Net Energy Analysis For A Grid-Connected Solar Powered Supermarket In Port Harcourt City

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***Abstract*— Net energy analysis for a grid-connected photovoltaic (PV) solar-powered supermarket in Port Harcourt city is studied. Basically, in grid-connected PV power system, the difference in the imported energy from the grid and the exported energy to the national power grid is used to compute the net energy, which can be surplus, deficit or net zero when the two energy parameters values are equal. In this paper, net energy analysis is done for a supermarket that has daily energy demand of 23.5 kWh per day. The mathematical expressions for the net energy analysis are presented and the simulation for the net energy analysis was implemented using PVSyst software. In all, the results show that the annual load demand is 8,559.6 kWh while the annual energy supplied from the PV power source to the load is 8,411.2 kWh which gives annual deficit energy of 148.4 kWh. This deficit energy is supplied from the grid. However, the annual excess energy generated by the PV power source is equal to the annual energy injected to the grid which is 32,403 kWh. Hence the annual net energy of the entire PV power system is 32,254.6 kWh. Essentially, the energy generated from the PV array is in excess of the load demand. Hence, greater portion of the energy generated from the PV is injected to the grid.**

Keywords*— *Net energy, solar fraction, grid-connected, photovoltaic, solar powered , net zero energy

1. INTRODUCTION

Today, the power industry has undergone tremendous transformations. Democratization of energy production and the emergence of net metering has given the consumers the opportunity to produce, consume, connect to the grid with the ability to export and import energy based on the net energy at the consumer site [1,2,3,4,5,6,7,8,9,10,11]. Basically, net metering technology allow the consumer to connect to the national power grid from which the consumer can import energy to meet its load demand [12,13,14,15,16,17]. At the same time, the net meter allows the consumer to produce energy locally and export to the grid [18,19,20,21,22,23,24,25]. In that case, the consumer pays for the net energy; if the imported energy is more than the exported energy, otherwise the grid will be the one to pay the consumer for the excess energy exported to the grid from the consumer site.

In this paper, the focus is analysis of the net energy situation that can arise when the local energy source at the consumer site is from photovoltaic solar system. Nowadays, solar power has gotten much prominence in Nigeria due to the perennial challenges of power supply from the national grid [26,27, 28,29, 30,31, 32,33, 34,35, 36, 37]. Also, solar power is green power and there is steady decrease in the PV system components cost [38,39, 40,41, 42,43, 44,45, 46, 47, 48,49,50,51,52,53]. As such, cost benefit is part of the driving factors for the adoption of PV solar power.

In any case, in order to setup a solar power system, appropriate component size selection is essential and there are some mathematical expressions for determining the PV system component sizes. Hence, in this paper, the requisite mathematical expressions for the analysis are presented along with the requisite load data and meteorological data for case study consumer site. The PVSyst renewable energy system simulation software is used to implement the analysis.

2 METHODOLOGY

2.1 The mathematical model for net energy PV power system

In grid-connected PV power system, the difference in the imported energy from the grid and the exported energy to the national power grid is used to compute the net energy, which can be surplus, deficit or net zero when the two energy parameters values are equal. Let E_{DD} represent the energy demand per day and E_{YD} represent the energy demand per year, then;

$$E_{YD} = 365(E_{DD}) \quad (1)$$

The study considered a supermarket daily electric energy demand profile which is shown in Table 1. Let E_{Wp} represent the individual PV module peak power rating in kW, N_{PV} represent the number of PV module used in the power system, PSH represent the daily peak sun hour, and f_{PV_derat} represents the PV module derating factor, and E_{PVA} represent the PV array energy production per year, then;

$$E_{PVA} = 365(P_{Wp})(N_{PV})(PSH)(f_{PV\_derat}) \quad (2)$$

Let E_{SCOM} represent the portion of the energy consumed by the load per year, E_{YIMP} represent the energy imported from the grid per year, E_{YEXP} represent the energy exported to the national power grid per year, and E_{NET} represent the net energy in the system per year, then;

$$E_{SCOM} = \mathrm{E_{YD}} = 365(\mathrm{E_{DD}}) \quad (3)$$

$$E_{YIMP} = maximum(E_{SCOM} - E_{PVA},\ 0) \quad (4)$$

$$E_{YEXP} = maximum(E_{PVA} - E_{SCOM},\ 0) \quad (4)$$

$$E_{NET} = E_{YEXP} - E_{YIMP} \quad (5)$$

Hence, net zero energy situation occurs when $E_{PVA} = E_{SCOM}$ and $E_{YEXP} = E_{YIMP}$. Essentially, in respect of the supermarket daily electric energy demand, the parameters of the PV power system are selected such that $E_{PVA} = E_{SCOM}$ = electric energy demand per year.

