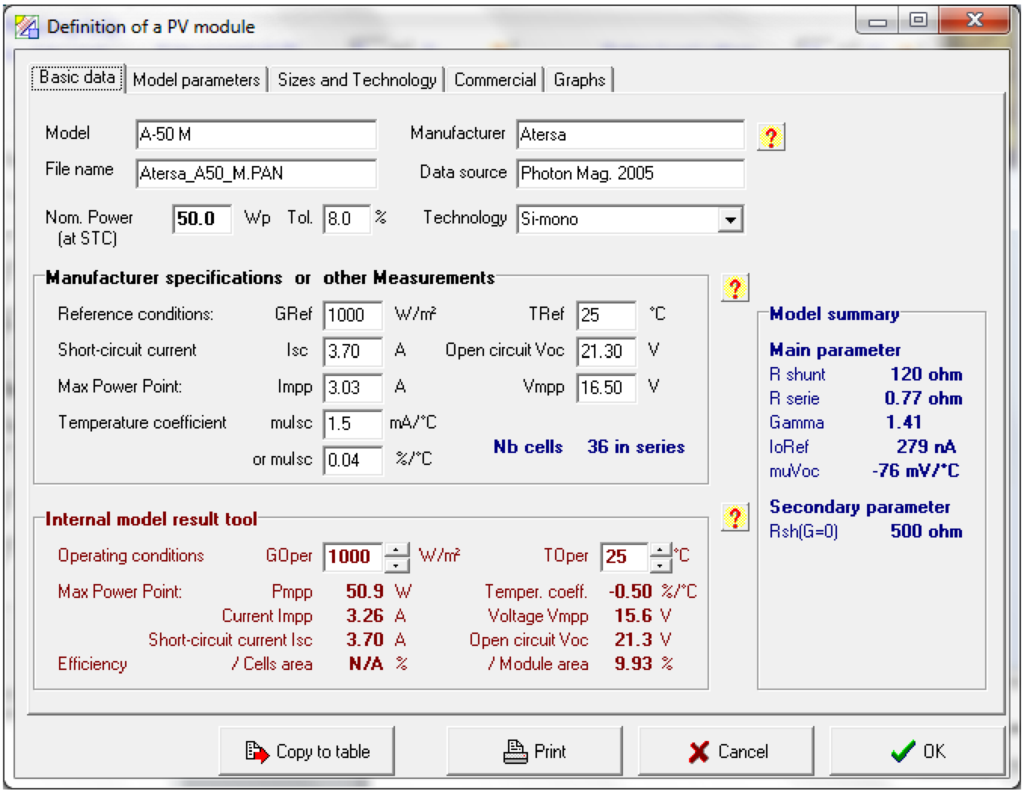

Figure 2: The details of the selected PV module

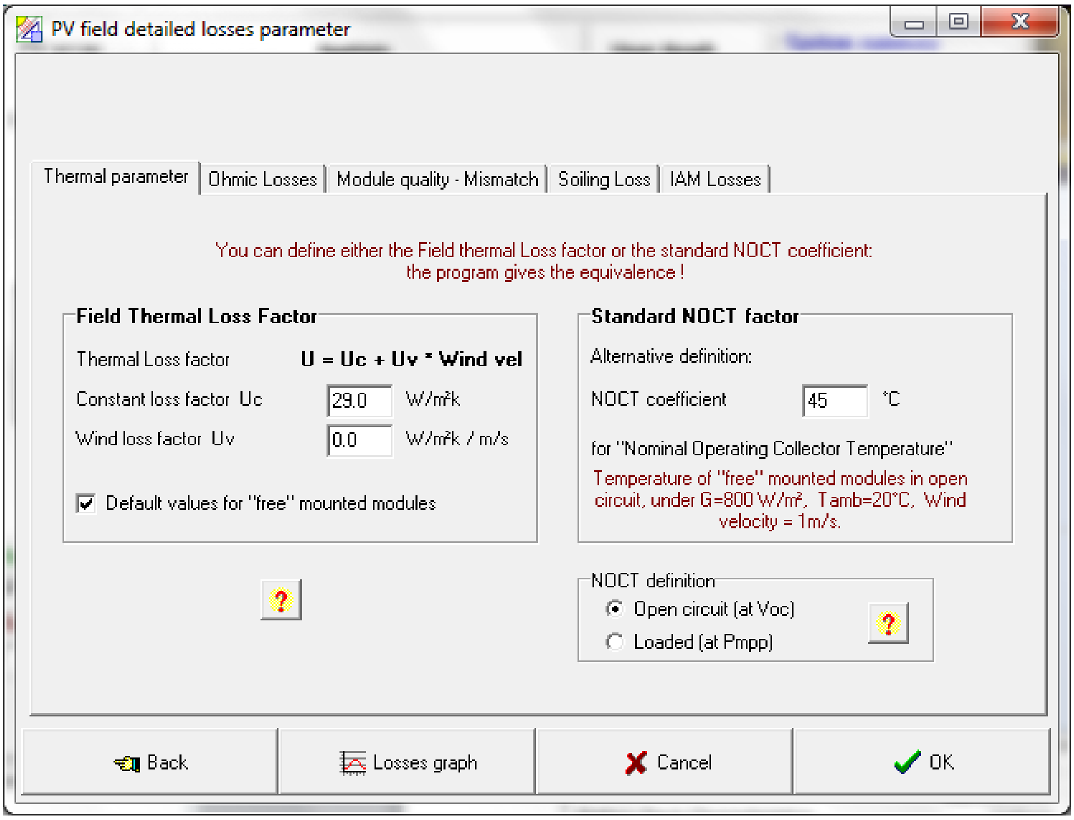

Figure 3: The thermal loss factor setting for the free-standing PV module

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Stand Alone System: Simulation parameters

Project :	**AKSU_TLOSS**			
Geographical Site		**AKSUMKPATENIN**	**Country**	**Nigeria**
Situation	Latitude	4.6°N	Longitude	7.8°E
Time defined as	Legal Time	Time zone UT+1	Altitude	18 m
	Albedo	0.20		
Meteo data :	AKSUMKPATENIN from NASA-SSE, Synthetic Hourly data			

Simulation variant :	**New simulation variant**			
	Simulation date	26/12/18 13h40		

Simulation parameters				
Collector Plane Orientation	Tilt	8°	Azimuth	0°
PV Array Characteristics				
PV module Si-mono	Model	**A-50 M**		
	Manufacturer	Atersa		
Number of PV modules	In series	1 modules	In parallel	7 strings
Total number of PV modules	Nb. modules	7	Unit Nom. Power	50 Wp
Array global power	Nominal (STC)	**350 Wp**	At operating cond.	311 Wp (50°C)
Array operating characteristics (50°C)	U mpp	14 V	I mpp	23 A
Total area	Module area	**3.6 m²**		
PV Array loss factors				
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind velocity = 1m/s.)			NOCT	45 °C
Wiring Ohmic Loss	Global array res.	22 mOhm	Loss Fraction	3.2 % at STC
Module Quality Loss			Loss Fraction	4.0 %
Module Mismatch Losses			Loss Fraction	4.0 % (fixed voltage)
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05
System Parameter	System type	**Stand Alone System**		