2.2 The meteorological data of the case study supermarket site and the daily load demand of the supermarket

The case study supermarket is located at latitude and longitude of 4.837655, 7.025225 respectively. The map visualization showing the supermarket location is shown in Figure 1. The solar radiation and ambient temperature data based on the supermarket location are shown in Table 1. The load demand of the case study supermarket based on the electrical appliances used and the number of hours they are used per day is shown in Table 2. Modelling of the hourly distribution of the load demand profile was done using PVSyst software as shown in Figure 2. The PVSyst graphical presentation of the hourly distribution of the load demand profile is shown in Figure 3. In all, the daily energy demand is 23.5 kWh/day and the monthly energy demand is 704 kWh/month. The schematic diagram of the grid connected PV power supply is presented in Figure 4 while Figure 5 shows the grid-connected PV system configuration used for the simulation in PVSyst software.

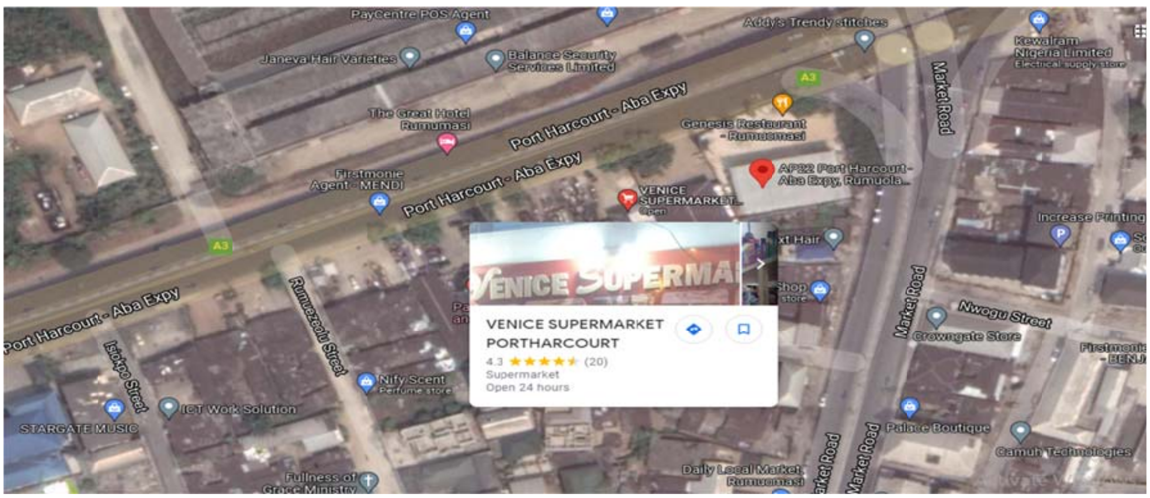

Figure 1. The map visualization showing the supermarket location (with latitude and longitude of 4.837655, 7.025225 respectively)

Table 1.The site radiation and ambient temperature data for the simulation of net zero PV component parameter selection

Meteo File Rumuokor Port Harcourt_Nasa_SYN.MET, Monthly accumulations

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Meteo for Rumuokor Port Harcourt - Synthetically Generated Data

Plane: tilt 7°, azimuth 0°, Albedo 0.20

Interval beginning	GlobHor kWh/m².mth	DiffHor kWh/m².mth	GlobInc (Hay model) kWh/m².mth	T Amb °C
January	161.2	57.97	169.4	25.7
February	146.7	58.24	151.0	26.0
March	148.8	70.99	149.4	26.0
April	138.0	69.00	135.7	26.2
May	131.1	67.27	126.9	26.0
June	106.2	61.20	102.5	25.3
July	100.4	62.62	97.7	24.6
August	106.0	65.72	104.0	24.3
September	102.9	65.40	102.6	24.5
October	114.1	66.65	115.9	24.8
November	126.3	61.20	131.1	25.1
December	153.4	57.35	162.2	25.4
Year	1535.2	763.61	1548.4	25.3

Table 2 The supermarket daily electric energy demand profile

Electric Appliance	Wattage (W)	Qty.	Hours of operation per day	Daily energy demand (Wh/day)
Refrigeration	200	2	9	3600
Air condition	1000	1	9	9000
Computer	120	1	9	1080
Printer	110	1	9	990
Television	70	1	9	630
Fans	60	4	9	2160
Lighting	20	6	9	1080
Other Miscellaneous	400	1	9	3600
Power for testing Electronic products	340	1	4	1360
Total				**23500**

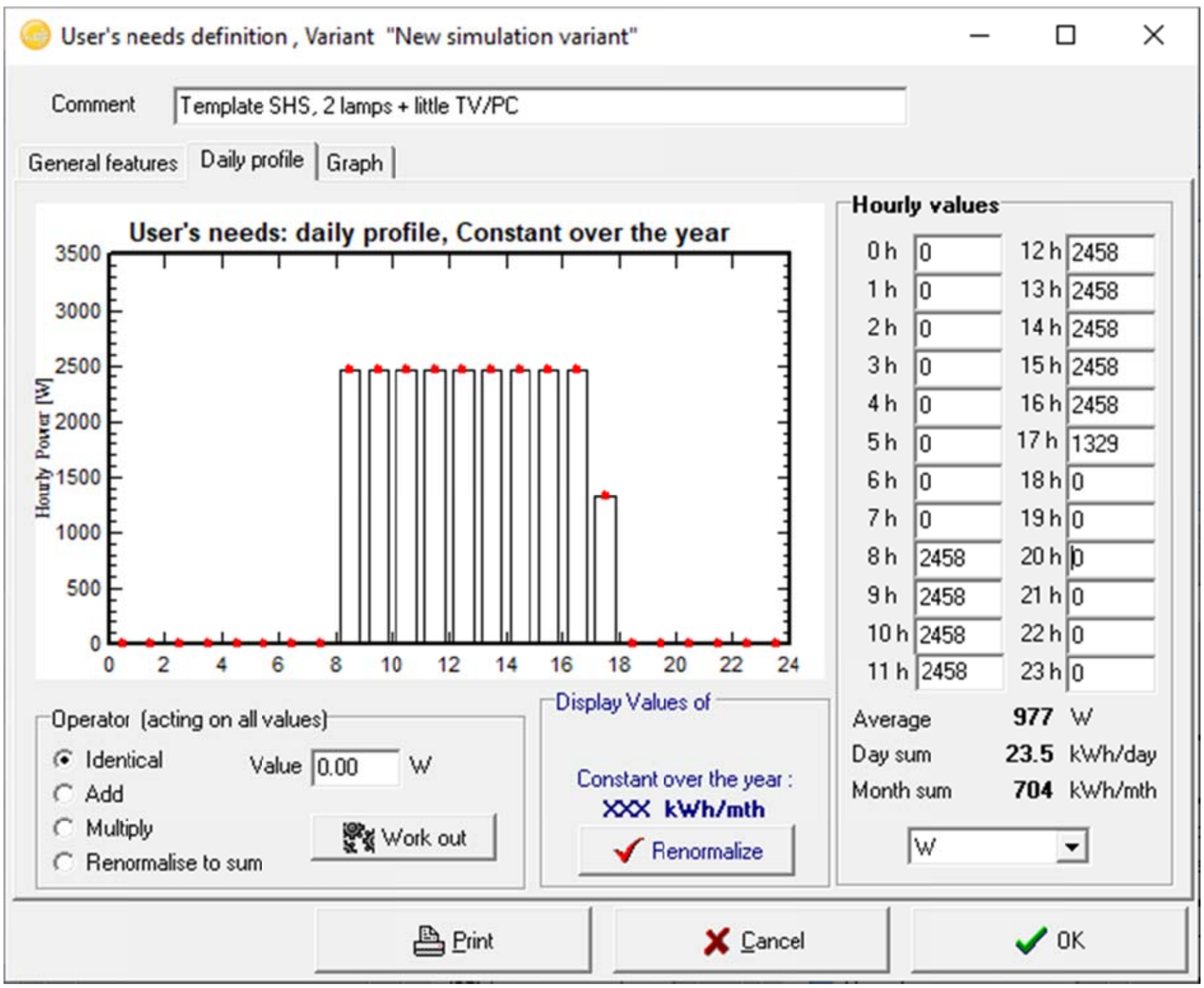

Figure 2 The modelling of the hourly distribution of the load demand profile using PVSyst software