Battery	Model	**Dryfit A600 / 4 OPzV200**		
	Manufacturer	Sonnenschein		
Battery Pack Characteristics	Voltage	14 V	Nominal Capacity	1200 Ah
	Nb. of units	7 in series x 6 in parallel		
	Temperature	Fixed (20°C)		
Regulator	Model	General Purpose Default		
	Technology	Undefined	Temp coeff.	-5.0 mV/°C/elem.
Battery Management Thresholds	Charging	15.8/15.3 V	Discharging	13.7/14.7 V
	Back-Up Genset Command	13.8/15.0 V		
User's needs :	Daily household consumers	Constant over the year		
	average	1.0 kWh/Day		

Figure 4: The detailed simulation parameters for the free-standing PV module and the close roof-mounted PV module

III. RESULTS AND DISCUSSION

The PVSyst simulation main result for the case of free-standing PV modules is shown in Figure 5. The system produced 416 kWh per year and about 365 kWh per year is delivered to the load while the rest of available energy is lost due to various factors , as shown in Figure 6. Particularly, according to the loss diagram in Figure 6, about 10.2 % of the available energy is lost due to the PV module cell temperature. Furthermore, the results in Figure 5 show that the system has a solar fraction of 100 % ; that means that all the user energy demand are satisfied. In essence, there is no missing energy (or there is zero missing energy, as shown in Figure 5 and Table 2) and the loss of load probability is also, zero. Table 2 shows that the annual average operating efficiency of the PV array is 7.4 % which is lower than its STC eficency of 9.93 %.

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Stand Alone System: Main results

Project : **AKSU_TLOSS**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	8°	azimuth	0°
PV Array	Nb. of modules	7	Pnom total	**350 Wp**
Battery	Model	Dryfit A600 / 4 OPzV2	Technology	sealed, Gel
battery Pack	Nb. of units	42	Voltage / Capacity	**14 V / 1200 Ah**
User's needs	Daily household consumers	Constant over the year	global	365 kWh/year

Main simulation results				
System Production	**Available Energy**	**416 kWh/year**	Specific prod.	1189 kWh/kWp/year
	Used Energy	365 kWh/year	Excess (unused)	4.4 kWh/year
	Performance Ratio PR	67.2 %	Solar Fraction SF	100.0 %
Loss of Load	Time Fraction	0.0 %	Missing Energy	0.0 kWh

Figure 5 The PVSyst simulation main result for the case of free-standing PV module

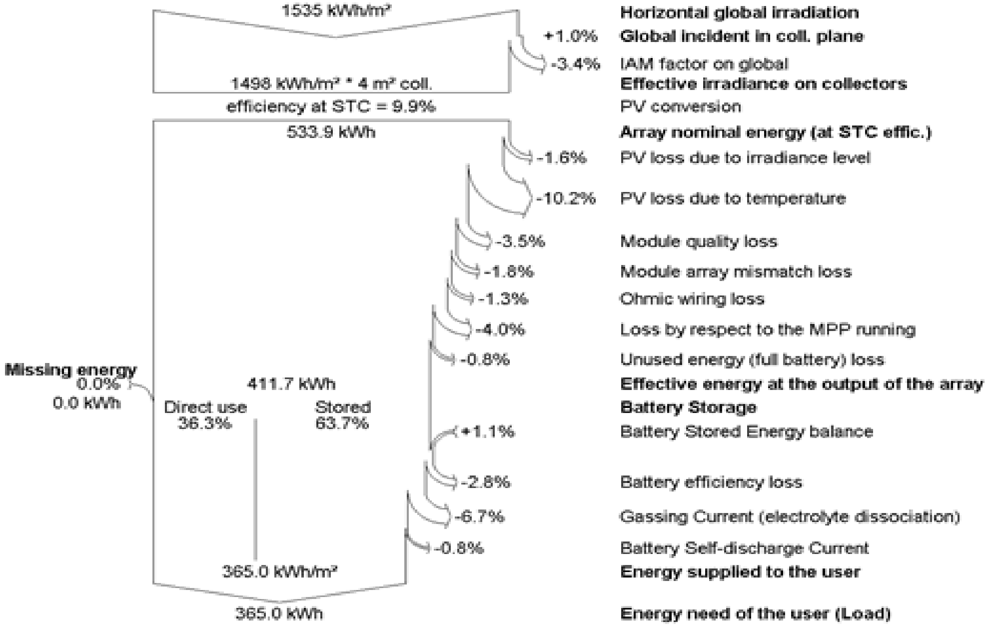

Figure 6 : The loss diagram for the case of free-standing PV module

Table 2: The system energy use and PV array temperature loss and PV array efficiency for the case of free-standing PV module

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Simulation variant : New simulation variant

Close Print Export Help

New simulation variant

Customised table

	E Load kWh	E User kWh	E Miss kWh	Pr LOL %	T LOL Hour	TArray °C	TempLss kWh	EffArrR %
January	31.00	30.99	0.007	0.00	0	43.06	7.292	7.01
February	28.00	27.99	0.010	0.00	0	42.67	6.420	6.64
March	31.00	30.99	0.008	0.00	0	40.29	5.543	7.18
April	30.00	29.99	0.006	0.00	0	39.33	4.980	7.01
May	31.00	31.00	0.002	0.00	0	37.87	4.010	7.62
June	30.00	30.00	-0.000	0.00	0	35.30	2.700	7.75
July	31.00	31.00	-0.000	0.00	0	33.69	2.396	7.80
August	31.00	31.00	-0.000	0.00	0	34.16	2.725	7.84
September	30.00	30.00	-0.000	0.00	0	34.83	2.724	7.84
October	31.00	31.00	-0.000	0.00	0	35.72	3.702	7.74
November	30.00	30.00	0.000	0.00	0	38.97	4.785	7.64
December	31.00	31.00	0.004	0.00	0	42.04	6.508	7.37
Year	365.00	364.96	0.036	0.00	0	38.15	53.786	7.40

The PVSyst simulation main result for the case of close roof-mounted PV module is shown in Figure7. The system produced 350 kWh per year and about 344 kWh per year is delivered to the load while the rest of available energy is lost due to various factors, as shown in Figure 8. According to the loss diagram in Figure 8, about 17.7 % of the available energy is lost due to the PV module cell temperature. Furthermore, the results in Figure 7 show that the system has a solar fraction of 94.3 % ; that means that about 5.7 % of the user energy demand are not satisfied. In essence, there is a missing energy of 20.7 kWh, as shown in Figure 7 and Table 3) and that missing energy is equivalent to the 5.7 % loss of load probability. Table 3 shows that the annual average operating efficiency of the PV array is 6.28 %.