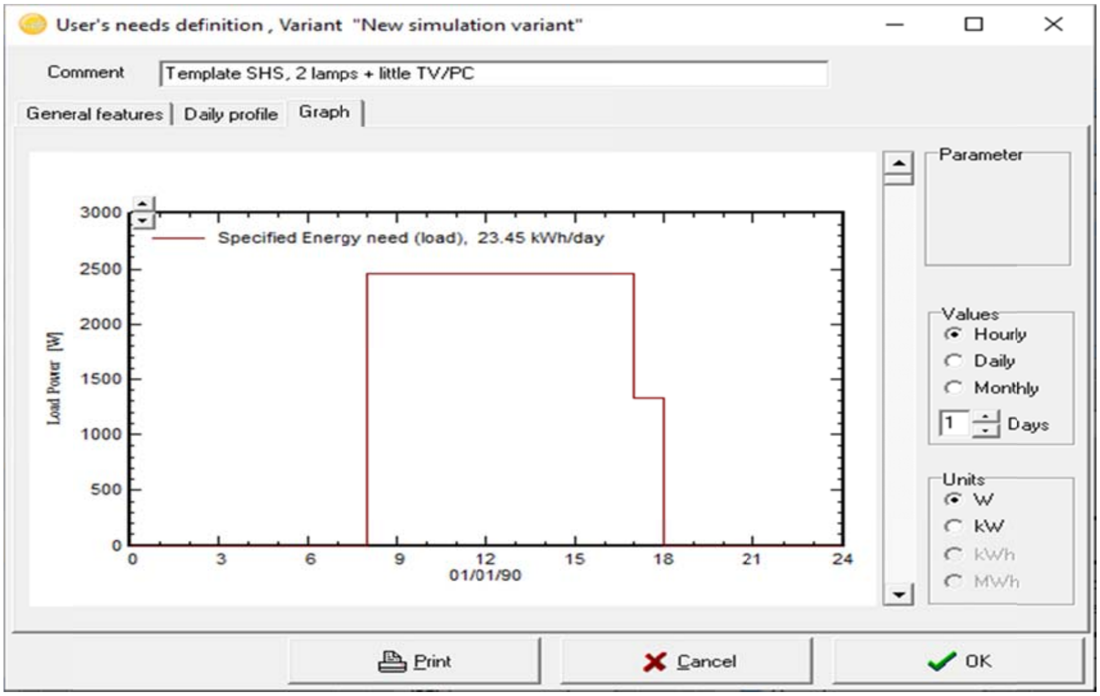

Figure 3 The PVSyst graphical presentation of the hourly distribution of the load demand profile