The comparison of the PV array cell temperature (°C), energy loss due to array cell temperature (kWh) for and the PV array operating efficiency (%) for the free-standing PV module and for the close roof-mounted PV array are shown in Figure 9. The results show that for all the 12 months, the system with the roof-mounted PV array has higher cell temperature which resulted in higher energy loss in the PV array due to high cell temperature. Also, the cell operating efficiency for the system with roof-mounted PV is less than that of the free-standing PV module.

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Stand Alone System: Main results

Project : **AKSU_TLOSS**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	8°	azimuth	0°
PV Array	Nb. of modules	7	Pnom total	**350 Wp**
Battery	Model	Dryfit A600 / 4 OPzV2	Technology	sealed, Gel
battery Pack	Nb. of units	42	Voltage / Capacity	**14 V / 1200 Ah**
User's needs	Daily household consumers	Constant over the year	global	365 kWh/year

Main simulation results				
System Production	**Available Energy**	**350 kWh/year**	Specific prod.	1000 kWh/kWp/year
	Used Energy	344 kWh/year	Excess (unused)	0.4 kWh/year
	Performance Ratio PR	63.4 %	Solar Fraction SF	94.3 %
Loss of Load	Time Fraction	5.7 %	Missing Energy	20.7 kWh

Figure 7 The PVSyst simulation main result for the case of close roof-mounted PV module

Loss diagram over the whole year

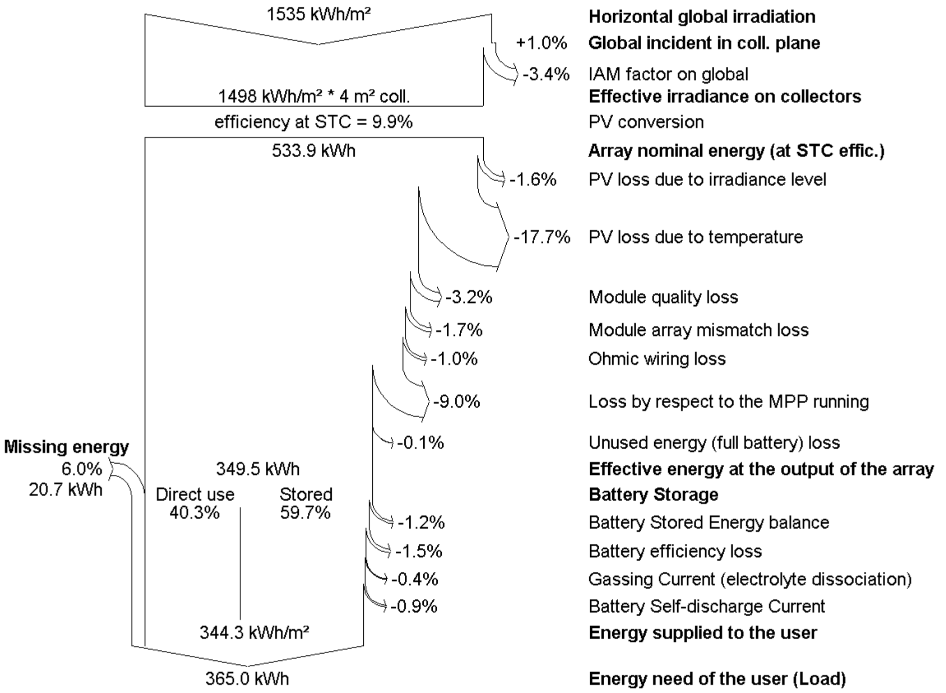

Figure 8: The loss diagram for the case of close roof-mounted PV module

Table 3: The system energy use and PV array temperature loss and PV array efficiency for the close roof-mounted PV module