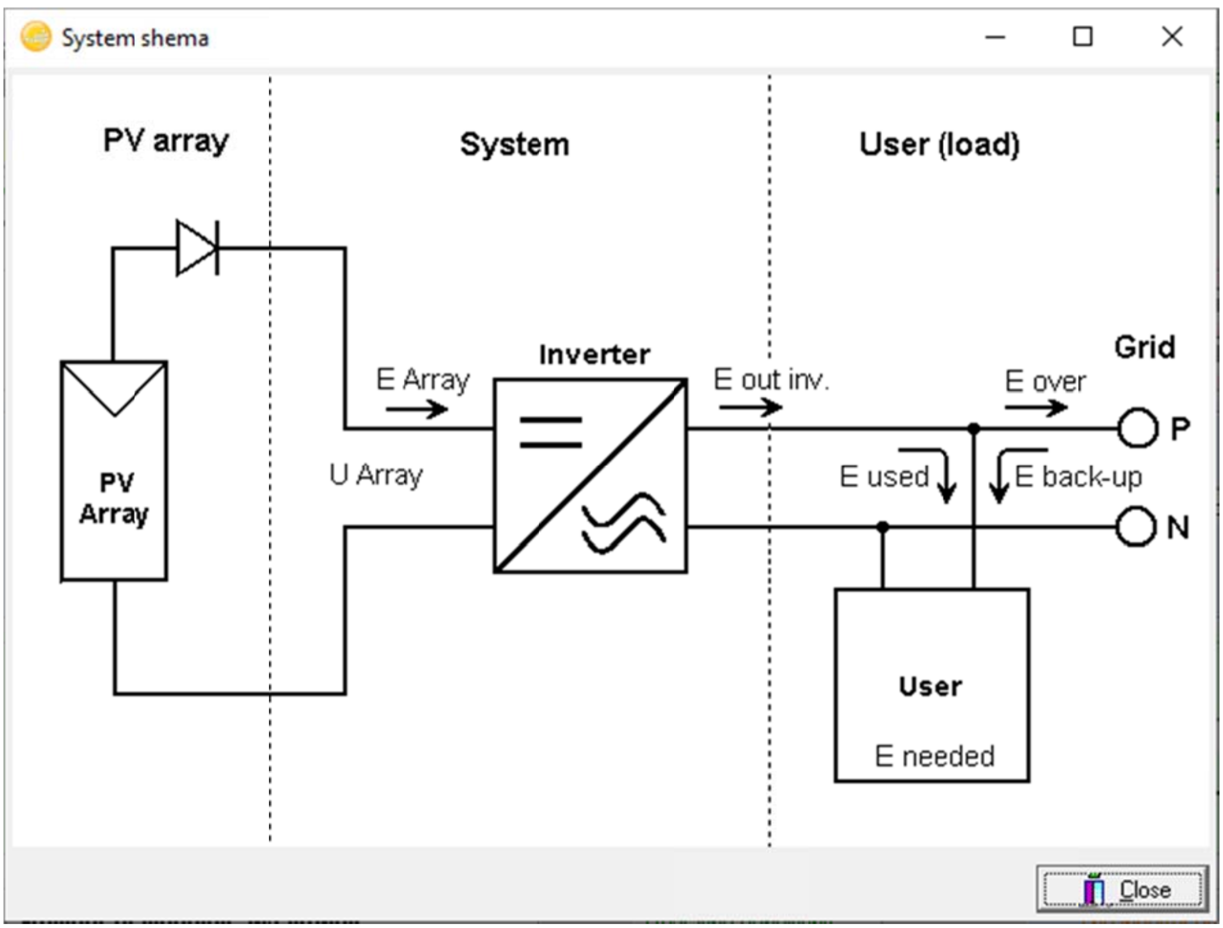

Figure 4 The schematic diagram of the grid-connected PV power supply

Figure 5 The system configuration used for the simulation of the grid-connected PV power supply system

The core parameters of the PV module used in the PV the grid-connected power supply system is shown in Figure 6. According to the parameter values in Figure 6, the selected PV module has standard test condition (STC) efficiency of 18.44 % and rated watt peak power of 300 Wp at STC. The graph of the efficiency versus cell temperature for different incident irradiation values for the PV module is shown in Figure 7. The graph of Figure 7 shows that the operating efficiency of the PV module can increase to a value close to 20 % if the cell temperature drops from the STC value of 25 °C to a value of about 1 °C. Conversely, the PV module efficiency can decrease to a value close to 15 % if the cell temperature increases from the STC value of 25 °C to a value of about 60 °C. The impact of cell temperature on the effective watt peak power of the PV module is shown in Figure 8. At STC temperature of 25 °C the PV has power output of 303.0 W. However, at 10 °C cell temperature the power output of the PV module can be as high as 320.6 W whereas at cell temperature of 70 °C the output power can drop to 247.3 W.

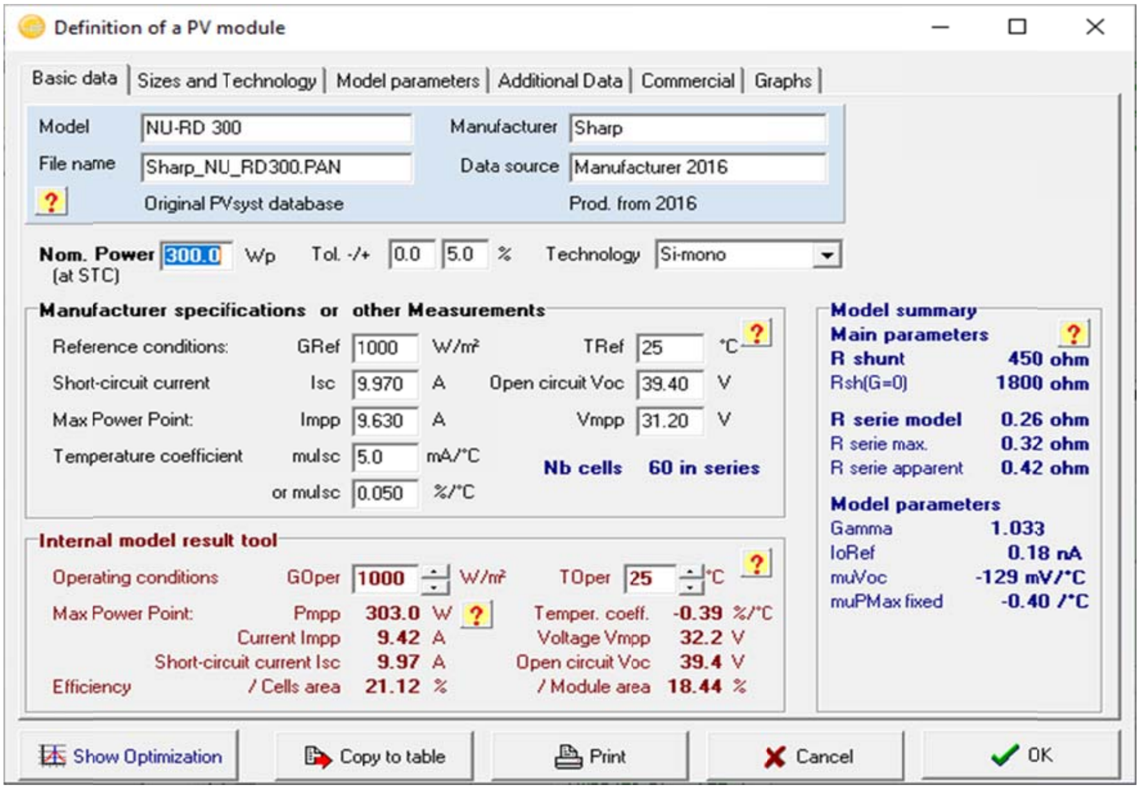

Figure 6 The core parameters of PV module used in the PV the grid-connected power supply system

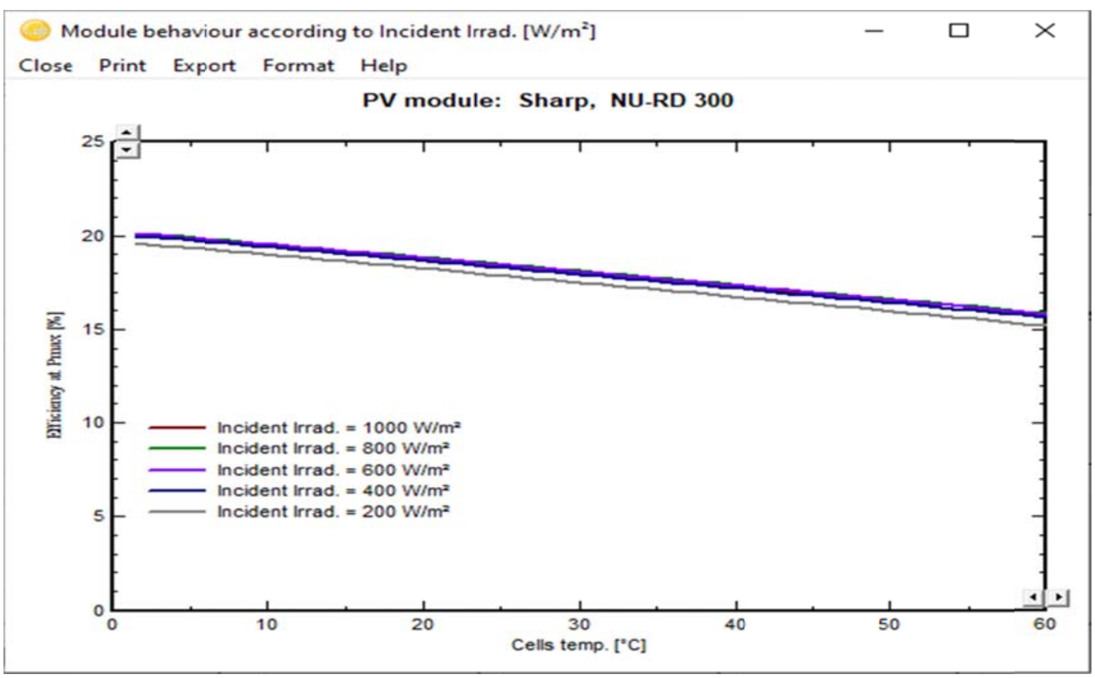

Figure 7 The graph of the efficiency versus cell temperature for different incident irradiation values for the PV module