New simulation variant
Customised table

	E Load kWh	E User kWh	E Miss kWh	Pr LOL %	T LOL Hour	TArray °C	TempLss kWh	EffArrR %
January	31.00	31.00	0.00	0.0	0	55.98	12.43	5.47
February	28.00	28.00	0.00	0.0	0	54.96	10.76	5.54
March	31.00	31.00	0.00	0.0	0	51.36	9.55	5.95
April	30.00	30.00	-0.00	0.0	0	49.99	8.56	5.94
May	31.00	31.00	-0.00	0.0	0	47.29	6.97	6.50
June	30.00	30.00	-0.00	0.0	0	43.11	4.72	6.96
July	31.00	26.85	4.15	13.3	99	40.85	4.28	7.09
August	31.00	14.45	16.55	53.4	397	41.86	4.86	6.79
September	30.00	30.00	-0.00	0.0	0	42.74	4.87	6.86
October	31.00	31.00	-0.00	0.0	0	44.22	6.48	6.69
November	30.00	30.00	-0.00	0.0	0	49.05	8.17	6.51
December	31.00	31.00	0.00	0.0	0	54.39	11.17	6.15
Year	365.00	344.30	20.70	5.7	496	47.98	92.81	6.28

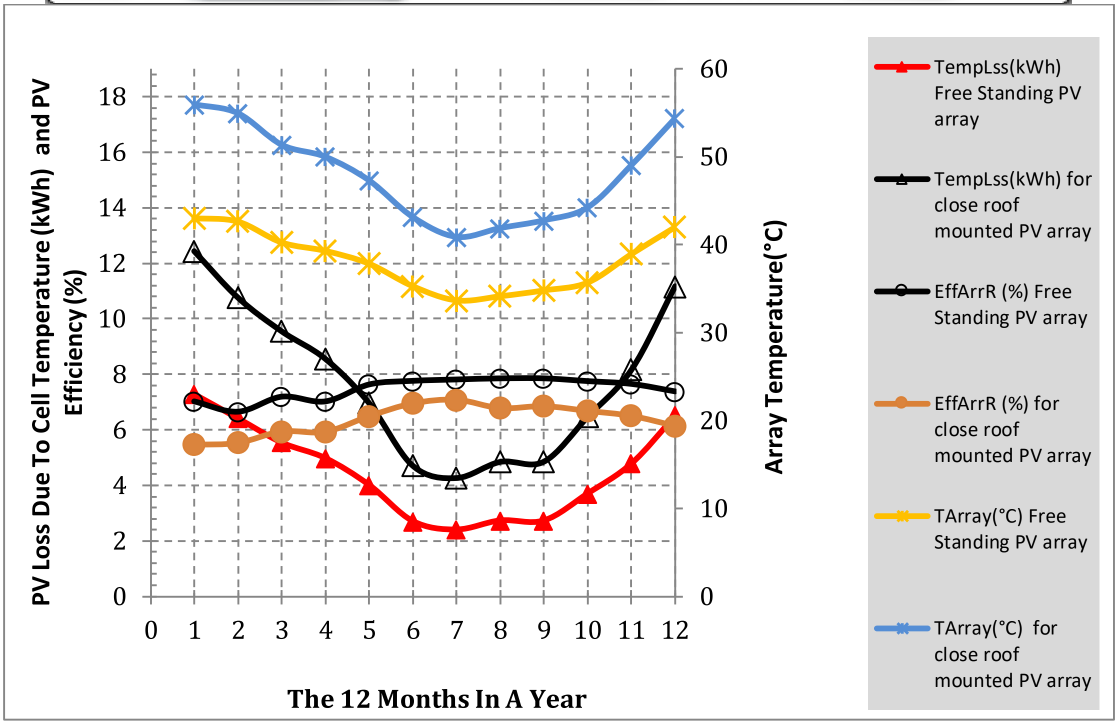

Figure 9: Comparison of the PV array cell temperature (°C), energy loss due to array cell temperature (kWh) for and the PV array operating efficiency (%) for the free-standing PV module and for the close roof-mounted PV array

IV. CONCLUSION

The effect of thermal loss factor on the performance of off-grid solar power system is presented. In particular, the PVSyst default thermal loss factor for a free-standing PV module and for a close roof-mounted PV module are used in the simulation and evaluation of the yearly energy yield, loss of load probability, PV array cell temperature, array energy loss due to cell temperature and the operating PV array efficiency for a off-grid PV power system. The result showed that the roof-mounted PV array has higher operating cell temperature which leads to higher array energy loss due to high temperature and eventually lower array operating efficiency. In all, the rooftop solar PV power is significantly affected by the PV module mounting approach and approaches that will reduce the cell temperature is required for more efficient PV energy yield for roof-mounted PV modules.

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