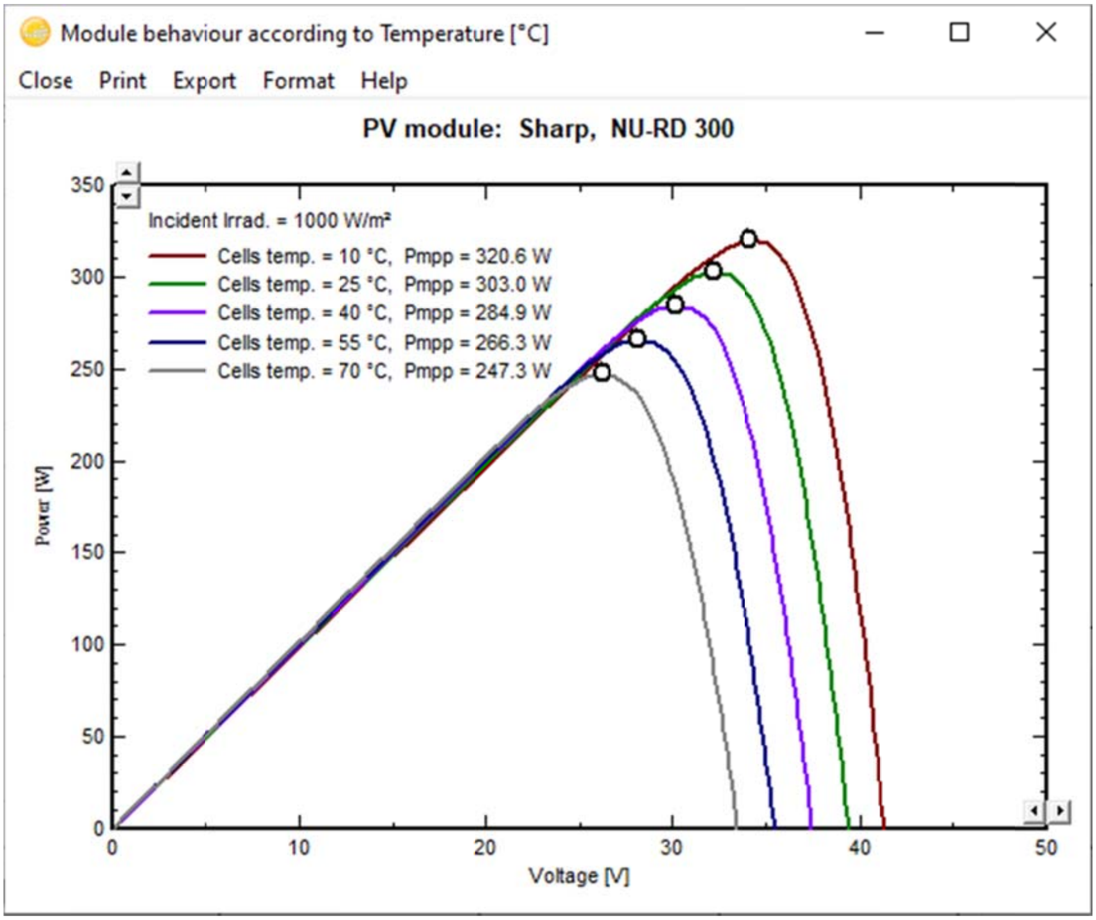

Figure 8 The graph of the watt peak power versus operating voltage for different cell temperature values for the PV module

3 RESULTS AND DISCUSSION

The simulation for the net energy analysis was implemented using PVSyst based on the PV system configuration shown in Figure 5. The screenshot of the simulation results showing the main energy outputs of the PV power system is shown in Figure 9 and Figure 10. The results in Figure 9 and Figure 10 show the monthly and annual energy generated by the PV array (E Avail), the monthly and annual energy demand of the load (E Load), the monthly and annual energy supplied to the user (E user), the monthly and annual energy supplied or injected to the grid (E_Grid), and the solar fraction (SolFrac) which is the fraction of the load demand that is actually supplied from the PV power system. The hourly distribution of the energy injected into the grid is shown in Figure 11. In all, the annual load demand is 8,559.6 kWh while the annual energy supplied from the PV power source to the load is 8,411.2 kWh which gives annual deficit energy of 148.4 kWh. This deficit energy is supplied from the grid. However, the annual excess energy generated by the PV power source is equal to the annual energy injected to the grid (E_Grid) which is 32,403 kWh. Hence the annual net energy of the entire PV power system is 32,403 kWh - 148.4kWh = 32,254.6 kWh.

Simulation variant : New simulation variant

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New simulation variant
Energy use and User's needs

	E Avail	E Load	E User	E_Grid	SolFrac
	kWh	kWh	kWh	kWh	
January	3737	727.0	711.1	3026	0.978
February	3429	656.6	649.0	2780	0.988
March	3721	727.0	723.0	2998	0.994
April	3550	703.5	699.6	2851	0.994
May	3487	727.0	724.7	2762	0.997
June	3132	703.5	692.3	2440	0.984
July	2980	727.0	717.4	2262	0.987
August	2850	727.0	708.4	2141	0.974
September	3212	703.5	681.2	2530	0.968
October	3440	727.0	698.8	2741	0.961
November	3486	703.5	688.8	2797	0.979
December	3792	727.0	716.9	3075	0.986
Year	40814	8559.6	8411.2	32403	0.983

Figure 9 The screenshot of the simulation results showing the main energy outputs

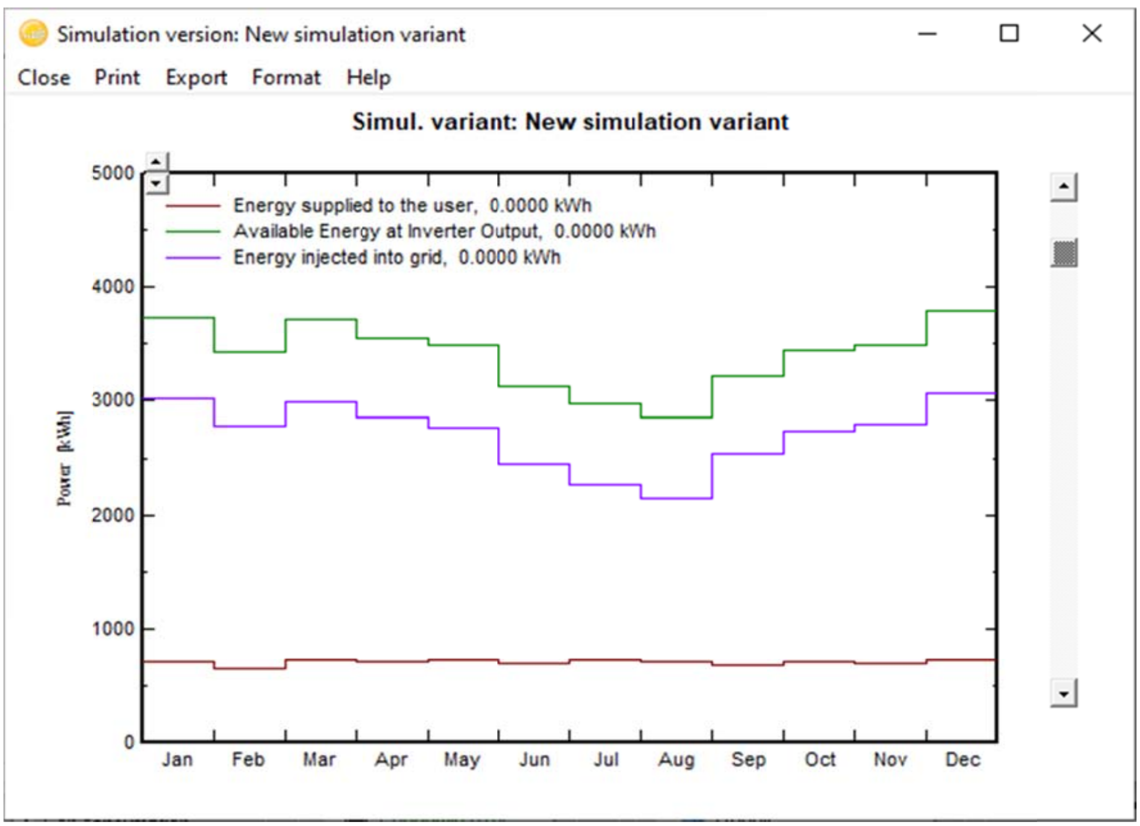

Figure 10 The graph plot of the monthly energy generated by the PV array (E Avail), the monthly energy supplied to the user (E user) and the monthly energy supplied or injected to the grid (E_Grid) and annual

New simulation variant

Monthly Hourly sums for E_Grid [kWh]

	0H	1H	2H	3H	4H	5H	6H	7H
January	0	0	0	0	0	0	0	65
February	0	0	0	0	0	0	0	52
March	0	0	0	0	0	0	0	67
April	0	0	0	0	0	0	0	86
May	0	0	0	0	0	0	0	96
June	0	0	0	0	0	0	1	83
July	0	0	0	0	0	0	0	70
August	0	0	0	0	0	0	0	65
September	0	0	0	0	0	0	0	101
October	0	0	0	0	0	0	1	111
November	0	0	0	0	0	0	1	112
December	0	0	0	0	0	0	0	91
Year	0	0	0	0	0	0	4	999

	8H	9H	10H	11H	12H	13H	14H	15H
January	119	245	361	408	441	467	388	285
February	106	240	335	392	412	394	337	266
March	124	253	358	431	442	417	364	290
April	143	258	345	383	401	395	356	271
May	145	253	347	387	403	380	323	238
June	117	220	295	328	350	329	302	229
July	108	208	280	314	331	313	270	205
August	96	190	268	306	306	294	264	195
September	155	258	333	339	349	333	290	215
October	160	258	347	376	406	382	308	230
November	173	269	325	379	390	383	348	252
December	150	295	380	437	449	445	379	276
Year	1597	2948	3974	4479	4680	4532	3930	2953

	16H	17H	18H	19H	20H	21H	22H	23H
January	169	76	2	0	0	0	0	0
February	168	74	3	0	0	0	0	0
March	177	73	3	0	0	0	0	0
April	149	60	2	0	0	0	0	0
May	137	51	1	0	0	0	0	0
June	129	54	4	0	0	0	0	0
July	110	50	3	0	0	0	0	0
August	112	45	1	0	0	0	0	0
September	115	40	1	0	0	0	0	0
October	124	38	0	0	0	0	0	0
November	130	35	0	0	0	0	0	0
December	134	38	0	0	0	0	0	0
Year	1655	632	21	0	0	0	0	0

Figure 11The hourly distribution of the energy injected into the grid

4 CONCLUSION

The analysis of the net energy of a photovoltaic solar power system that is connected to the national grid is presented. The analysis was done using PVSyst simulation software. The energy load profile is based on the electrical appliance in a case study supermarket. Based on the computed load demand and the meteorological data of the case study location, the PVSyst software was used to select the requisite components of the PV power supply system and also to simulate the operation and energy output of the system. In all, based on the simulation results, the energy generated from the PV array is in excess of the load demand. As such greater portion of the energy generated from the PV is injected to the grid.

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